Strømningsmålling

Kompetansemål:

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

Emne for lekesjonen: Teknologier for flowmåling

Oppgave 1 - 20; besvar oppgave 1-10 som forberedelse til leksjon

Læringsmål: Målet for leksjonen er å gi en oversikt ovre ulike måleprinsipper som brukes for å måle strømning.

- Kunne navngi og beskrive virkemåte for ulike måleelementer som brukes i trykkbaserte strømningsmålere.
- Kunne navngi og beskrive virkemåte for ulike måleprinsipper for hastighetsbaserte strømningsmålere.
- Kunne forklare måleprinsippet til en Coriolis strømningsmåler
- Kunne forklare måleprinsippet til fortrengingsmålere
- Kunne forklare måleprinsippet til termiske strømningsmålere.

Emne for leksjonen: Fluid dynamikk

Oppgave 21 - 40; besvar oppgave 21-30 som forberedelse til leksjonen

Målet for leksjonen er å bygge en intuisjon for hvordan fluider strømer i rør ved å regne på ulike eksempler.
Læringsmål:

- Kunne forklar hva viskositet er og hvilken enhet absolutt viskositet måles i
- Kunne forklare hva Reynolds nummer og regne ut dette for strømning i rør.
- Kunne forklare forskjellen på turbulent og laminær strømning
- Kunne forklare og bruke Law of Continuity
- Kunne forklare og bruke Bernoullis formel

Emne for leksjonen: Trykkbaserte strømningsmålere

Oppgave 41 - 60; besvar oppgave 41-50 som forberedelse til leksjonen

Målet for leksjonen er å gi en oversikt over trykkbaserte strømningsmålere, hvordan disse installeres og at disse krever kvadratrotuttrekker.

Læringsmål:

- Kunne forklare forskjellen på volumentrisk strømning og massestrømning.
- Kunne forklare hva som menes med kvadratrotuttrekker og regne med signalstyre inn og ut av en kvadratrotuttrekker.
- Kunne beskrive riktig installasjon av trykkbaserte stømningsmålere.
- Kunne regne på oppgaver med strømningn i trykkbaserte strømningsmålere.

Del 4

Emne for leksjonen: Hastighetsbasert strømningsmålere

Oppgave 61 - 90; besvar oppgave 61-70 som forberedelse til leksjonen
Målet for leksjonen er å gi en oversikt over måleprinsippene for hastighetsbaserte strømningsmålere.

Læringsmål:

- Kunne installere og regne ut k-verdi for turbin strømningsmåler
- Kunne installere og renge ut k-verdi for vortex strømningsmålere.
- Kunne installere magnetiske strømningsmålere
- Kunne installere ultralyd strømningsmålere.

Del 5

Emne for leksjonen: Andre strømningsmålere.

Oppgave 91-120; besvar oppgave 91-99 som forberedelse til laksjonen (remainder for practice)

Målet for leksjonen er å gi en oversikt over måleprinsippene for ulike strømningsmålere som ikke kommer inn under de andre kateboriene.

Læringsmål:

- Kunne installere coriolis strømningsmålere.

Oppgave 1

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

Trykkbaserte strømningsmålere virker med å tvinge et fluid til å *akselerere* eller *deakselerere* mens det strømmer igjennom et rør. Dette gjør at det oppstår en trykkforsjell. Plukk ut noen av de forskjellige måleelementene (metoder) som brukes til å skape denne akselerasjonen eller deakselerasjonen. (hint. Venturirør er et eksempel)

For hvert ev måleelementene finn ut om de virker med å akselerere eller deakselerere fluidet. Forklar hvorfor du tror det.

I hvilken del av måleelementet er trykket størst, der hvor hastigheten er størst eller der hvor hastigheten er minst. (Hint. så på hvordan DP-cellen er tilkoblet.)

Suggestions for Socratic discussion

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04020

Oppgave 2

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

To vanlige typer av "variabelt areal" strømningsmwler er *rotameter* og *Weirs*. Forklar hvordan hver av disse strømningsmålerene virker, og nøyaktiv hvor strømningsarealet varierer ettersom strømningsraten øker eller minker.

Suggestions for Socratic discussion

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04021

Oppgave 3

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

Forklar hvordan et turbinflowmeter måler hastigheten til et fluid når strømmer igjennom et rør.

Forklar hva *von Kármán* effekten er, og hvordan den kan utnyttet til å måle hastigheten til en gass eller en væske.

Forklar hvordan en elektromagnetisk strømningmåler måler hastigheten til et fluid.

Forklar hverdan en ultralyd strømningsmåler måler hastigheten til et fluid.

Explain how an *optical* flowmeter measures fluid velocity. Forklar hvordan et optisk flowmeter måler hastigheten til et fluid.

| Suggestions for Socratic discussion |

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04022

Oppgave 4

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

Positiv fortrenings strømningsmålere har beveglige deler for å måle når et fluid passerer igjennom dem, de skiller seg likevell fra andre strømningsmålere med beveglige deler (som f.eks. turbinmeter). Forklar hva som er anderledes med positiv fortrengings strømningsmålere.

| Suggestions for Socratic discussion |

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04025

Oppgave 5

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

En spesiell type strømningsmåler er *Corilis*-strømningsmåler. Forklar så godt du kan hvordan denne type strømningsmåler virker.

| Suggestions for Socratic discussion |

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04023

Oppgave 6

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

Det føles kaldere ute når det blåser, forklar hvordan dette prinsippet kan brukes til å måle hastigheten til et fluid i et rør.

Ut fra de måtene du vet at varme kan overføres, hvilken brukes av temiske flowmeter? *varmeleding*, *konveksjon* eller, *varmestråling*.

| Suggestions for Socratic discussion |

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04024

Oppgave 7

Skummles "Continuous Fluid flow Measurment" kapittelet i afgv.pdf for spesifikt å besvare disse spørsmålene:

Describe what a *weighfeeder* is, and what sort of process material flowrate it is designed to measure.

| Suggestions for Socratic discussion |

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04026

Oppgave 8

Skim the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook to specifically answer these questions:

You have already explored how *load cells* may be used to infer the amount of material stored in process vessels. Explain how these same devices may be used to infer flowrate in and out of the same vessels using the *change-of-quantity* technique.

Suppose an instrument technician decides to build a flowmeter for her propane-fueled barbecue, by placing the propane fuel tank on top of an electronic weigh scale (like a standard bathroom scale). Explain how the technician could take the measurements given by this scale and somehow convert them to register as a *flowrate* of propane gas.

Suggestions for Socratic discussion

- Identify different strategies for "skimming" a text, as opposed to reading that text closely. Why do you suppose the ability to quickly scan a text is important in this career?

file i04027

Oppgave 9

Read and outline the "Work, Energy, and Power" subsection of the "Classical Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
file i04028

Oppgave 10

Calculate the amount of potential energy stored in the mass of an elevator plus its cargo of potatoes (570 pounds) as it lifts up to a height of 10 feet. Express this potential energy in both British and metric units. Also, identify which equation is more convenient to use for this calculation: $E_p = Fx$ or $E_p = mgh$?

Calculate the kinetic energy of a bullet with a mass of 150 grains (9.7198 grams) traveling at a velocity of 2820 feet per second, expressing your answer in both British and metric units.

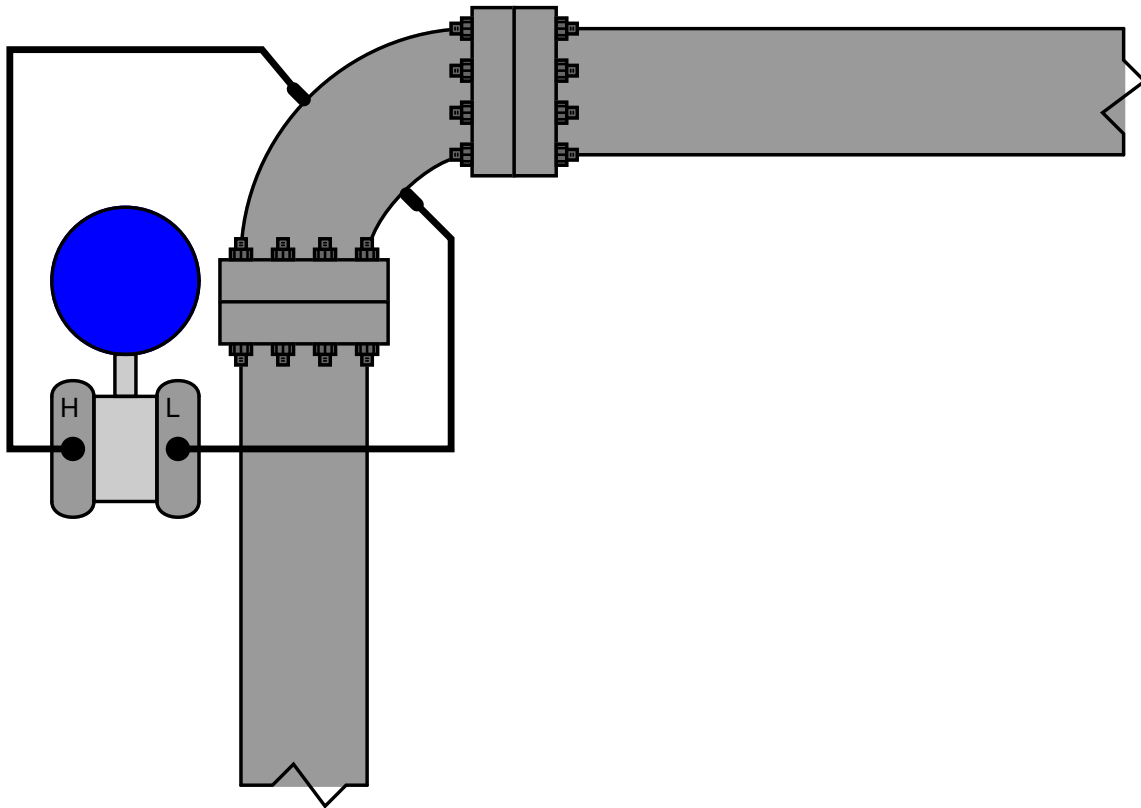$\boxed{\textbf{Suggestions for Socratic discussion}}$

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

- Describe the various energy-transfer operations taking place when a crane lifts a heavy weight and then sets it down in a different location.

- If a crane lifts a weight 10 feet above the ground, then sets that weight down on top of an object 6 feet above the ground, is energy still conserved? Explain in detail.

- Identify how to secure a crane in a zero-energy state prior to performing maintenance work on it.

- Which has a greater effect on a moving object's kinetic energy: an increase in mass or an increase in velocity?

- If an automobile doubles its speed, how much longer (distance) will it take to skid to a complete stop if the driver suddenly applies the brakes?
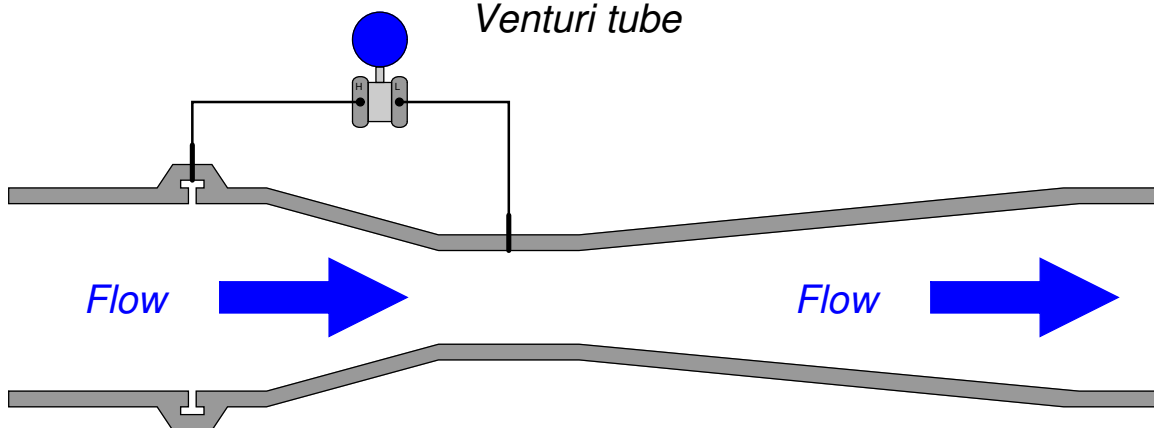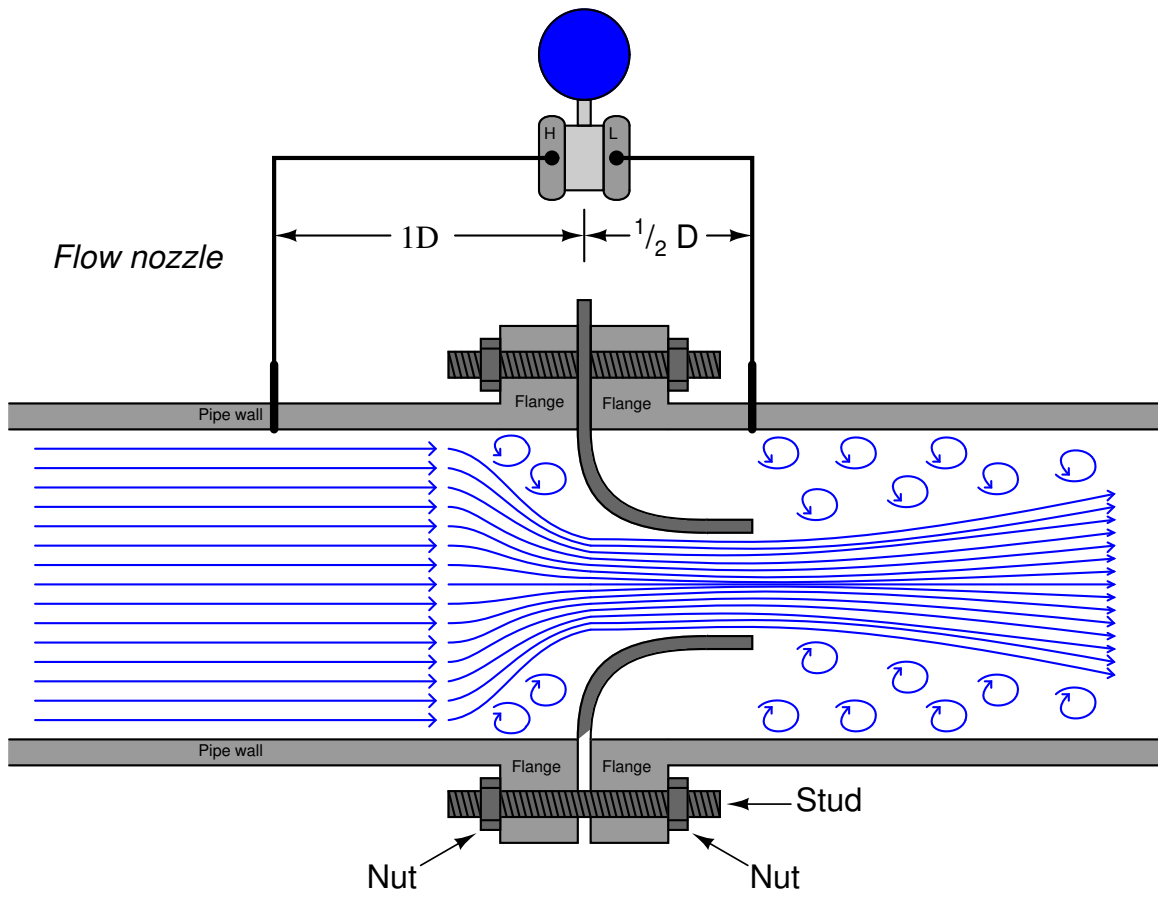
file i04029

Den etablerte måleblenden er en av mange forskjellige måleelementer som virker ved å generere en trykkforskjell. Forklar kort hvordan hvert av disse måleelementene virker.
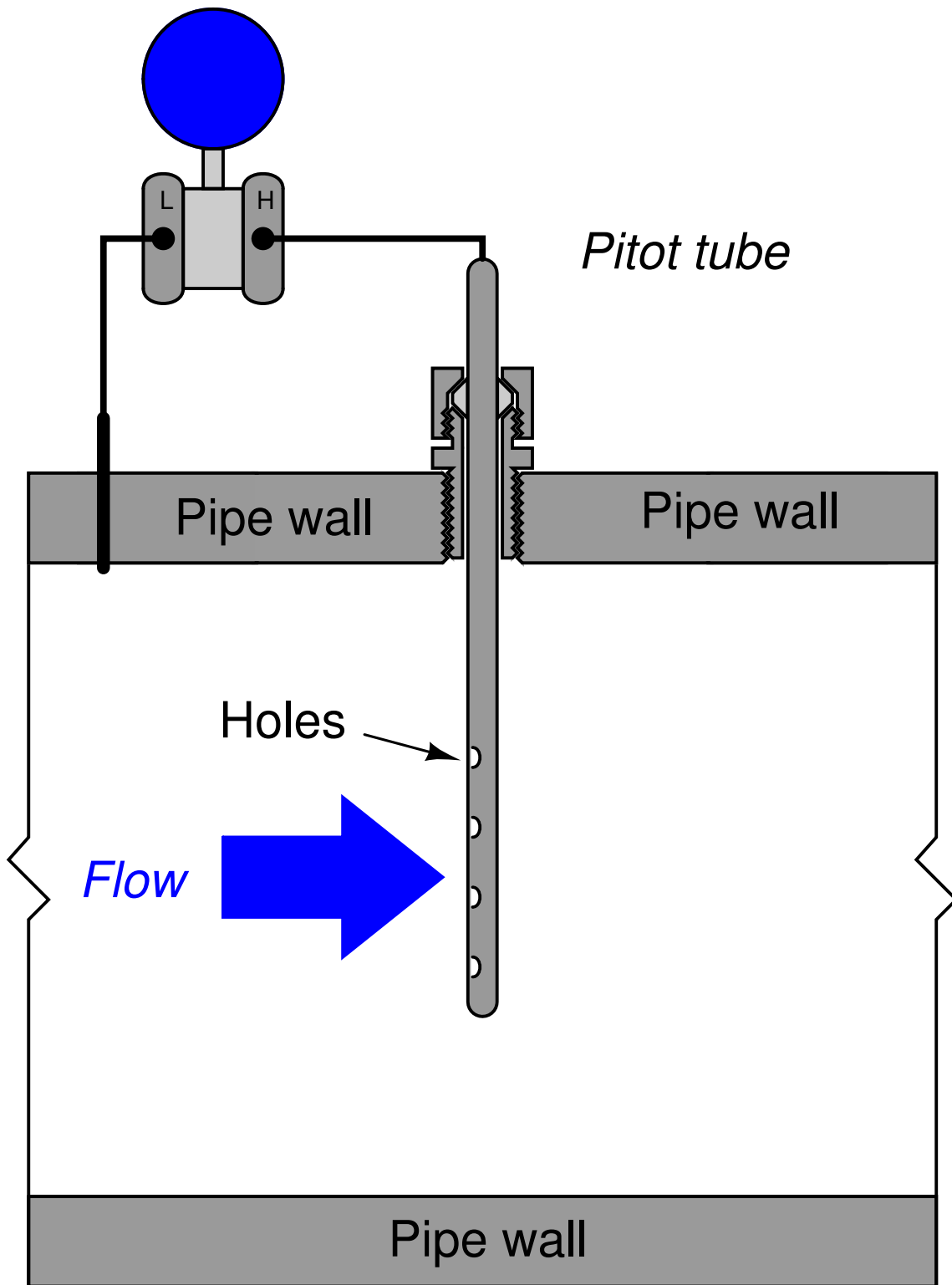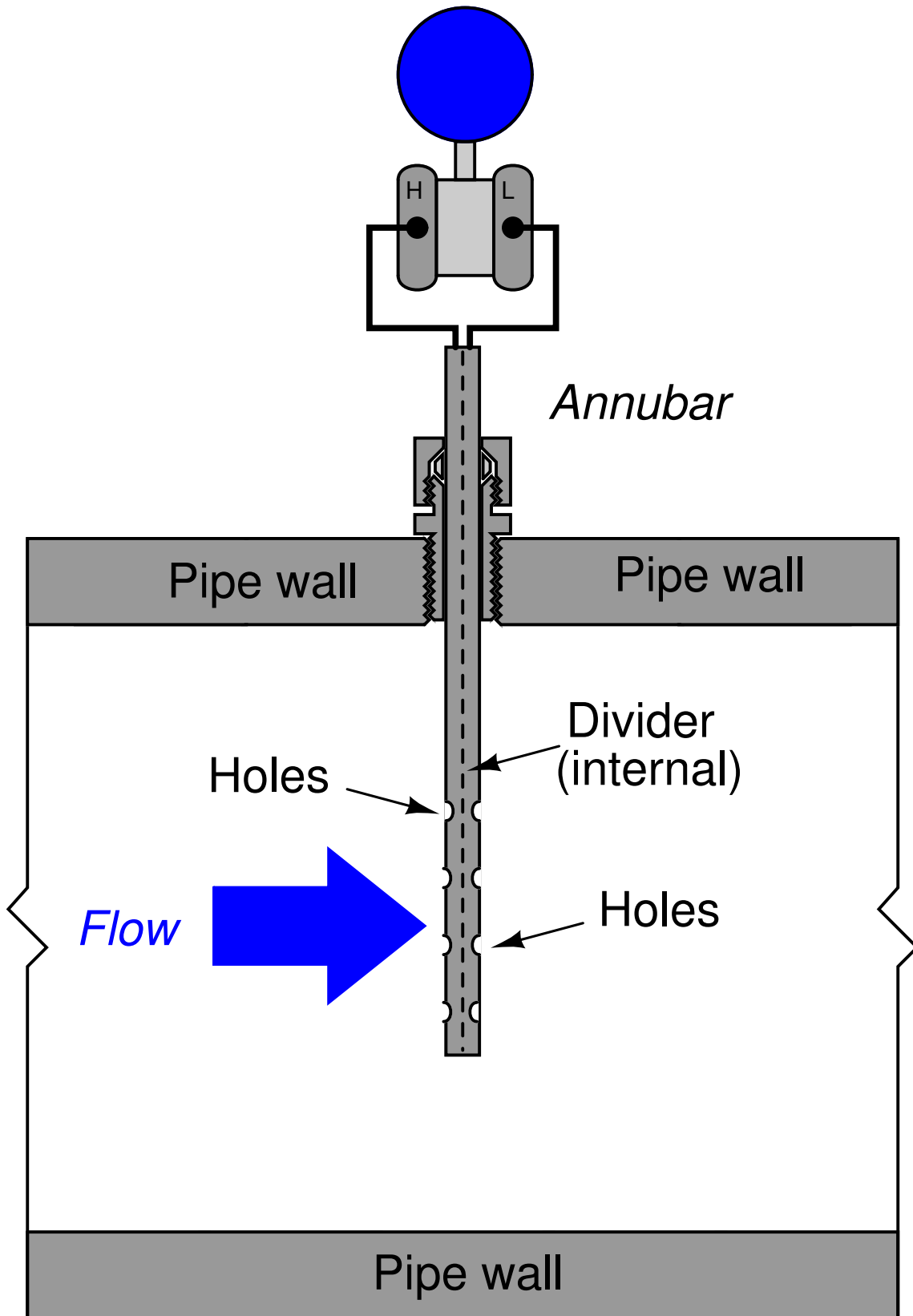
Pipe elbow

Venturi tube

Flow

Flow

Flow nozzle

1D

$^1/_2$ D

H   L

Pipe wall

Flange   Flange

Pipe wall

Flange   Flange

Stud

Nut   Nut

Pitot tube

Pipe wall

Pipe wall

Holes

Flow

Pipe wall

Annubar

Pipe wall

Pipe wall

Divider
(internal)

Holes

Flow

Holes

Pipe wall

Force-measuring mechanism

Target

Pipe wall

Pipe wall

Flow

Drag disk

Pipe wall

V-cone

Segmental wedge
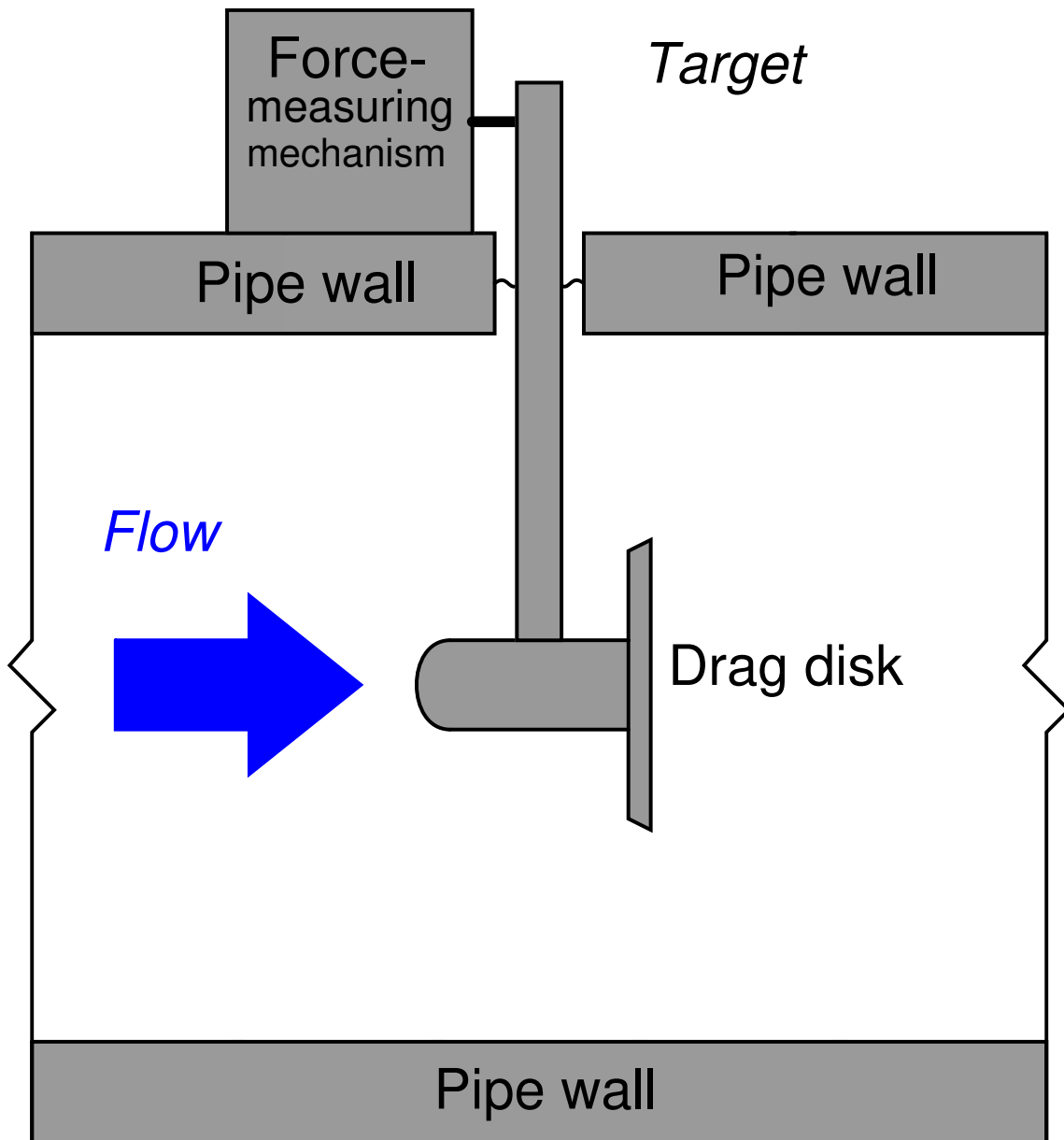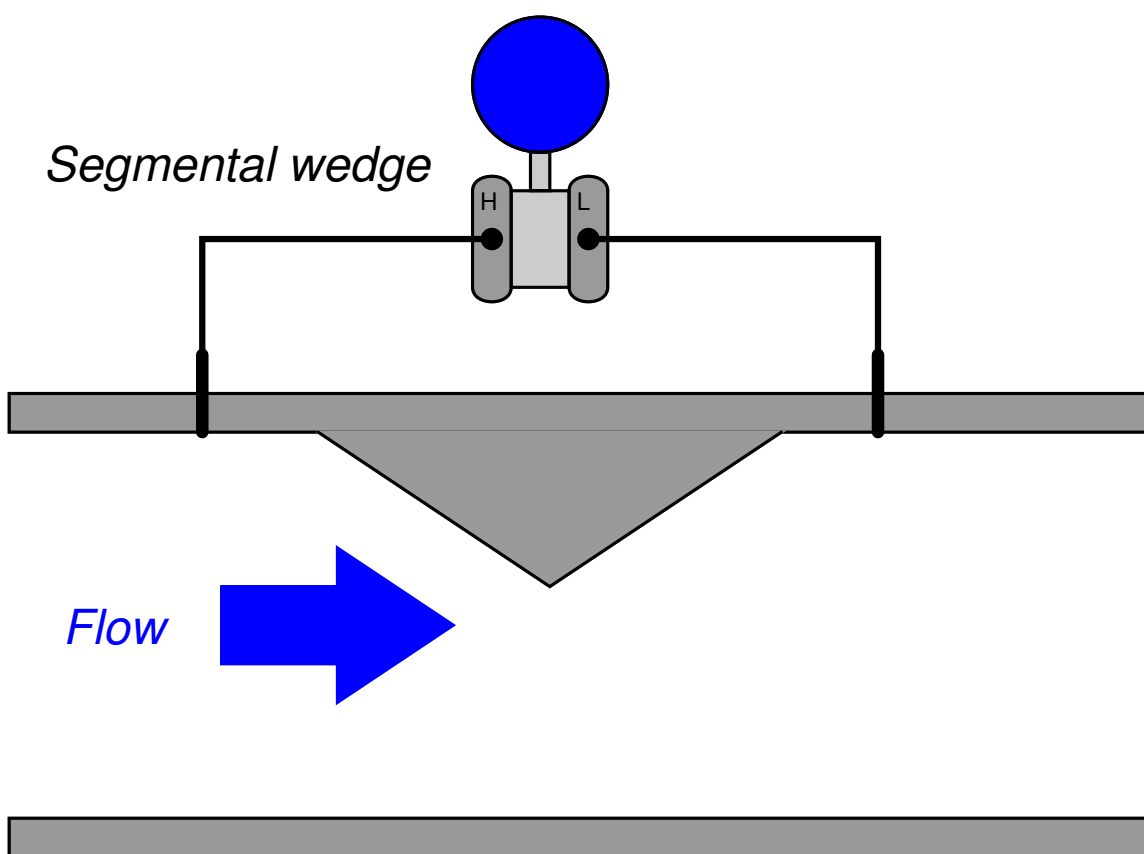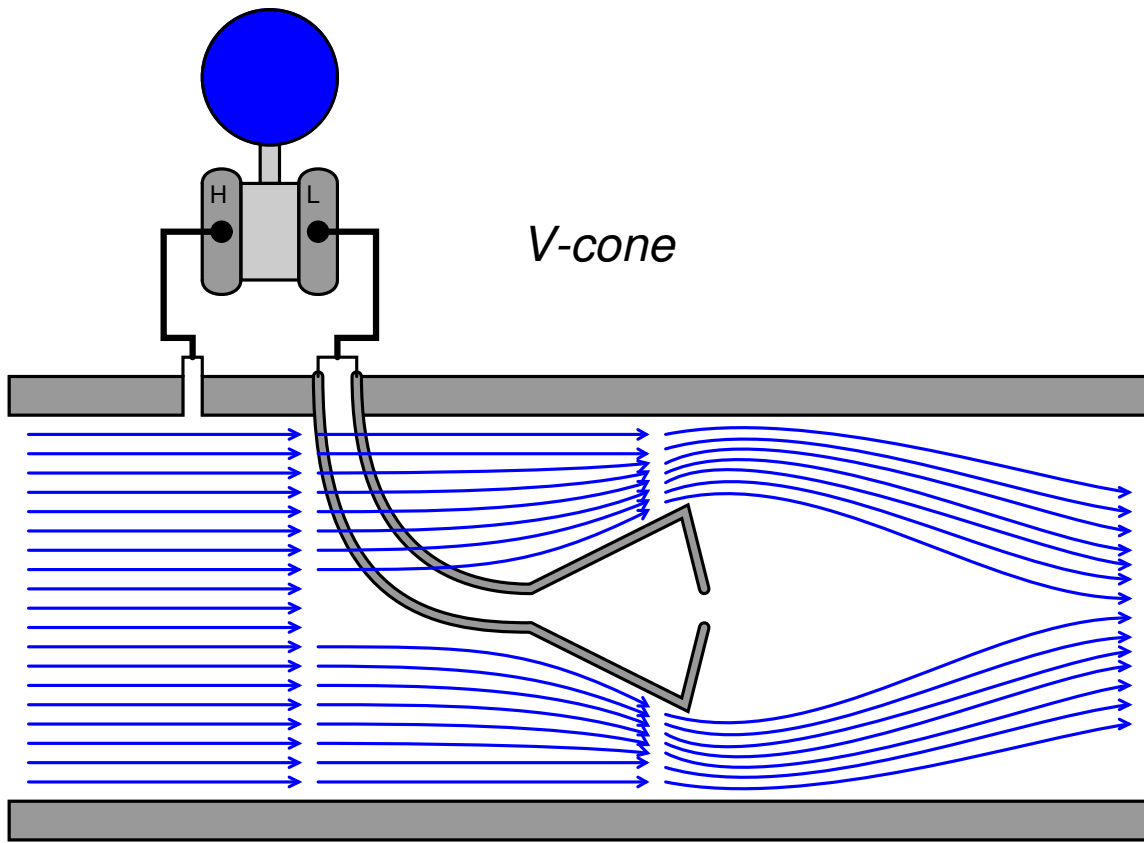
Flow

Oppgave 12

Michael Faraday, den berømte Engelsek fysikeren, prøvde en gang å elektrisk måle strømingen i elven Themsen. Teknikkenhans, som ikke virket, var basert på at en ledende væske beveger seg igennom et magnetfelt. Forklar hva Michael Faraday gjorde og hvordan vi kan bruke denne teknikken til å måle strømningen i et rør.

Oppgave 13

Noen dyr bruker ekkolokasjon for å finne veien i mørket. Ubåter bruker sonar til det samme. Forklar hvordan dette prinsippet kan brukes til å akustisk måle avstanden til et objekt. Hvordan kan vi bruke dette til å måle hastigheten til et objekt?

Oppgave 14

Hva menes med massestrøm sett i forhold til volumstrøm?

Oppgave 15

På kalde dager, blir følelsen av temperatur forstyrret om det blåser. Selv om et thermometer ikke vil vise lavere temperatur når det blåser, så føles det kaldere. Denne effekten bruke av i værmeldinger som føles som temperatur.

Den samme effekten kan brukes til å måle massestrømning. Strømningsmålere basert på dette prinsippet kalles terminsk strømningsmåler. Forklar hvordan termiske strømningsmålere er konstruert.

Oppgave 16

Coriolis massestrømningsmålere har flere fordeler over andre strømingsmålere. Dette gjør at det ofte er verdt den høye kostnaden som er forbundet med anskaffelse. List opp noen av fordelen og eventuelt ulamper med denne teknologien.

Oppgave 17

Det er et problem en eller annen plass i dette væskestrømningsreguleringssystemet. Regulatoren er i auto-modus, med et settpunkt på 65%, men likevell viser FT og FIC 0.3% (nesten ingen strømning).
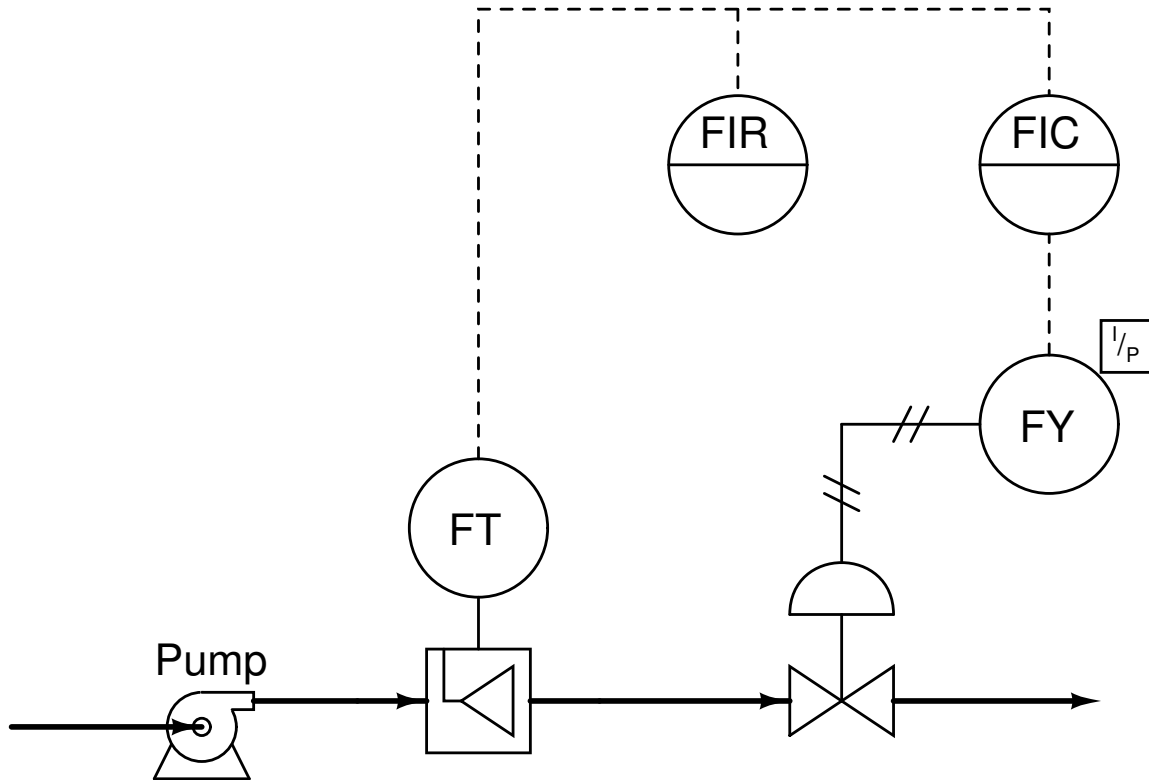
Forklar hvordan du ville feilsøkt i dette systemet, og hvilke mulige feil som kan forårsake at regulatorn ikke klarer å holde settpunktet.

Suggestions for Socratic discussion

- Explain how you could divide this control system into distinct areas or zones which you may then begin to refer to when "dividing and conquering" the problem.

file i02518

Oppgave 18

Oppgave 19

Oppgave 20

Oppgave 21

Les og understrek afgv.pdf/Phusices/Fluid Mechanics/Fluid Viscosity kapittelet. Noter sidenummer med viktige illustasjoner, bilder, formler og annen viktig informasjon. Forbered deg på å kunne diskutere emnet fluid viskositet.

file i04030

Oppgave 22

Les og understrek afgv.pdf/Phusices/Fluid Mechanics/Reynolds Number. Noter sidenummer med viktige illustasjoner, bilder, formler og annen viktig informasjon. Forbered deg på å kunne diskutere emnet fluid viskositet.
file i04031

Oppgave 23

Les og understrek afgv.pdf/Phusices/Fluid Mechanics/Law of Continuity. Noter sidenummer med viktige illustasjoner, bilder, formler og annen viktig informasjon. Forbered deg på å kunne diskutere emnet fluid viskositet.
file i04032

Oppgave 24

Vi har et rør som det strømmer olje med en strømningsrate på 120 m³/h og en temperatur på 50°C. Begge seksjonene er etter schedule 40. Den første delen av røret har dimensjon DN200 (ID=202.74mm) og den andre delen har dimensjon DN65 (ID=62.68mm)
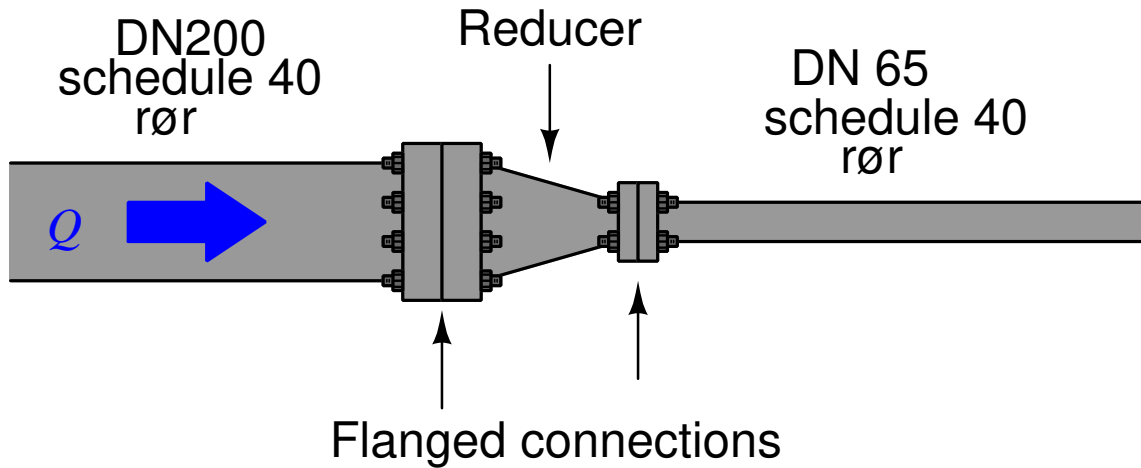
Regn ut hastigheten for fluidet i røret h hver av seksjonene. Regn også ut den volumentriske strømningsraten i *gallons per minute* (GPM).

I hvilken seksjon av røret har oljestrømmen høyest reynolds nummer?

| Suggestions for Socratic discussion |

- This question is a good application of the *Law of Continuity*, but this law is really nothing more than an expression of a more fundamental law in physics. What is this more fundamental law, and what does it tell us about flow through a pipe?

- Once we know the fluid velocity in one section of the pipe, show how we may calculate the velocity in the other section of the pipe using nothing but a ratio of pipe diameters ($\frac{7.981}{2.469}$), rather than re-calculate the continuity formula again ($v = \frac{Q}{A}$).

- Where along this pipe will individual fluid molecules possess the greatest kinetic energy?

Schedule 40 Pipe 8 Inch (DN200 mm)
Standard : ANSI/ASME B36.10(Steel Pipe)
– Size : NPS 8 Inch
– Size : DN200 mm
– Inside Dimeter(Pipe ID) : 202.74 mm
– Outside Dimeter(Pipe OD) : 219.1 mm
– Pipe Wall Thickness : 8.18 mm
– Pipe Weight : 42.55 Kilogram per meter (kg/m)
– Pipe Weight Including Water : 74.81 Kilogram per meter (kg/m)
NPS = Nominal pipe size(inch) / DN = Diameter nominal(mm)

Schedule 40 Pipe 2 1/2 Inch (DN65 mm)

Standard : ANSI/ASME B36.10(Steel Pipe)
– Size : NPS 2 1/2 Inch
– Size : DN65 mm
– Inside Dimeter(Pipe ID) : 62.68 mm
– Outside Dimeter(Pipe OD) : 73 mm
– Pipe Wall Thickness : 5.16 mm
– Pipe Weight : 8.63 Kilogram per meter (kg/m)
– Pipe Weight Including Water : 11.71 Kilogram per meter (kg/m)
NPS = Nominal pipe size(inch) / DN = Diameter nominal(mm)
file i04033

Oppgave 25

A flowmeter installed in a 6-inch schedule 40 pipe (internal diameter = 6.065 inches) to measure the flow of olive oil requires a Reynolds number of at least 12,500 to function properly. Calculate the minimum flow rate of oil through this pipe that the flowmeter can measure, assuming the oil's density is 57.3 pounds per cubic foot and its absolute viscosity is 111 centipoise.

Additionally, calculate the minimum average flowing velocity of the olive oil for the flowmeter to properly function.

$\boxed{\textbf{Suggestions for Socratic discussion}}$

- How may a piping system be modified to increase the Reynolds number of the flow, for the sake of measuring that flow rate with a flowmeter requiring a high Reynolds number? Keep in mind that the actual flow rate is fixed here – we must vary something else to boost Reynolds number for any given flow rate.

- Does the temperature of the liquid have any effect on its Reynolds number? Why or why not?

- If this pipe were flowing water rather than olive oil, what would the minimum flow rate be to satisfy the Reynolds number requirement of this flowmeter?

file i04034

Oppgave 26

Read and outline the "Bernoulli's Equation" subsection of the "Fluid Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
file i04035

Oppgave 27

Read and outline the "Flow Through a Venturi Tube" subsection of the "Fluid Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
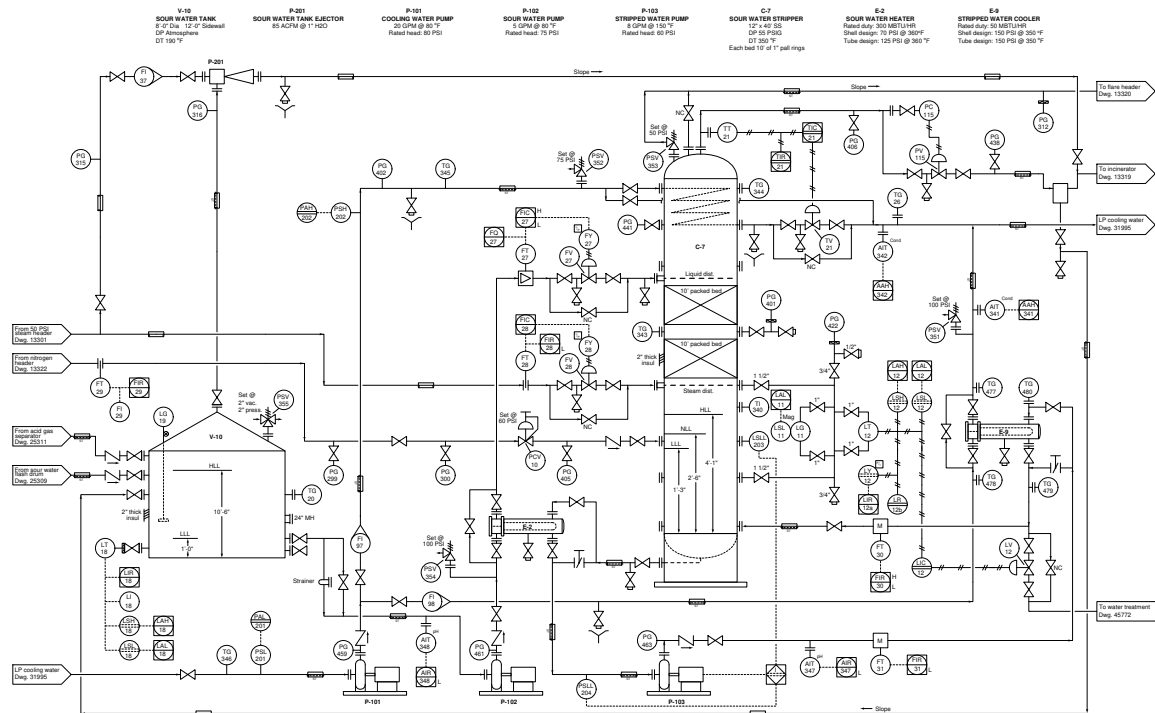
file i04036

Oppgave 28

Examine this P&ID and explain how a vacuum is produced in the sour water storage tank (V-10):

Furthermore, identify what operators would have to do in order to halt the production of vacuum, to make it safe to open an access hatch on V-10 for inspection. Also, identify how the level of sour water inside the tank is measured.
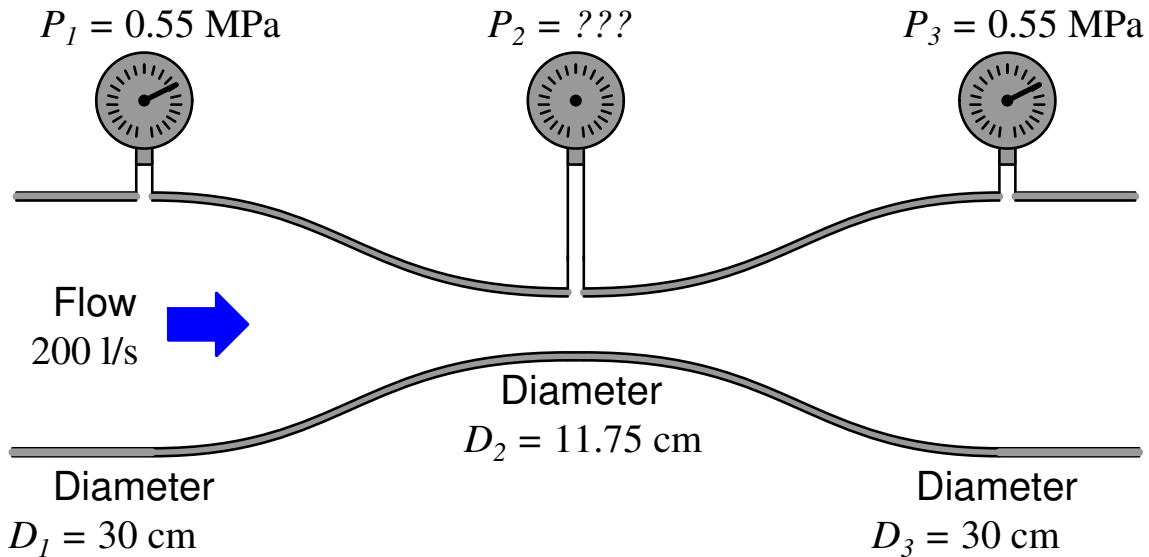

Suggestions for Socratic discussion

- Identify how this sour water storage tank is protected against excessive pressure or vacuum, which could rupture it or collapse it, respectively.

file i03490

Oppgave 29

Bruk Bernoulli's formel for å regne ut trykket P_2. Massetettheten til fluidet er $\rho = 800 kg/m$

Bernoulli's formel:

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

Where,
z = Height of fluid, in meter (m)
ρ = Mass density of fluid, in kg per kubikkmeter (kg/m^3)
g = Acceleration of gravity (9.81 m/s^2)
v = Hastigheten til fluidet i meter per sekund (m/s)
P = Trykket av fluidet i Pascal (Pa=N/m^2)

Til slutt regn ut differansetrykket i dette venturi måleelementet. (ΔP)

Suggestions for Socratic discussion

- The textbook outlines a general strategy for generating a problem-solving plan when tackling problems with complex mathematical formulae. Specifically, this strategy involved writing out the formulae and linking variables between formulae with arrow symbols. Explain how this strategy works, and show how it may be applied to the solution of this problem.

- A very helpful strategy for tackling Bernoulli's equation problems is to create a table in which to place each of the "head" terms of that equation. Explain why this is helpful to manage this specific type of problem.

- Once we know the velocity of the fluid (v) at any point in the tube, is there a way to easily solve for the velocity in any other point in the tube based on a ratio of tube diameters? For instance, here we know there is a 5:12 ratio of diameters from

the throat to the mouth of the tube. How can we employ this 5:12 ratio to easily determine the velocity at one point (either mouth or throat) knowing the velocity at another?

<u>file i00452</u>

Oppgave 30

Bruk Bernoulli's formel for å regne ut trykket P_2. Massetettheten til fluidet er $\rho = 800 kg/m$

P_1 = 0.55 MPa P_2 = ??? P_3 = 0.55 MPa

Flow
400 l/s

Diameter
D_2 = 11.75 cm

Diameter
D_1 = 30 cm

Diameter
D_3 = 30 cm

Bernoulli's formel:

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

Where,
z = Height of fluid, in meter (m)
ρ = Mass density of fluid, in kg per kubikkmeter (kg/m^3)
g = Acceleration of gravity (9.81 m/s^2)
v = Hastigheten til fluidet i meter per sekund (m/s)
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Til slutt regn ut differansetrykket i dette venturi måleelementet. (ΔP)

Suggestions for Socratic discussion

- The textbook outlines a general strategy for generating a problem-solving plan when tackling problems with complex mathematical formulae. Specifically, this strategy involved writing out the formulae and linking variables between formulae with arrow symbols. Explain how this strategy works, and show how it may be applied to the solution of this problem.

- A very helpful strategy for tackling Bernoulli's equation problems is to create a table in which to place each of the "head" terms of that equation. Explain why this is helpful to manage this specific type of problem.

- Venturi tubes are often used to create *vacuums*, by passing some fluid through the venturi at high speed and then providing a vacuum tap at the throat. Automobile engine carburetors and atomizing spray guns are two prominent examples of this.

In industry, another example is the so-called *steam eductor*, using a jet of high-velocity steam through a venturi to create continuous suction (vacuum). Are there any advantages to using eductors to create vacuums as opposed to using mechanical vacuum pumps? Are there any disadvantages to the use of eductors for creating vacuums?

file i00451

Oppgave 31

As best as possible, define *Reynolds number* for a fluid flow using your own words.

Regn ut reynolds nummer for 32 liter vann per sekund (at 20° C) som strømmer i et rør med en diameter på 22 cm.
file i00440

Oppgave 32

Jeg kan fylle et kar på 4 liter kjøkken springen på 30 sekunder. Røret til kjøkkenspringen har en ID=12.5mm. Regn ut Reynols tall for denne strømningen. Vil det være turbulent eller laminær stømning?
file i00442

Oppgave 33

If we poke a hole at the bottom of a vessel containing an otherwise static column of liquid, we have an application for Bernoulli's equation at three different points in the system:
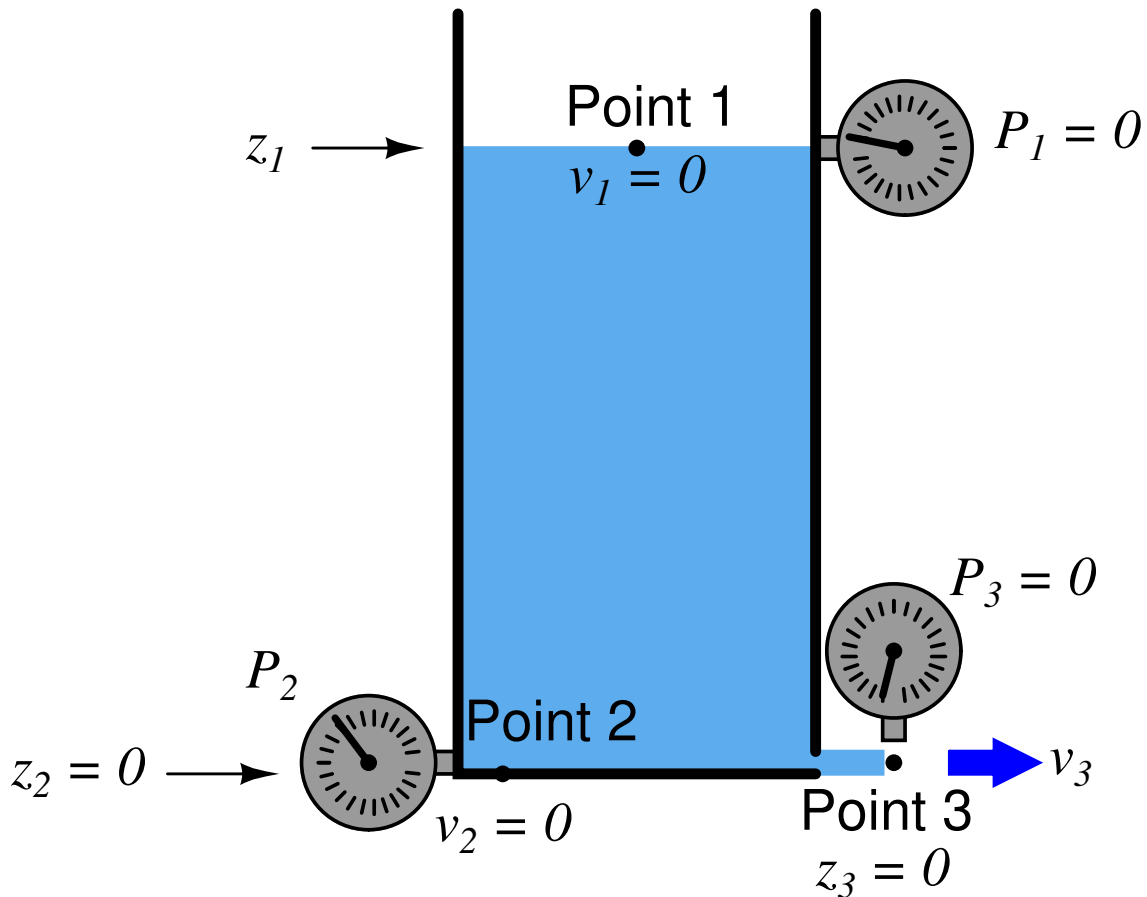
Note that point 1 has no velocity or pressure, but it does have elevation (height); point 2 has no velocity or elevation, but it does have pressure; and point 3 has no elevation or pressure, but it does have velocity.

Use Bernoulli's equation to write a new equation relating the elevation of point 1 with the pressure of point 2 and the velocity of point 3, and then solve for the velocity at point 3 in terms of the other two points' non-zero variables.
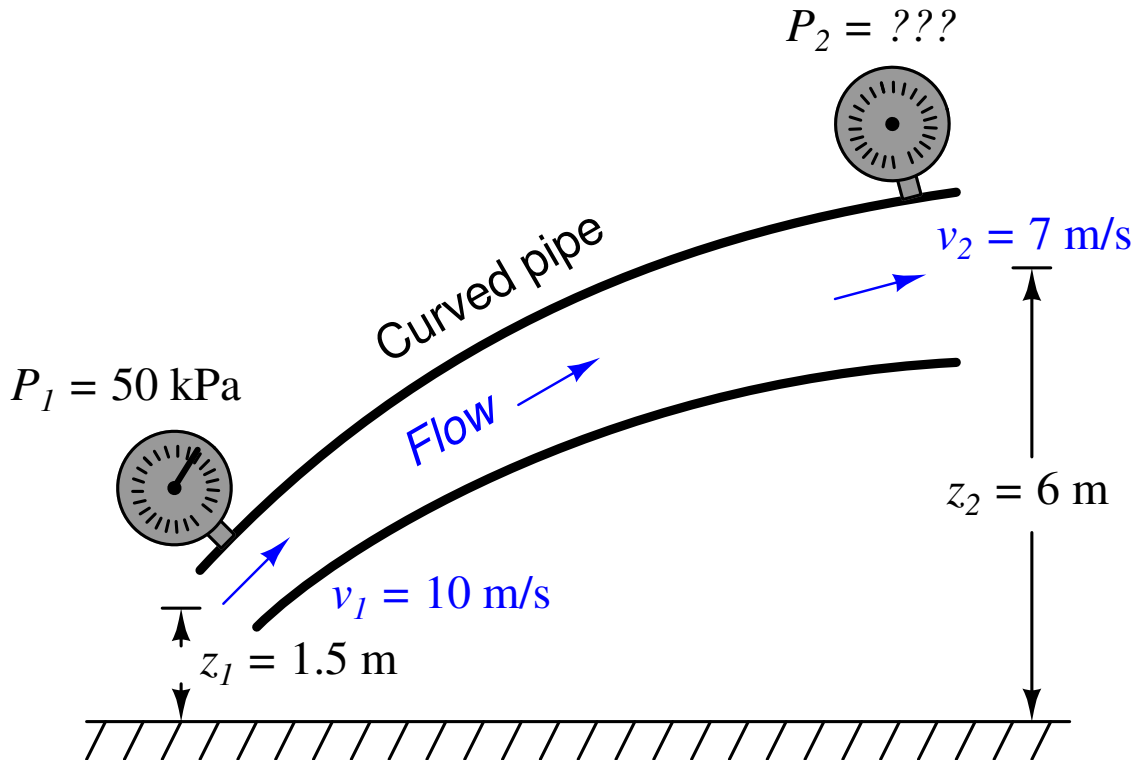
Bernoulli's equation:

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

file i00446

Oppgave 34

Regn ut trykket på utløpet av dette røret (P_2), om en antar at det strømmer vann ($\rho =$ 998.19) og at strømningen skjer uten friksjon.(en får ikke trykktap som følge av friksjon mot rørveggen).

$P_2 = ???$

$v_2 = 7$ m/s

Curved pipe

$P_1 = 50$ kPa

Flow

$z_2 = 6$ m

$v_1 = 10$ m/s

$z_1 = 1.5$ m

Bernoulli's equation:

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

Suggestions for Socratic discussion

- One way students commonly fail to arrive at the correct answers with Bernoulli's Law calculations is by using incompatible units of measurement. Show how all the units of measurement provided to you in this question are compatible in their given forms, with no need for conversion.

file i00450

Oppgave 35

Both Bernoulli's and Torricelli's equations provide a mathematical relationship between pressure and flow rate, which means we should be able to measure pressure and thereby infer flow:

Differential pressure resulting from pressure drop at venturi throat:
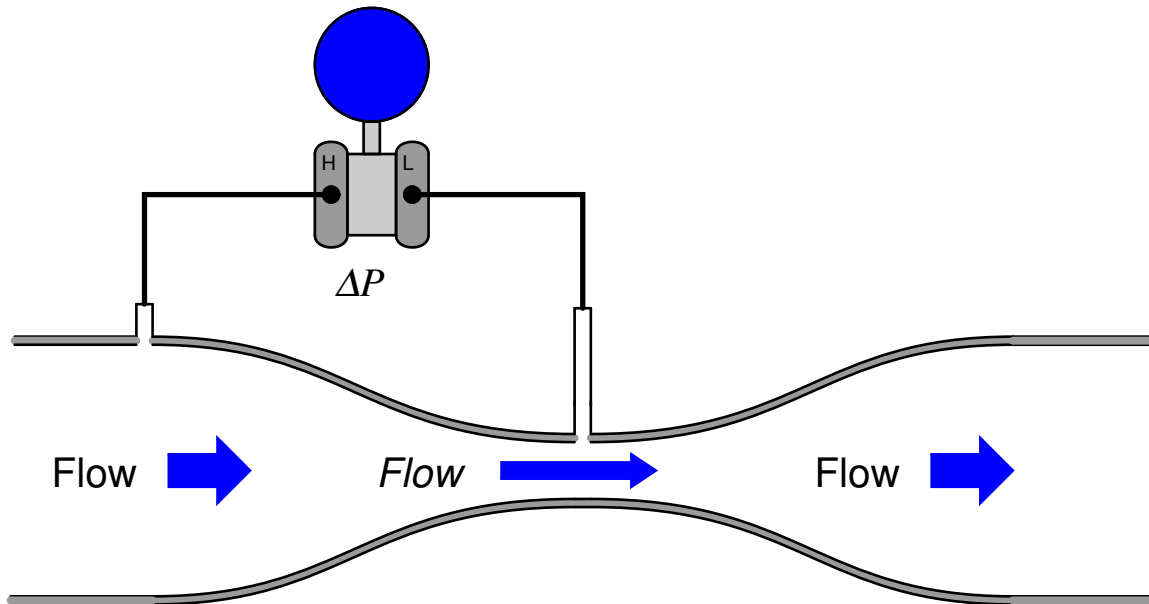
Hydrostatic pressure resulting from liquid column height:
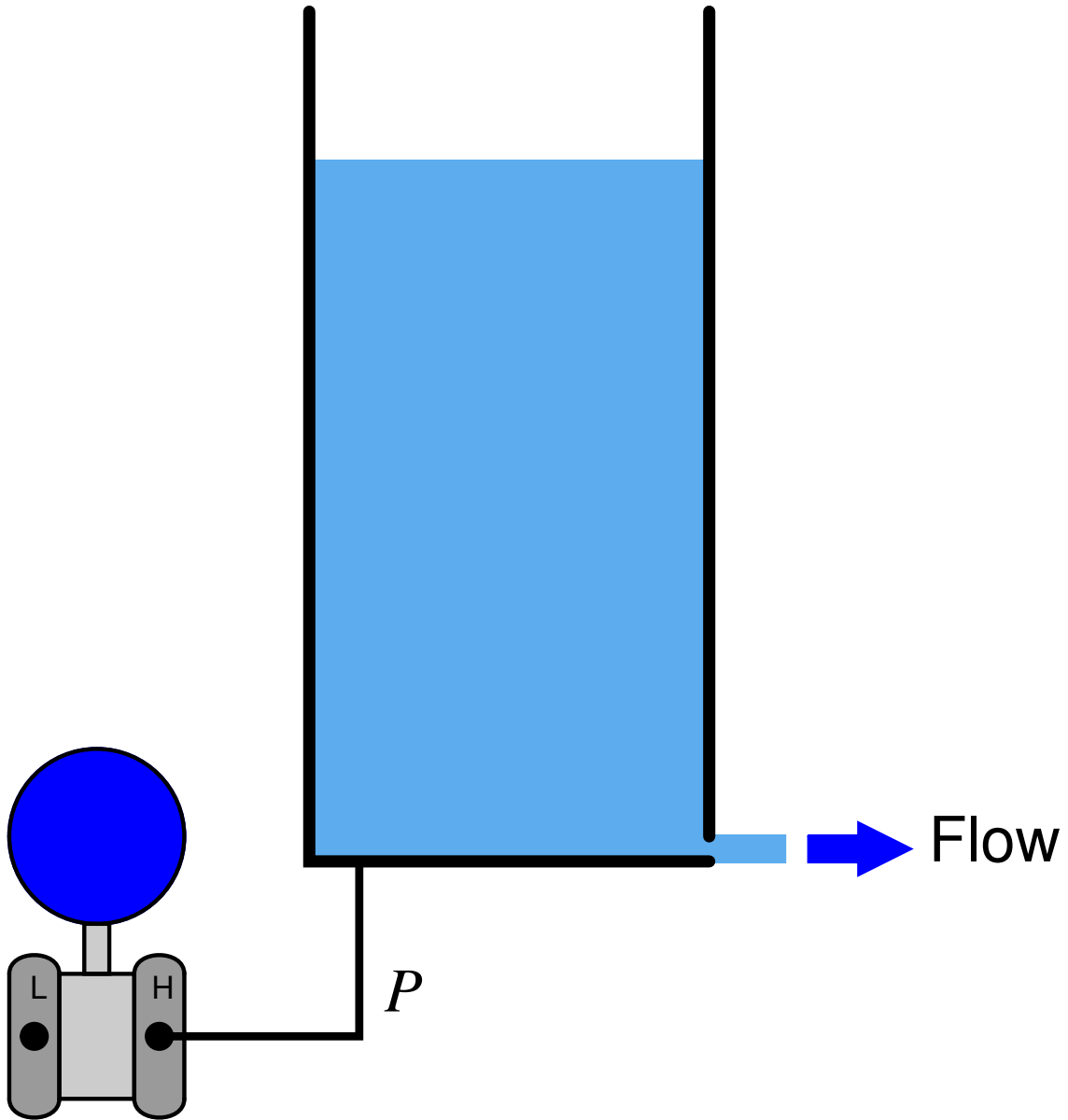
One problem, though, is that the mathematical relationship in either of these scenarios is *not* linear. Based on Bernoulli's and/or Torricelli's equations, what type of relationship is this? What would we have to do to the pressure transmitter's signal to obtain a linear representation of flow?

<u>file i00453</u>

Oppgave 36

Regn ut trykkene P_1 and P_2, anta at massetettheten til fluidet er 886.45 kg/m^3.

P_2 = ???

DN20
(schedule 80)
ID = 19.37 cm

2.77 meter

DN15
(schedule 80)
ID = 14.40 cm

P_1 = ???

2 meter

P = 2 MPa

P = 0.1 MPa

DN20
(schedule 40)
ID = 20.27 cm

Pump

DN20
(schedule 40)
ID = 20.27 cm

Q = 454 m^3/h
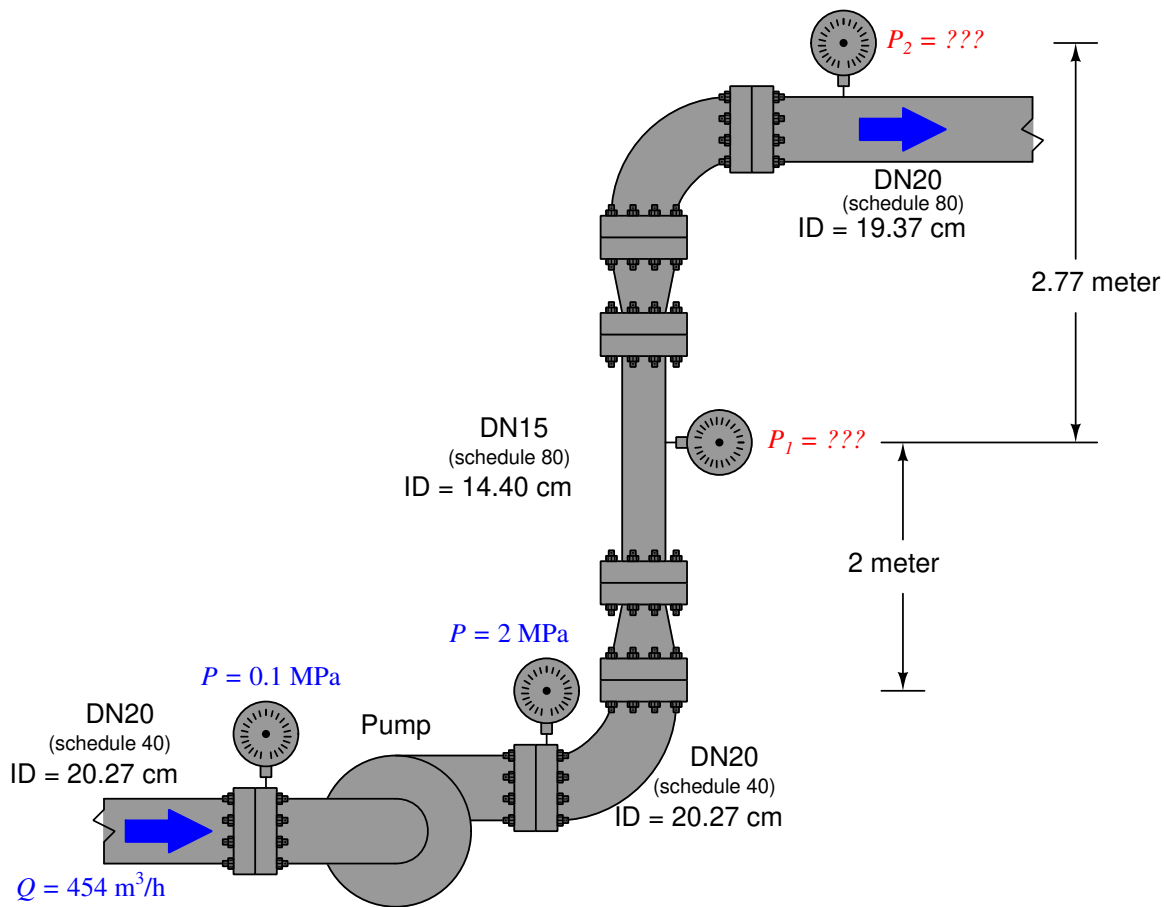
Also, comment on whether or not Bernoulli's equation could be used to compare the suction and discharge pressures of the pump, being that those two pressures (145 and 302 PSI) are measured on the same size pipe, with the same flow rate, and very similar elevations (heights).
<u>file i00457</u>

Oppgave 37

Oppgave 38

Oppgave 39

Oppgave 40

Oppgave 41

Read and outline the "Venturi Tubes and Basic Principles" subsection of the "Pressure-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04037

Oppgave 42

Read and outline the "Volumetric Flow Calculations" and "Mass Flow Calculations" subsections of the "Pressure-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04038

Oppgave 43

Read and outline the "Square-Root Characterization" subsection of the "Pressure-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04039

Oppgave 44

Read and outline the "Orifice Plates" subsection of the "Pressure-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04040

Oppgave 45

Read and outline the "Other Differential Producers" subsection of the "Pressure-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04041

Oppgave 46

Read and outline the "Proper Installation" subsection of the "Pressure-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04042

Oppgave 47

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 $Q = 270$ m³/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:

- $Q = 110$ m³/h ; ΔP = _____ kPa

- $Q = 55$ m³/h ; ΔP = _____ kPa

- $Q = 140$ m³/h ; ΔP = _____ kPa

- $Q = 215$ m³/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 48

Suppose a 6 inch V-cone flow element is sized to generate a ΔP of 30 kPa at a flow rate of 160 m³/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 m³/h ; ΔP range = _____

- Q range = 0 to 140 m³/h ; ΔP range = _____

- Q range = 0 to 180 m³/h ; ΔP range = _____

- Q range = 0 to 230 m³/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 49

A horizontal venturi tube at a seawater desalinization plant is sized to produce 37.25 kPa while flowing at 1400 m³/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 m³/h, and at a lighter density of 1.01 g/cm³.

Assuming a water density of 1.03 g/cm³ 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/cm³ 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 50

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 51

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 52

Calculate the pressure at the discharge end of this pipe (P_2), assuming water as the fluid (with a mass density $\rho = 1005.5$ kg/m^3), 9.81 m/s^2 as the acceleration of gravity (g), and frictionless flow (no pressure loss due to friction):

$P_2 = ???$

$v_2 = 1.2$ m/s

Curved pipe

Flow

$P_1 = 0.814$ MPa

$z_2 = 6.4$ m

$v_1 = 3$ m/s

$z_1 = 2.13$ m
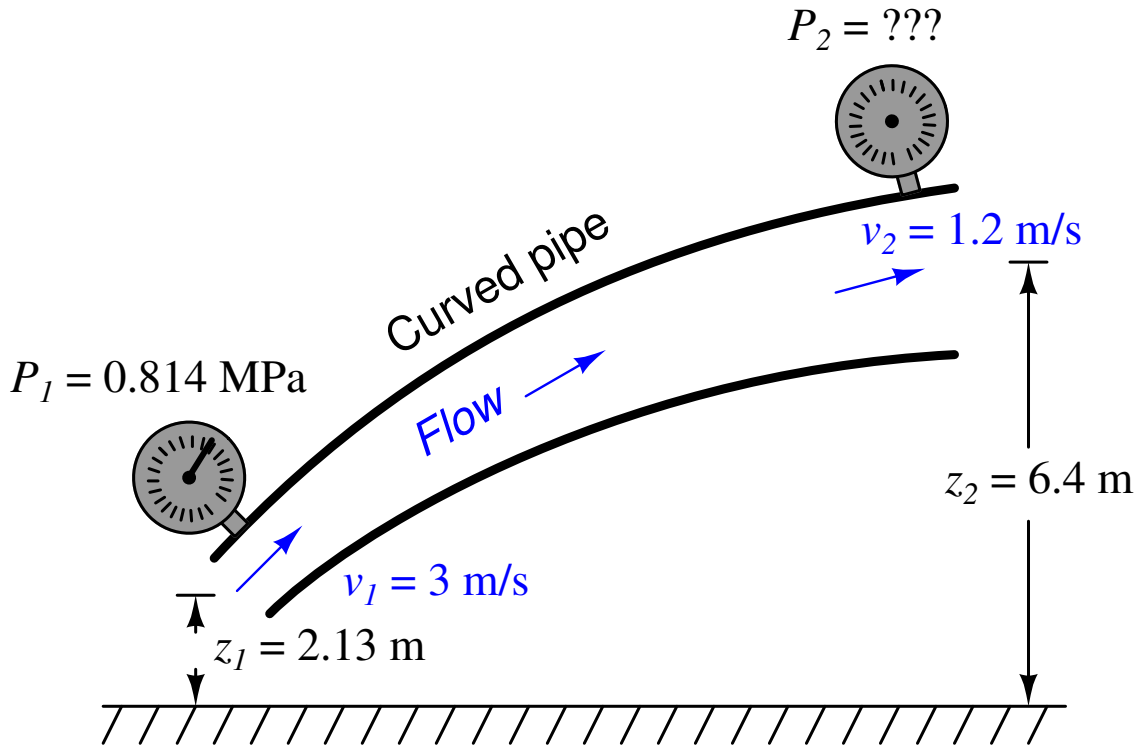
Bernoulli's equation:

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

file i02978

Oppgave 53

The following illustration shows a portion of water piping from an overhead view, looking down toward the ground (a "birds-eye" view). The pipe itself is completely level (parallel) with the ground, so that all points along the pipe centerline are at the same height:
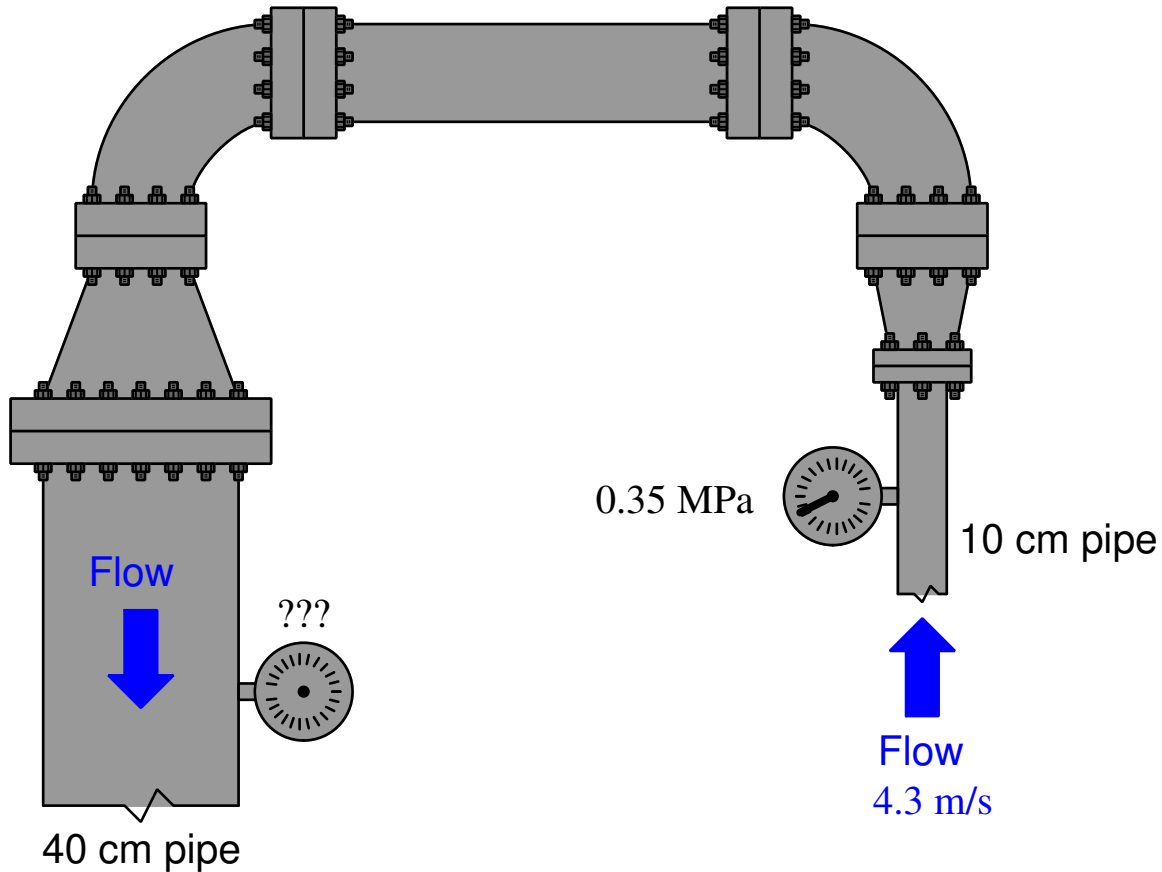

0.35 MPa

10 cm pipe

Flow

???

Flow
4.3 m/s

40 cm pipe

The inlet pressure gauge shows 0.35 MPa, and the velocity of the water entering through the 10 cm pipe is known to be 4.3 meters per second. Both pressure gauges are fixed at the centerline of the pipe, and are thus at the exact same height. Calculate the pressure registered at the outlet gauge (on the 40 cm pipe section) in units of MPa, assuming inviscid (frictionless) flow throughout, and a mass density for water of $\rho = 1005.5$ kg/m³.

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 i02979

Oppgave 54

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).

Oppgave 55

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)?

Oppgave 56

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/m³, where the throat diameter is one-half that of the entrance diameter:
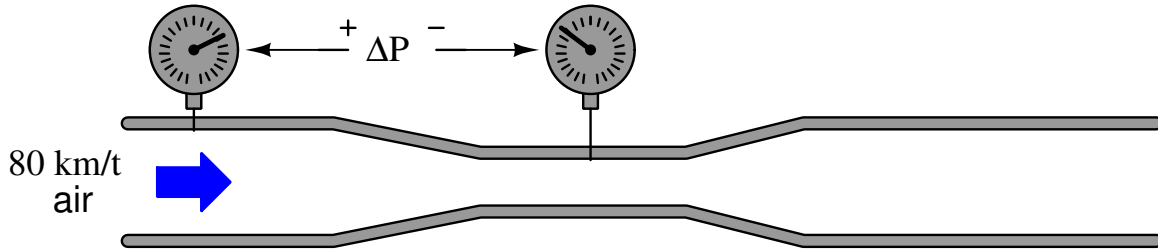
Also, how much pressure will the venturi tube develop at twice the air speed (160 km/h)?

Oppgave 57

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 ($Q = Av$).
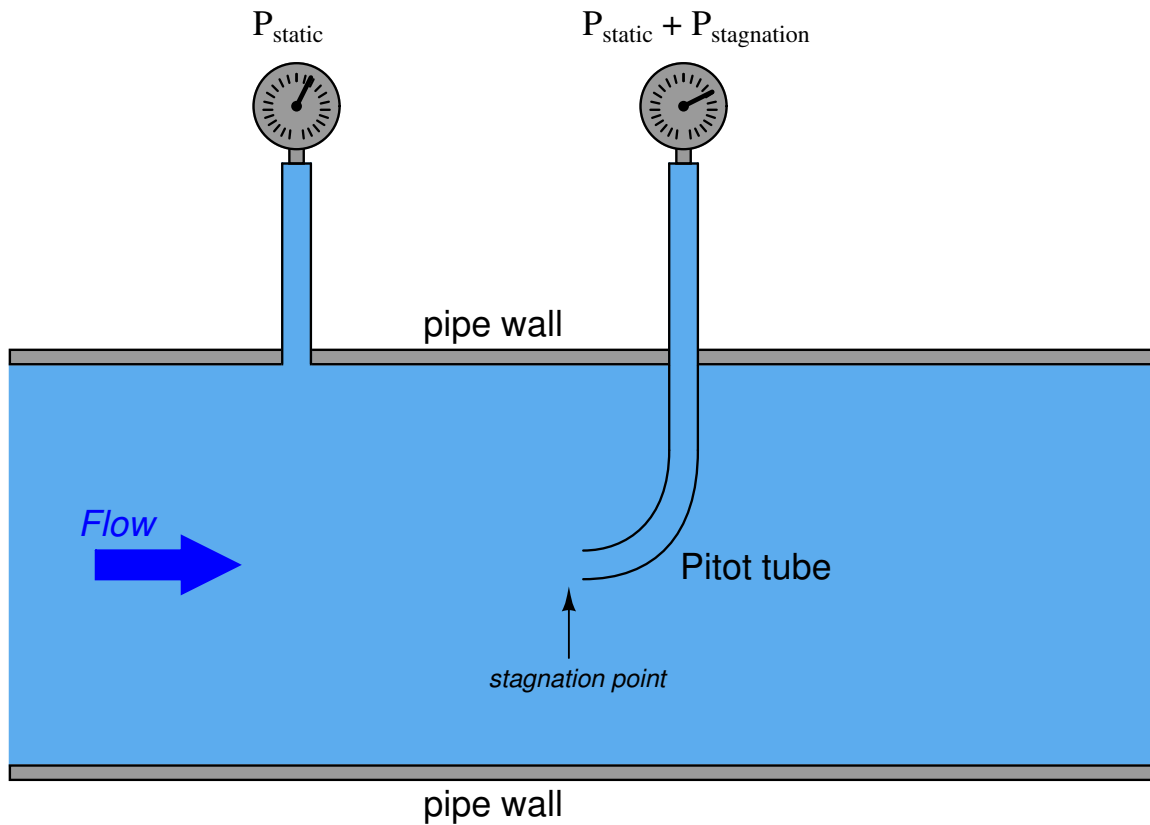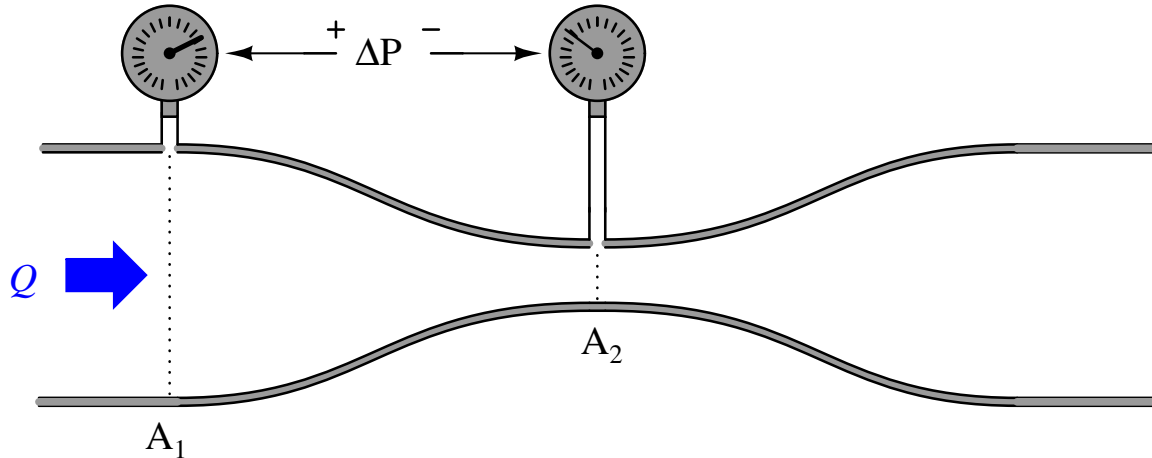

Bernoulli's equation:

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

Oppgave 58

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.

<u>file i00733</u>

Oppgave 59

Oppgave 60

Oppgave 61

Read and outline the "Turbine Flowmeters" subsection of the "Velocity-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

<u>file i04055</u>

Oppgave 62

Suppose a turbine flowmeter used to measure the flow of natural gas has a "K factor" equal to 0.02688 SL per pulse. Calculate the following:

The total amount of gas volume passed through the flowmeter after a digital counter circuit records 2,594,620 pulses.

The flow rate through the meter (i SLM) with the pulse signal having a frequency of 94 Hz.

The amount of time required (in units of hours and minutes) to accumulate 525,000 pulses (on a digital counter circuit) give a steady flow rate of 170 SLM.

Suppose someone entered the wrong K factor value into the digital electronic transmitter connected to the turbine meter's pickup coil. Would this cause a *zero shift*, a *span shift*, a *linearity error*, or a *hysteresis error*? Explain your reasoning.

Suggestions for Socratic discussion

- The label "Standard Cubic Feet" means one cubic foot of volume with the gas at room temperature and atmospheric (sea-level) pressure. Explain why we might use the unit of "Standard Cubic Feet" to express the flow of a gas through a pipe rather than simple "Cubic Feet".

- What advantages does a turbine meter have for measuring natural gas flow that make it well-suited for this application?

- Explain what would be necessary to make a turbine flowmeter register the true *mass flow rate* of the fluid rather than just the volumetric flow rate.

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

file i04057

Oppgave 63

Read and outline the "Vortex Flowmeters" subsection of the "Velocity-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
file i04058

Oppgave 64

Contractors install this vortex flowmeter, equipped with a pulse output (1 pulse per 25 gallons), to totalize flow through a pipe:
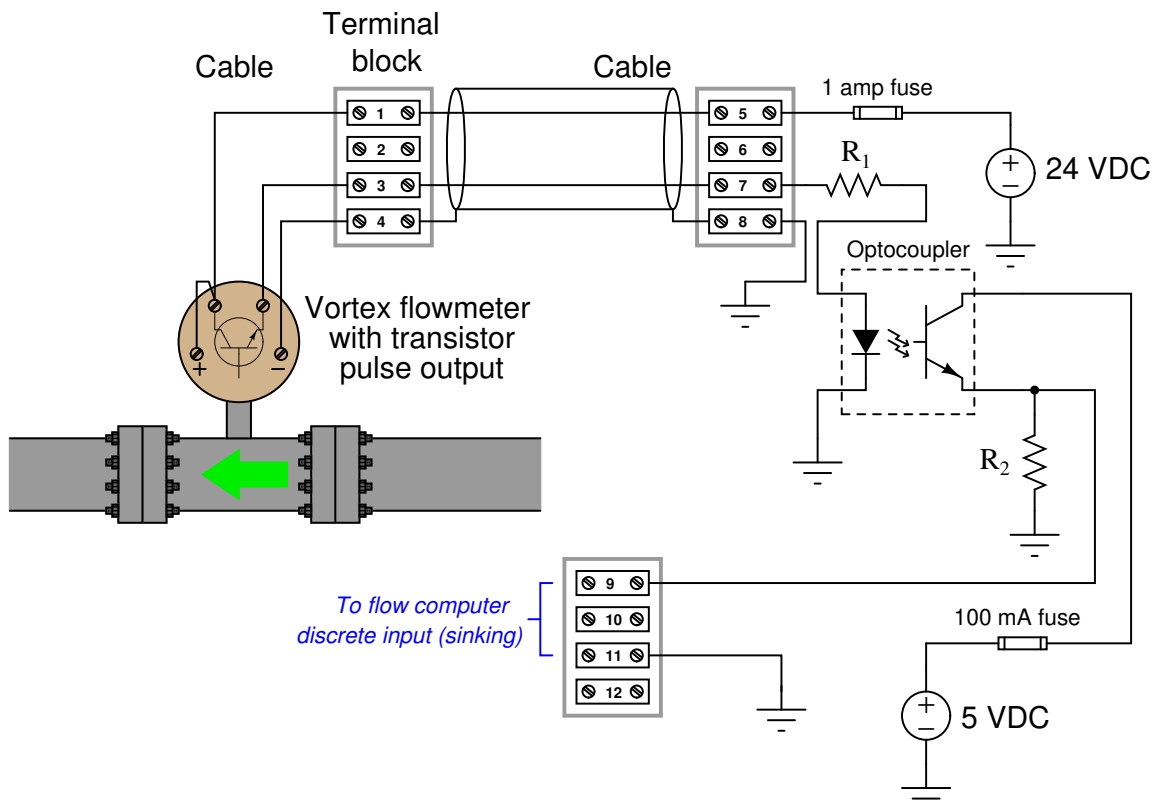
Unfortunately, the flow computer connected to this circuit is not registering any accumulated flow, even though an operator has verified flow through the pipe at approximately 370 gallons per minute. Your first step is to disconnect the flow computer input from this circuit (so it is wired exactly as shown) then to take your DC voltmeter and measure voltage between terminals 1 and 4: there, your meter registers 23.1 volts DC. Your next step is to measure DC voltage across the collector and emitter terminals of the optocoupler's transistor: there your meter registers 0 volts.

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
R_1 failed open		
R_2 failed open		
R_1 failed shorted		
R_2 failed shorted		
1 amp fuse blown		
100 milliamp fuse blown		
24 VDC source dead		
5 VDC source dead		

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.

Oppgave 65

Suppose a vortex flowmeter is used to measure the flow rate of fuel oil into a large combustion boiler. The vortex meter has a "K factor" equal to 0.09667 liter per pulse. Calculate the following:

The sensor frequency at a fuel oil flow rate of 8510 liter per hour.

The total amount of fuel consumed by the boiler after a digital counter circuit records 800,000 pulses.

The fuel oil flow rate (in cubic feet per minute) at a sensor frequency of 35 Hz.

Suppose someone entered the wrong K factor value into the digital electronic transmitter connected to the vortex meter's sensor. Would this cause a *zero shift*, a *span shift*, a *linearity error*, or a *hysteresis error*? Explain your reasoning.

| **Suggestions for Socratic discussion** |

- Identify how we could set up this vortex flowmeter to record the total amount of fuel oil consumed by the boiler every 24 hours, and then log those values in records for operator reference.

- Explain how you could use simple test equipment to measure the frequency of the signal output by the vortex shedding sensor while the flowmeter was in operation. Note: some vortex flowmeters provide test points for you to connect electronic test equipment directly to the sensor inside the pipe!

- If the temperature of the fuel oil were to increase slightly, would it affect the vortex flowmeter's measurement accuracy? Explain why or why not.

- Explain what would be necessary to make a vortex flowmeter register the true *mass flow rate* of the fluid rather than just the volumetric flow rate.

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

file i04059

Oppgave 66

Acetone – a valuable industrial solvent (chemical formula C_3H_6O) – may be manufactured from isopropyl alcohol (chemical formula C_3H_8O) in a chemical reaction that breaks two atoms of hydrogen away from each molecule of alcohol, leaving acetone and hydrogen gas (H_2) as byproducts:

$$C_3H_8O \rightarrow C_3H_6O + H_2$$
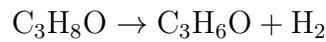
A simplified flow diagram for this process is shown here:

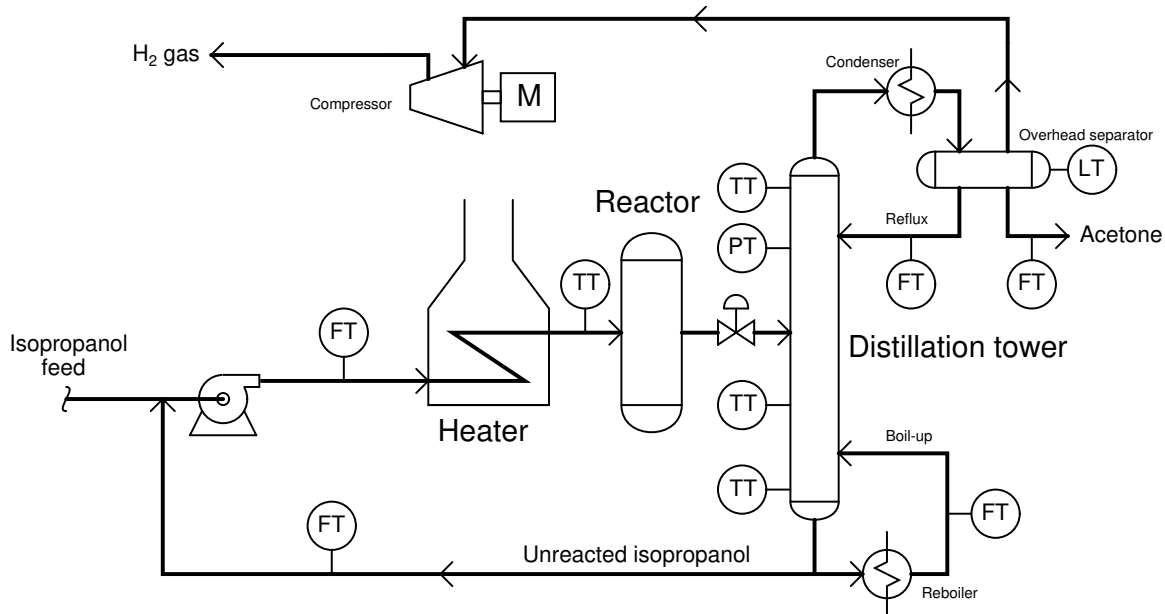Suppose the decision is made to use a vortex flowmeter to measure acetone reflux flow into the distillation tower. This particular vortex flowmeter has a minimum Reynolds number value of 10,000 as specified by the manufacturer. Calculate the minimum flow rate of acetone at 20 °C this vortex meter will be able to measure given a schedule-40 pipe size of DN40 (ID=40.94). Assume a density of 790 kg/m³ and an absolute viscosity of 36 mPa s for acetone at this temperature.

Suggestions for Socratic discussion

- Why would you as a technician (not an engineer) need to know anything about *minimum flow cutoff* for a vortex flowmeter? Identify a practical scenario where this knowledge might become important for you to do your job.

- Explain what the *Reynolds number* of a flowing fluid means in your own words. Specifically, what effects are manifest from different Reynolds number values?

- What is the purpose of a *distillation tower* in this particular process and how does it work?

- If you are familiar with distillation tower operation, identify which sunstance has the lower boiling point: acetone or isopropyl alcohol.

file i04060

Oppgave 67

Read and outline the "Positive Displacement Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04061

Oppgave 68

Read pages 2-3 through 2-5 of the "Rosemount Model 8800C and Model 8800A Smart Vortex Flowmeter" reference manual (publication 00809-0100-4003 Revision JA), and answer the following questions:

Explain why a vertical pipe orientation is preferred for this type of flowmeter, identifying the proper direction(s) of flow for different process fluids.

Figure 2-2 shows preferred mounting positions for hot pipes – explain why these positions are preferred to other alternative positions.

Identify the minimum upstream and downstream straight-pipe lengths for this flowmeter.

Figure 2-9 on page 2-12 shows the bolt-tightening sequence recommended for flange-mounted flowmeter installations. Examine each of the sequences shown, and explain why the sequence of bolt-tightening matters. Hint: the exact same principle is involved when tightening lug nuts on a car wheel, and it is called *cross-torquing*.

 Suggestions for Socratic discussion

- Explain why the manual recommends you "install valves downstream of the meter when possible".

- This manual mentions the option of pressure and temperature compensation for the vortex flowmeter. Explain why one might choose to apply this type of compensation in a specific process application. Also, explain why compensating pressure and temperature sensors should be located downstream of the vortex flowmeter rather than upstream.

- Suppose you needed to "cross-torque" the bolts on a machine component, but did not have a manual to specify which bolts to torque in what order. Explain how you could apply a general cross-torquing procedure to *any* multi-bolt application.

- Suppose you were asked to build a circuit to interpret the pulse output from this model of vortex flowmeter, blinking an LED on and off with the pulse frequency. Sketch this circuit, being sure to note which screw terminals on the flowmeter to connect your circuit to.

file i04063

Oppgave 69

Turbine flow meters are almost self-explanatory in their operation. Compare and contrast the turbine flow meter against the standard orifice plate flow meter as a flow-measuring device. What are some of the advantages of turbine meters over orifice plates? Are there any significant disadvantages?

Also, compare signal linearity between the two flow measurement technologies: we know that orifice plates require square-root characterization to obtain a linear response to flow rate. Is the same true for turbine meters? Why or why not?

file i00497

Oppgave 70

A turbine flowmeter measuring cooling water for a large power generator uses an electronic circuit to convert its pickup coil pulses into a 4-20 mA analog current signal. The "K factor" for the turbine element is 0.0101 liter per pulse, and the 4-20 mA analog output is ranged from 0 to 500 l/m flow. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured flow (l/m)	Pickup signal frequency (Hz)	Percent of output span (%)	Output signal (mA)
250			
412			
	305		
	780		
		63	
		49	
			10
			16

Suggestions for Socratic discussion

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

- Suppose you were asked to check the accuracy of the frequency-to-current converter circuit for this flowmeter. What sort of test equipment would you use, and how could you perform the test with the flowmeter still installed in the cooling water pipe?

- Could the pulse output of the pickup coil be used directly as a flow signal, or is the converter circuit absolutely necessary?

- Explain how a PLC could be used to *totalize* the water flow through this flowmeter, to provide total usage values at the end of each day.

file i00101

Oppgave 71

Suppose two water pipes of different diameter both have blunt objects ("bluff bodies") in the paths of their respective water flows. A pressure sensor device located near each of the bluff bodies measures the frequency of the vortices produced:

Small-diameter pipe

Large-diameter pipe
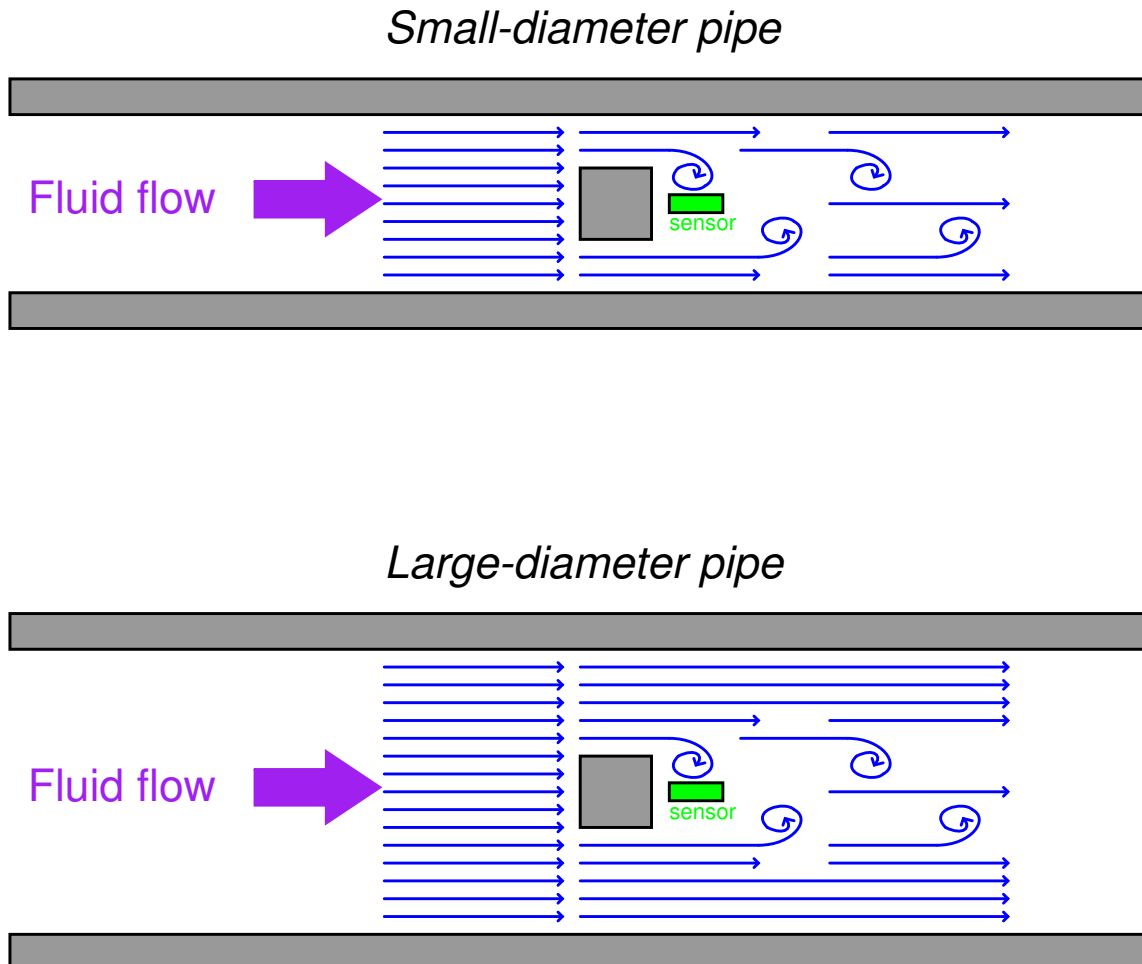
If the bluff bodies in both pipes have the same physical dimensions, and the vortex shedding frequencies are the same in both scenarios, which pipe carries a greater volumetric flow rate of water? Or, do they carry the same amount of flow? Why or why not??
file i00495

Oppgave 72

Compare and contrast the vortex-shedding flow meter against the standard orifice plate flow meter. What are some of the advantages of vortex meters over orifice plates? Are there any significant disadvantages?

Also, compare signal linearity between the two flow measurement technologies: we know that orifice plates require square-root characterization to obtain a linear response to flow rate. Is the same true for vortex meters? Why or why not?
file i00494

Oppgave 73

Research the necessary upstream and downstream straight-pipe requirements for vortex and turbine meters, and identify how these requirements compare against the typical requirements of orifice plates. For review's sake, why do we need a certain minimum length of straight pipe length upstream and downstream of a flow-measuring device?

Oppgave 74

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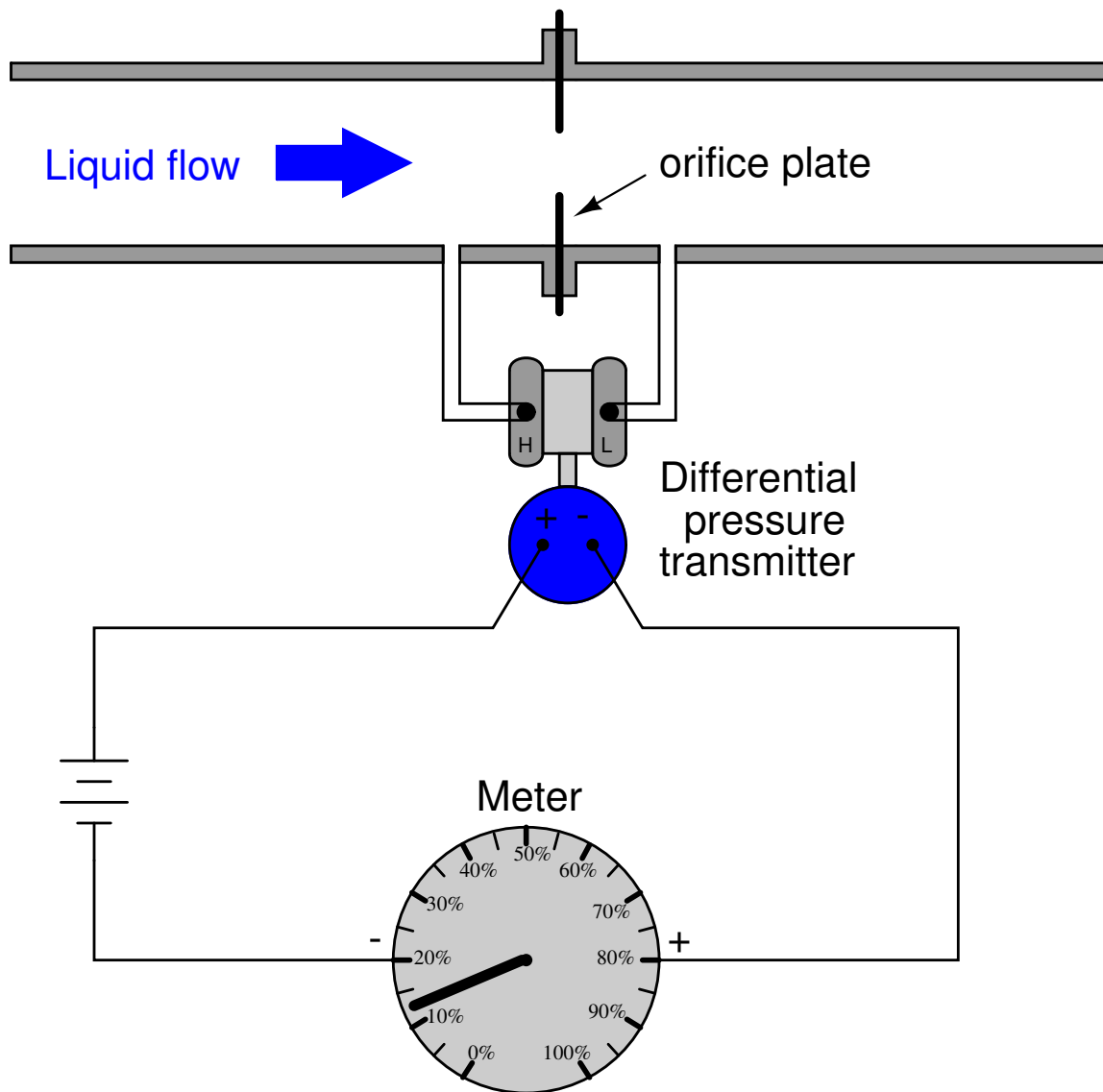
Hint: what will the meter indicate when the actual flow rate is at 0%, 50%, and 100%?

Oppgave 75

Read and outline the "Magnetic Flowmeters" subsection of the "Velocity-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
file i04064

Oppgave 76

Read pages 2-2 through 2-18 of the "Rosemount Series 8700 Magnetic Flowmeter Flowtubes" reference manual (publication 00809-0100-4727 Revision DA), and answer the following questions:

Identify the minimum upstream and downstream straight-pipe runs necessary for reliable flow measurement using one of these magnetic flowmeters.

Two cables connect the remotely-mounted transmitter ("head") unit to the flowtube. Identify the purpose of each cable; specifically, what each one connects to inside the flowtube.

Identify the proper direction of process liquid flow when the flowtube is mounted vertically or at an angle, and explain why this is the preferred direction.

Suggestions for Socratic discussion

- Explain why it is important to <u>not</u> run cables from two different magnetic flow transmitters to their respective flowtube assemblies through the same electrical conduit.

- Explain why cable termination procedures must be strictly adhered to, including not stripping back the cable shield more than half an inch, and also bonding the shield conductors (only) to the flowtube case.

- Comment on the flange bolt torquing sequences shown on page 2-7. Are these sequences arbitrary, or is there some general principle we should recognize here?

file i04066

Oppgave 77

Magnetic flowmeters exhibit special advantages and disadvantages when compared to other flow-measuring technologies. For each of the following strengths and weaknesses, explain *why* it is this way for a magnetic flowmeter:

Strengths:

- Short upstream/downstream straight-pipe requirements: 5 up and 3 down (typically)

- Output is linearly related to volumetric flow rate – no square root characterization required

- Good rangeability

- Bidirectional measurement possible

Weaknesses:

- Does not work with nonconducting fluids

- Excellent electrical grounding of the flowmeter is *essential*

- Coating of electrodes may affect performance

- Needs to be installed in pipe with electrodes horizontal, never vertical

Suppose a magflow meter is operating with a partially-filled pipe, with both electrodes still fully contacting the liquid. Will this operating condition cause a *zero shift*, a *span shift*, a *linearity error*, or a *hysteresis error*? Explain your reasoning.

Suppose the flowstream through a magflow meter contains some non-conductive solids in addition to conductive liquid. Will this affect the accuracy or reliability of the flowmeter? Explain why or why not.

file i00525

Oppgave 78

Read and outline the "Ultrasonic Flowmeters" subsection of the "Velocity-Based Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
file i04068

Oppgave 79

Read selected portions of the "Daniel Ultrasonic Gas Flowmeter" manual for the 3400 series SeniorSonic and JuniorSonic flowmeters (part number 3-9000-740 Revision H), and answer the following questions:

Read page 3-22 and identify the minimum straight-pipe lengths upstream and downstream required for proper operation of the flowmeter.

Read page 3-22 and identify how closely the diameter of the meter flowtube must match the inside diameter of the pipe it connects to.

Read page 3-22 and identify how closely a temperature-sensing probe (i.e. thermowell with RTD) may be installed to the meter flowtube, and which side (upstream or downstream) it should be on.

Read pages 5-1 through 5-5 and identify the operating principle (Doppler or transit-time) used in both the SeniorSonic and JuniorSonic gas flowmeters.

| Suggestions for Socratic discussion |

- Why should the Senior flowmeter be installed with chords oriented horizontally?

- Why should the Junior flowmeter be installed with chords 45 degrees off vertical?

- How many paths (chords) are used in the Senior versus the Junior models?

- How does the general design of the Senior model differ from that of the Junior model?

file i04070

Oppgave 80

Transit-time ("counterpropagation") ultrasonic flowmeters infer the flow rate of a gas or a liquid by measuring the time it takes for sound waves to travel both upstream and downstream through a moving fluid:

$$Q = k\frac{t_{up} - t_{down}}{(t_{up})(t_{down})}$$

Where,
Q = Volumetric flow rate
k = Constant of proportionality
t_{up} = Time for sound pulse to travel upstream (against the flow)
t_{down} = Time for sound pulse to travel downstream (with the flow)

Perform a "thought experiment" where the fluid inside an ultrasonic flowmeter is standing still, and demonstrate how this equation gives a value of zero for Q.

$\boxed{\textbf{Suggestions for Socratic discussion}}$

- A strong emphasis is placed on performing "thought experiments" in this course. Explain why this is. What practical benefits might students realize from regular mental exercises such as this?

- Perform a thought experiment demonstrating how the speed of sound is irrelevant for this type of flowmeter, based on an analysis of the formula shown above. Use the substitutions $t_{up} = \frac{L}{c-v}$ and $t_{down} = \frac{L}{c+v}$ to define travel time in terms of path length (L), fluid velocity (v), and speed of sound (c).

file i04071

Oppgave 81

Ultrasonic flowmeters exhibit special advantages and disadvantages when compared to other flow-measuring technologies. For each of the following strengths and weaknesses, explain *why* it is this way for an ultrasonic flowmeter:

Strengths:

- May be attached to the *outside* of a pipe

- Relatively inexpensive on large pipes

- Work on liquids, gases, and some vapors

- Output is linearly related to volumetric flow rate – no square root characterization required

- Good rangeability

- Bidirectional measurement possible

Weaknesses:

- Calibration varies with speed of sound in fluid for some types (which?)

- Efficiently coupling sensors to pipe can be challenging

- May require long straight-pipe lengths to condition flow

- May suffer false readings from sound waves "ringing around the pipe" instead of going through the fluid

file i00529

Oppgave 82

Magnetic flowmeters only function when measuring the flow of *electrically conductive* fluids. First, explain why electrical conductivity is an essential property of the fluid. Second, identify common fluids that *cannot* be detected by a magnetic flowmeter. Third, determine whether slight changes in conductivity have any effect on the accuracy of a magnetic flowmeter (e.g. if the conductivity of the fluid decreased by a factor of two, would the output voltage similarly decrease by the same factor?).
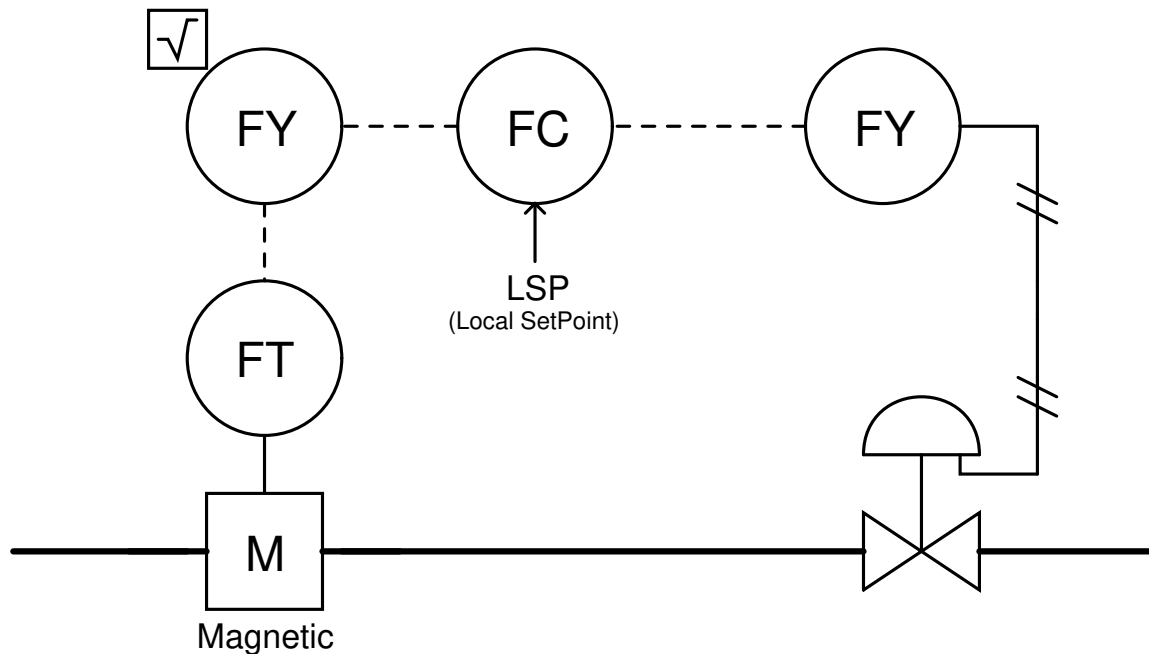file i00523

Oppgave 83

Explain the difference(s) between an *AC* magnetic flowmeter and a *DC* magnetic flowmeter. Also, describe why there are two types (i.e. what advantages do each type of magnetic flowmeter enjoy?)
file i00524

Oppgave 84

The following flow control system (as built) refuses to maintain process flow at a steady setpoint. It seems "sluggish" to respond to changes at high flow rates, and control at low flow rates is very erratic (rapid cycling in the measured flow). From the control scheme shown here, can you determine the problem?

Oppgave 85

Noen dyr bruker ekkolokasjon for å finne veien i mørket. Ubåter bruker sonar til det samme. Forklar hvordan dette prinsippet kan brukes til å akustisk måle avstanden til et objekt. Hvordan kan vi bruke dette til å måle hastigheten til et objekt?

Oppgave 86

Describe the operational principles of two types of *ultrasonic* flowmeter technologies: *Doppler* and *transit-time*. What physical properties of the fluid stream affect an ultrasonic flowmeter's calibration?

Oppgave 87

The two major types of ultrasonic flowmeters work best in different fluid streams. One type "prefers" a clean fluid stream, while the other "prefers" a flow stream containing particulate matter or bubbles. Identify which ultrasonic flowmeter type is best suited to which type of flow stream, and explain why.

Oppgave 88

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 89

Oppgave 90

Oppgave 91

Read and outline the introduction of the "True Mass Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

Convert a volumetric flow rate of water equal to 500 CFM (cubic feet per minute) into units of pounds (mass) per second.
file i04072

Oppgave 92

Read and outline the "Coriolis Flowmeters" subsection of the "True Mass Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.
file i04073

Oppgave 93

Refer to pages 4 and 5 of the "Micro Motion 'ELITE' Coriolis Flow and Density Meters" product datasheet (publication PS-00374 Revision L), and answer the following questions:

Compare the turndown performance of a Coriolis flowmeter against that of a typical orifice plate flowmeter, and identify which one has better performance. Explain *why* one has better performance than the other.

Examine the graph of accuracy versus flow rate on page 4 and explain the meaning of the "turndown ratio" limits shown on the graph (e.g. 100:1, 20:1, 2:1). Explain what *turndown* means for any measuring instrument.

Select an appropriate model of flowmeter for measuring the flow rate of water up to 25 GPM.

Select an appropriate model of flowmeter for measuring the flow rate of natural gas up to 400 SCFM (at a line pressure of 500 PSI).

| **Suggestions for Socratic discussion** |

- Page 10 contains tables showing the effect of process temperature and process pressure on measurement accuracy, both for flow rate and for density. Explain why changes in process pressure and/or process temperature would have this effect on a Coriolis flowmeter.

- Pages 17 through 22 show illustrations of these Coriolis flowmeters. For each of the given drawings, identify where the two vibrating tubes are located, and what shape those tubes take.

file i04076

Oppgave 94

Suppose we are measuring the flow rate of a liquid using a Coriolis flowmeter, and the volumetric flow rate of the liquid increases (with liquid density remaining the same). Will the amplitude of the meter tubes' "undulating" motion increase, decrease, or remain the same given this change in flow? Will the meter tubes' resonant frequency of vibration increase, decrease, or remain the same? Explain your answers.

Now suppose we are using the same Coriolis flowmeter to measure liquid flow, but this time the liquid's density becomes greater (i.e. the liquid becomes denser) with no change in volumetric flow. Again, qualitatively identify the change in undulation amplitude, and also in resonant frequency, for the flowmeter's metal tubes, and explain your answers.

Finally, suppose the flow through this Coriolis meter stops completely. How will changes in fluid density affect the tubes' motion, given a condition of zero flow? Again, explain your answers.

Suggestions for Socratic discussion

- A strong emphasis is placed on performing "thought experiments" in this course. Explain why this is. What practical benefits might students realize from regular mental exercises such as this?

file i00728

Oppgave 95

Calculate the mass flow rate of a liquid having a density of 950 kg/m^3 flowing through a pipe at a volumetric rate (Q) of 250m^3/h.

$W = $ _____ kg/m

$W = $ _____ kg/sec

Suggestions for Socratic discussion

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

- Which unit of measurement do you think is best for *custody transfer* applications: GPM or lb/min? Explain your reasoning.

- When expressing mass flow in Imperial measurements, the unit of "lbm" is often used. Why is the letter "m" appended to the symbol for pound? Is there another Imperial unit for mass other than "lbm"??

file i04081

Oppgave 96

Coriolis massestrømningsmålere har flere fordeler over andre strømingsmålere. Dette gjør at det ofte er verdt den høye kostnaden som er forbundet med anskaffelse. List opp noen av fordelen og eventuelt ulamper med denne teknologien.

file i00539

Oppgave 97

The "flare" at an oil refinery functions as a safe way to quickly dispose of pressurized hydrocarbon compounds, by burning them far away from anything else that might be flammable. In this system, as with most flare systems, a "knockout drum" exists to separate vapors from liquid, so that only vapors are sent to the flare tip to be burned. Any captured liquid is drained to the Oily Water Sewer (OWS) system:
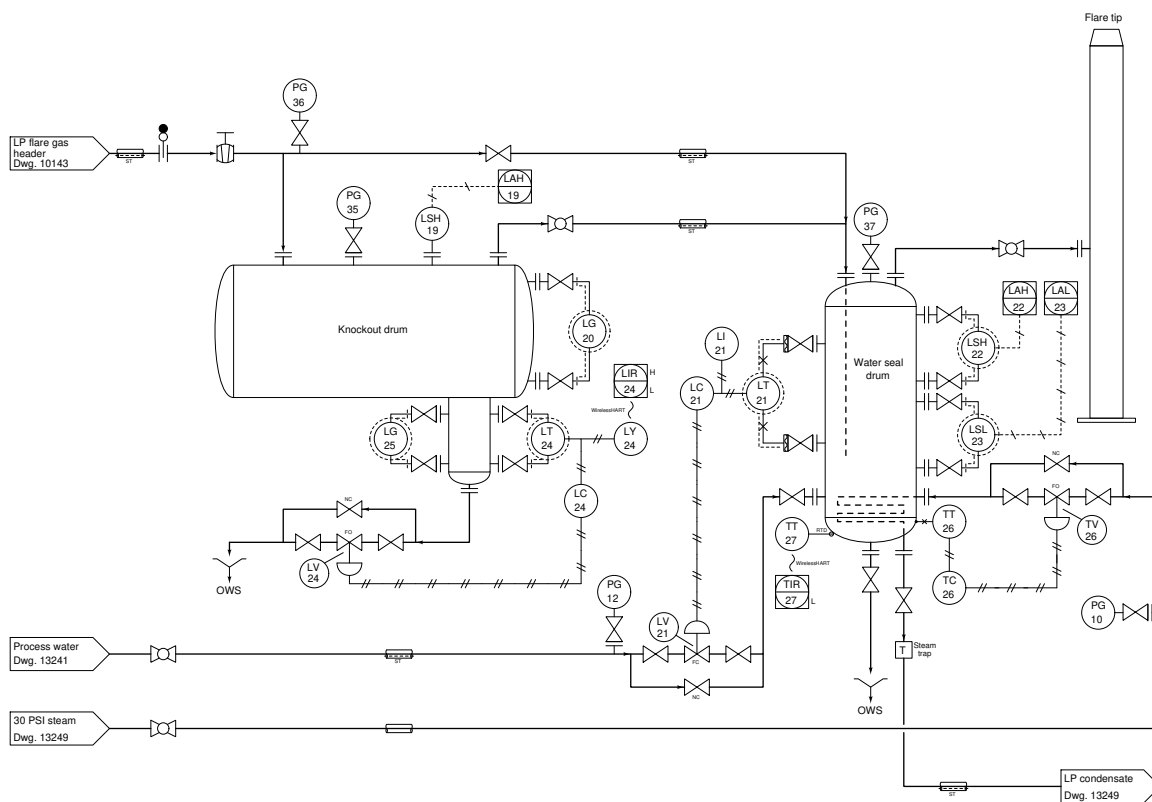
As with most flare systems, the exact composition of material sent to the flare to be burned is both highly variable and unknown from moment to moment. In a typical refinery, anything from hydrogen gas to diesel fuel might get sent to the flare during a "depressurization" event.

Suppose operations personnel at this refinery wish to monitor the total flow rate of hydrocarbon material burned at the flare. Engineers are debating what type(s) of flowmeter might be used for this task, and where exactly it should be placed in the piping system.

Brainstorm some different flow-sensing technologies, and then determine whether or not each one of them could be applied to this problem.

file i00977

A large natural gas compressor takes in gas from three different sources, "knocks out" any liquid that might be entrained in the gas, and then boosts the pressure of that gas for transport through miles of piping:
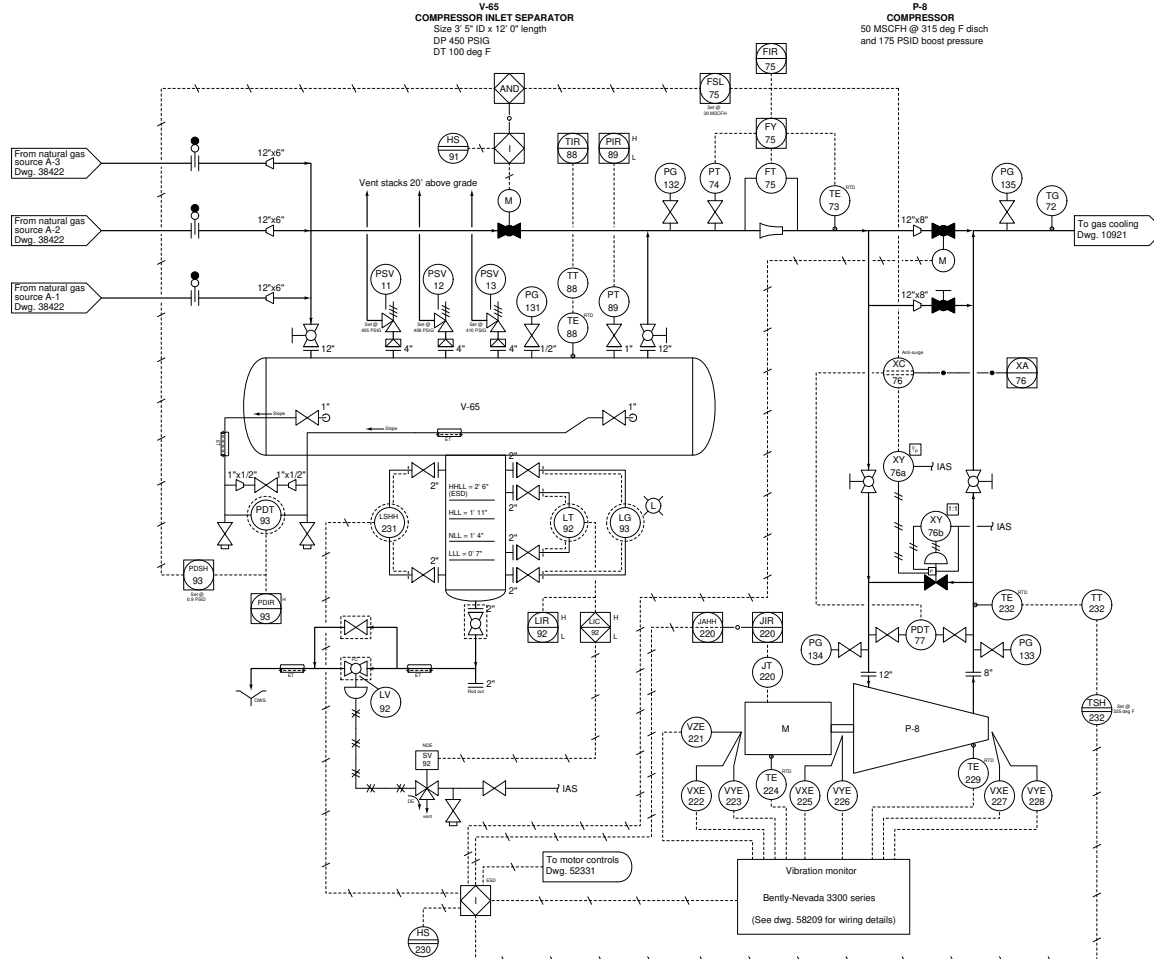
Flowmeter FT-75 has been in service for many years, but unfortunately does not provide good enough turndown for operations' needs when the compressor is operated at a fraction of its rated capacity. Engineers are debating what type(s) of flowmeter might be used to replace FT-75.

First, explain what "turndown" means in the context of this flowmeter, and explain why this particular type of flowmeter might not provide good enough turndown.

Brainstorm some different flow-sensing technologies, and then determine whether or not each one of them could be applied here.

file i00978

Oppgave 99

In this process, liquefied manure from a dairy farm is mixed with pre-consumer food waste for anaerobic digestion, the purpose of which being to produce "biogas" which is largely methane and burns similarly to natural gas. This biogas is used as fuel for a large engine, which turns a generator to make electricity. The heated coolant from this engine is piped back to the digester vessel to maintain the organic matter at a temperature similar to the internal temperature of a cow's digestive tract. Some of the biogas is recycled back into the digester as a means of stirring the liquefied mixture to prevent solids from settling at the bottom and clogging the system:
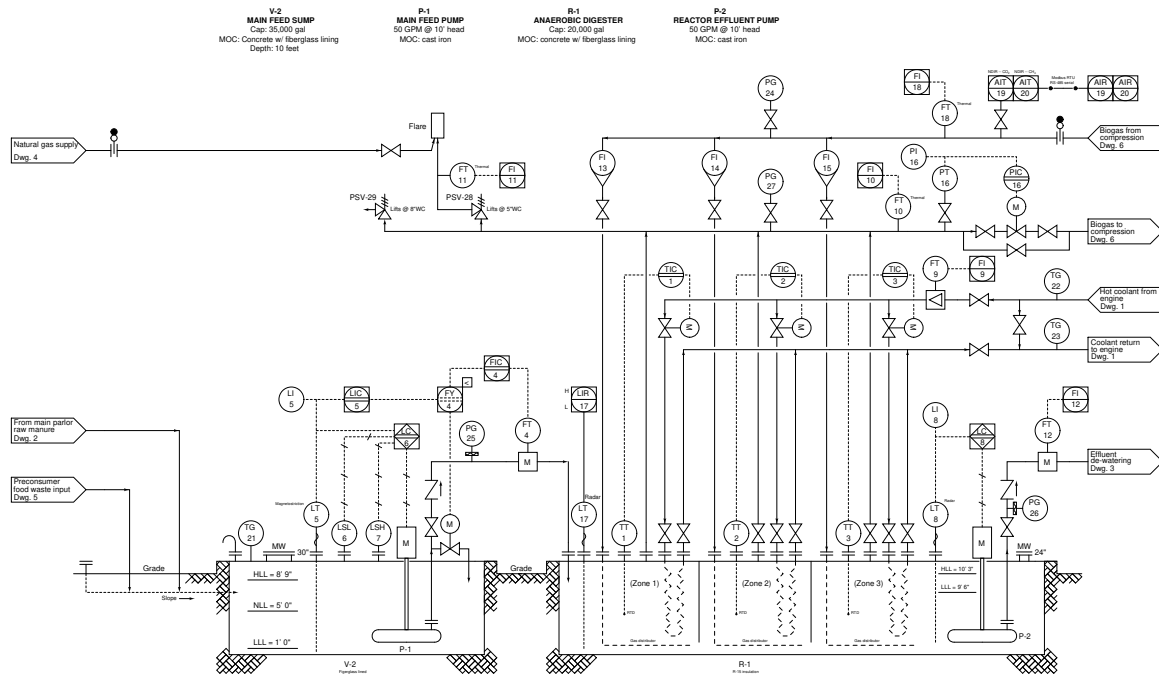
Identify the following flowmeter types and comment on why those types are particularly well-suited to the fluid stream they're measuring:

- FT-4 (influent to digester)

- FT-9 (coolant flow from engine)

- FT-10 and FT-18 (biogas flow)

- FT-12 (effluent flow to de-watering)

file i02146

Oppgave 100

Oppgave 101

Oppgave 102

58

Oppgave 103

Read and outline the "Weirs and Flumes" subsection of the "Variable-Area Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04082

Oppgave 104

Calculate the electrical resistance of a 100 ohm RTD (α= 0.00385) at the following temperatures:

- T = 120 ^{o}C ; R = _____

- T = 390 ^{o}F ; R = _____

Calculate the temperature of a 100 ohm RTD ($\alpha = 0.00392$) at the following resistances:

- R = 115 Ω ; T = _____

- R = 180 Ω ; T = _____

| **Suggestions for Socratic discussion** |

- Identify some advantages RTDs hold over thermocouples.

- Identify some advantages thermocouples hold over RTDs.

file i04079

Oppgave 105

What is a flow *prover*, and why is it periodically necessary to use one to re-calibrate positive-displacement flowmeters?
file i00546

Oppgave 106

There are several different types of flow meter devices broadly grouped under the classification of *positive displacement*. Describe the operational principle of a positive displacement flowmeter. Also, describe what physical properties of the fluid stream affect a positive displacement flowmeter's calibration.
file i00544

Oppgave 107

Suppose both a thermal mass flowmeter and a Coriolis mass flowmeter monitor gas flow going through the exact same pipe. Normally, the gas flowing through this pipe is pure helium (specific heat $c = 1.24$ cal/g-K), and the thermal mass flowmeter has been calibrated for helium gas. Then one fine day an operator places a few shutoff valves in the wrong positions and sends hydrogen gas (specific heat $= 3.41$ cal/g-K) down the line instead of helium.

Not knowing that the wrong gas is now flowing through this pipe, the operator adjusts a manual flow control valve to stabilize the flow rate at its normal value, looking at the thermal mass flowmeter's indication as the process variable.

First, explain why the two flowmeters no longer agree with each other (assuming they registered in perfect agreement while sensing the flow of helium gas).

Second, identify whether the Coriolis flowmeter registers *more* mass flow than the thermal flowmeter or *less* mass flow than the thermal flowmeter.

Finally, identify which of the two flowmeters (if any!) still registers the true mass flow rate with hydrogen going down the line instead of helium.

| **Suggestions for Socratic discussion** |

- Explain what *specific heat* means, and give a practical example from everyday life.

- What does this "thought experiment" tell us about Coriolis versus thermal mass flowmeters in general? Which of these flowmeter types do you think costs less?

- Thermal mass flow measurement is used almost universally for intake air flow measurement on automobile engines with electronic controls. Do you think the same type of problem exists in this application that we saw in our "thought experiment"?

- Suppose the gas composition does not change (i.e. it is still pure helium), but the line pressure increases. How will each of these mass flowmeters respond to this one process condition change?

- Suppose the thermal mass flowmeter were replaced with an orifice plate and DP sensor. Would this solve the problem of discrepancies between flowmeters resulting from fluid composition changes? Explain why or why not.

file i04080

Oppgave 108

Read and outline the "Thermal Flowmeters" subsection of the "True Mass Flowmeters" section of the "Continuous Fluid Flow Measurement" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04077

Oppgave 109

Perform a "thought experiment" where natural gas moves through a thermal mass flowmeter having just one (heated) RTD temperature sensing element. Explain what happens to the temperature of this element as the gas flow rate increases and decreases, and how the flowmeter's electronics would interpret this temperature change as a change in flow.

Now, perform another "thought experiment" where a constant flow of natural gas changes temperature as it moves through a thermal mass flowmeter having just one (heated) RTD temperature sensing element. Explain what happens to the temperature of this element as the incoming gas increases and decreases in temperature, and how the flowmeter's electronics would interpret this temperature change as a change in flow.

Finally, explain why all thermal flowmeters are built with *two* temperature sensors, one heated and one unheated.

Suggestions for Socratic discussion

- A strong emphasis is placed on performing "thought experiments" in this course. Explain why this is. What practical benefits might students realize from regular mental exercises such as this?

- Do you think a thermal mass flowmeter would be a good candidate technology for *natural gas* flow metering? Explain why or why not.

file i04078

Oppgave 110

Identify any area(s) of your study in which you would like to become stronger. Examples include technical reading, electrical circuit analysis, solving particular types of problems, time management, and/or skills applied in the lab. Cite specific examples if possible, and bring these to your instructor's attention so that together you may target them for improvement. As a starting point, try consulting the list of topics on the first page of the worksheet for the upcoming mastery exam, as well as the "General Values and Expectations" list near the beginning of the worksheet identifying the habits and qualities necessary for success in this career.

Next, identify practical strategies you will use to strengthen these areas. Examples include focusing on specific types of problem-solving whenever those types appear in the home-work, working through practice problems for a particular subject, and/or coordinating with your lab team to give you more practice on specific skills.

<div style="border:1px solid black; display:inline-block; padding:4px;">**Suggestions for Socratic discussion**</div>

- One useful strategy is to maintain a *journal* of all you've learned in a course of study. Explore ways you could take the work you're already doing to prepare for homework (daily discussions with your instructor) and turn this into a journal or even a weblog ("blog") for your own reflection and eventual use as a portfolio to showcase your capabilities to employers.

- Where exactly are the practice problem worksheets located on the *Socratic Instrumentation* website?

- Peruse the "feedback questions" for this (and/or past) course sections to identify any questions related to areas you would like to strengthen.

file i00999

Oppgave 111

An ecological survey team installs a Cippoletti weir in a small stream to measure water flow through it. Calculate the amount of water flow (in units of ft^3/sec) represented by a crest height ("head") of 5 inches. Assume the weir has a crest width of 4 feet and that the crest height is being measured by a level sensor located 3 feet upstream of the weir.

Also, convert this flow value into units of gallons per minute.

| **Suggestions for Socratic discussion** |

- Why do you think a weir would be a good candidate technology for measuring the flow rate of water down a small stream?

- Do you see any ways that a Cippoletti weir could experience problems measuring water flow down a natural stream? If so, can you think of a better flowmeter technology for this application?

file i04084

Oppgave 112

A municipal wastewater treatment plant uses a 6-foot-wide Parshall flume to measure the flow of effluent (treated water leaving the facility, also called "outfall"). Calculate the head (height of water) immediately upstream of this flume at an effluent flow rate of 5,460 GPM.

| **Suggestions for Socratic discussion** |

- Why do you think a flume is a good candidate technology for measuring the flow rate of wastewater?

- How did you need to apply *algebra* to solve for the height of water in this flume?

file i04085

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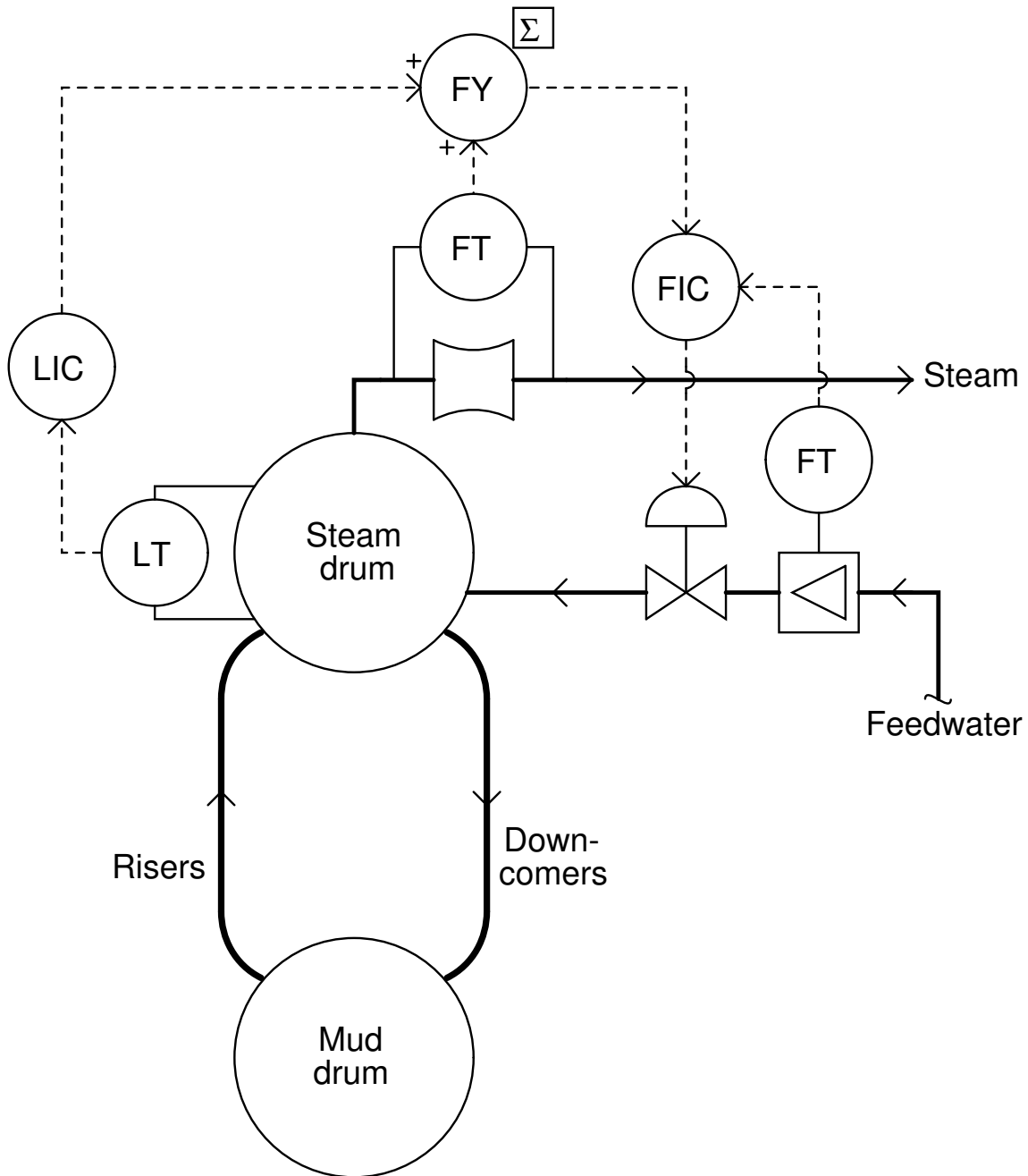
Supposing this venturi tube normally develops a differential pressure of 100 inches water column at a flow rate of 970 pounds per minute with a steam density of $\rho = 1.33$ lbm/ft^3, calculate the following:

- 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 = _____

- 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 114

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):

0-150" H_2O
3-15 PSI

√

3-15 PSI
0-40 bbl/hr

FT —//——//— FY —//——//— FI

FE
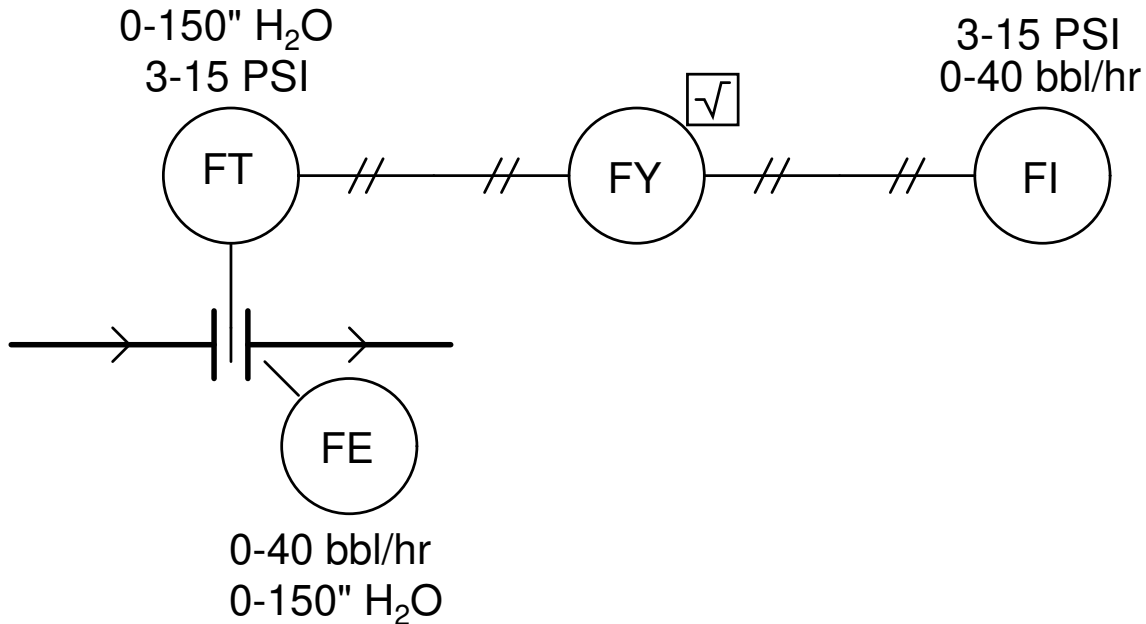
0-40 bbl/hr
0-150" H_2O

- **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 115

Suppose we need to measure the volumetric flow rate of deionized water (purified by triple-distillation) used as "make-up" water for a chemical experiment in a laboratory, from a maximum flow rate of 20 GPM down to a minimum flow rate of 1 GPM. Identify the most appropriate technologies from this list, and explain why they others will not work:

- Magnetic

- Coriolis

- Pitot tube

- Ultrasonic

- Orifice plate

- Thermal

- Vortex

- Positive displacement

- Pipe elbow

Suggestions for Socratic discussion

- If we needed to measure mass flow rather than volumetric flow, would this change our selection of flowmeter? Explain why or why not.

- Identify which of these flowmeters are bidirectional, and explain why based on their principles of operation.

file i04088

Oppgave 116

Suppose we need to install a flowmeter in a location where there is plenty of upstream straight-length pipe, but no downstream straight-length pipe (i.e. the flowmeter immediately discharges into an elbow). Identify the most appropriate technologies from this list, and explain why they others will not work:

- Magnetic

- Coriolis

- Ultrasonic

- Vortex

- Positive displacement

- Venturi tube

file i04089

Oppgave 117

Suppose we are measuring the flow rate of a gas using a turbine flowmeter. This is a simple turbine flowmeter, with one turbine spinning freely, generating electronic pulses via a "pick-up" coil sensing the passing of turbine blades.

If the density of this gas suddenly increases with no change in volumetric flow, will the turbine speed increase, decrease, or stay the same?

file i00730

Oppgave 118

A thermal mass flowmeter uses two RTD sensing elements (one heated, one unheated) to infer mass flow rate through a pipe. The following circuit converts the difference in RTD temperatures into a voltage signal for a microprocessor to interpret:
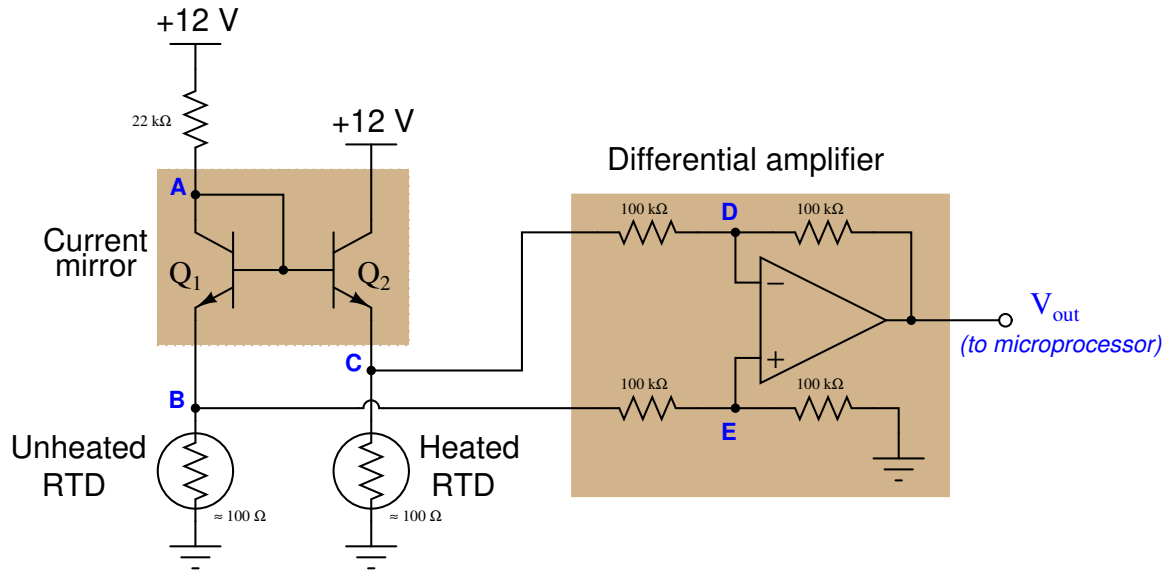
A *current mirror* works to keep current through both RTDs equal, while a differential amplifier measures the difference in voltage drops across the two RTDs.

Unfortunately, this flowmeter is not functioning as it should. The microprocessor reports an over-ranged flow measurement even when the flowmeter has been "blocked in" by closing block valves both upstream and downstream in the pipe. You are summoned to troubleshoot this circuit, and you begin by measuring the output voltage from the amplifier – you read 0 volts DC with your voltmeter. Next, you measure voltage between test points **C** and **B**, again measuring 0 volts DC.

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
22 kΩ resistor failed open		
Unheated RTD failed open		
Heated RTD failed open		
Unheated RTD failed shorted		
Heated RTD failed shorted		
Transistor Q_1 failed shorted C-E		
Transistor Q_2 failed shorted C-E		
12 VDC source dead		

Also, explain why these initial voltage measurements made sense to take. In other words, explain what each measurement told you about the nature of the fault.

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.

Oppgave 119

In this question, you will be asked to research several different types of flowmeters and determine their specifications with regard to piping geometry (minimum upstream and downstream straight-pipe lengths), minimum or maximum Reynolds number, fluid types, and any other special advantages or disadvantages. This will require a significant amount of research on your part, but the exercise is well worth the effort, because it will educate you on the proper applications of each flowmeter type. This will enable you to make educated decisions on the type of flowmeter to choose for a wide range of fluid flow measurement applications.

Shown here is the standard "form" you should use in researching each flowmeter type:

- **Principle of operation:** *A one-sentence description of what physical phenomenon is used to detect or infer flow rate.*

- **Fluid type(s):** *Gas, liquid, or either.*

- **Minimum straight-run piping lengths (in units of "pipe diameters"):**

- **Reynolds number range:** *Minimum or maximum Reynolds number for pipe flow (not flow through the throat of the device).*

- **Typical accuracy (in percent of full-flow value):**

- **Bidirectional flow measurement:** *Yes or no.*

- **Inherently measures true mass flow:** *Yes or no.*

- **Special advantages:** *Brief description of any peculiar advantages of this device over other flowmeter devices.*

- **Special disadvantages:** *Brief description of any peculiar disadvantages of this device as compared to other flowmeter devices.*

Research these aspects for the following flowmeter types:

- <u>**Orifice plate**</u>

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Venturi tube</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **Pitot tube or Annubar**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **Vortex**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **V-cone**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **Segmental wedge**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **Magnetic**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Coriolis</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Weir</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Thermal</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Ultrasonic</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Turbine</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Positive displacement</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Rotameter</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Pipe elbow</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Target</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

- **<u>Flume</u>**

-

- Principle of operation:

-

- Fluid type(s):

-

- Minimum straight-run piping lengths (in units of "pipe diameters"):

-

- Reynolds number range:

-

- Typical accuracy (in percent of full-flow value):

-

- Bidirectional flow measurement:

-

- Inherently measures true mass flow:

-

- Special advantages:

-

- Special disadvantages:

<u>file i00541</u>

82

Oppgave 120

Calculate values for the following calibration table, for a displacer-style transmitter measuring water flow through a V-notch weir. The displacer is cylindrical in shape, has a length of 12 inches (matching the weir's V-notch depth), and a diameter of 2 inches. The percentage in the calibration table refers to percent of the weir's flow range, not the percentage of displacer submergence:
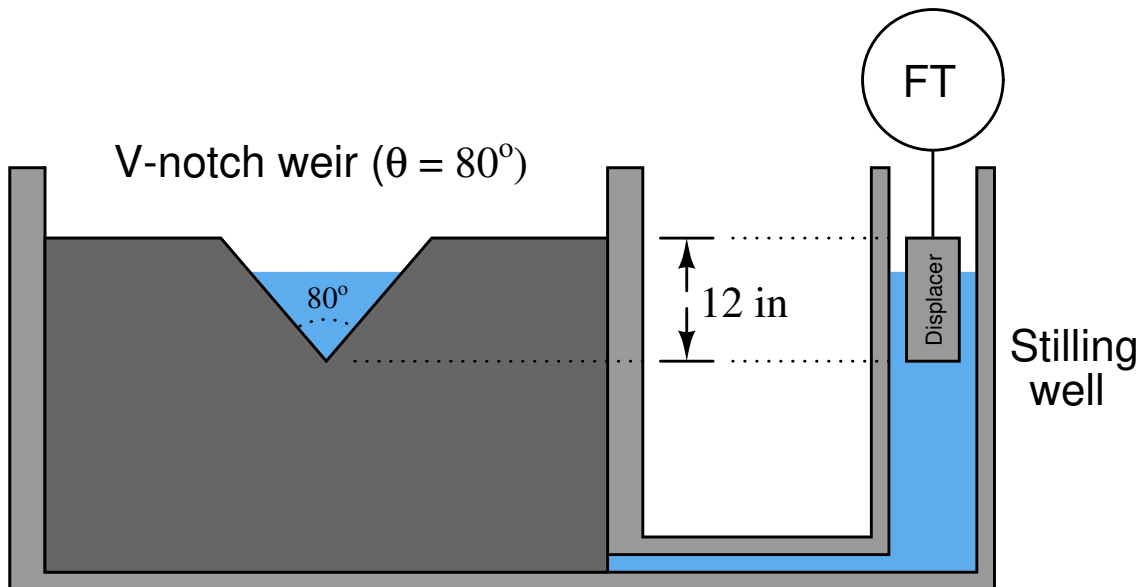
Be sure to show your work!

Water flow rate (ft³/s)	Percent of flow span (%)	Depth that displacer is submerged (in)	Buoyant force (lb)
	0		
	10		
	25		
	50		
	75		
	90		
	100		

file i00684

Oppgave 121

Convert the volumetric flow rate of 35 gallons per minute (35 GPM) into a *mass* flow rate in pounds per minute, assuming the fluid in question is water.

file i00724

Oppgave 122

A turbine flowmeter with a k factor of 53 pulses per gallon generates a pulse signal with a frequency of 381 Hz. Calculate the volumetric flow rate.

file i03050

Oppgave 123

Suppose we are measuring the flow rate of a weak acid solution using a magnetic flowmeter. The conductivity of the acid is well within the acceptable range for this meter, and so it works just fine.

Now suppose the acid solution grows in strength (greater acid concentration). This will increase the conductivity of the solution, because there are now more ions available to carry an electric current. What effect will this have on the magnetic flowmeter's calibration? Will someone have to re-calibrate the flowmeter in order for it to properly measure the acid flow again? If so, will this be a zero or a span shift? Which way will the zero and/or span shift, higher or lower? Explain your answer(s)!

file i00729

Oppgave 124

The fundamental equation for an orifice plate is based on Bernoulli's Law:

$$z_1 \rho g + \frac{v_1^2 \rho}{2} + P_1 = z_2 \rho g + \frac{v_2^2 \rho}{2} + P_2$$
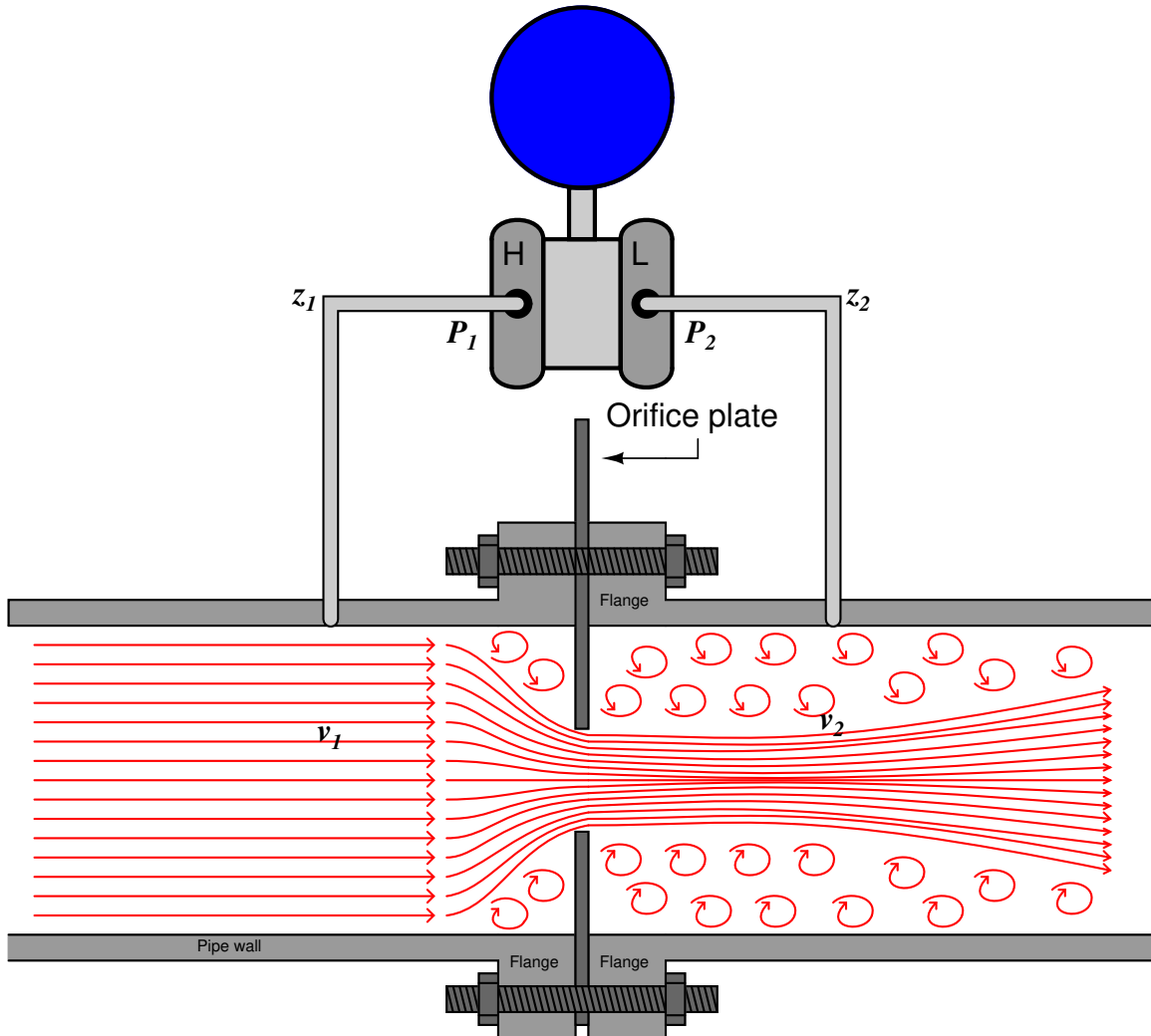
Assuming the same height at both measuring points z_1 and z_2, Bernoulli's equation simplifies to this:

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

Collecting like terms to either side of the equation:

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

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

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

If we know that the vena contracta velocity is substantially greater than the full-diameter pipe velocity, we may express the equation as an approximation:

$$\frac{2\Delta P}{\rho} \approx v_2^2$$

$$v_2 \approx \sqrt{\frac{2\Delta P}{\rho}}$$

We know that v_2, in turn, directly relates to flow (Q), and so we may write this as an equation once more using a proportionality constant k to incorporate all sizing variables and coefficients:

$$Q = k\sqrt{\frac{\Delta P}{\rho}}$$

Based on this equation, determine what a differential pressure transmitter will do if the fluid going through an orifice plate suddenly becomes *denser* without changing volumetric flowrate (i.e. the velocity v through the pipe remains the same while ρ increases).

file i00731

Oppgave 125

An orifice plate is used to measure the flow rate of ultra-pure water at a pharmaceuticals processing facility where the customary unit for liquid flow measurement is "liters per minute" (LPM). Calculate the following parameters in this flow measurement loop, at two different flow rates (78 LPM and 120 LPM):
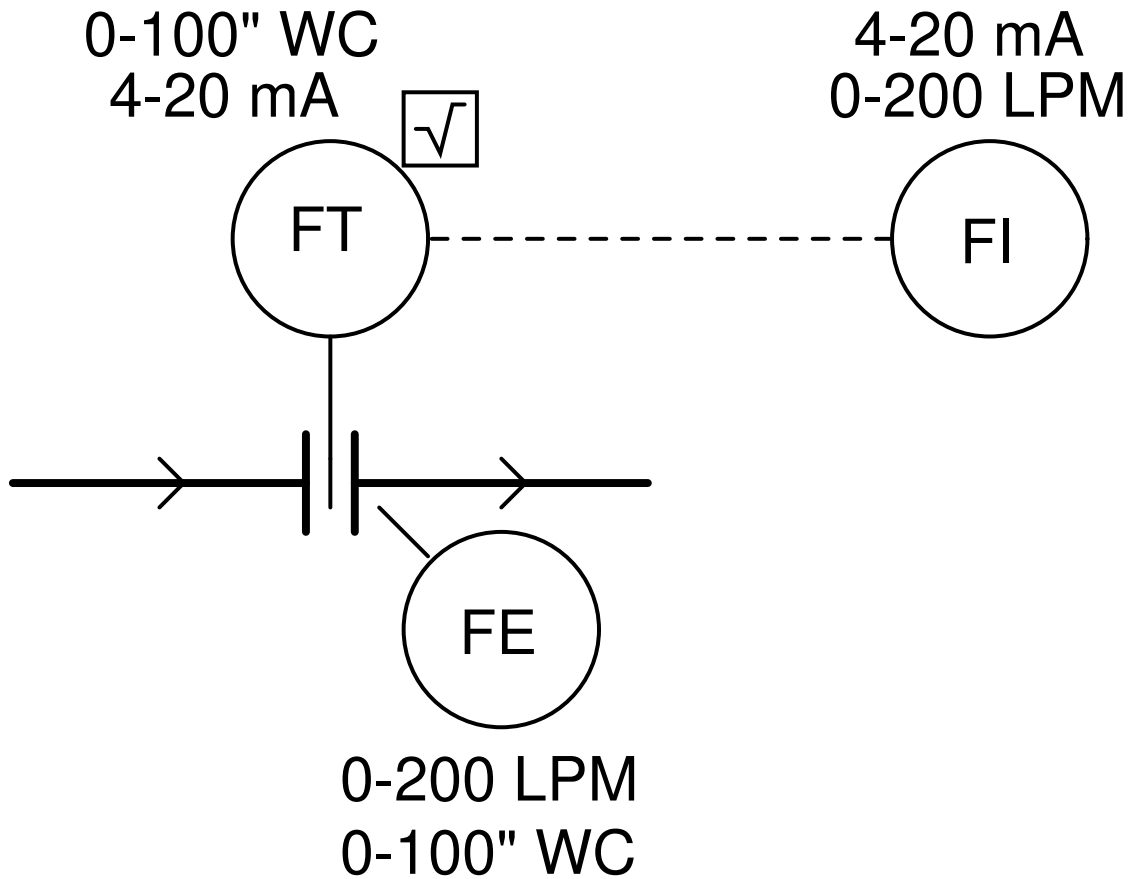
Note that the transmitter is equipped with internal square root characterization, so that no external square root computer is required.

- **At a flow rate of 78 LPM:**

- Orifice plate $\Delta P =$ _____ " H_2O

- Differential pressure transmitter output signal = _____ mA

- Flow indicator reading = _____ LPM

- **At a flow rate of 120 LPM:**

- Orifice plate $\Delta P =$ _____ " H_2O

- Differential pressure transmitter output signal = _____ mA

- Flow indicator reading = _____ LPM

- A poor choice of flowmeters for this particular application would be *magnetic*. Explain why

Oppgave 126

Weirs and flumes are frequently equipped with stilling wells to provide a "quiet" liquid height for an instrument to measure, usually an ultrasonic or displacer sensor such as the type used to measure liquid level in a closed vessel:
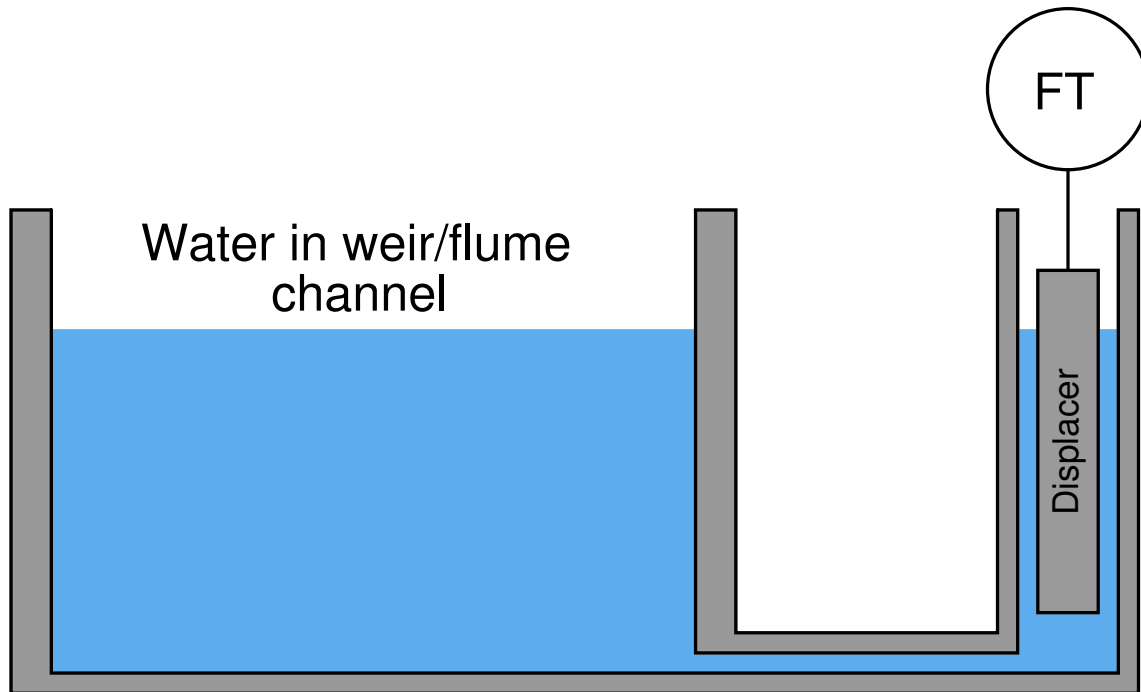
This level-sensing instrument usually provides the characterization necessary to linearize the weir or flume's nonlinear flow/height response. If the level-sensing instrument is ultrasonic, the flow characterization may be done in the same digital computer that calculates liquid level by timing the sound echoes.

However, there is a low-technology way to do the same thing. If we use a displacer rather than a digital ultrasonic sensor, we may perform this same characterization by carefully choosing the correct non-cylindrical displacer shape, so that liquid height in the stilling well does not linearly translate to buoyant force felt by the transmitter unit.

Suppose we are setting up a transmitter on a Cippoletti weir, whose flow rate varies with the 1.5 power of liquid height in the stilling well ($Q \propto H^{1.5}$). Choose the correct profile of displacer for this application, to properly linearize the liquid height into a flow signal that we may read directly:

Which displacer has the correct profile?
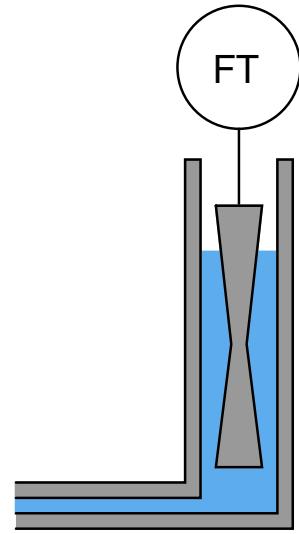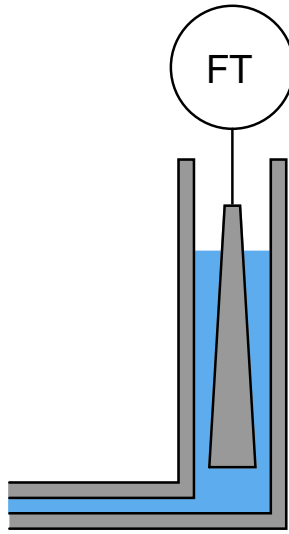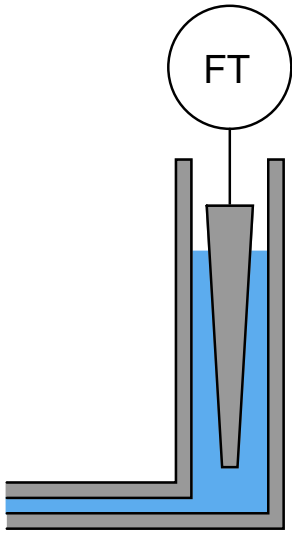
Oppgave 127

A "smart" differential pressure transmitter is configured to measure the differential pressure created by an orifice plate, and also to perform the square-root function necessary to linearize the orifice plate's signal:
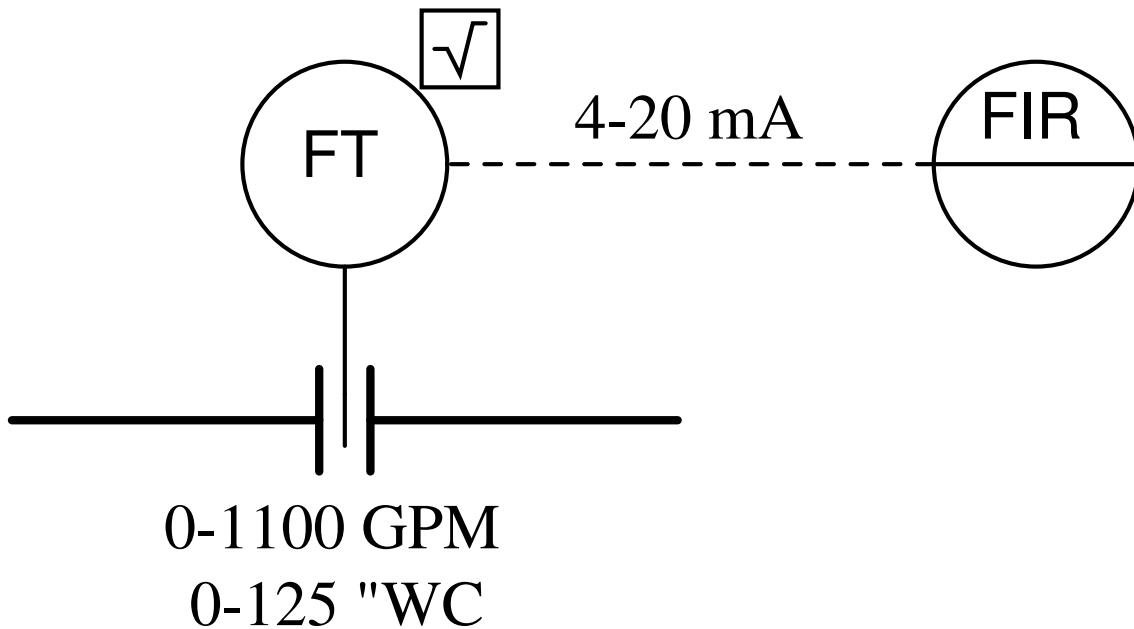
Calculate the following:

- Loop current at 350 GPM = _____ mA

- Differential pressure at 600 GPM = _____ "WC

Oppgave 128

Suppose an old orifice plate is replaced by a new orifice plate with a larger hole. What effect will this change have on the differential pressure generated by the plate at any given flow rate? What effect will this change have on the amount of flow it can measure with the same ΔP range?

Oppgave 129

An industrial cooling tower uses a vortex flowmeter to measure the flow rate of water through an 8-inch pipe (bore size = 7.981 inches). Calculate the *minimum* water flow rate measurable by this flowmeter, assuming a minimum necessary Reynolds number value of 20,000.

- Why do vortex flowmeters suffer from *low-flow cutoff*?

- Supposing we needed better low-flow measurement capability in this cooling water flow measurement application than what this flowmeter can deliver, what alternative(s) do you suggest? Keep in mind that we need to minimize cost while making our choices!

file i04086

Oppgave 130

Suppose a venturi tube is installed on a steam line to measure the flow of high-pressure steam coming from a powerhouse boiler and going to a steam turbine (to generate electricity). The contractors who installed the flowmeter left you with this mess:
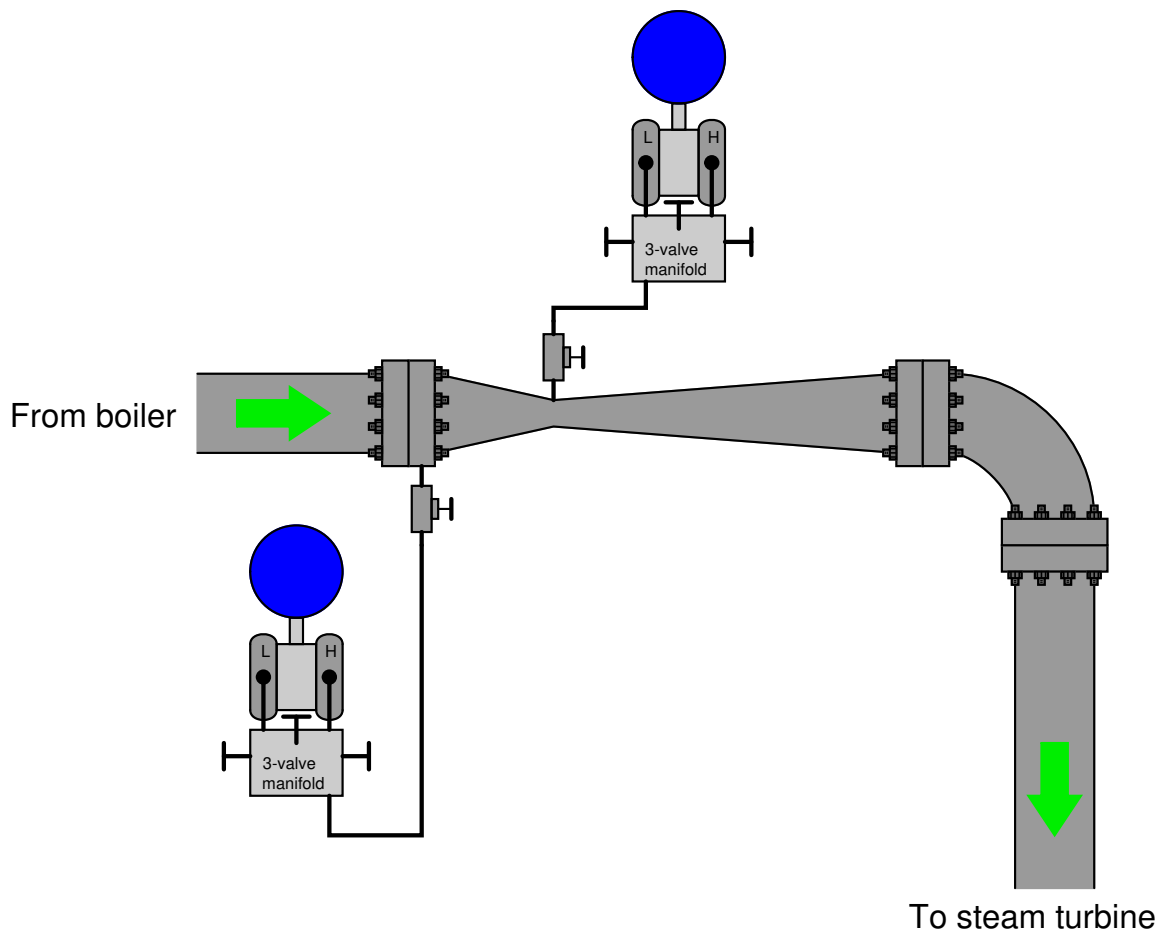
Explain what is wrong with this installation, and what must be done to fix it.
file i00054

Oppgave 131

The flow computer connected to this turbine flowmeter (with electronic pick-up) does not register any flow, even though we know there to be fluid flowing through the pipe. A voltmeter connected between terminals TB1-1 and TB1-3 registers approximately 11.0 volts DC, and 10.8 volts AC at a frequency of 86 Hz:
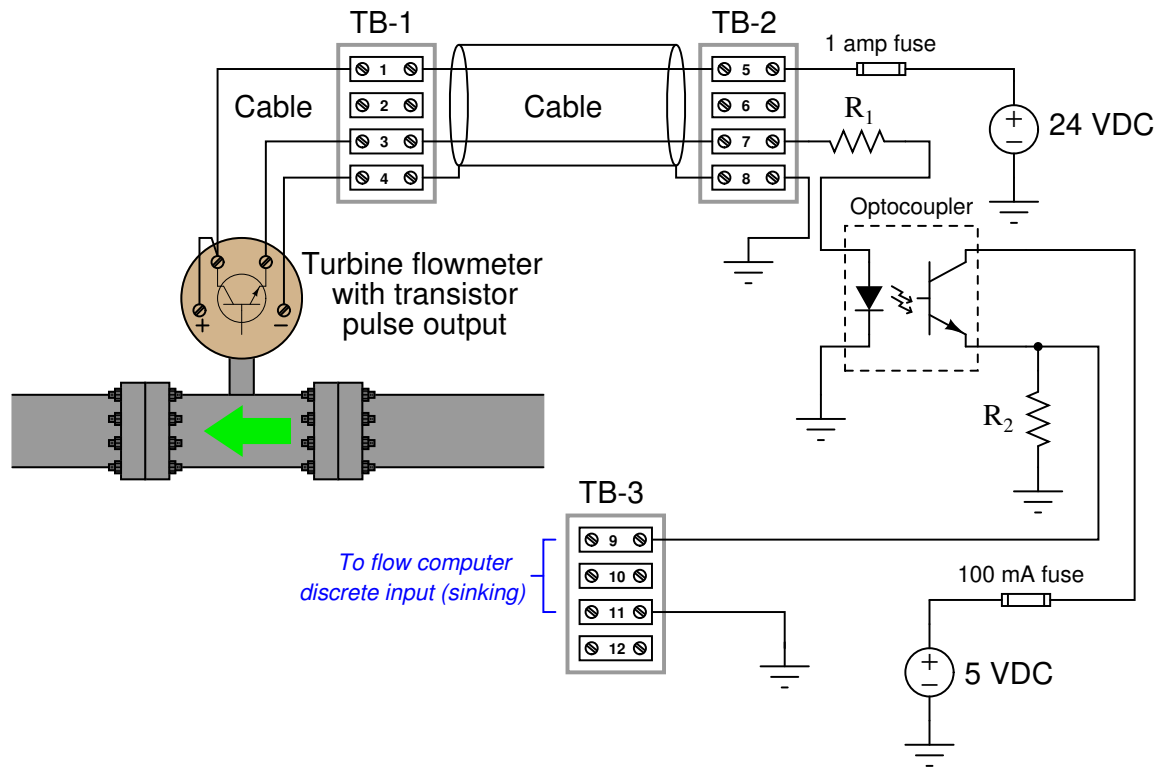
Determine the diagnostic value of each of the following tests. Assume only one fault in the system, including any single component or any single wire/cable/tube connecting components together. If a proposed test could provide new information to help you identify the location and/or nature of the one fault, mark "yes." Otherwise, if a proposed test would not reveal anything relevant to identifying the fault (already discernible from the measurements and symptoms given so far), mark "no."

Diagnostic test	Yes	No
Measure DC voltage between terminals TB2-5 and TB2-8		
Measure resistance between TB2-7 and TB2-8 with the 1 amp fuse pulled		
Measure DC voltage across 100 mA fuse		
Measure DC voltage across 1 amp fuse		
Measure AC voltage between terminals TB3-9 and TB3-11		
Measure continuity of conductor connecting terminals TB1-4 and TB2-8		

<u>file i00500</u>

Oppgave 132

Calculate the required fluid velocity in order to reduce the pressure at the narrow throat to 0 PSIG, then also calculate the volumetric flow rate corresponding to this velocity in units of GPM:

10 PSI

0 PSI

$v = ???$

$Q = ???$

1" ID

4" ID
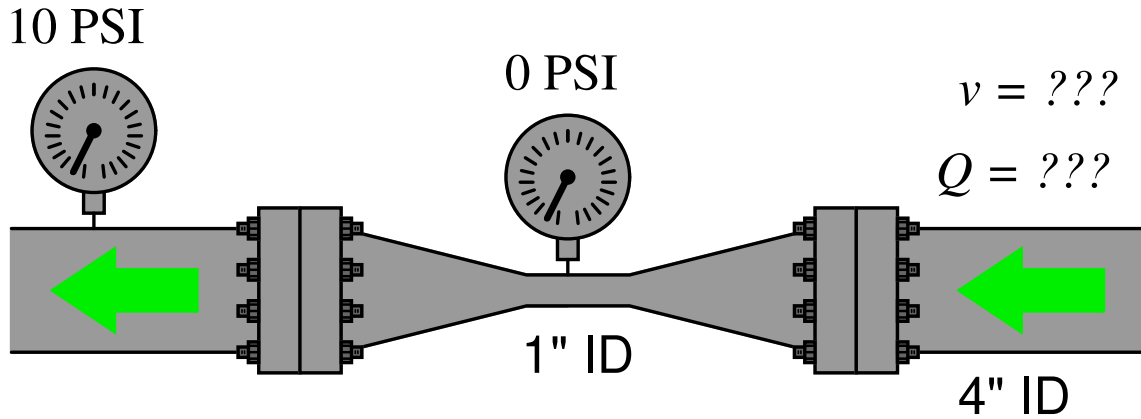
The inside diameter (ID) of the throat is 1 inch, while the inside diameter of the wide pipe is 4 inches. Assume the fluid to be water ($\rho = 1.94$ slugs/ft^3) at a constant downstream pressure of 10 PSIG:

Hint: the trick to solving for velocity (v) is to reduce Bernoulli's equation so that it contains just that one unknown variable. In other words, you need to be able to express the velocity at the 1-inch throat in terms of the velocity at the 4-inch pipe, so you will have just one v in the equation rather than a v_1 and a v_2.

file i00052

Oppgave 133

In this paint mixing system, clear *base* and dark *pigment* are mixed together to form a paint with the desired coloring. A control valve positioned by hand (the human operator) throttles the flow of base, and that amount of flow is matched by pigment automatically throttled by a flow controller, to achieve a set ratio of pigment to base flow:
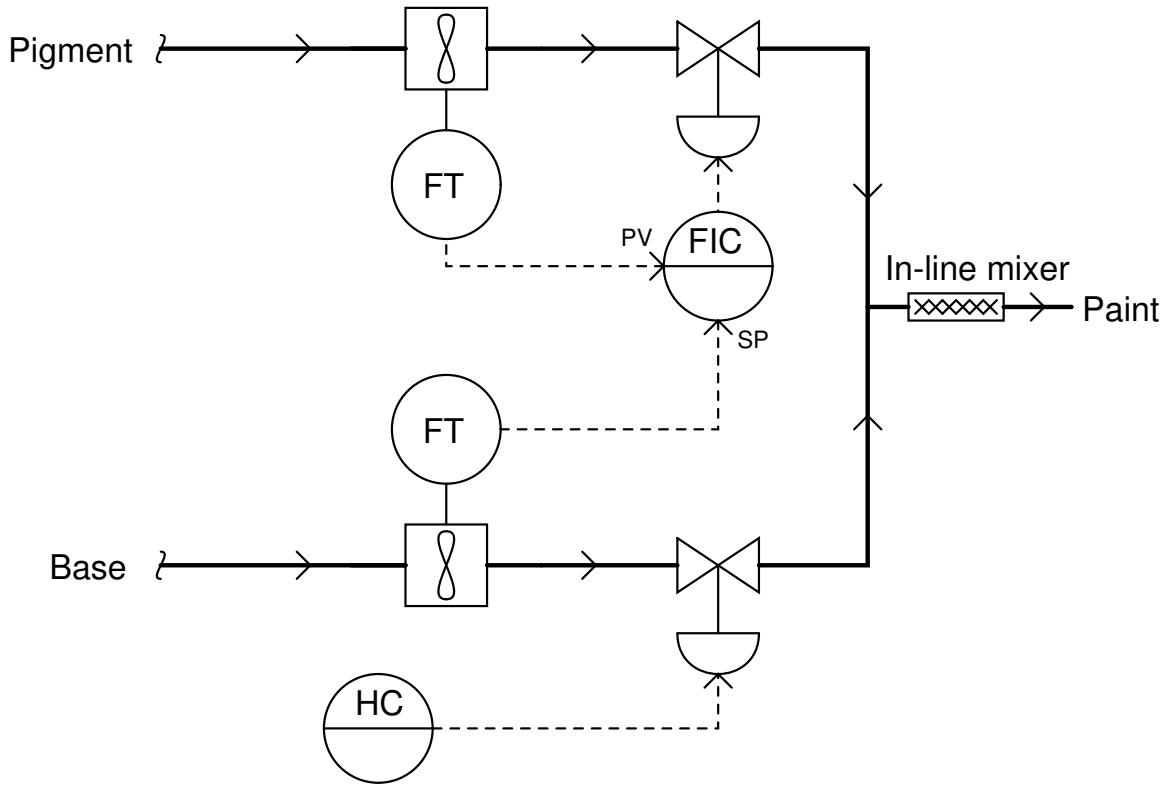
After a couple of years of successful operation, the system begins to output paint that is "paler" in color than it should be. Identify the likelihood of each specified fault for this control system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for the pale-colored paint.

Fault	Possible	Impossible
Base flowmeter registering reading too low		
Pigment flowmeter registering too low		
Base flowmeter registering reading too high		
Pigment flowmeter registering too high		
Base control valve leaking by		
Pigment control valve leaking by		
Mixer plugged		
Controller in manual mode		

file i00050

Oppgave 134

Two flowmeters are used to simultaneously measure the flow rate of a liquid through a pipe coming from a positive displacement pump:
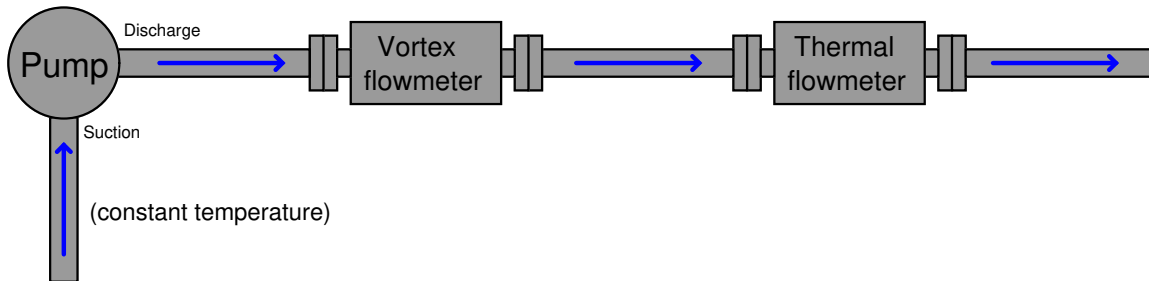
Suppose the positive displacement pump continues to turn at a constant speed, with the temperature of the incoming liquid constant. Suddenly, a steam pipe located near the pump breaks open, directing hot steam at the discharge pipe of the pump, heating the fluid as it exits the pump.

Determine the effect this change in fluid discharge temperature will have on the output signals coming from both flowmeters (vortex and thermal), then explain your answer in detail.

Oppgave 135

The equation for determine volumetric flow rate (Q) of a liquid with a certain specific gravity (G_f) through a control valve given the upstream and downstream liquid pressures (P_1 and P_2, respectively) is as follows:
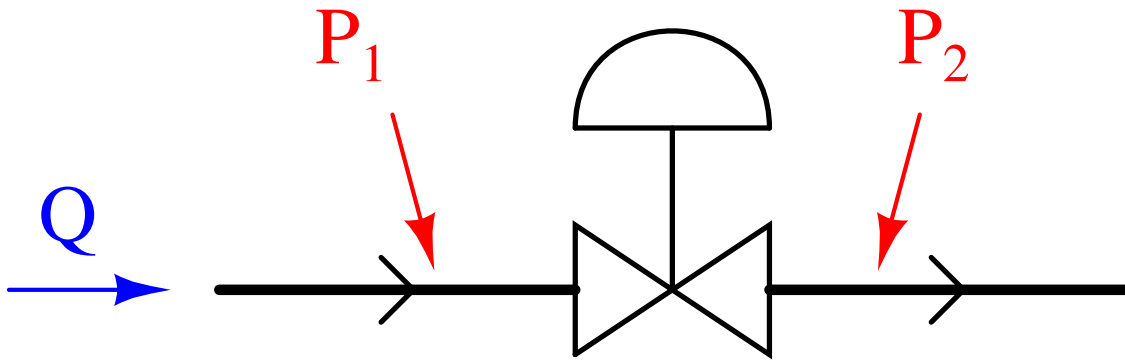
$$Q = C_v \sqrt{\frac{P_1 - P_2}{G_f}}$$

The variable C_v is called the *flow coefficient* of the control valve, and it varies from zero at full-closed to a certain maximum value (depending on valve size and type) at wide-open.

Manipulate this equation to solve for downstream pressure (P_2) in terms of the other variables. Be sure to show all your work!

$P_2 =$

Oppgave 136

The flow rate of a fluid measured by a *counterpropagation* ("transit-time") ultrasonic flowmeter is given by the following formula:

$$Q = k\frac{t_{up} - t_{down}}{(t_{up})(t_{down})}$$
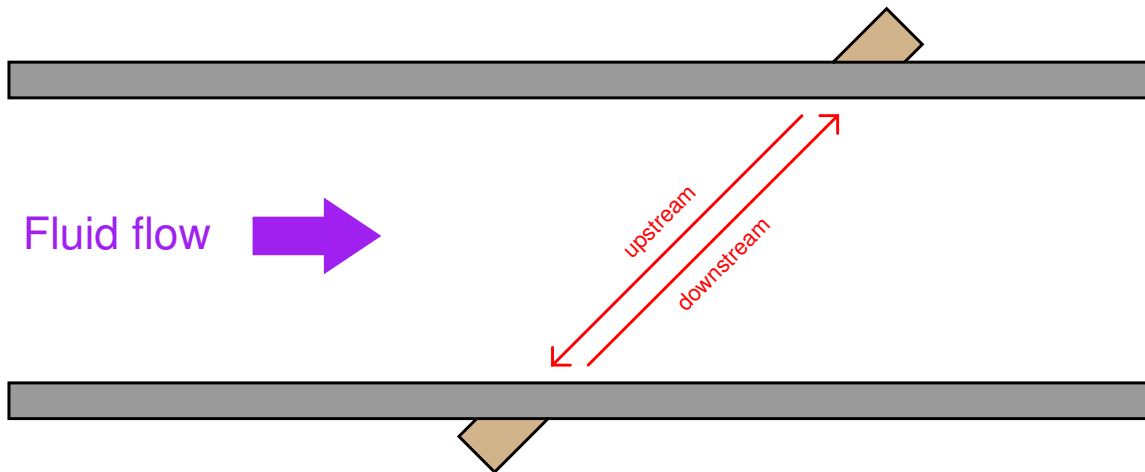
Knowing that the time for a sound wave to propagation upstream is equal to the length of the travel path divided by the difference in sound wave and fluid velocities ($t_{up} = \frac{L}{c-v}$) and that the time for a sound wave to propagation downstream is equal to the length of the travel path divided by the sum of sound wave and fluid velocities ($t_{down} = \frac{L}{c+v}$), prove that the flow rate measurement (Q) does not depend on the speed of sound through the fluid (c). In other words, substitute these mathematical definitions for t_{up} and t_{down} into the flowmeter equation and simplify to show that c is eliminated (canceled out) in the end.

An electronic temperature transmitter has an input range of 100 to 500 degrees Fahrenheit (type J thermocouple) and an output range of 4 to 20 mA. When subjected to a series of simulated temperatures (5-point up/down test), it responds as such:

Simulated temperature (deg F)	Output signal (mA)
100	4.1
200	8.0
300	11.75
400	16.0
500	20.2
400	16.0
300	11.75
200	8.0
100	4.1

Graph this instrument's ideal transfer function on the graph below, along with its *actual* transfer function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, *linearity*, and/or *hysteresis*).
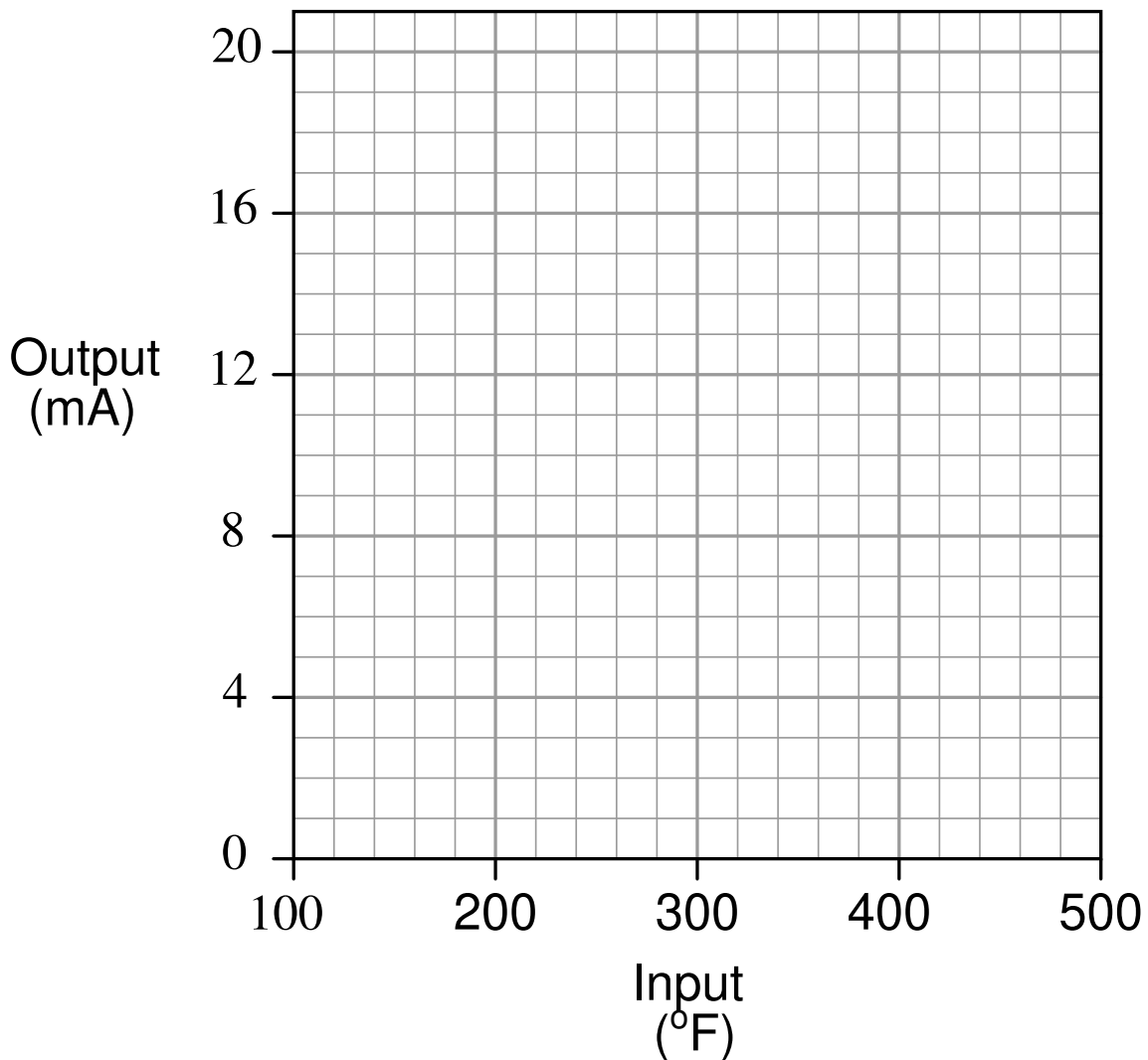
Hint: a computer spreadsheet program might be a useful tool in graphing this instrument's response. Feel free to attach a printed copy of a spreadsheet graph instead of hand-sketching one on this page.

file i03489

Oppgave 138

An antimicrobial agent called *acrolein* used to protect diesel fuel from fungal growth may be manufactured by reacting propylene with steam and air in a reactor vessel:
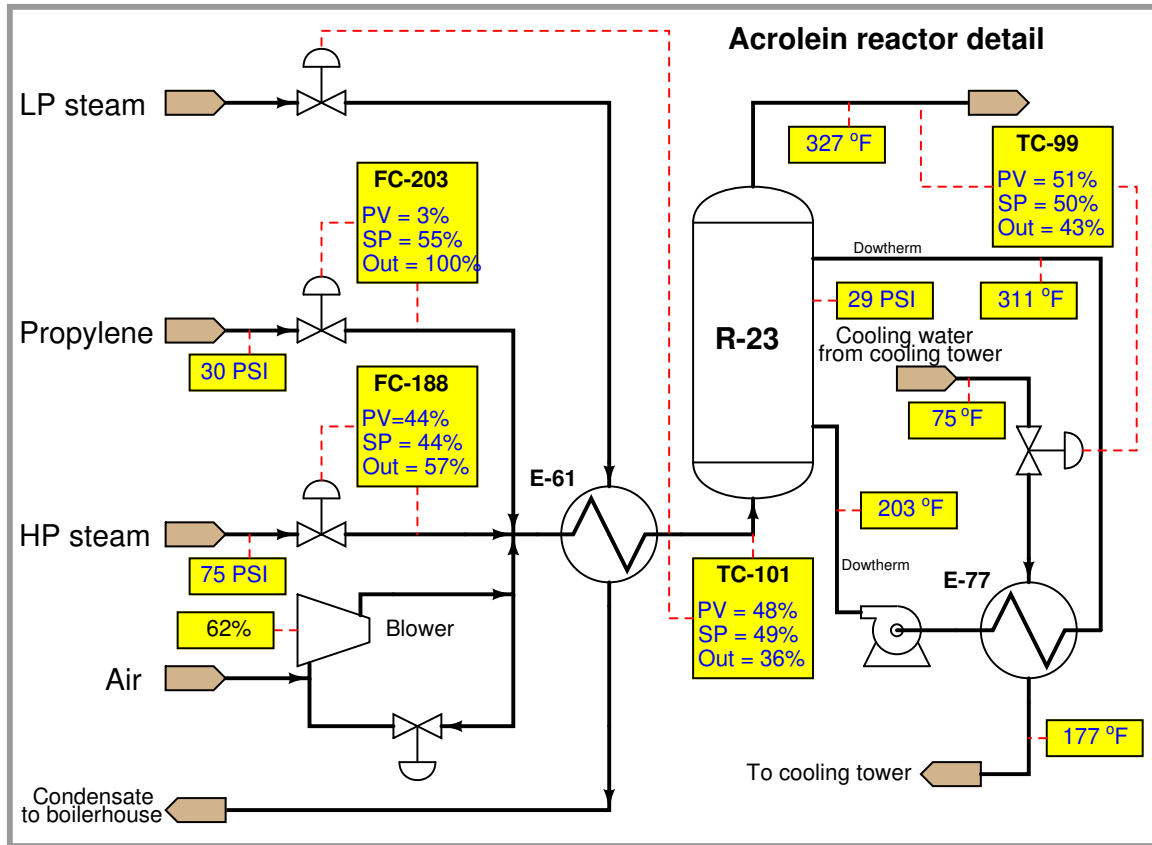
Suppose operators call you to troubleshoot a problem they are having with this process, and to help you start they show you this graphic display on one of their DCS workstations. Identify the problem in this process, suggest at least two possible causes for it, and identify the next diagnostic step you would take to confirm the cause(s).

file i01310

Oppgave 139

The field coil of this AC magnetic flowmeter is energized by 60 Hz line AC power, the coil exhibiting a known quantity of inductance as well as wire resistance:
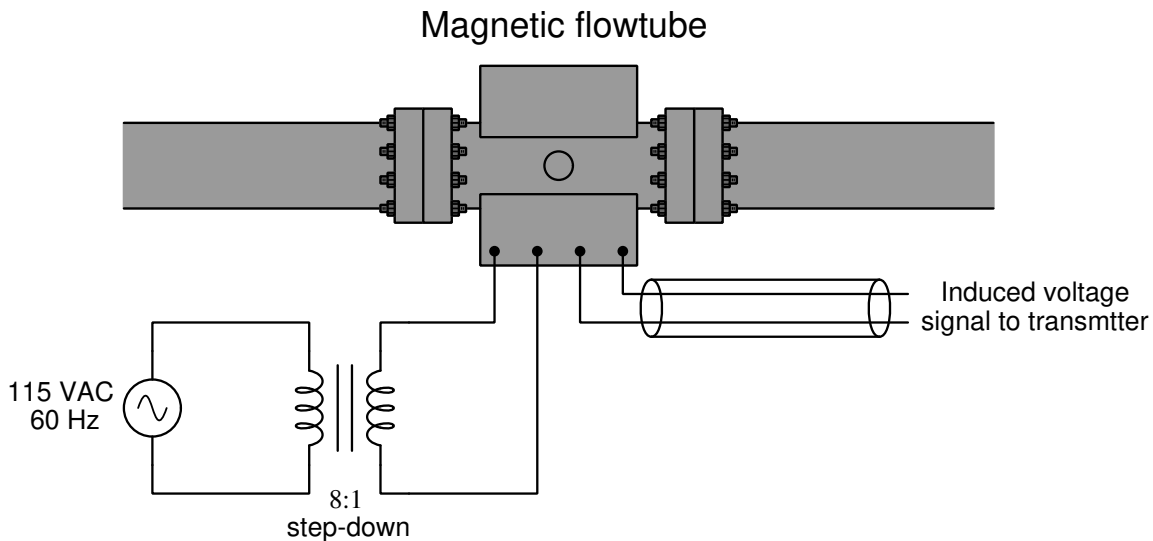
Magnetic flowtube

The *magnitude* of the induced voltage signal is a function of the field coil's magnetic flux density (B), the velocity of the fluid moving through the flowtube (v), and the diameter of the flowtube (d). The *phase angle* of the induced voltage signal will be the same as the phase angle of the current through the field coil, relative to the source voltage.

Calculate the magnitude and phase angle of the induced voltage signal, given the following parameters:

- Flowtube diameter = 14 centimeters

- Magnetic flux density = 1.0 millitesla, RMS

- Field coil resistance = 11 ohms

- Field coil inductance = 4.1 millihenrys

- Fluid velocity = 6.3 meters per second

file i00045

Svar 1

Svar 2

Svar 3

Svar 4

Svar 5

Svar 6

Svar 7

Svar 8

Svar 9

Svar 10

Partial answer:

Elevator energy = 5700 ft-lb

Bullet energy = 2648.2 ft-lb

Svar 11

Hint: to explain how each of these head-generating primary flow elements functions, begin by identifying the location of the flow's *vena contracta*.

Svar 12

I'll let you figure out the answer to this question!

Svar 13

The time elapsed between the generation of an acoustic pulse and the reception of its echo (reflected off the solid object) is directly proportional to the distance between the pulse source and the object. *Velocity* is simply the first derivative of distance with respect to time ($v = \frac{dx}{dt}$).

Svar 14

Mass flow measurement entails detecting units of mass (pounds, kilograms, etc.) passing by a specific point in a pipe or tube. Volumetric flow measurement entails detecting units of volume (cubic feet, gallons, liters, etc.) passing by a specific point in a pipe or tube. Mass flow measurement will give true mass figures for the fluid flow rate. Volumetric flow measurement must be corrected for fluid density in order to obtain real figures for mass.

Svar 15

Thermal mass flowmeters use an electric heating element and at least two temperature sensors to detect difference in temperature related to convection.

The calibration of a thermal flowmeter depends on the fluid's thermal conductivity, as well as its specific heat (the amount of heat energy it absorbs per mass unit per temperature rise), similar to how an orifice plate's calibration depends on the fluid's density. If either or both of these factors are variable in the process flow stream, a thermal mass flowmeter will give erratic indications, just as an orifice plate will give erratic readings of flow if the process fluid's density changes randomly.

An example of a substance with a very high specific heat value is *hydrogen* gas. If a thermal mass flowmeter is calibrated to accurately read the mass flow rate of air, for example, and then it is subjected to a stream of hydrogen gas, it will falsely register an excessive flow rate for the hydrogen due to that gas's extremely large specific heat value.

Advantages:

- Very high accuracy

- Immunity to upstream/downstream piping disturbances

- Provides real measurement of mass flow, fluid density, and fluid temperature

- Excellent rangeability

- Immunity to changes in density – this makes Coriolis flowmeters particularly well-suited for measuring non-Newtonian fluids

- Bidirectional

Disadvantages:

- Relatively low operating temperature limit ($< 800^o$ F)

- Difficulty measuring multi-phase flows (e.g. gas + liquid)

- Prohibitively expensive for large pipe sizes

- Cannot measure low-pressure gases very well (Coriolis forces too small)

- May suffer errors from external vibrations

Mass flow measurement is obtained by measuring the phase shift of the tube's oscillation between the two ends.

Density measurement is obtained by measuring the resonant frequency of the tubes. The basic equation for a mass-and-spring mechanical system is as follows:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Where,
f_r = Resonant frequency
k = Spring constant
m = Mass

Given a known tube mass and a known tube volume, knowing the resonant frequency of the tubes makes it quite easy to calculate the mass of the fluid filling the tubes, and thus the fluid density.

Temperature measurement comes from an RTD sensing fluid temperature as it enters the tube assembly.

Svar 17

One possible fault has to do with the control valve: perhaps something has happened to make it fail closed (loss of air supply, signal, etc.). Other possible problems include the following:

- Pump not running (no source of fluid power to motivate flow)

- Very poor controller tuning

- Wrong controller action

- Valve failed closed (loss of air supply, signal, etc.)

- Transmitter failed, showing no flow when in fact there is

A good "first test" for troubleshooting the loop is to check the controller output: is it trying to open up the valve?

Svar 18

Svar 19

Svar 20

Svar 21

Svar 22

Svar 23

Svar 24

Partial answer:

$\overline{v}$ through the 8-inch pipe = 201.49 feet per minute.

Svar 25

Partial answer:

Q (minimum) = 2900.1 GPM

Svar 26

Svar 27

Svar 28

Svar 29

$P_2 = 0.43$ MPa

Follow-up question: calculate the *differential* pressure between either P_1 or P_3 and P_2.

Svar 30

$P_2 = 0.018$ MPa

Note: even slight amounts of rounding error may add up to skew the P_2 pressure calculation so that it ends up being as high as 1 PSI instead of half of a PSI. In order to avoid incurring rounding errors, you must store all intermediate calculated results in your calculator's memory locations rather than write them on paper and re-enter them. This is a good practice in general, not only because it avoids unnecessary rounding being introduced into your calculations, but also because it completely avoids simple keystroke errors!

Svar 31

The *Reynolds number* for a fluid flow is the ratio of a fluid's inertial (motion) forces as compared to its friction (viscous) forces.

To calculate Reynolds number given metric units:

$$\text{Re} = \frac{D\overline{V}\rho}{\mu}$$

Where,
Re = Reynolds number (unitless)
D = Diameter of pipe, in meters (m)
$\overline{V}$ = Average velocity of fluid, in meters per second (m/s)
ρ = Mass density of fluid, in kilograms per cubic meter (kg/m^3)
μ = Absolute viscosity of fluid, in Pascal-seconds (Pa · s)

Re = 184.5

Svar 32

Re ≈ 13.7 = *turbulent*

Reynolds numbers less than 2,000 usually correspond to laminar flows, while Reynolds numbers above 10,000 usually correspond to turbulent flows. Reynolds numbers between 2,000 and 10,000 usually represent conditions of mild turbulence called "transitional flow." Bear in mind these cutoff points are *very approximate*, and depend on many factors including pipe geometry and wall smoothness.

Examples of Reynolds number thresholds for laminar vs. turbulent flows are given here, from different sources:

- Re < 2,000 = "Laminar"

- 2,000 < Re < 10,000 = "Transitional"

- Re > 10,000 = "Fully developed turbulent"

- Source: R. Siev, J.B. Arant, B.G. Lipták; Chapter 2.8: Laminar Flowmeters; *Instrument Engineer's Handbook, Process Measurement and Analysis, Third Edition*; pg. 105

- Re > 10,000 = "Definitely turbulent"

- Source: W.H. Howe, J.B. Arant, B.G. Lipták; <u>Chapter 2.14: Orifices</u>; *Instrument Engineer's Handbook, Process Measurement and Analysis, Third Edition*; pg. 153

- Re < 2,000 = "Laminar"

- 2,000 < Re < 4,000 = "Transitional"

- Re > 4,000 = "Turbulent"

- Source: Instrument Society of America; <u>Chapter 2: Fluid Properties – Part II</u>; *ISA Industrial Measurement Series – Flow*; pg. 11

- Re < 2,100 = "Laminar"

- Re > 3,000 = "Turbulent"

- Source: Tyler G. Hicks, P.E.; <u>Laminar Flow in a Pipe</u>; *Standard Handbook of Engineering Calculations*; pg. 1-202

- Re < 1,200 = "Laminar"

- Re > 2,500 = "Turbulent"

- Source: Tyler G. Hicks, P.E.; <u>Piping and Fluid Flow</u>; *Standard Handbook of Engineering Calculations*; pg. 3-384

You've got to laugh when you see such vastly different threshold values given in the exact same reference book!

- Re < (about) 2,000 = "Laminar"

- Re > 2,000 = "Turbulent"

- Source: Douglas C. Giancoli; <u>Chapter 10: Fluids</u>; *Physics (Third Edition)*; pg. 11

- Re < (about) 2,000 = "Laminar"

- 2,000 < Re < 4,000 = "Transitional"

- Re > 4,000 = "Turbulent"

- Source: Schoolcraft Publishing; <u>Chapter 20: Properties of Fluid Flow</u>; *Process Instrumentation – Volume I*; pg. 258

Another source, laughable in its attempt to precisely demarcate the threshold of turbulence, gives these figures:

- Re < 2,320 = "Laminar"

- Re > 2,320 = "Turbulent"

- Source: Website (`http://flow.netfirms.com/reynolds/theory.htm`)

It should be noted that laminar flow can be sustained at Reynolds numbers significantly in excess of 10,000 under very special circumstances. For example, in certain coiled capillary tubes, laminar flow may be sustained all the way up to Re = 15,000, due to something known as the *Dean effect*!

$$z_1\rho g + \frac{v_1^2\rho}{2} + P_1 = z_2\rho g + \frac{v_2^2\rho}{2} + P_2 = z_3\rho g + \frac{v_3^2\rho}{2} + P_3$$

$$z_1\rho g + 0 + 0 = 0 + 0 + P_2 = 0 + \frac{v_3^2\rho}{2} + 0$$

$$z_1\rho g = P_2 = \frac{v_3^2\rho}{2}$$

$$v_3 = \sqrt{2gz_1}$$

$$v_3 = \sqrt{\frac{2P_2}{\rho}}$$

The Pitot tube converts the outlet stream's velocity head $(\frac{v^2\rho}{2})$ into a stagnation pressure head (P), then into an elevation head $(z\rho g)$.

Challenge question: explain why a *Pitot tube* placed in the path of the outlet stream generates a liquid column equal in height to z_1:
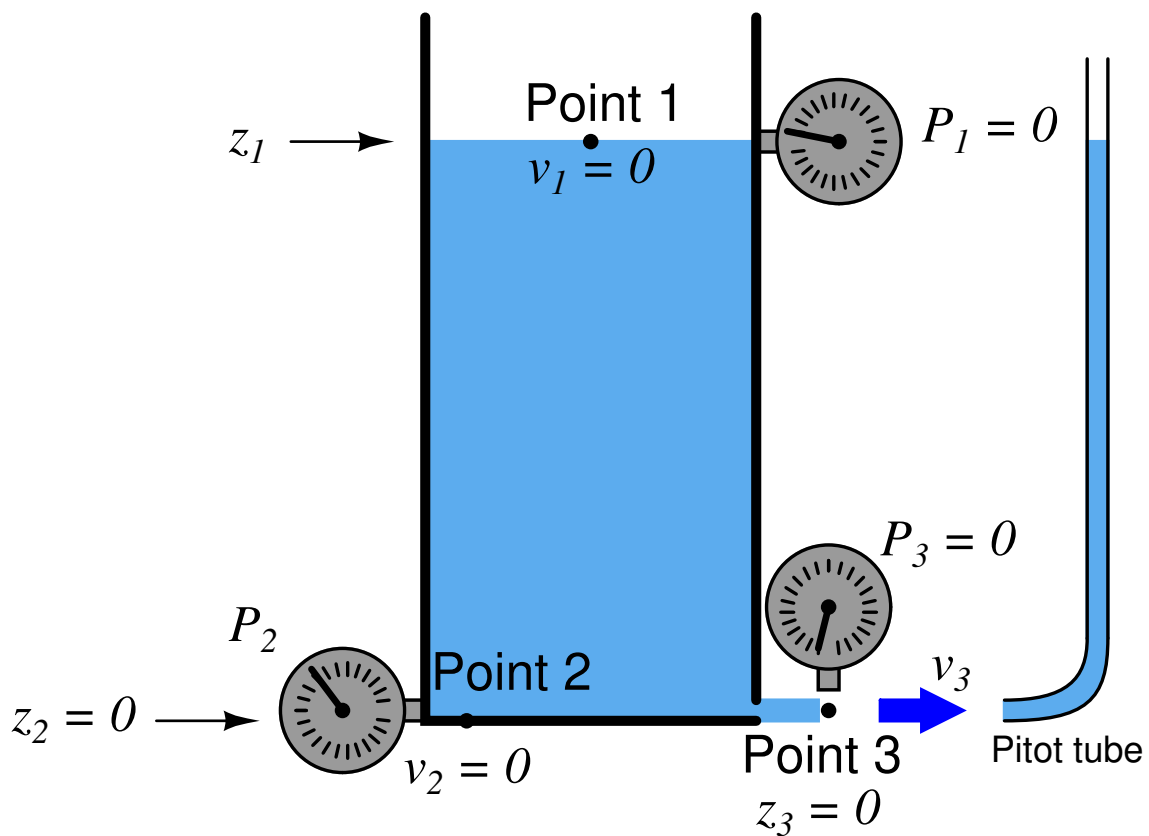
Svar 34

$P_2 = 31.39$ kPa

It is tempting to alter Bernoulli's Equation to handle measurements in inches rather than feet (especially the annoying unit of pressure measurement: pounds per square *foot*, rather than PSI). However, caution must be exercised when attempting this, because there is more to it than simply converting feet into inches every place you see "ft" in the equation.

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

There is the unit of "feet" lurking inside the unit of "slugs" which must also be accounted for. Here is the standard weight-mass-gravity equation relating slugs to pounds:

$$W = mg$$

$$[\text{lb}] = [\text{slug}] \left[\frac{\text{ft}}{\text{s}^2} \right]$$

If we re-write the unit analysis equation to show slugs as a compound unit, we see that "feet" lurks within:

$$[\text{lb}] = \left[\frac{\text{lb} \cdot \text{s}^2}{\text{ft}} \right] \left[\frac{\text{ft}}{\text{s}^2} \right]$$

Thus, expressing g in inches per second squared would require us to invent a new unit of mass (lb $\cdot$ s^2 per in) instead of slugs (lb $\cdot$ s^2 per ft).

Svar 35

The relationship between pressure and flow is quadratic.

Svar 36

$P_1 = 296.77$ PSI $P_2 = 293.27$ PSI

Bernoulli's equation assumes no gain or loss of energy between the two locations compared, and so it *cannot* be used to contrast the pump's suction and discharge pressures. The pump is a machine that adds energy to the fluid going through it, and so the assumption of equal (total) energy between the incoming and outgoing flow streams is not correct.

Svar 37

Svar 38

Svar 39

Svar 40

Svar 41

Svar 42

Svar 43

Svar 44

Svar 45

Svar 46

Svar 47

Partial answer:

- $Q = 110$ m³/h ; ΔP $= 4.15$ kPa

- $Q = 55$ m³/h ; ΔP $= 1.04$ kPa

- $Q = 140$ m³/h ; ΔP $= 6.75$ kPa

- $Q = 215$ m³/h ; ΔP $= 15.85$ kPa

Svar 48

Partial answer:

- Q range $= 0$ to 110 m³/h ; ΔP range $= 0$-14.18 kPa

- Q range $= 0$ to 140 m³/h ; ΔP range $= 0$-22.97 kPa

- Q range $= 0$ to 180 m³/h ; ΔP range $= 0$-37.97 kPa

- Q range $= 0$ to 230 m³/h ; ΔP range $= 0$-62.00 kPa

Svar 49

Partial answer:

$\Delta P = 10.25$ kPa at 740 m³/h and 1.01 g/cm³

$Q = 1058$ m³/h flow rate at 3.1 PSID and 1.03 g/cm³

$Q = 796.6$ m³/h flow rate at 12 kPaD and 1.02 g/cm³

Svar 50

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 51

$Q = Av = \pi(\frac{0.254m}{2})^2 \cdot 7.62 = 0.386$ m³/s $= 6120$ GPM

Svar 52

$P_2 = 0.776$ MPa

Svar 53

$P_{out} = 0.359$ MPa

Note: with a pipe diameter ratio of 4:1 (out:in), the exit velocity will be *16 times* slower than the inlet velocity $(1:4)^2 = (1:16)$.

Svar 54

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 55

P at 80 km/h $= 276.82$ Pa

P at 160 km/h $= 1107.3$ Pa

Svar 56

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

$$\Downarrow$$

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

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

ΔP at 80 km/h = 4485.6 Pa

ΔP at 160 km/h = 17942 Pa

Svar 57

Assuming no difference in height (z):

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

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

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

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

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

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

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

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

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

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

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

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

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 58

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 59

Svar 60

Svar 61

Svar 62

Partial answer:

The amount of time required to accumulate 525,000 pulses (on a digital counter circuit) give a steady flow rate of 170 SLM = **1 hour, 23 minutes**

Svar 63

Svar 64

Svar 65

Partial answer:

The total amount of fuel consumed by the boiler after a digital counter circuit records 800,000 pulses = **77,339.5 liter**

Svar 66

$$Re = \frac{Dv\rho}{\mu} \Rightarrow v = \frac{Re\mu}{D\rho} = \frac{10000 \cdot 36mPas}{40.94mm \cdot 790kg/m = 0.099m/s}$$

$$Q = Av = \pi(\frac{40.95mm}{2}) \cdot 0.099m/s = 0.13l/s = 7.81l/m$$

Svar 67

Svar 68

- **Advantages of turbine meters over orifice plates**

- Very high accuracy

- Linear output requires no square-root characterization

- Better rangeability due to linear response to flow

- **Advantages of orifice plates over turbine meters**

- Typically cheaper

- Cleanliness of flow stream not as critical

- Turbine may become bound if viscous or fibrous solids are present in the flow stream

- Less wear over time (no bearings to wear out)

Svar 70

Measured flow (l/m)	Pickup signal frequency (Hz)	Percent of output span (%)	Output signal (mA)
250	412.5	50	12
412	679.8	82.4	17.18
184.8	305	36.97	9.915
472.7	780	94.55	19.13
315	519.8	63	14.08
245	404.3	49	11.84
187.5	309.4	37.5	10
375	618.8	75	16

$$Q = kf$$

Where,
f = Frequency in Hertz (pulses per second)
k = Calibration factor in liter per pulse
Q = Volumetric flow rate in liter per second

$$Q = \frac{kf}{60}$$

Where,
f = Frequency in Hertz (pulses per second)
k = Calibration factor in pulses per gallon
Q = Volumetric flow rate in gallons per minute

Svar 71

The large pipe carries a greater volumetric rate of water flow than the small pipe.

Since the vortex shedding frequency is proportional to the fluid *velocity*, we know that the flow velocities in both cases must be the same (given identical bluff body geometries). However, since the larger pipe has a greater cross-sectional area, an identical velocity equates to a greater *volume* rate of water moving past the bluff body and sensor.

Svar 72

- **Advantages of vortex meters over orifice plates**

- Immune to changes in fluid density (and therefore temperature and pressure as well)

- Linear output requires no square-root characterization

- Better rangeability due to linear flow response (at least down to the "cut off" point)

- **Advantages of orifice plates over vortex meters**

- Cheaper for very large pipe sizes

- Orifice plates may be more tolerant of low-frequency pipe vibrations

- Some orifice plates may measure bidirectional flow

- Able to sense flow down to zero (vortex flowmeters will "cut off" at some low flow rate)

Low-flow cutoff is a problem unique to vortex flowmeters. At low flow rates, the Reynolds number drops below the turbulent threshold, at which point fluid viscosity prevents vortices from shedding. The vortex street simply ceases to exist at any flow rate below this critical point, meaning the flowmeter's output goes to zero at any flow rate below the cutoff point.

Svar 73

Vortex meter and turbine meter both: 15 to 50 pipe diameters upstream; 5 pipe diameters downstream.

Svar 74

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 75

Svar 76

Svar 77

Answer to second question: most oils and concentrated alcohols have very low conductivity and thus cannot be measured by a magnetic flowmeter. Gases and vapors suffer the same problem.

In answer to the third question, I offer the following electrical "thought experiment." Consider the effect of doubling the series resistance in this circuit:
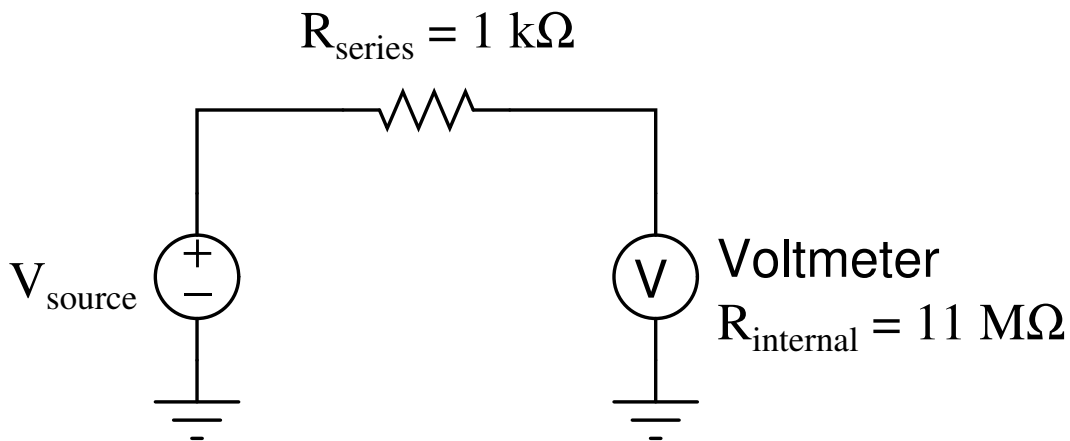
$$R_{series} = 1 \text{ k}\Omega$$

V_{source} (V) Voltmeter
$R_{internal} = 11 \text{ M}\Omega$

Does the voltmeter accurately measure V_{source} ?

$$R_{series} = 2 \text{ k}\Omega$$

V_{source} (V) Voltmeter
$R_{internal} = 11 \text{ M}\Omega$
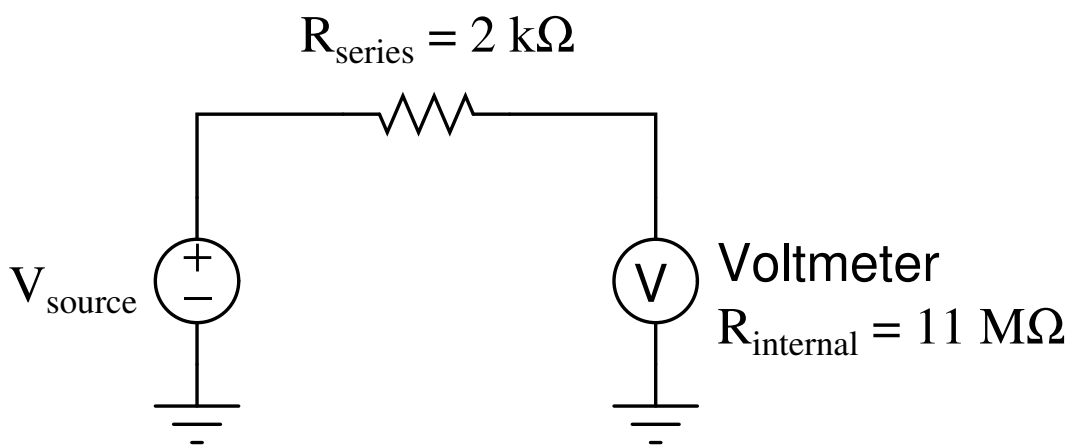
Does the voltmeter accurately measure V_{source} ?

Svar 83

"AC" flowmeters indeed use alternating current to energize their field windings, but "DC" meters do not use steady direct current. Rather, "DC" flowmeters use *pulsed* magnetic fields, sometimes of consistent polarity and other times with reversing polarity (making them "alternating" after all!).

Dual-frequency magflow meters attempt to capitalize on the best features of both DC and AC techniques, by employing specialized pulse waveforms.

DC magflow meters enjoy good rejection of "noise" voltages, while AC magflow meters typically exhibit faster response times.

Svar 84

Since the output of a magnetic flowmeter is linear with regard to flow, there is no need for square root extraction, as indicated by the first "FY" device in the loop. Square-rooting the flow signal will only cause problems if there is no need to do so!

Svar 85

The time elapsed between the generation of an acoustic pulse and the reception of its echo (reflected off the solid object) is directly proportional to the distance between the pulse source and the object. *Velocity* is simply the first derivative of distance with respect to time ($v = \frac{dx}{dt}$).

Svar 86

Flow stream velocity may be measured via the use of sound waves transmitted and received through the liquid. One sonic technology, called *Doppler*, infers velocity by the change in sound frequency between the transmitted sound wave and the received sound wave.

Another sonic flowmeter technology, called *transit-time*, measures liquid velocity by measuring the difference between upstream and downstream velocities of sound waves transmitted through the fluid.

Doppler flowmeter calibration depends on the speed of sound through the process fluid. Transit-time flowmeter calibration does not. Ultrasonic flowmeters are not suitable for multiphase (vapor/liquid mixed) flows, and thus the pipe must be completely full of liquid (no gas pockets) or completely full of gas (no puddles or streams of liquid) in order to function properly.

Svar 87

Transit-time = clean flow streams ; Doppler = flow streams containing particulate and/or bubbles.

Svar 88

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 89

Svar 90

Svar 91

Svar 92

Svar 93

Svar 94

Increased volumetric flow rate with constant density: the undulating motion of the tubes will *increase* in amplitude due to the greater inertial forces, but the resonant frequency of the tubes will *remain the same* because the tubes' mass has not changed.

Increased density with constant volumetric flow rate: the undulating motion of the tubes will *increase* in amplitude due to the greater inertial forces resulting from an increased mass flow rate, and the resonant frequency of the tubes will *decrease* due to increased tube mass.

Changes in fluid density at zero flow: there will be no undulating motion, because there will be no Coriolis force with zero flow. The tubes' resonant frequency, however, will vary inversely with fluid density. One practical caveat is that there will need to be *some* flow in order to push a new fluid of different density into the flowmeter's vibrating tubes, in order to sense that new density.

Svar 95

$$W = \rho Q = 250m/h \cdot 950kg/m = 3958kg/m = 66.0kg/s$$

Advantages:

- Very high accuracy

- Immunity to upstream/downstream piping disturbances

- Provides real measurement of mass flow, fluid density, and fluid temperature

- Excellent rangeability

- Immunity to changes in density – this makes Coriolis flowmeters particularly well-suited for measuring non-Newtonian fluids

- Bidirectional

Disadvantages:

- Relatively low operating temperature limit ($< 800^o$ F)

- Difficulty measuring multi-phase flows (e.g. gas + liquid)

- Prohibitively expensive for large pipe sizes

- Cannot measure low-pressure gases very well (Coriolis forces too small)

- May suffer errors from external vibrations

Mass flow measurement is obtained by measuring the phase shift of the tube's oscillation between the two ends.

Density measurement is obtained by measuring the resonant frequency of the tubes. The basic equation for a mass-and-spring mechanical system is as follows:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Where,
f_r = Resonant frequency
k = Spring constant
m = Mass

Given a known tube mass and a known tube volume, knowing the resonant frequency of the tubes makes it quite easy to calculate the mass of the fluid filling the tubes, and thus the fluid density.

Temperature measurement comes from an RTD sensing fluid temperature as it enters the tube assembly.

Svar 97

First, the proper location of the vapor flowmeter: between the knockout drum and the water-seal drum, or between the water-seal drum and the flare tip. Proper straight-pipe lengths should be observed in order to achieve best measurement accuracy.

- **Orifice plate/venturi/etc.** – Probably not suitable, due to the unknown density (ρ) of the vapors going through the pipe. If a gas density analyzer were added to the system, and its signal used along with absolute pressure and temperature compensation, accurate measurement of either volumetric or mass flow might be possible.

- **Positive displacement** – Probably not suitable, due to possible particulate matter in the gas stream, and rapid temperature changes. Most importantly, if this flowmeter ever jammed, it would "plug up" the flare and prevent its safe operation!

- **Turbine** – Possibly suitable. Pressure and temperature compensation would both be necessary to calculate true volumetric flow rate, however.

- **Vortex** – Probably not suitable, due to low-flow cutoff interfering with operation at low flare flow rates. Even if minimum flow could be ensured, pressure and temperature compensation would both be necessary to calculate true volumetric flow rate.

- **Magnetic** – Definitely unsuitable, due to non-conductivity of vapors in general.

- **Ultrasonic** (Doppler) – Definitely unsuitable, due to lack of objects in flow stream to reflect sound waves.

- **Ultrasonic** (transit time) – Possibly suitable. Pressure and temperature compensation would both be necessary to calculate true volumetric flow rate, however.

- **Coriolis** – Definitely suitable, but most likely too expensive to consider for this application.

- **Thermal mass** – Definitely unsuitable, due to the unknown and randomly changing specific heat of flare vapors.

Svar 98

Turndown refers to the ratio of minimum to maximum flow rate that may be accurately sensed by a particular flowmeter while remaining within acceptable limits of measurement error. Differential-pressure based flowmeters such as this venturi tube typically exhibit turndown ratios of only 4:1 (or sometimes worse) due to measurement uncertainties caused by uneven impulse line liquid heights, DP sensor calibration error, etc. The nonlinear nature of the flow/pressure relationship is the root of this problem.

- **Positive displacement** – Probably not suitable, due to possible particulate matter in the gas stream, and the high volume of flow expected. High volumes would require either a huge flowmeter, or would induce undue wear and tear in the fast-moving meter mechanism.

- **Turbine** – Possibly suitable. Pressure and temperature compensation would both be necessary to calculate true volumetric flow rate, however.

- **Vortex** – Possibly suitable, so long as the minimum flow rate exceeded the low-flow cutoff point for the flowmeter. If minimum flow could be ensured, pressure and temperature compensation would both be necessary to calculate true volumetric flow rate.

- **Magnetic** – Definitely unsuitable, due to non-conductivity of vapors in general.

- **Ultrasonic** (Doppler) – Definitely unsuitable, due to lack of objects in flow stream to reflect sound waves.

- **Ultrasonic** (transit time) – Possibly suitable. Pressure and temperature compensation would both be necessary to calculate true volumetric flow rate, however.

- **Coriolis** – Definitely suitable, but most likely too expensive to consider for this application.

- **Thermal mass** – Possibly suitable, so long as the specific heat of the natural gas was relatively stable over time. If not, compensation may be possible using a gas chromatograph to analyze the composition of the natural gas stream (gas chromatography is typically done anyway in the gas pipeline industry to determine the chemical heating value of the gas!).

- **FT-4 (influent to digester):** This is a magnetic flowmeter, which is a good choice for this application because it is non-restrictive, linear, and handles entrained solids with ease.

- **FT-9 (coolant flow from engine):** This is a vortex flowmeter, which is a good choice for this application because it is linear-responding and senses a flow rate that is unlikely to drop below the meter's low-flow cutoff point (because engine coolant flow is critically important and therefore will be at or near full flow at all times).

- **FT-10 and FT-18 (biogas flow):** These are thermal flowmeters, which is a good choice for this application because it is a technology yielding true mass flow rate (ideal for regulatory monitoring, for carbon credits), is linear, and is relatively inexpensive. The only potential problem in this application is the potential of the biogas composition to change with changes in biomass chemistry. Thermal mass flowmeters are dependent upon the fluid's specific heat value remaining constant (or at least known), and in this case changes in biogas composition may effect specific heat and therefore introduce errors.

- **FT-12 (effluent flow to de-watering):** This is another magnetic flowmeter, which is a good choice for this application because it is non-restrictive, linear, and handles entrained solids with ease.

Svar 100

Svar 101

Svar 102

Svar 103

Svar 104

Svar 105

A "prover" is a precision device used to measure a flow rate for a short period of time. Provers are typically of the piston-and-cylinder design, measuring flow rate by timing how long it takes the piston to travel a certain distance (i.e. displace a certain volume of fluid).

Periodic re-calibration of positive-displacement flowmeters is necessary because they all suffer from internal friction and mechanical wear.

Svar 106

Positive displacement flowmeters of all types use mechanisms to move specific volumes of fluid through with each rotation or other mechanism cycle. Many positive displacement meters resemble pump mechanisms in design.

Because positive displacement meters move specified volumes of fluid through them per cycle, they are immune to changes in viscosity, density, and other fluid parameters. However, it must be understood that the quantity being measured is actual volume, not *standardized* volume units. In other words, a positive displacement gas flowmeter inherently measures in units such as cubic feet per minute (CFM), not standard cubic feet per minute (SCFM).

Svar 107

Svar 108

Svar 109

As flow increases, temperature decreases.

As incoming temperature increases, sensor temperature increases as well. This is interpreted to be *less* flow.

In order to compensate for the fluid's temperature entering the flowmeter and thus cancel any effects resulting from temperature change, we must have an unheated sensor that detects the fluid's "ambient" temperature.

Svar 110

Svar 111

Svar 112

$H = 7.697$ inches

Svar 113

Partial answer:

- Differential pressure at 550 lbm/min mass flow and $\rho = 1.30$ lbm/ft^3 = __**32.89 "W.C.**__

- Mass flow rate at 90 "W.C. = __**920 lbm/min**__

Svar 114

Partial answer:

- **At a flow rate of 10 bbl/hr:**

- Differential pressure transmitter output signal = **<u>3.75</u>** PSI

- Square root extractor output signal = **<u>6</u>** PSI

- **At a flow rate of 31 bbl/hr:**

- Orifice plate ΔP = **<u>90.09</u>** " H_2O

- Flow indicator reading = **<u>31</u>** bbl/hr

Svar 115

Svar 116

Svar 117

Svar 118

Note: All data obtained from the *Instrument Engineer's Handbook, Process Measurement and Analysis, Fourth Edition*, except where noted. Accuracy figures given here are conservative.

- **<u>Orifice plate</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 50 D upstream, 5 D downstream ; 12 D up and 5 D down typical.*

-

- Reynolds number range: *10,000 or greater for concentric, square-edge orifice plates ; special orifices may work well at lower Reynolds number values.*

-

- Typical accuracy (in percent of full-flow value): *+/- 0.5%*

-

- Bidirectional flow measurement: *Yes, with square-edged orifice plate and symmetrical upstream/downstream tap locations such as flange or corner.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Relatively inexpensive and applicable to a wide range of fluids.*

-

- Special disadvantages: *Square-edged orifice plates are particularly sensitive to wear, making them unsuitable for abrasive flow measurement.*

- **<u>Venturi tube</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 26 D upstream, 2 D downstream ; 4 D up and 0 D down typical.*

-

- Reynolds number range: *100,000 minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 0.75%*

-

- Bidirectional flow measurement: *No.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *High pressure recovery.*

-

- Special disadvantages: *Requires flowmeter spool – cannot sandwich between flanges or be inserted through a tap.*

- **<u>Pitot tube or Annubar</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 30 D upstream, 5 D downstream.*

-

- Reynolds number range: *50,000 minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 5% typical ; +/- 1% possible with custom calibration.*

-

- Bidirectional flow measurement: *No.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *May be inserted into pipe through tap.*

-

- Special disadvantages: *Most pitot tubes sample flow profile at one point only, possibly leading to inaccurate measurements.*

- **<u>Vortex</u>**

-

- Principle of operation: *Von Kármán effect of vortices produced alternately from a blunt object in the flow path.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 50 D upstream, 5 D downstream ; 20 D up and 5 D down typical.*

-

- Reynolds number range: *20,000 to 7,000,000 is where the Strouhal number remains constant at about 0.17.*

-

- Typical accuracy (in percent of full-flow value): *+/- 2%*

-

- Bidirectional flow measurement: *No.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *High pressure recovery, easy integration of fluid volume (counting pulses), insertable elements possible.*

-

- Special disadvantages: *Pipe vibrations may fool the vortex detector.*

- **V-cone**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *2 D up (!) and 5 D down typical.*

-

- Reynolds number range: *8,000 minimum (according to manufacturer).*

-

- Typical accuracy (in percent of full-flow value): *+/- 0.25% if two ΔP transmitters used.*

-

- Bidirectional flow measurement: *No.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Fewer upstream straight-pipe lengths required to condition flow compared to other head-based flow elements.*

-

- Special disadvantages: *Requires flowmeter spool – cannot sandwich between flanges or be inserted through a tap.*

- **<u>Segmental wedge</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *10 to 30 D upstream (Source:* `http://www.flowmeterdirectory.com/flowmeter_artc/flowmeter_artc_02021` *and no downstream requirement specified. One manufacturer (ABB) claims that their wedge flow element requires "minimum upstream and downstream piping requirements" (Source:* `http://www.abb.com`*), whatever that means.*

-

- Reynolds number range: *As low as 500 (!).*

-

- Typical accuracy (in percent of full-flow value): *+/- 5% typical ; +/- 0.75% possible with custom calibration.*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Well suited for viscous and slurry applications.*

-

- Special disadvantages: *Requires flowmeter spool – cannot sandwich between flanges or be inserted through a tap.*

- **<u>Magnetic</u>**

-

- Principle of operation: *Electromagnetic induction, as a conductive fluid flows perpendicular to a magnetic field.*

-

- Fluid type(s): *Liquids only, that are electrically conductive (1 μS/cm conductivity minimum).*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 5 D upstream, 3 D downstream ; 3 D up and 2 D down typical.*

-

- Reynolds number range: *No minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 2% for AC ; +/- 1% for DC.*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Obstructionless, work well with slurries.*

-

- Special disadvantages: *Can be expensive for large pipe sizes, fouling of electrodes by insulating deposits such as minerals from "hard" water or oil residue may cause problems.*

- **<u>Coriolis</u>**

-

- Principle of operation: *Inertial force of a fluid flowing in a rotating reference frame (the "Coriolis" force).*

-

- Fluid type(s): *Either gas or liquid, although liquid is easier due to greater density.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *No special piping requirements.*

-

- Reynolds number range: *No minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 0.1% (!)*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *Yes!*

-

- Special advantages: *High accuracy, offers fluid density and temperature measurements independent from mass flow measurement.*

-

- Special disadvantages: *Sensitive to certain vibrations, cannot be used on temperatures above about 800º F, transmitter must be factory-matched to flow tube to be accurate.*

- **<u>Weir</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Liquid in an open channel.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *No special piping requirements.*

-

- Reynolds number range: *Liquid must be fairly low in viscosity.*

-

- Typical accuracy (in percent of full-flow value): *+/- 10%*

-

- Bidirectional flow measurement: *Theoretically possible, but seldom practiced.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Simple and inexpensive.*

-

- Special disadvantages: *Suitable only for open-channel flow.*

- **Thermal**

-

- Principle of operation: *Cooling of a heated element by fluid convection.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 10 D upstream.*

-

- Reynolds number range: *No minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 2%*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *Yes!*

-

- Special advantages: *Function better for low-flow gas streams than most other mass flowmeter technologies.*

-

- Special disadvantages: *Usually practical only for low flow rates.*

- **Ultrasonic**

-

- Principle of operation: *Time-of-flight for sound waves changing with fluid velocity, Doppler effect on reflected sound waves.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *20 D upstream, 5 D downstream ; possibly more upstream if disturbances are severe.*

-

- Reynolds number range: *No minimum, although meter calibration varies with Reynolds number.*

-

- Typical accuracy (in percent of full-flow value): *+/- 1% for transit-time, +/- 5% for Doppler.*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *May be bolted to outside of pipe for non-intrusive flow measurement.*

-

- Special disadvantages: *Sound waves may "ring around the pipe" without even going through the fluid, causing false readings.*

- **<u>Turbine</u>**

-

- Principle of operation: *Windmill operation: fluid turns a bladed turbine at a speed dependent on the fluid's velocity.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *Up to 50 D upstream, 5 D downstream ; 20 D up and 5 D down typical.*

-

- Reynolds number range: *Liquid must be fairly low in viscosity, otherwise fluid drag on the turbine blades will affect low-flow accuracy.*

-

- Typical accuracy (in percent of full-flow value): *+/- 1%*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *High accuracy and repeatability, easy integration of fluid volume (counting pulses).*

-

- Special disadvantages: *Moving parts will wear over time, can be damaged from overspeeding.*

- **<u>Positive displacement</u>**

-

- Principle of operation: *Measuring precise volumes of fluid passing through with a positive-displacement mechanism.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *No special piping requirements.*

-

- Reynolds number range: *No minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 1% or better. Flow "provers" may attain extremely high accuracies.*

-

- Bidirectional flow measurement: *Yes.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Inherently totalizes (integrates) flow rate into a fluid volume quantity.*

-

- Special disadvantages: *Greatest friction and mechanical wear of any flowmeter type.*

- **<u>Rotameter</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *No special piping requirements.*

-

- Reynolds number range: *No minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 5%*

-

- Bidirectional flow measurement: *No.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Inexpensive, reads out directly for people to see.*

-

- Special disadvantages: *Not suitable for very high pressures, due to need for transparent viewing tube; fluid must be fairly clear; limited to relatively low flow rates.*

- **<u>Pipe elbow</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *25 D upstream, 10 D downstream typical.*

-

- Reynolds number range: *10,000 minimum.*

-

- Typical accuracy (in percent of full-flow value): *+/- 10%*

-

- Bidirectional flow measurement: *Yes, if taps at 45º position.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Pipe elbow is already there – cheap!*

-

- Special disadvantages: *Poor accuracy.*

- **<u>Target</u>**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Gas or liquid.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *10 to 30 D upstream (Source:* `http://www.geocities.com/ull_km1980/flowmeterselectionguide.html`*). Downstream = 10 D (Source:* `http://www.hersheymeasurement.com/specsheets/Target_Flow_M`

-

- Reynolds number range: *No minimum with proper calibration.*

-

- Typical accuracy (in percent of full-flow value): *+/- 0.5% for standard, +/- 5% for insertion.*

-

- Bidirectional flow measurement: *Theoretically possible, but seldom practiced.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Insertion design is relatively easy to install in large pipes.*

-

- Special disadvantages: *Difficult to calibrate.*

- **Flume**

-

- Principle of operation: *Differential pressure caused by energy exchange between kinetic and potential forms.*

-

- Fluid type(s): *Liquid in an open channel.*

-

- Minimum straight-run piping lengths (in units of "pipe diameters"): *No special piping requirements.*

-

- Reynolds number range: *Liquid must be fairly low in viscosity.*

-

- Typical accuracy (in percent of full-flow value): *+/- 10%*

-

- Bidirectional flow measurement: *No.*

-

- Inherently measures true mass flow: *No.*

-

- Special advantages: *Simple and inexpensive, no pockets for solids to collect in (unlike a weir).*

-

- Special disadvantages: *Suitable only for open-channel flow.*

Svar 120

Water flow rate (ft³/s)	Percent of flow span (%)	Depth that displacer is submerged (in)	Buoyant force (lb)
0	0	0	0
0.208	10	4.777	0.542
0.520	25	6.892	0.782
1.040	50	9.094	1.032
1.561	75	10.70	1.214
1.873	90	11.50	1.306
2.081	100	12	1.362

Svar 121

35 GPM = 292.1 pounds per minute

Follow-up question: explain why it is essential to solving the problem to know what type of fluid this is.

Svar 122

$Q = 431.3$ GPM (gallons per minute)

Svar 123

There is negligible effect on the flowmeter's calibration with changes in liquid conductivity.

A common misunderstanding with magnetic flowmeters is the relationship between liquid conductivity and magnetic flowmeter calibration. So long as the conductivity stays within the acceptable range for the meter, changes in conductivity have negligible effect on calibration. The flowmeter's voltage-measuring circuitry has such vastly greater impedance than the electrical path through the liquid, that any changes in liquid conductivity are "swamped" by the much greater input impedance of the meter.

Svar 124

If ρ increases without any change in v, the differential pressure ΔP will increase.

If ρ doubles, ΔP will double as well. However, we would actually need the ΔP to increase by a factor of *four (4)* in order to represent a doubling of flowrate, since the ΔP is customarily square-rooted to linearize the nonlinear behavior of the orifice plate. As it is, a doubling of fluid density will only cause the indicated flow rate to increase by a factor of $\sqrt{2}$. "Close, but no cigar," as the saying goes.

Svar 125

$$Q = k\sqrt{\Delta P}$$

At a volumetric flow rate of 200 liters per minute and a corresponding differential pressure of 100 "WC, the value of k will be 20.

- **At a flow rate of 78 LPM:**

- Orifice plate ΔP = **15.21** " H_2O

- Differential pressure transmitter output signal = **10.24** mA

- Flow indicator reading = **78** LPM

- **At a flow rate of 120 LPM:**

- Orifice plate ΔP = **36** " H_2O

- Differential pressure transmitter output signal = **13.6** mA

- Flow indicator reading = **120** LPM

Svar 126

FT

144
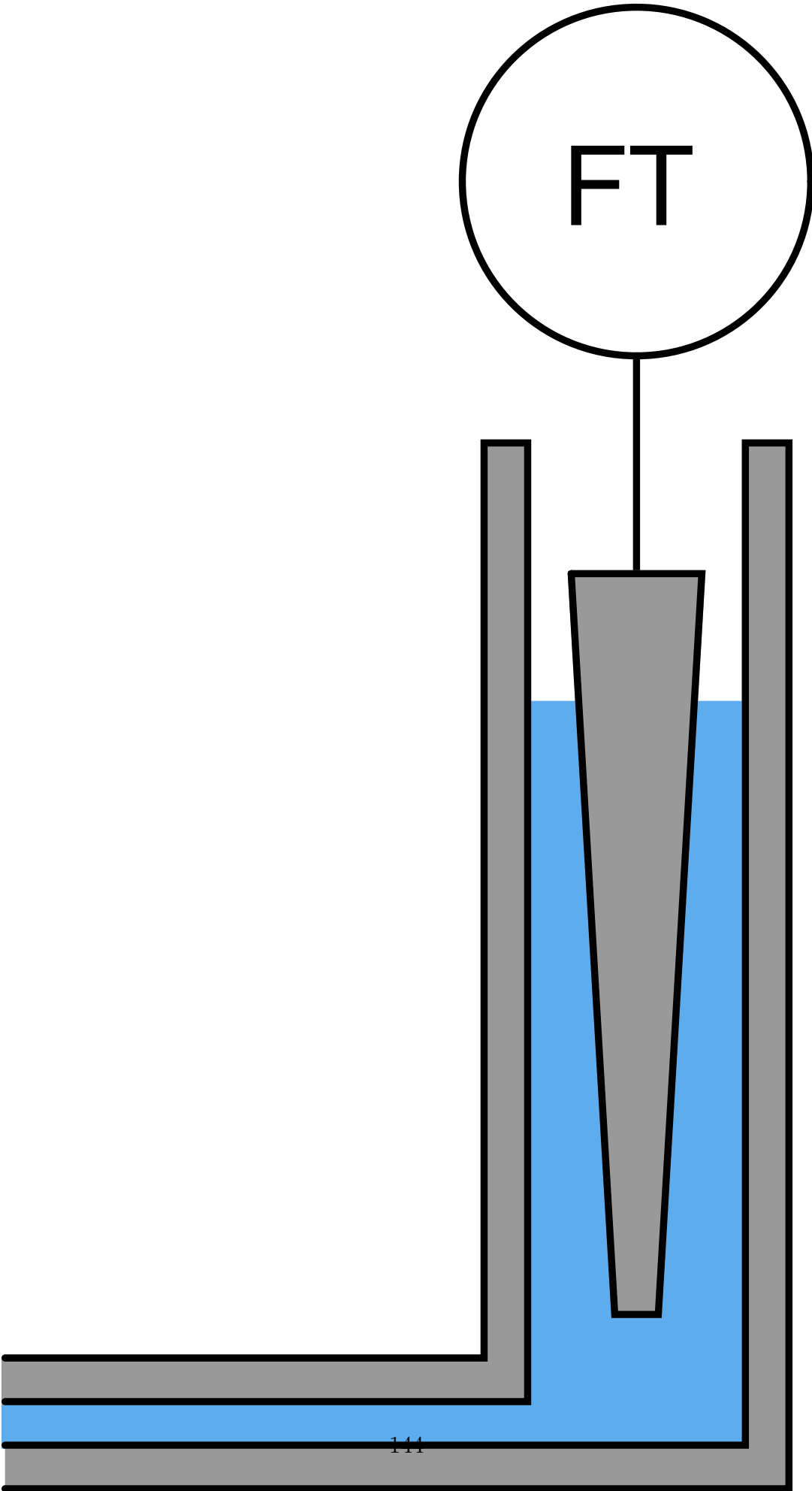
Now, explain *why* the displacer must have this kind of shape, and not one of the other shapes! Hint: sketch a graph of the weir's flow/height transfer function.

Svar 127

- Loop current at 350 GPM = **9.091** mA

- Differential pressure at 600 GPM = **37.19** "WC

Svar 128

A larger-hole orifice plate will generate *less* ΔP for any given flow rate, and can measure *greater* flow rates with the same ΔP range.

Svar 129

$$\text{Re} = \frac{(3160)G_f Q}{D\mu}$$

Where,
Re = Reynolds number (unitless)
G_f = Specific gravity of liquid (unitless)
Q = Flow rate (gallons per minute)
D = Diameter of pipe (inches)
μ = Absolute viscosity of fluid (centipoise)
3160 = Conversion factor for British units

Since the process fluid in question here is *water*, we know that both G_f and μ are equal to 1:

Solving for Q:

$$\text{Re} = \frac{(3160)G_f Q}{D\mu}$$

$$Q = \frac{(\text{Re})D\mu}{3160 G_f}$$

$$Q = \frac{(20000)(7.981)(1)}{(3160)(1)}$$

$$Q = \frac{(20000)(7.981)(1)}{(3160)(1)}$$

$$Q = 50.51 \text{ GPM}$$

Svar 130

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

Svar 131

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

Svar 132

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

Svar 133

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

Svar 134

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

Svar 135

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

Svar 136

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

Svar 137

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

Svar 138

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

Svar 139

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