Strømningsmålling

Kompetansemål:

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

Oppgaver

Oppgave 1

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"??

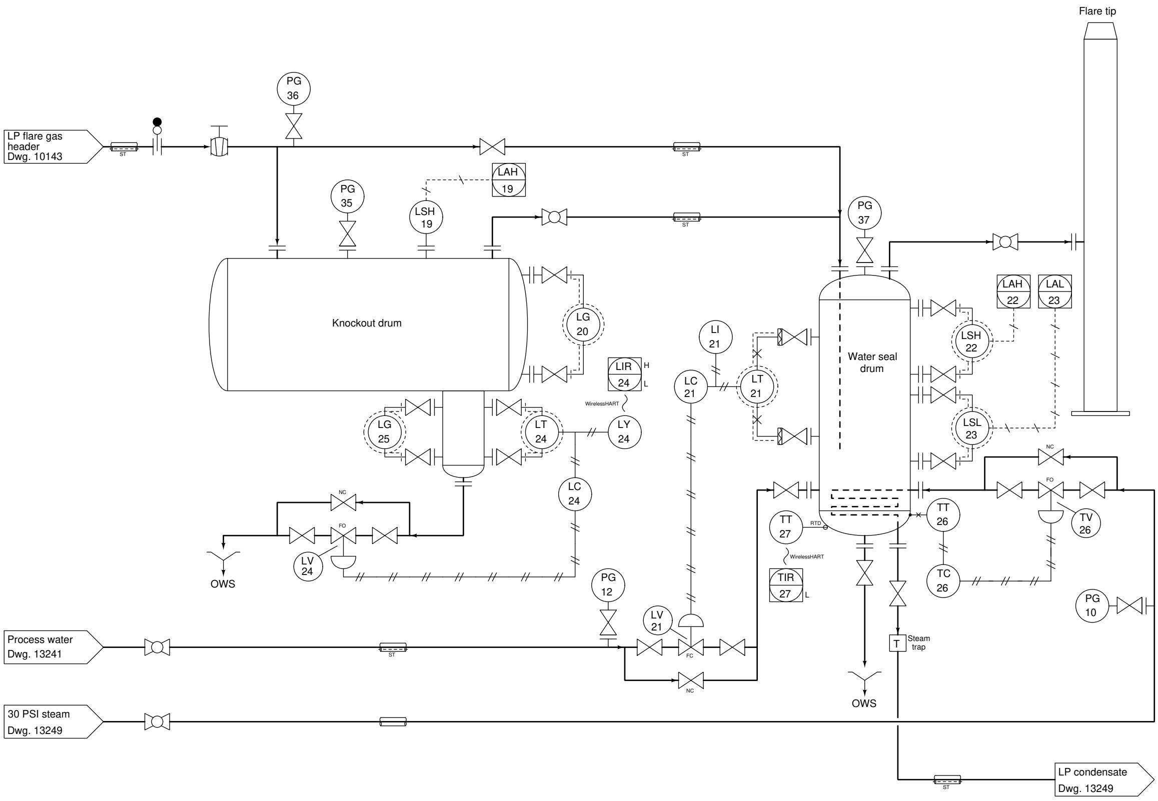
file i04081

Oppgave 2

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 3

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.

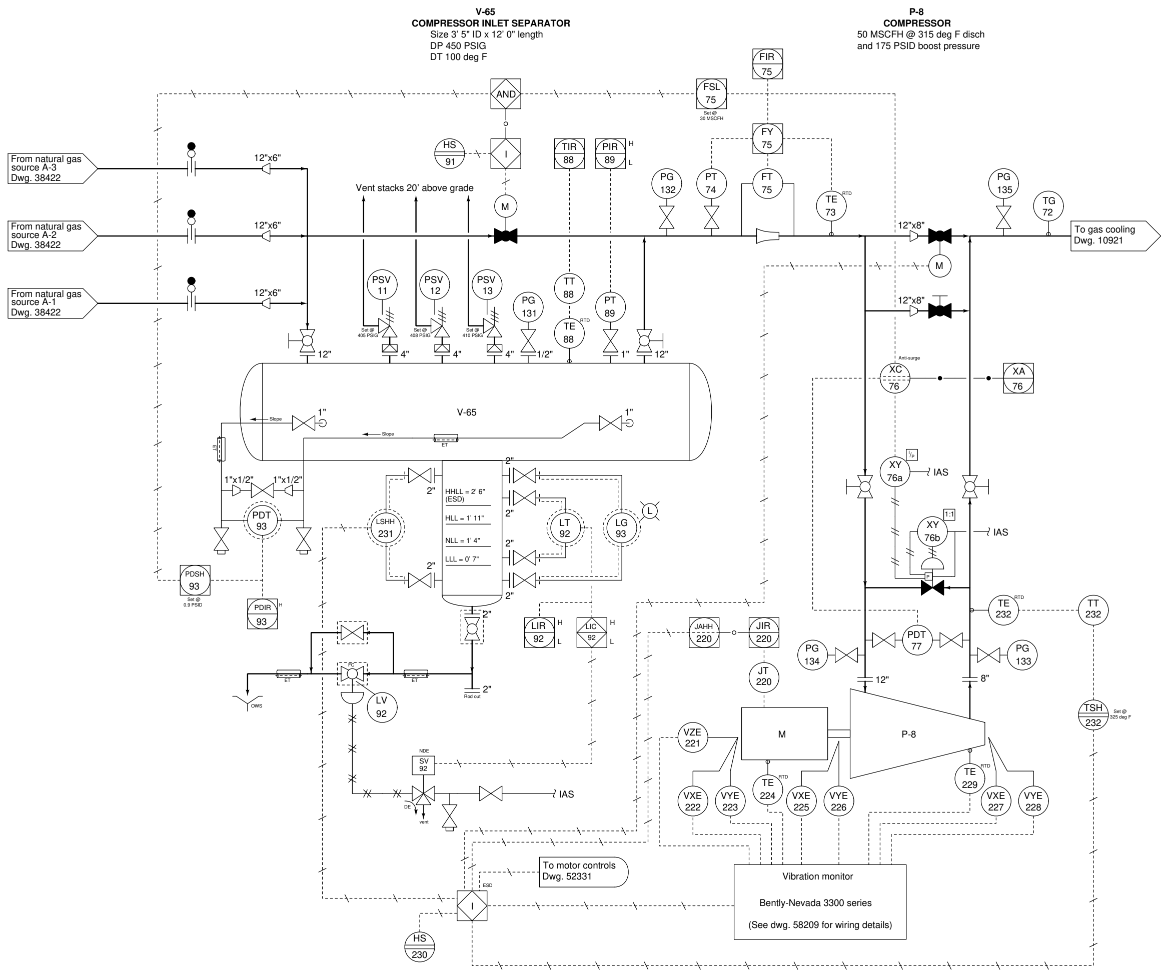
Suppose operations personnel at this refinery wish to monitor the total flow rate of hydrocarbon material burned at the flare. Engineers are debating what type(s) of flowmeter might be used for this task, and where exactly it should be placed in the piping system.

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

file i00977

Oppgave 4

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.

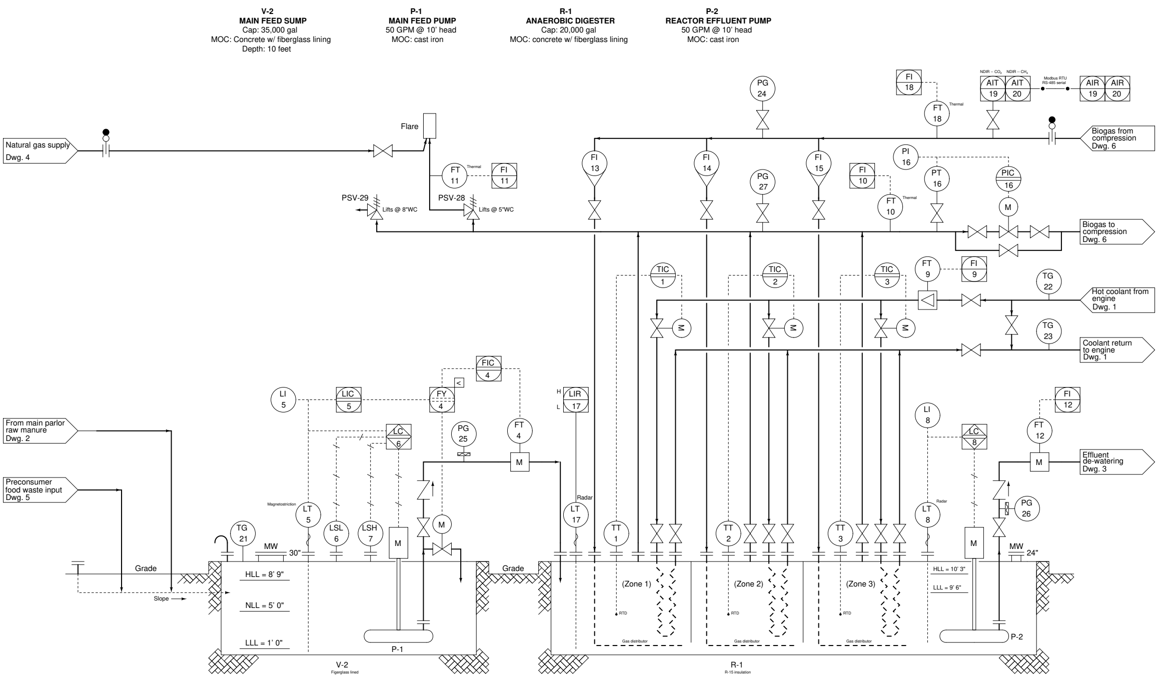
First, explain what “turndown” means in the context of this flowmeter, and explain why this particular type of flowmeter might not provide good enough turndown.

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

file i00978

Oppgave 5

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 6

Oppgave 7

Oppgave 8

Oppgave 9

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 10

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 (α = 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 11

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

Oppgave 12

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 13

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 14

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 15

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 homework, working through practice problems for a particular subject, and/or coordinating with your lab team to give you more practice on specific skills.

Suggestions for Socratic discussion

- 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 16

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 17

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

Oppgave 18

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 19

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

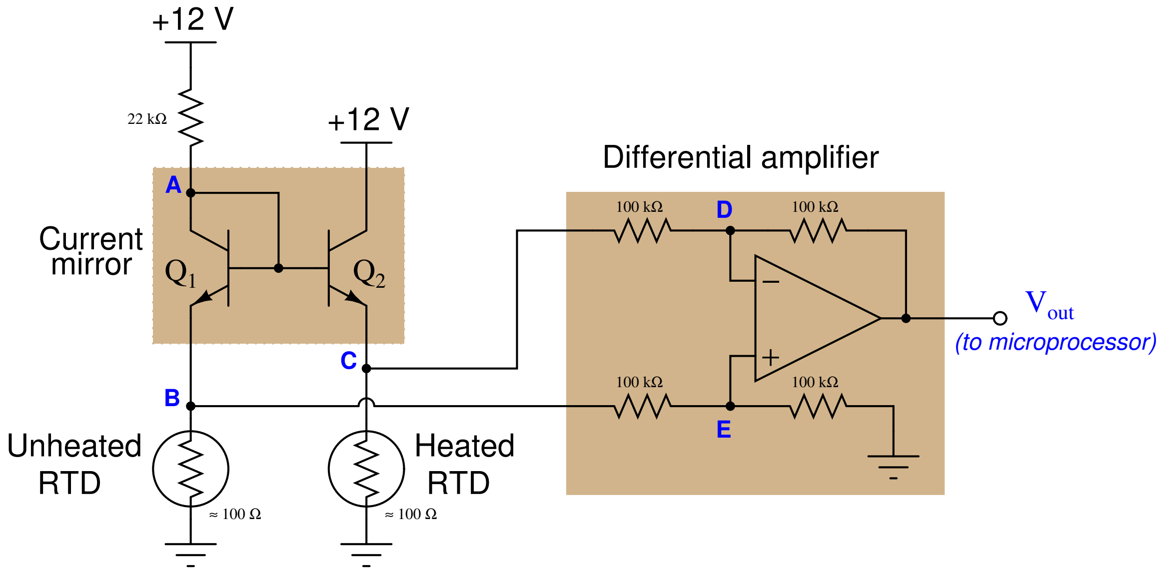
Oppgave 20

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 21

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.

file i02946

Oppgave 22

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:

- **Venturi tube**
-
- 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:

- **Coriolis**
-
- 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:

- **Ultrasonic**
-
- 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:

- **Turbine**
-
- 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:

- **Positive displacement**
-
- 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:

- **Rotameter**
-
- 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):

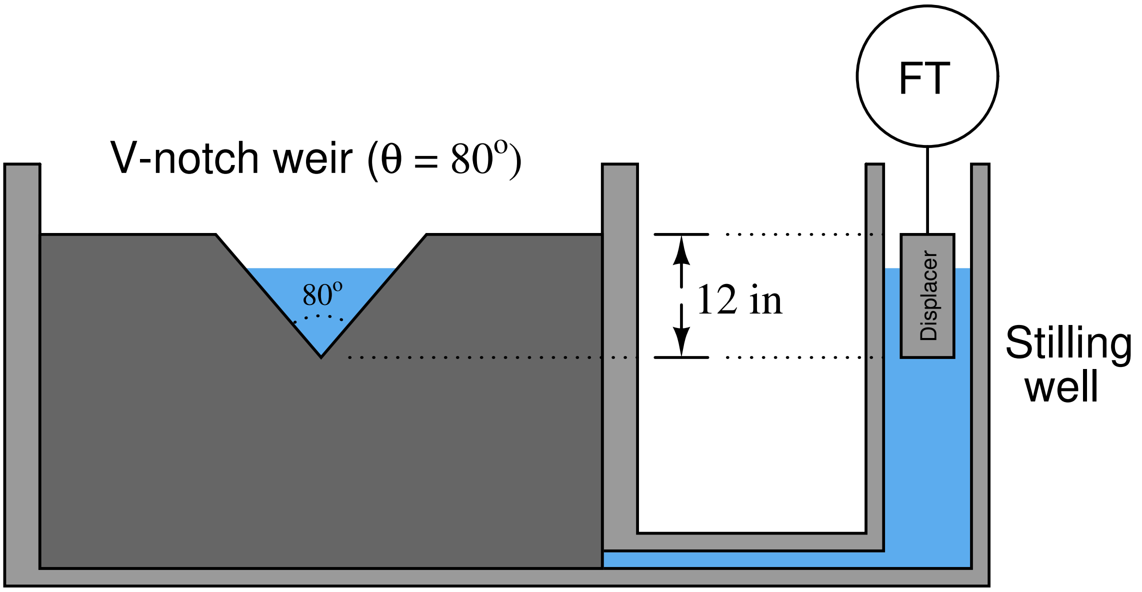
-
- Bidirectional flow measurement:
-
- Inherently measures true mass flow:
-
- Special advantages:
-
- Special disadvantages:

- **Flume**
-
- 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:

file i00541

Oppgave 23

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 (ft^3/s)	Percent of flow span (%)	Depth that displacer is submerged (in)	Buoyant force (lb)
	0		
	10		
	25		
	50		
	75		
	90		
	100		

file i00684

Oppgave 24

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 25

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 26

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.

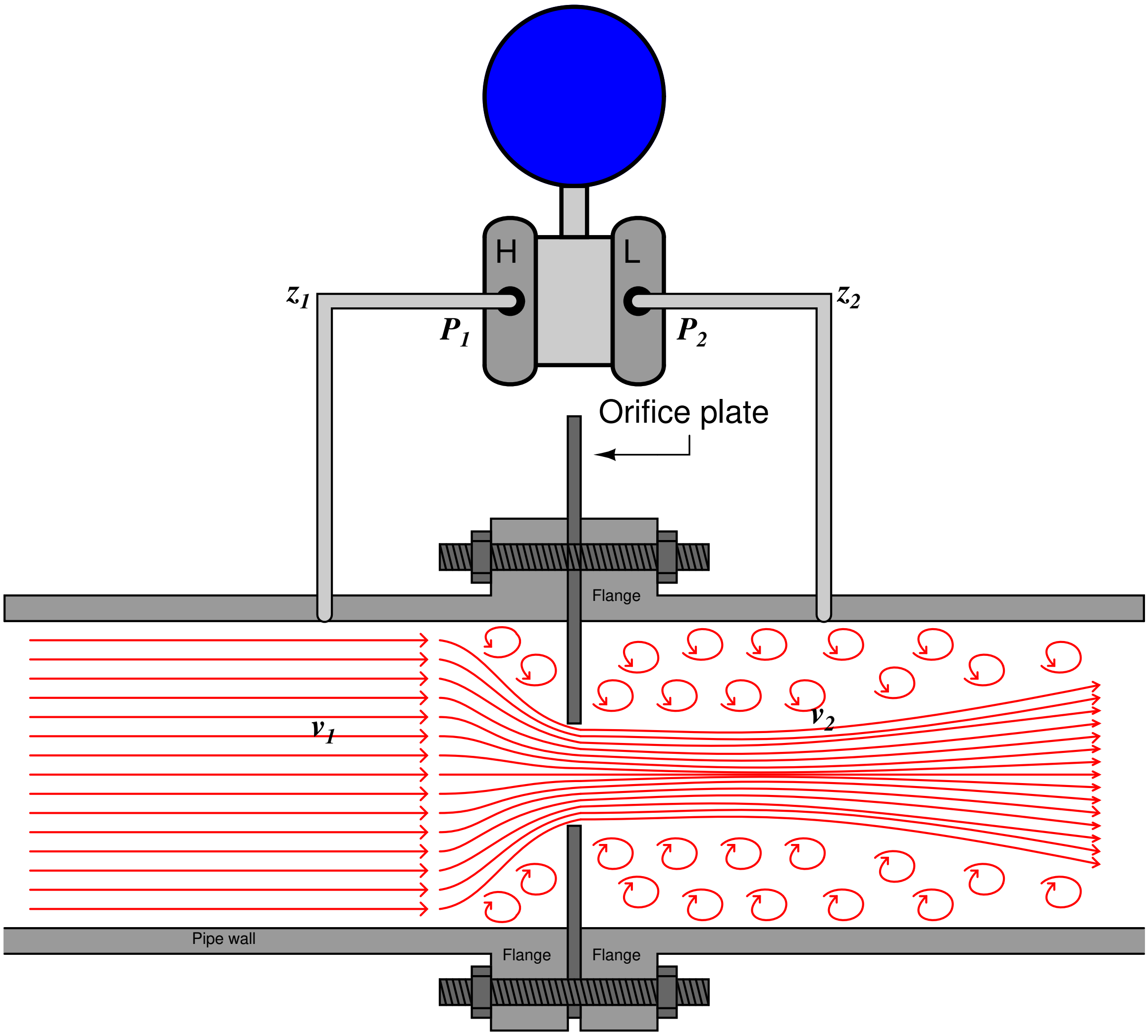
Now suppose the acid solution grows in strength (greater acid concentration). This will increase the conductivity of the solution, because there are now more ions available to carry an electric current. What effect will this have on the magnetic flowmeter's calibration? Will someone have to re-calibrate 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 27

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:

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

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

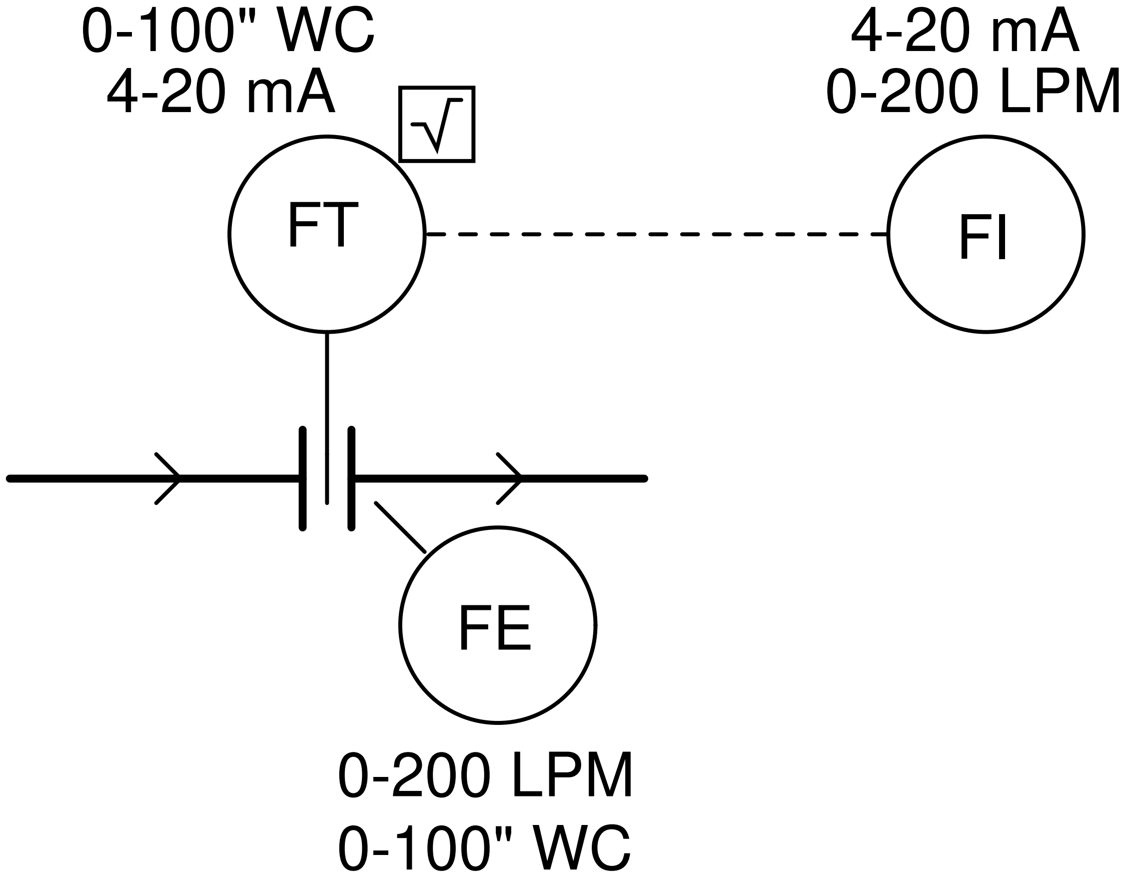
We know that v_2, in turn, directly relates to flow (Q), and so we may write this as an equation once more using a proportionality constant k to incorporate all sizing variables and coefficients:

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

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 28

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 ΔP = ________ " H_2O
- Differential pressure transmitter output signal = ________ mA
- Flow indicator reading = ________ LPM

- **At a flow rate of 120 LPM:**
- Orifice plate ΔP = ________ " H_2O
- Differential pressure transmitter output signal = ________ mA
- Flow indicator reading = ________ LPM

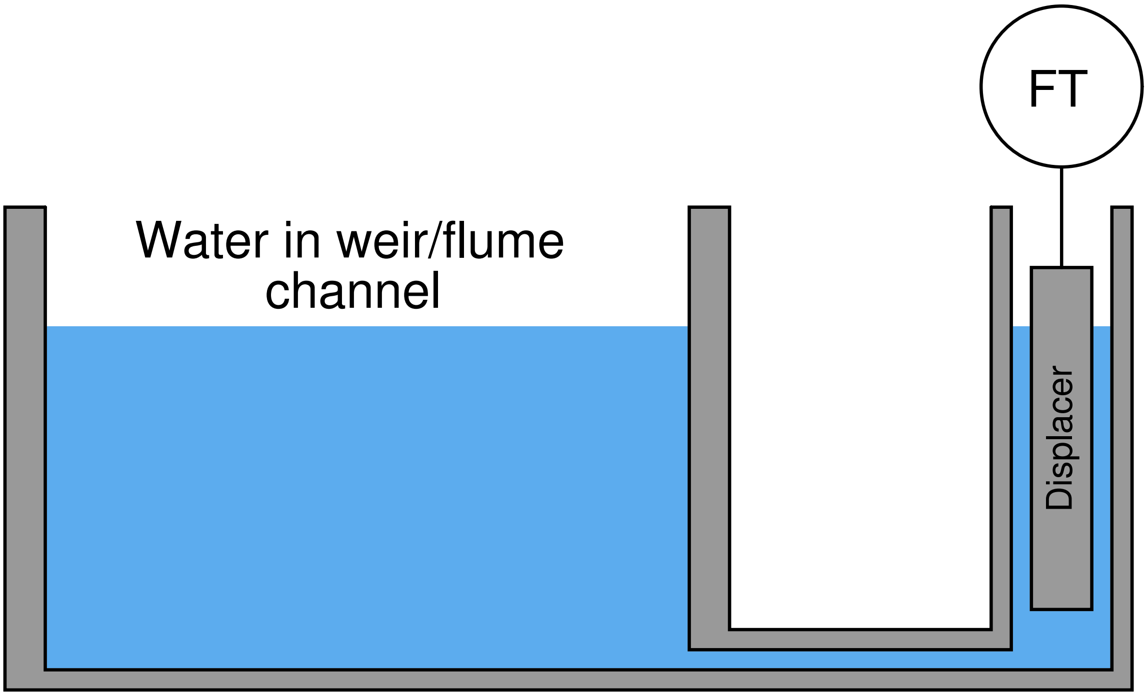
Suggestions for Socratic discussion

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

<u>file i00726</u>

Oppgave 29

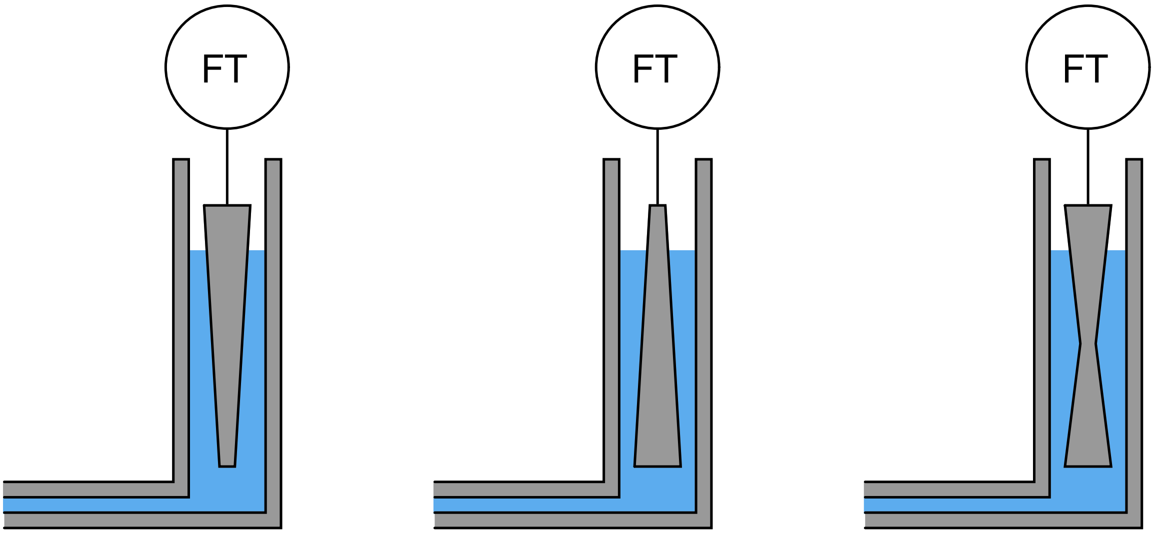
Weirs and flumes are frequently equipped with stilling wells to provide a "quiet" liquid height for an instrument to measure, usually an ultrasonic or displacer sensor such as the type used to measure liquid level in a closed vessel:



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:

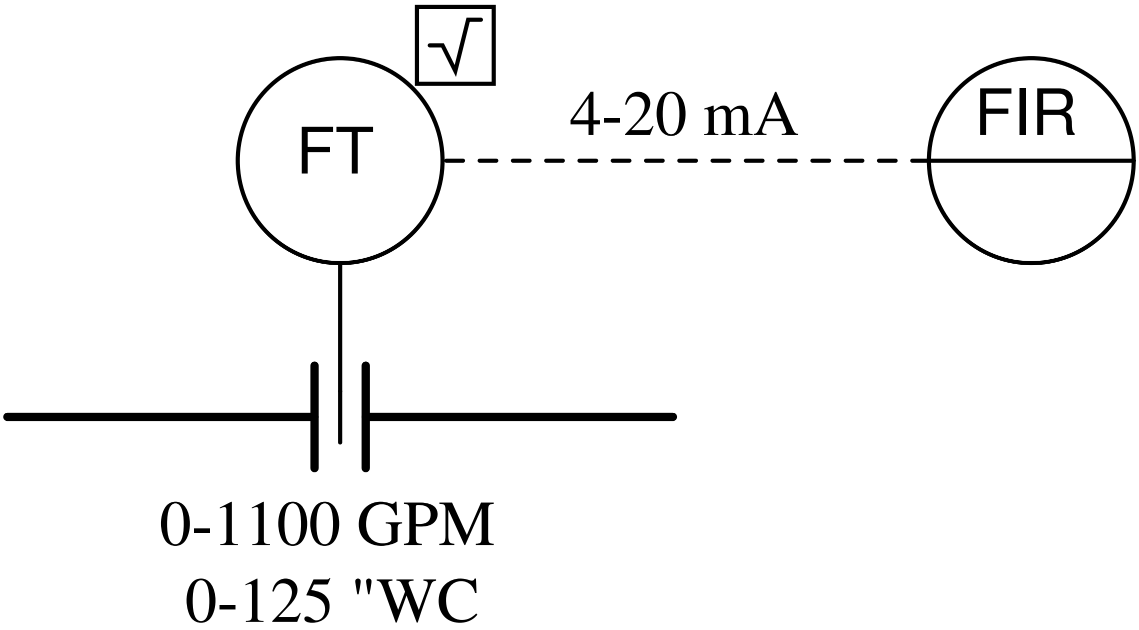
Which displacer has the correct profile?



file i00624

Oppgave 30

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

file i00708

Oppgave 31

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?

file i00727

Oppgave 32

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.

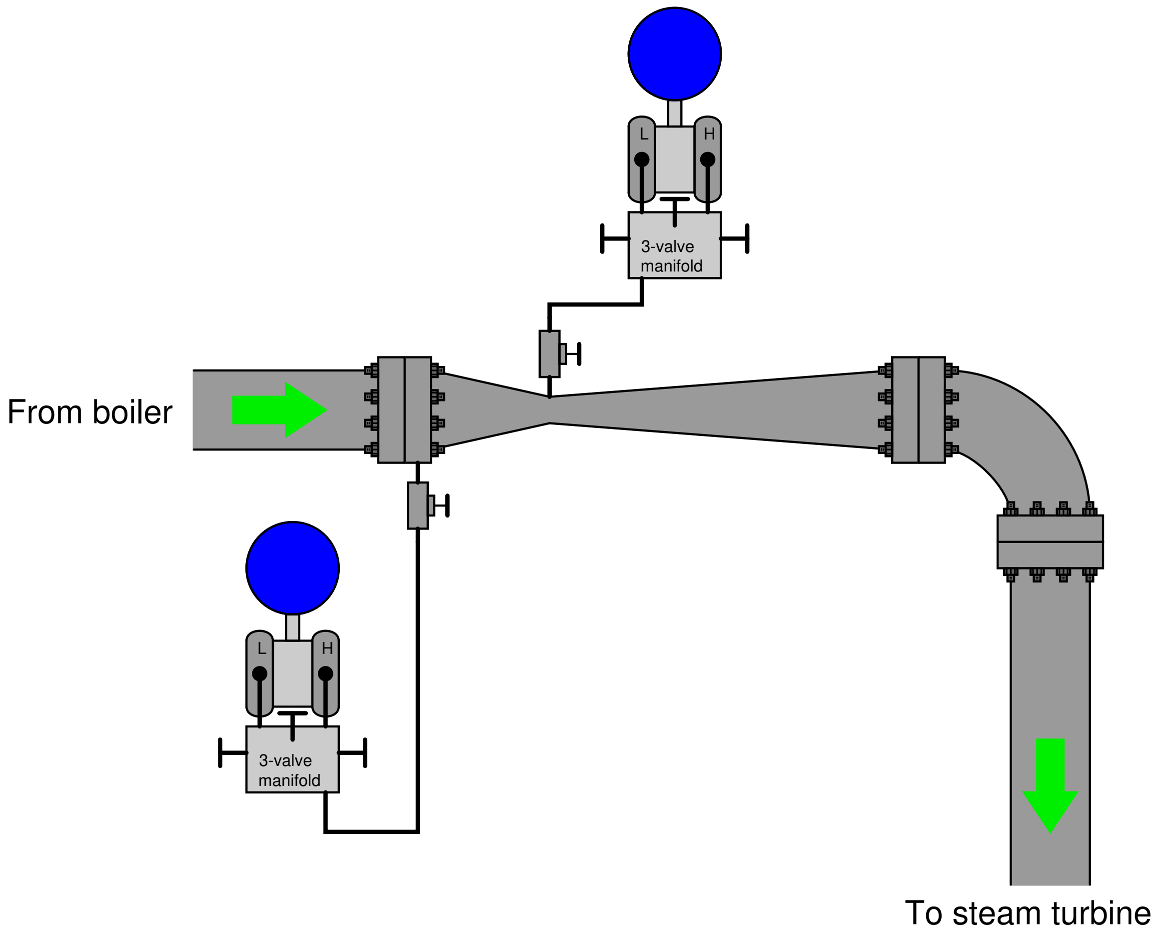
Suggestions for Socratic discussion

- 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 33

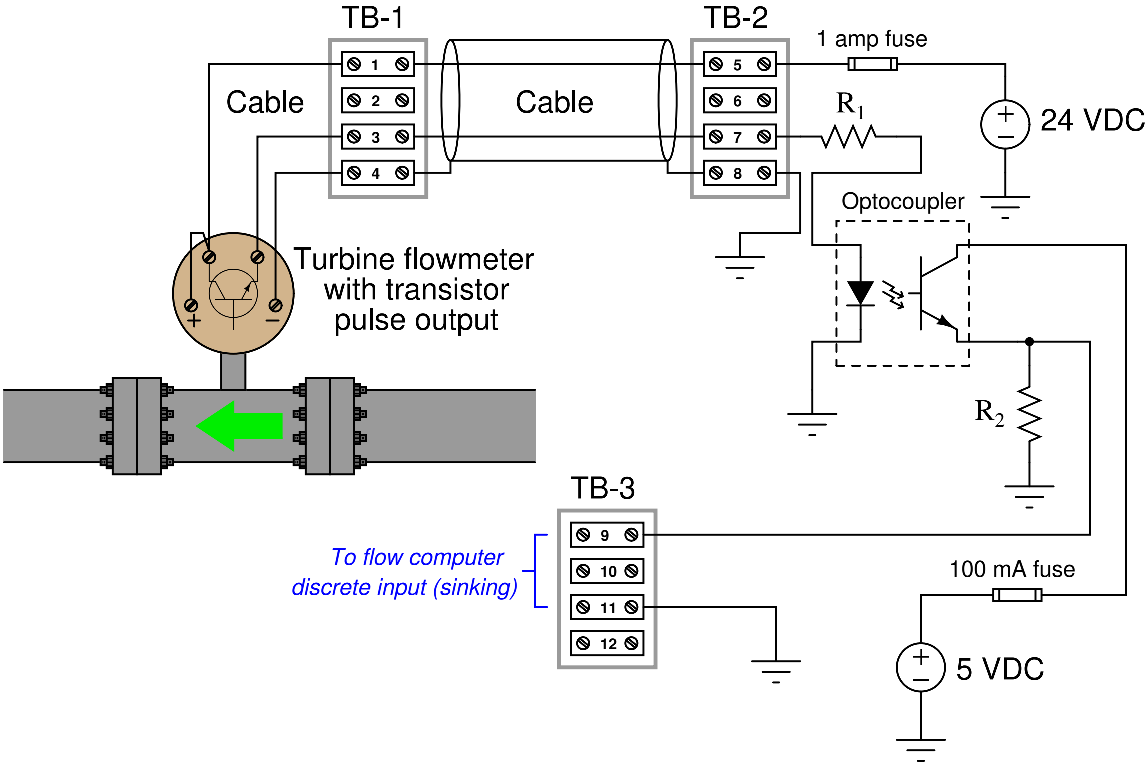
Suppose a venturi tube is installed on a steam line to measure the flow of high-pressure steam coming from a powerhouse boiler and going to a steam turbine (to generate electricity). The contractors who installed the flowmeter left you with this mess:



Explain what is wrong with this installation, and what must be done to fix it.
file i00054

Oppgave 34

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:



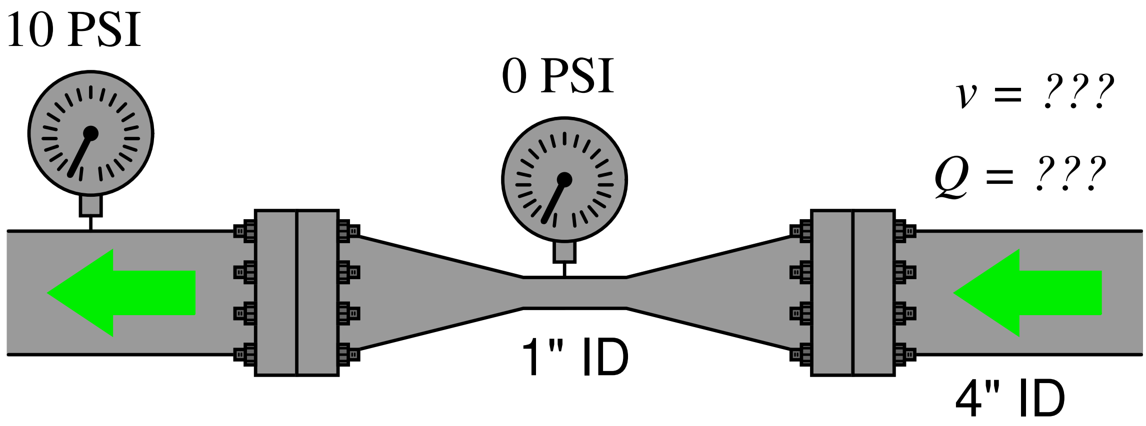
Determine the diagnostic value of each of the following tests. Assume only one fault in the system, including any single component or any single wire/cable/tube connecting components together. If a proposed test could provide new information to help you identify the location and/or nature of the one 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		

file i00500

Oppgave 35

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:



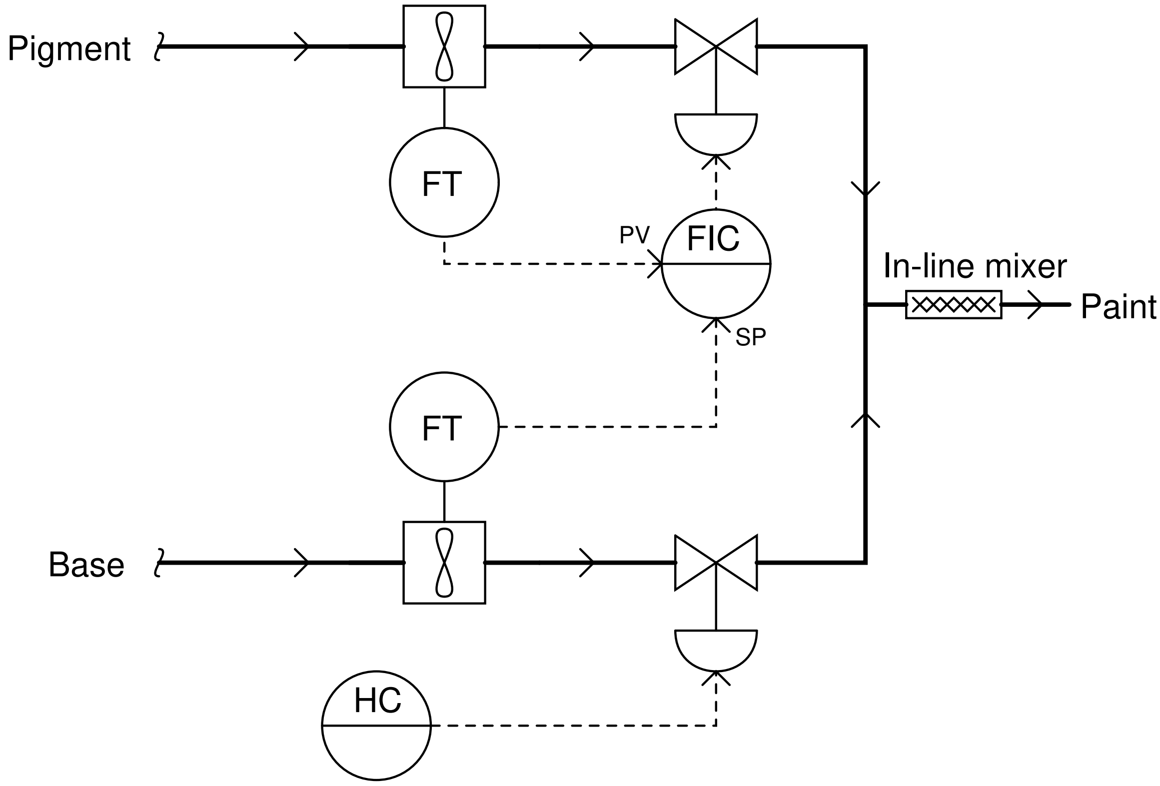
The inside diameter (ID) of the throat is 1 inch, while the inside diameter of the wide pipe is 4 inches. Assume the fluid to be water ($\rho = 1.94$ slugs/ft^3) at a constant downstream pressure of 10 PSIG:

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 36

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:



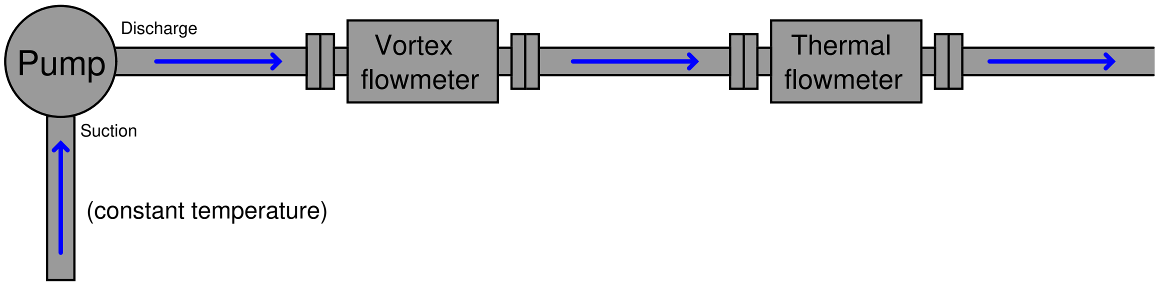
After a couple of years of successful operation, the system begins to output paint that is "paler" in color than it should be. Identify the likelihood of each specified fault for this control system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault 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 37

Two flowmeters are used to simultaneously measure the flow rate of a liquid through a pipe coming from a positive displacement pump:



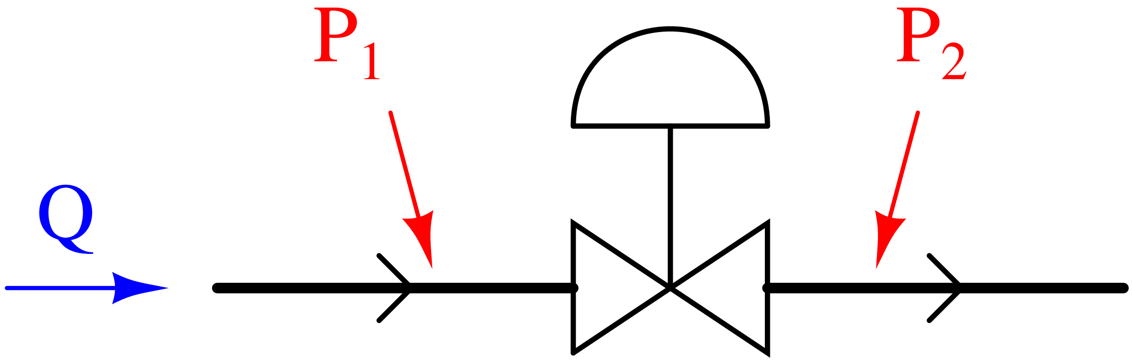
Suppose the positive displacement pump continues to turn at a constant speed, with the temperature of the incoming liquid constant. Suddenly, a steam pipe located near the pump breaks open, directing hot steam at the discharge pipe of the pump, heating the fluid as it exits the pump.

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.

file i03634

Oppgave 38

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!

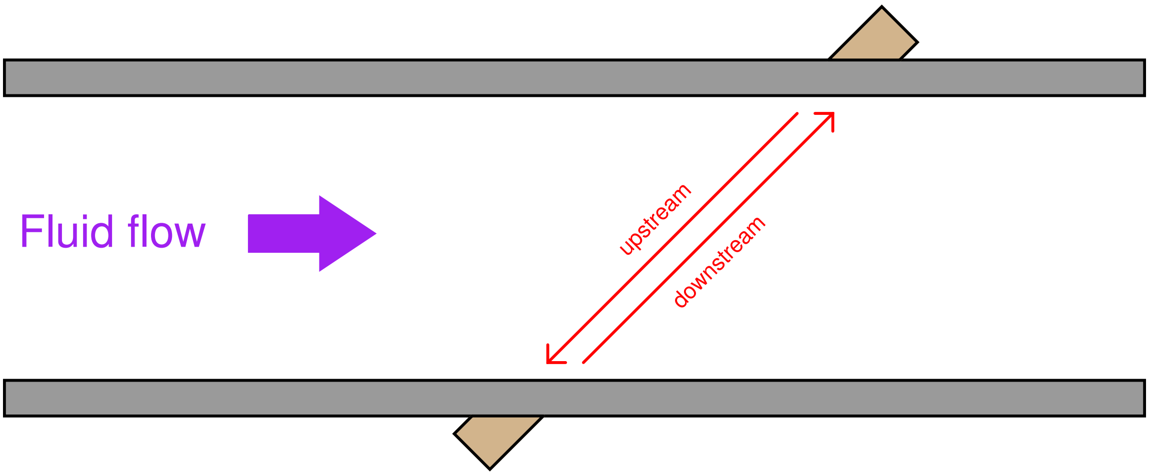
$P_2 =$

file i03297

Oppgave 39

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.

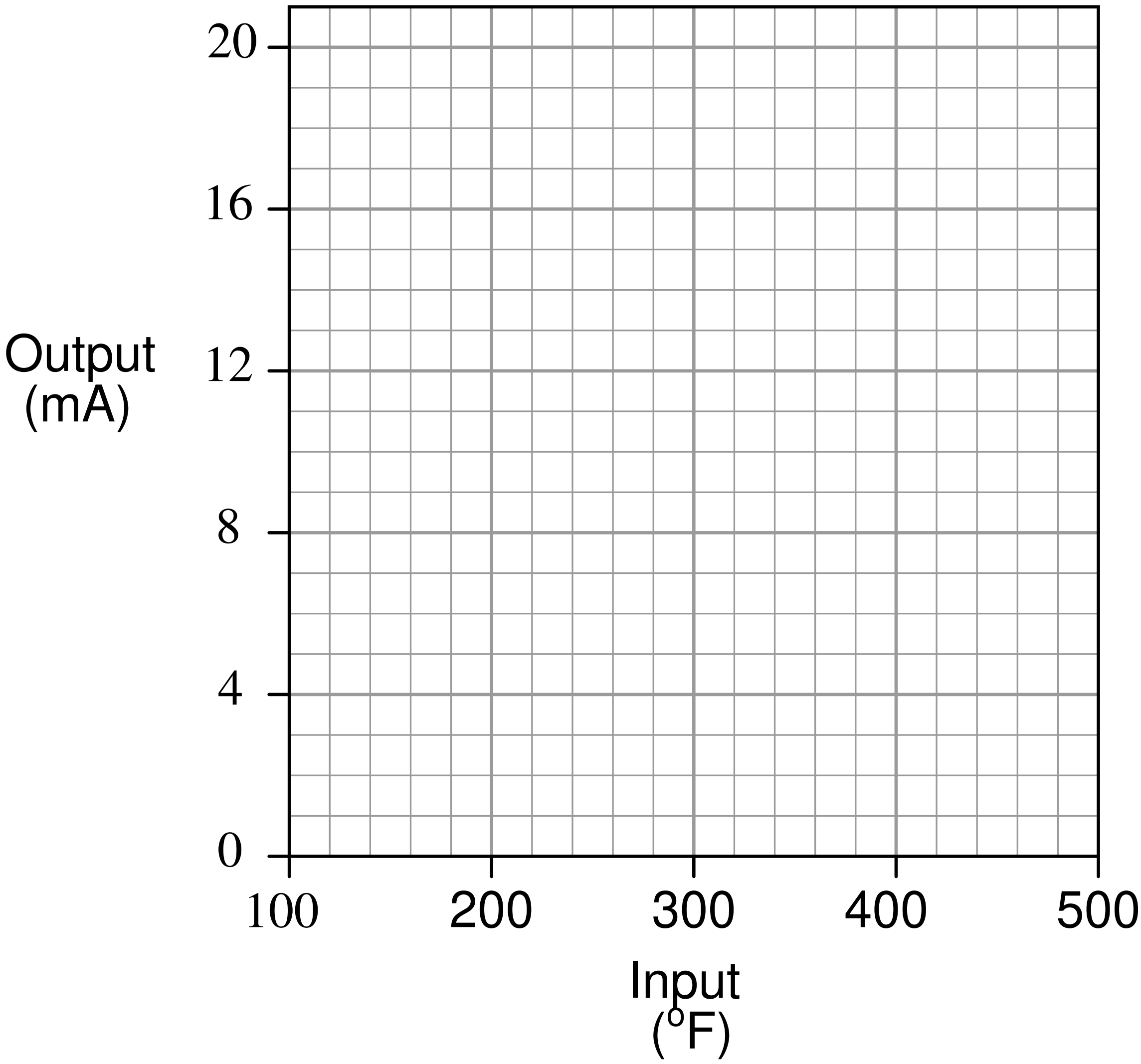
file i03522

Oppgave 40

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

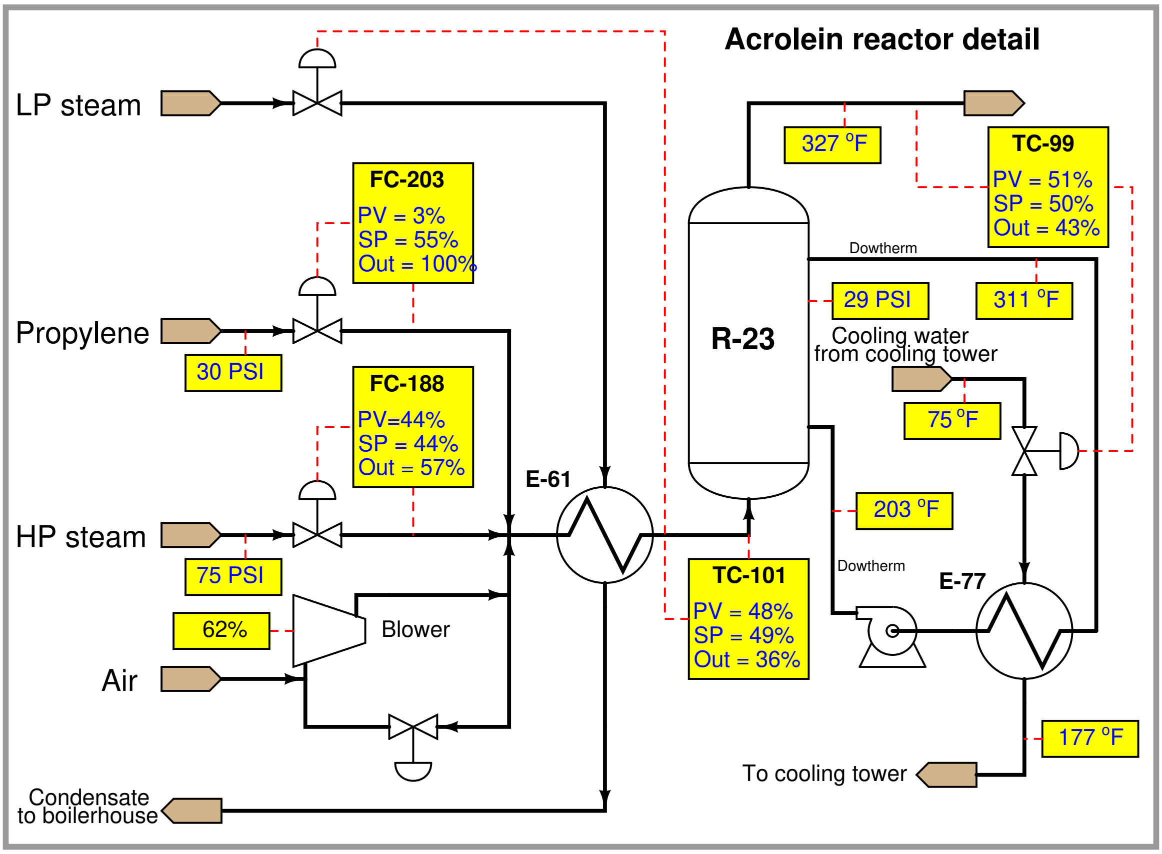
Graph this instrument's ideal transfer function on the graph below, along with its *actual* transfer function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, *linearity*, and/or *hysteresis*).



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 41

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

Svar

Svar 1

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

Svar 2

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 3

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 4

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!).

Svar 5

- **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 6

Svar 7

Svar 8

Svar 9

Svar 10

Svar 11

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 12

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 13

Svar 14

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 15

Svar 16

Svar 17

$H = 7.697$ inches

Svar 18

Svar 19

Svar 20

Svar 21

Svar 22

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.

- **Orifice plate**
-
- 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.*

- **Venturi tube**
-
- 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.*

- **Pitot tube or Annubar**
-
- 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.*

- **Vortex**
-
- 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.*

- **Segmental wedge**
-
- 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_a` *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.*

- **Magnetic**
-
- 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 $\mu S/cm$ 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.*

- **Coriolis**
-
- 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 800° F, transmitter must be factory-matched to flow tube to be accurate.*

- **Weir**
-
- 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.*

- **Turbine**
-
- 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.*

- **Positive displacement**
-
- 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.*

- **Rotameter**
-
- 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.*

- **Pipe elbow**
-
- 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 45° position.*
-
- Inherently measures true mass flow: *No.*
-
- Special advantages: *Pipe elbow is already there – cheap!*
-
- Special disadvantages: *Poor accuracy.*

- **Target**
-
- 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` *Downstream = 10 D (Source:* `http://www.hersheymeasurement.com/specsheets/Targe`
-
- 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 23

Water flow rate (ft^3/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 24

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 25

Q = 431.3 GPM (gallons per minute)

Svar 26

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 27

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 28

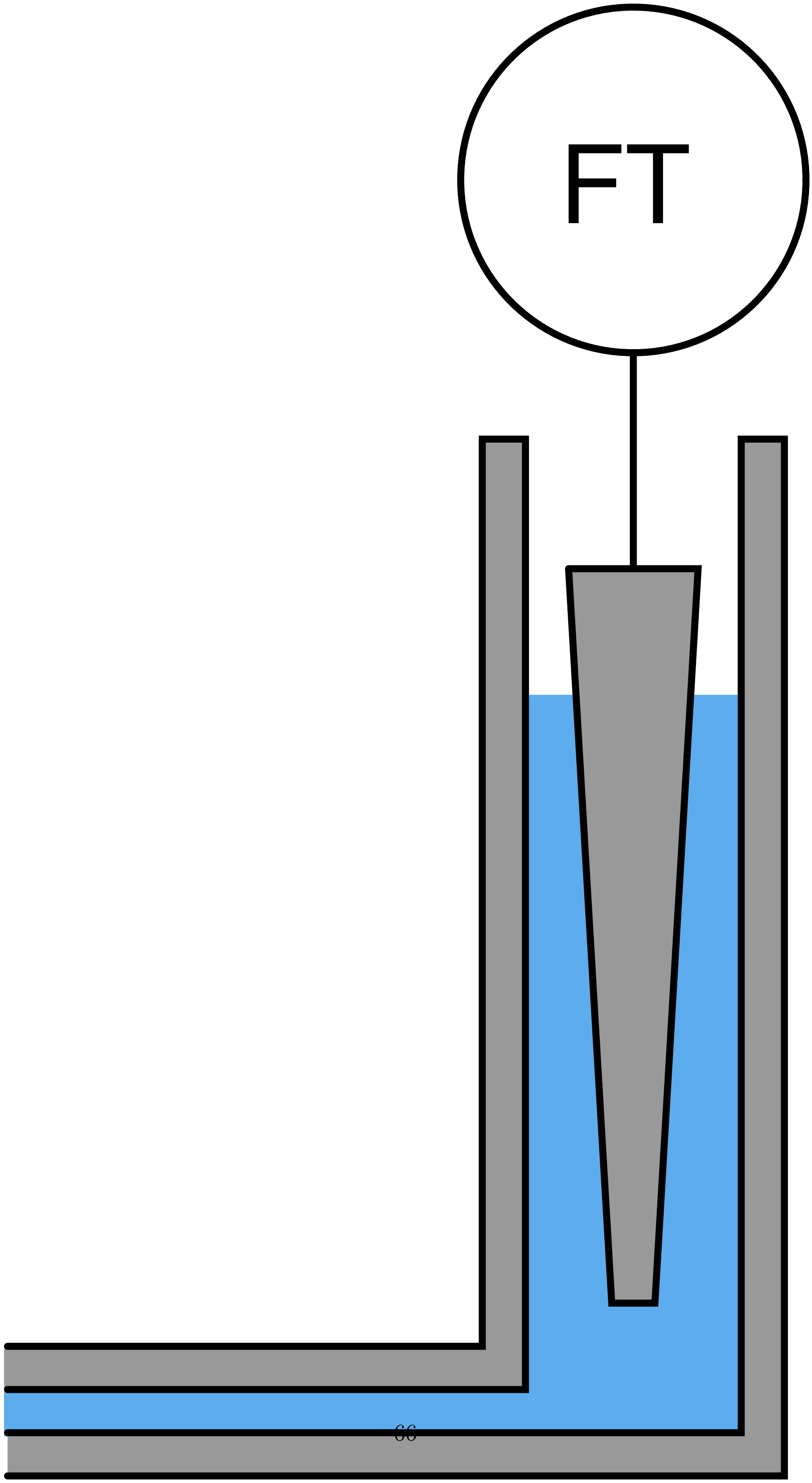
$$Q = k\sqrt{\Delta P}$$

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 29


FT

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 30

- Loop current at 350 GPM = **9.091** mA
- Differential pressure at 600 GPM = **37.19** "WC

Svar 31

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 32

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

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 33

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

Svar 34

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

Svar 35

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

Svar 36

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

Svar 37

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

Svar 38

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

Svar 39

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

Svar 40

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

Svar 41

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