Strømningsmålling

Kompetansemål:

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

Oppgaver

Oppgave 1

En fabrikk produserer en spesiell type væske som brukes i bilindustrien. Før væsken sendes ut til kunder, må den pumpes gjennom et rør for filtrering og kvalitetskontroll. Det er viktig for fabrikken å vite om væsken strømmer laminært eller turbulent i røret, da det kan påvirke filtreringsprosessen.

Oppgavedata:

- Rørets diameter, $D = 15$ cm.
- Volumetrisk strømningshastighet, $Q = 5$ liter/sekund.
- Tettheten av væsken, $\rho = 900$ kg/m^3.
- Den dynamiske viskositeten til væsken, $\mu = 1.5 \times 10^{-3}$ Pa·s.

Oppgaver:

1. Beregn strømningshastigheten, v, av væsken i røret.
2. Finn Reynolds-nummeret, Re, for denne strømningen.
3. Basert på verdien av Re, bestem om strømningen er laminær, overgangsperiode eller turbulent. (Bruk de generelle grensene: $Re < 2000$ for laminær, $2000 \leq Re \leq 4000$ for overgangsperiode, og $Re > 4000$ for turbulent.)

Tips:

- Strømningshastighet er gitt ved: $v = \frac{Q}{A}$, hvor A er tverrsnittsarealet av røret: $A = \pi \frac{D^2}{4}$.
- Reynolds-nummeret for strømning i et rør er gitt ved: $Re = \frac{\rho v D}{\mu}$.

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Oppgave 2

Du jobber som en automasjonsingeniør for et oljeselskap, og en del av din oppgave er å overvåke oljestrømningen i rørsystemet. På grunn av varierende temperaturer og trykkforhold, endres egenskapene til oljen, og det er viktig å vite om strømningen er laminær, turbulent eller i overgangsfasen. Dette kan fastslås ved å beregne Reynolds-nummeret.

Gitt informasjon:

- Diameteren av røret er $0,5$ meter.
- Oljen har en strømningshastighet på $1m/s$.
- Tettheten av oljen er $850kg/m^3$.
- Den dynamiske viskositeten til oljen er $1.5 \times 10^{-3} Pa \cdot s$.

Oppgaver:

1. Forklar kort hva Reynolds-nummeret representerer og hvorfor det er viktig i industrielle applikasjoner.
2. Bruk formelen for Reynolds-nummeret og den gitte informasjonen for å beregne det for denne spesifikke oljestrømningen.
3. Basert på ditt beregnede Reynolds-nummer, avgjør om strømningen er laminær, turbulent eller i overgangsfasen (Bruk følgende retningslinjer: $Re < 2000$ for laminær strømning, $2000 \leq Re < 4000$ for overgangsfasen, og $Re \geq 4000$ for turbulent strømning).
4. Diskuter kort hvilke implikasjoner det vil ha for automasjonssystemet ditt basert på typen strømning (laminær, turbulent eller overgang).

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Oppgave 3

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^o C) som strømmer i et rør med en diameter på 22 cm.
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Oppgave 4

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?
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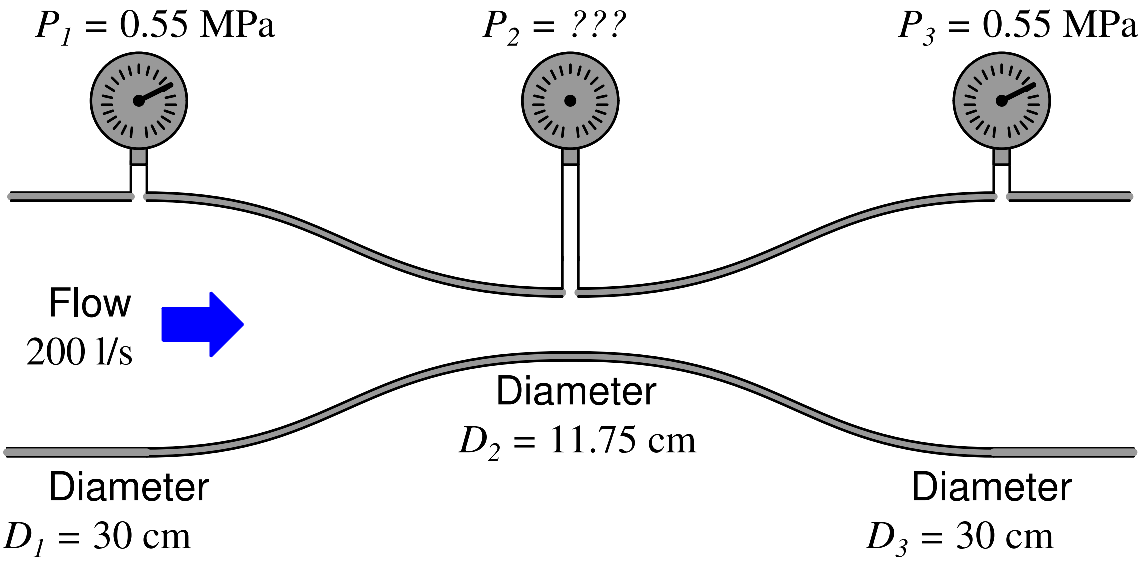
Oppgave 5

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?

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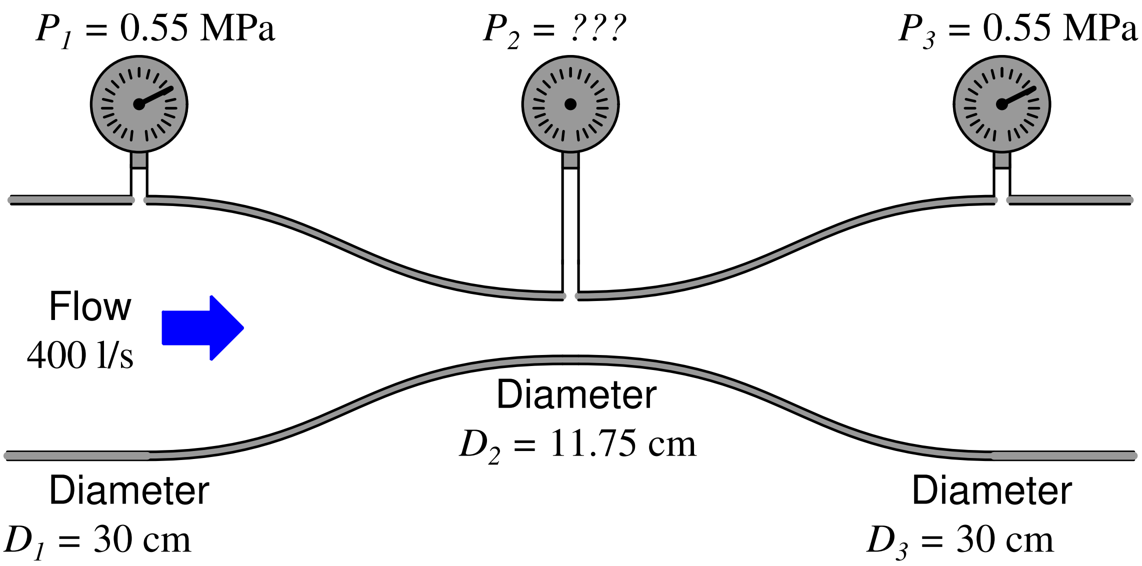
Oppgave 6

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,
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- 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?

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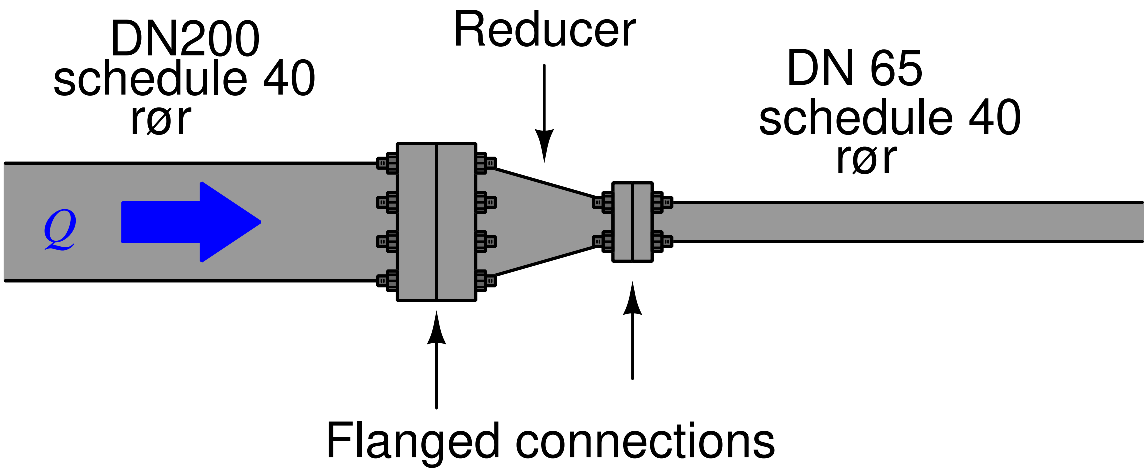
Oppgave 7

Vi har et rør som det strømmer olje med en strømningsrate på 120 m^3/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)
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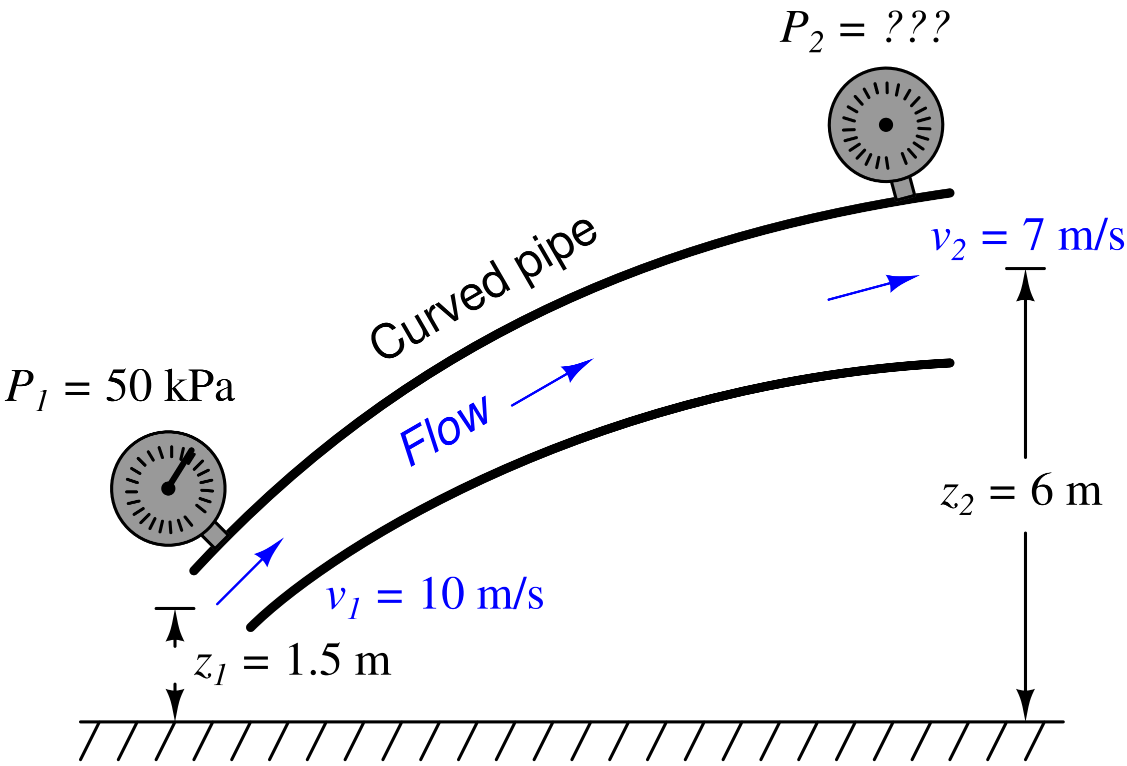
Oppgave 8

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).



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.

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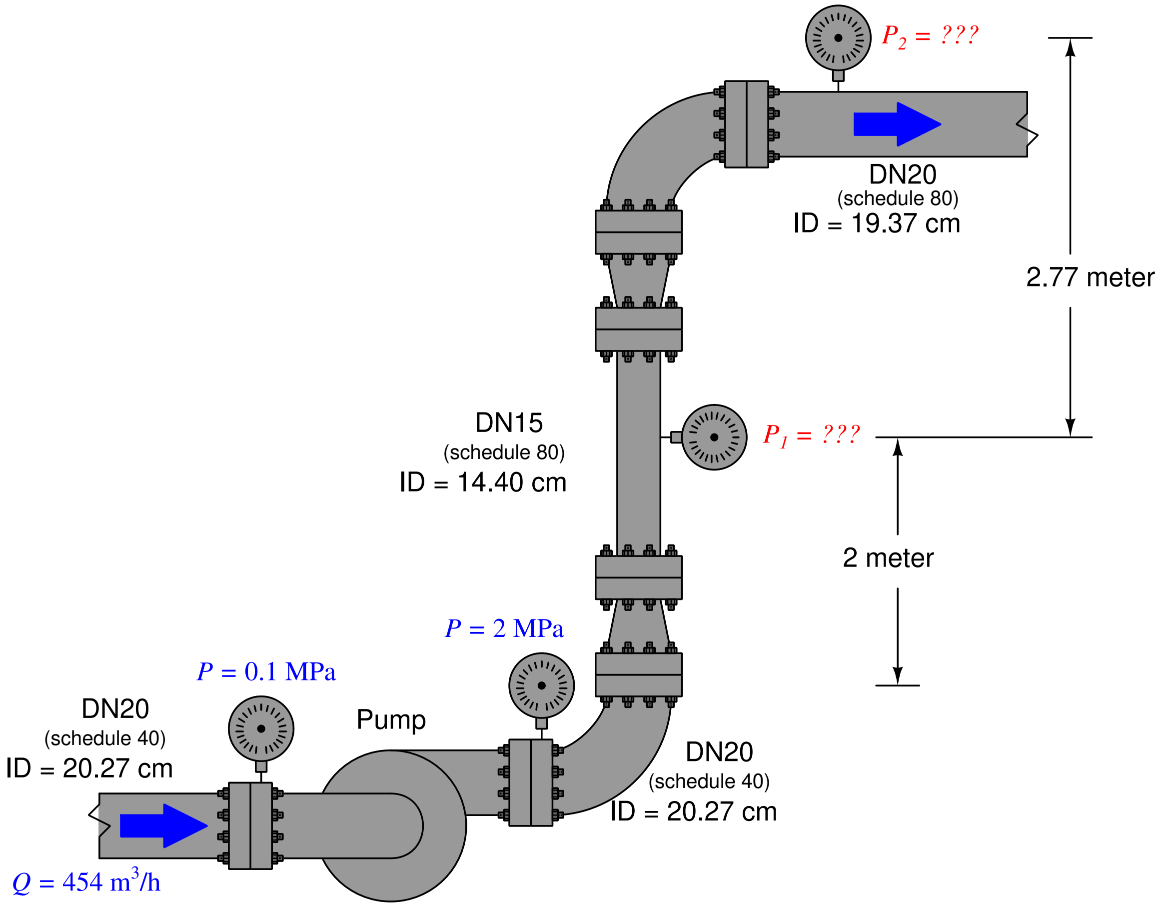
Oppgave 9

Regn ut trykkene P_1 and P_2, anta at massetettheten til fluidet er 886.45 kg/m³.

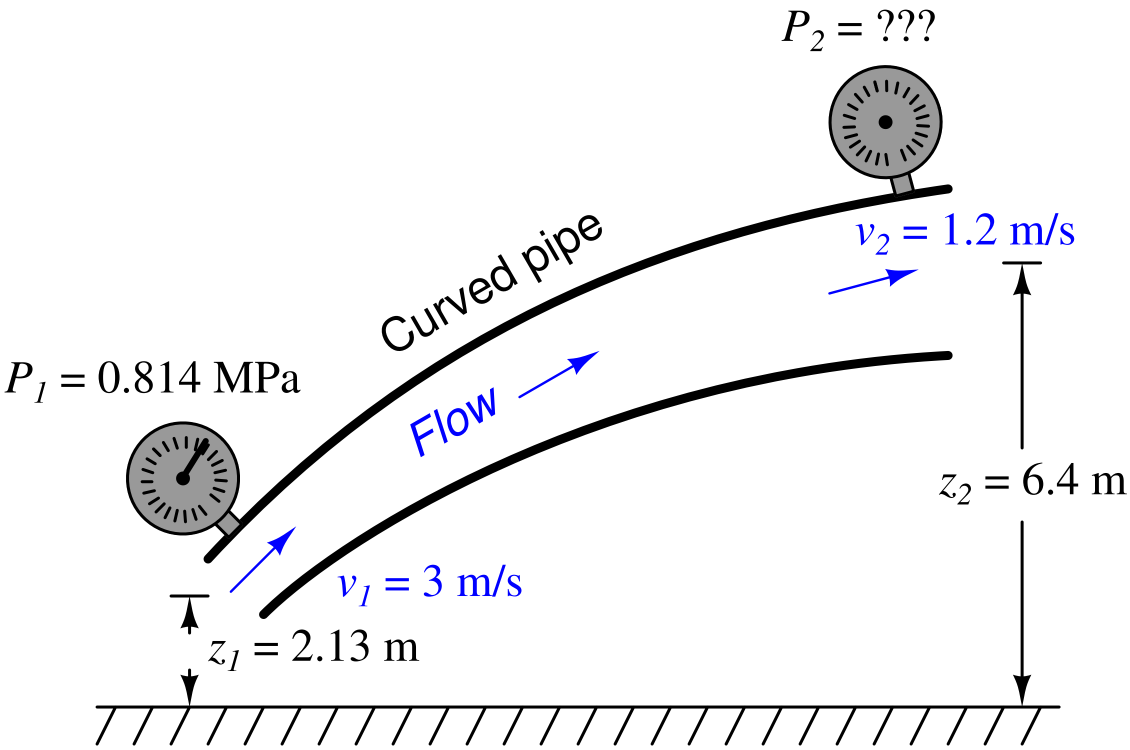


Also, comment on whether or not Bernoulli's equation could be used to compare the suction and discharge pressures of the pump, being that those two pressures (145 and 302 PSI) are measured on the same size pipe, with the same flow rate, and very similar elevations (heights).

file i00457

Oppgave 10

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):



Bernoulli's equation:

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

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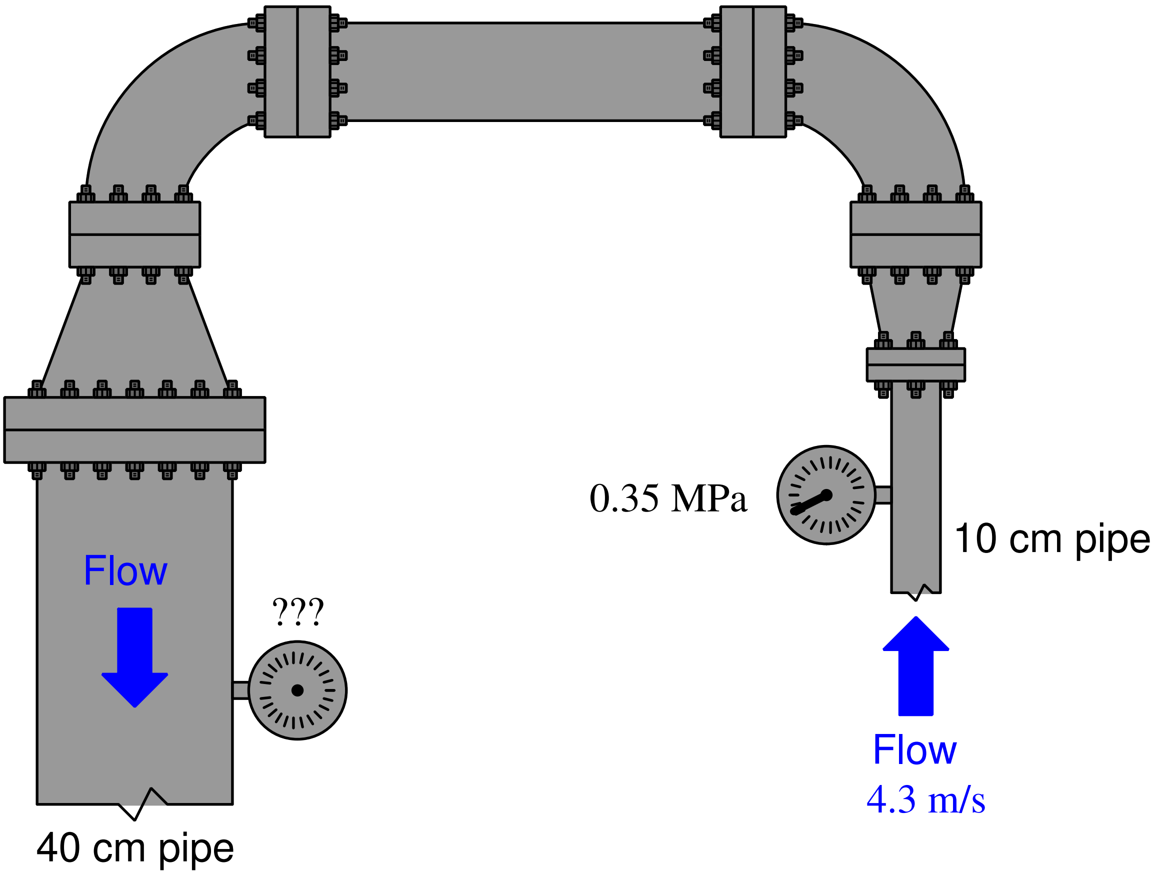
Oppgave 11

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:



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/m^3.

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

Svar

Svar 1

Svar 2

Svar 3

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:

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

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 = 184903

Svar 4

Re ≈ 13581 = *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; Chapter 2.14: Orifices; *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; Chapter 2: Fluid Properties – Part II; *ISA Industrial Measurement Series – Flow*; pg. 11

- Re < 2,100 = "Laminar"
- Re > 3,000 = "Turbulent"
- Source: Tyler G. Hicks, P.E.; Laminar Flow in a Pipe; *Standard Handbook of Engineering Calculations*; pg. 1-202

- Re < 1,200 = "Laminar"
- Re > 2,500 = "Turbulent"
- Source: Tyler G. Hicks, P.E.; Piping and Fluid Flow; *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; Chapter 10: Fluids; *Physics (Third Edition)*; pg. 11

- Re < (about) 2,000 = "Laminar"
- 2,000 < Re < 4,000 = "Transitional"
- Re > 4,000 = "Turbulent"
- Source: Schoolcraft Publishing; Chapter 20: Properties of Fluid Flow; *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*!

Svar 5

$P_2 = 0.42$ MPa

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

Svar 6

$P_2 = 0.018$ 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 7

Partial answer:

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

Svar 8

$P_2 = 31.39$ 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 9

$P_1 = 296.77$ PSI $\qquad P_2 = 293.27$ 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 10

$P_2 = 0.776$ MPa

Svar 11

$P_{out} = 0.359$ MPa

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