Introduction to Sample Systems

Session 7

Reboot & Review 4, 5, 6

Time Delay

SCAN ME

Insight-Analytical.com
Sales@Insight-Analytical.com
(403) 910-6280

INSIGHT ANALYTICAL

Introduction to Sample Systems

- ~~Inputs to Design~~
- ~~General Requirements~~
  - ~~Useful numbers~~
  - ~~Safe and reliable~~
  - ~~Response time~~
- Flow & Time Delay
  - ~~Fundamentals~~
  - ~~Delay Calculations~~
  - Pressure Drops
- Phase Behavior
  - Phase diagrams
  - Water & Condensation
  - Impact on useful numbers
  - Vaporizing liquid samples
- Sample Transport
  - Adsorption/Desorption
- Sample Extraction
  - Sample Taps & Probes
- Liquids control
  - Coalescers
  - Coolers & Condensers
  - Knockouts
- Filtration
  - Types & how they work
- Sample Conditioning
  - Remote Stations
  - Stream Switching
  - Layout Considerations
- Specific Applications

Plan for this week

- Discuss viscosity
- Darcy Equation for pressure drop
- Friction factors
- Moody Charts
- Sample Calculations

Properties of fluids

- For time delay calculations, we often only care if it is a gas or a liquid, not its composition
- Properties of fluids are important for sample system design, and this makes the chemical composition important
- Typical Properties of interest:
  - Density – how heavy is it?
  - Viscosity – how much does it resist flow ?
  - Bubble Point – At what temperature and pressure will gas bubbles form?
  - Dew Point – At what temperature and pressure will liquids condense?
  - Cloud Point – At what temperature will solids or waxes precipitate?
  - Phase diagram – what are the properties at other temps pressures ?

Molecular Weight and Density of Gases

If we know composition of a gas, we can determine average molecular weight.
If we also know the pressure and temperature we can calculate the density.

Chemical	MW	Conc	Contribution
Methane	16	74.2%	11.87 grams/mole
Carbon Dioxide	44	16.4%	7.22
Ethane	30	8.1%	2.43
Nitrogen	28	1.3%	0.36
Total		100%	21.88 grams/mole

At 1 bara (100 kPa) and 0°C (273K), one mole of gas occupies 22.7 liters.

Assume conditions are 6 psig (141 kPa) and 60°C (333K)

$$Density = \frac{MW}{22.7L} \times \frac{P_{process}}{1bara} \times \frac{273}{T_{Proces}} = \frac{21.88\ gr/mole}{22.7L/mole} \times \frac{141kPa}{100\ kPa} \times \frac{273K}{333K} = 1.11\frac{gr}{L} = 1.11\ \frac{kg}{m^3}$$

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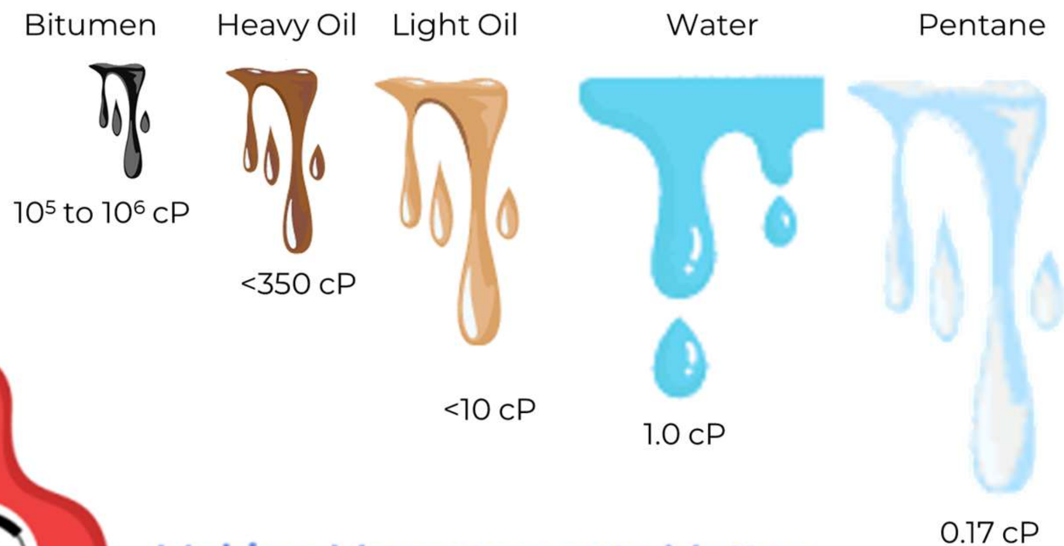
Density of liquids

- Usually the process data sheet will give us the density
- Doesn't vary much with temperature and pressure
- Has a much smaller effect and effective range than viscosity
- Density of light hydrocarbons (propane) around 500, water and heavy hydrocarbons 1000 kg/m3 (by contrast viscosity of propane around 0.15 and heavy oil around 300)

What is viscosity?

- Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid and is often referred to as the fluid's "thickness" or "stickiness". Syrup, for example, has a higher viscosity than water.



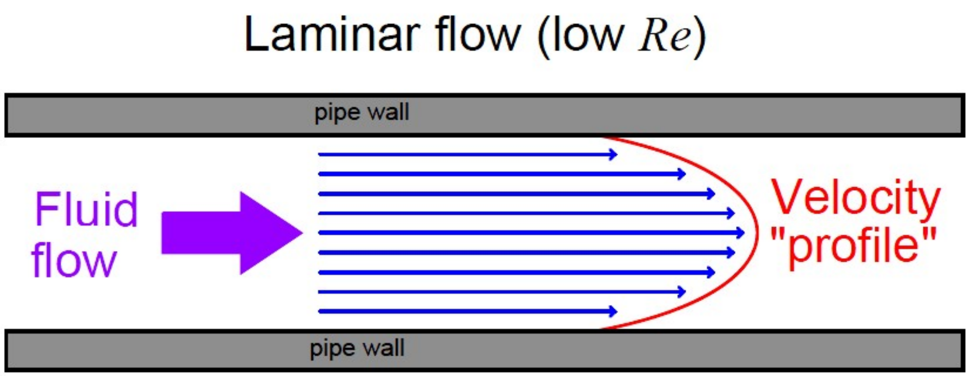
Common Units

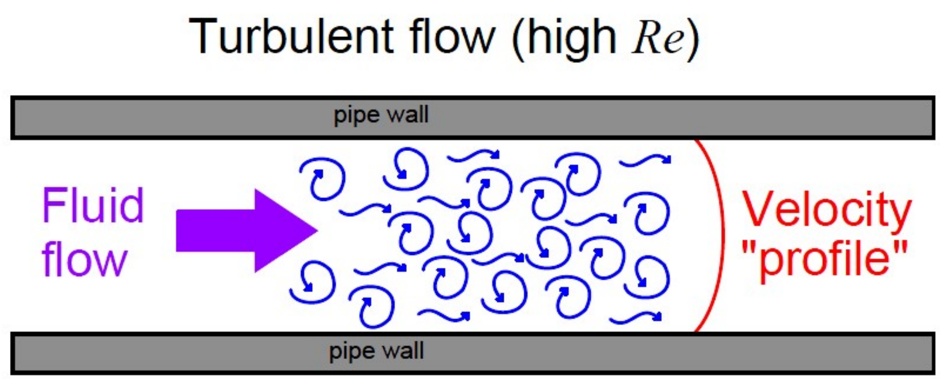
cP – Centipoise = 0.001 Pa·s

1 Pa·s = 1 kg/(m·s)

cSt – Centistokes (cP/density)

Flow Regimes





- Laminar flow occurs when fluids:
  - Flow at low speeds
  - Flow in narrow tubing
  - Are very viscous (don't pour easily)
- Turbulent flow occurs when fluids:
  - Flow at higher speeds
  - Flow in larger diameter tubing
  - Have low viscosity

We prefer turbulent flow in our sample systems if we can

Reynold's Numbers

- We prefer turbulent flow in our sample systems if we can
- Reynolds Number $Re = \frac{d\ v\rho}{\mu}$
  - Re < 2000 assume laminar
  - 2000 < Re < 4000 critical zone
  - Re > 4000 assume turbulent

$d\ \ diameter\ mm\ \ or\ \ m$

v velocity $\frac{\text{m}}{\text{s}}$

$\rho\ density\ \frac{kg}{m^3}$

μ viscosity cP or Pa $\cdot\ s$

Assume Velocity is 2 m/s in ½" sch 80 pipe (ID=12 mm)

Chemical	density	viscosity	Reynolds #
Pentane	600	0.17	85,000
Water	1000	1.0	24,000
Light Crude	820	3.0	6,500
Heavy Crude	950	300	75

Ie: For Pentane

$$Re = \frac{12\ \times 2\ \times 600}{0.17} = 84{,}700$$

Pressure Drop

- Pressure Drop can be substantial for liquids and should be always be calculated !

$$\Delta P = \frac{f \times L \times \rho \times v^2}{2 \times d}$$

- We can often start by assuming the friction factor f is 0.032, but can also estimate it from a Moody chart
- Ideally, we have more pressure drop than we need to account for pressure fluctuations and line blockage
- KNOW what your source of differential pressure is !

$d = \ diameter\ mm$

$v = \ \mathrm{velocity}\ \frac{\mathrm{m}}{\mathrm{s}}$

$\rho = density\ \frac{kg}{m^3}$

$L = \mathrm{length\ m}$

$\mathrm{f = moody\ friction\ factor}$

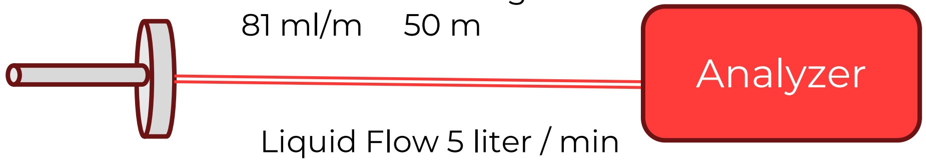
This gives ΔP in kPa

Pressure Drop Calculations

½" Sch 80 151 ml/m
0.5 m

Condensate ρ=740 kg/m³ ν = 1.2 cP

½" x 0.049" tubing 10.2 mm ID
81 ml/m 50 m



Liquid Flow 5 liter / min

$$\Delta P = \frac{f \times L \times \rho \times v^2}{2 \times d}$$

$$Re = \frac{d\ v\rho}{\mu}$$

Liquid sample

What is the volume in the probe and the line ?

$$Probe = 0.5m \times 151\frac{ml}{m} = 75\ ml$$

$$Line = 50m \times 81\frac{ml}{m} = 4050\ ml$$

What is the response time in seconds ?

$$time = \frac{Vol}{Flow} = \frac{4125\ ml}{500\ \frac{ml}{min}} = 0.825min = 49.5s$$

What is the velocity in m/s (distance/time)?

$$v = \frac{50m}{49.5s} = 1.0\frac{m}{s}$$

What is the Reynolds # ?

$$Re = \frac{10.2 \times 1.0 \times 740}{1.2} = 6290$$

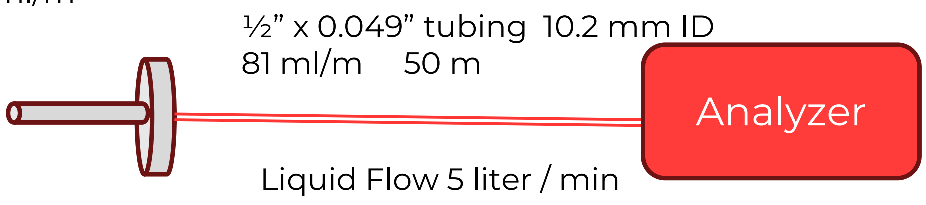
What is the pressure Drop (f=0.032)?

$$\Delta P = \frac{0.032 \times 50 \times 740 \times 1^2}{2 \times 10.2} = 58\text{ kPa}$$

Pressure Drop Calculations

½" Sch 80 151 ml/m
0.5 m

Condensate ρ=740 kg/m³ ν = 1.2 cP



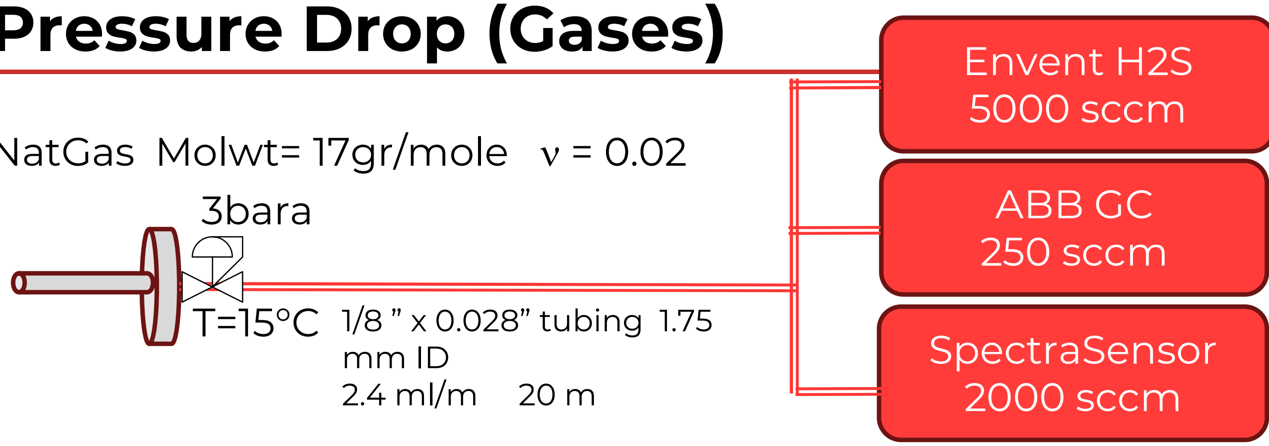
$$\Delta P = \frac{f \times L \times \rho \times v^2}{2 \times d}$$

$$Re = \frac{d\, v\rho}{\mu}$$

What happens if we change the line diameter ?

Line	ID mm	Volume ml	Time sec	Velocity m/sec	Re	DP kPa
1/2" x 0.049"	10.21	4094	49.128	1.02	6416	60.4
3/8" x 0.049"	7.04	1944	23.3	2.15	13524	268
1/4" x 0.035"	4.57	821	9.85	5.07	31,900	1492

Pressure Drop (Gases)



What is the flow in the line?

What is the density of the gas in the line?

What is the volume in the line?

What is the response time in seconds ?

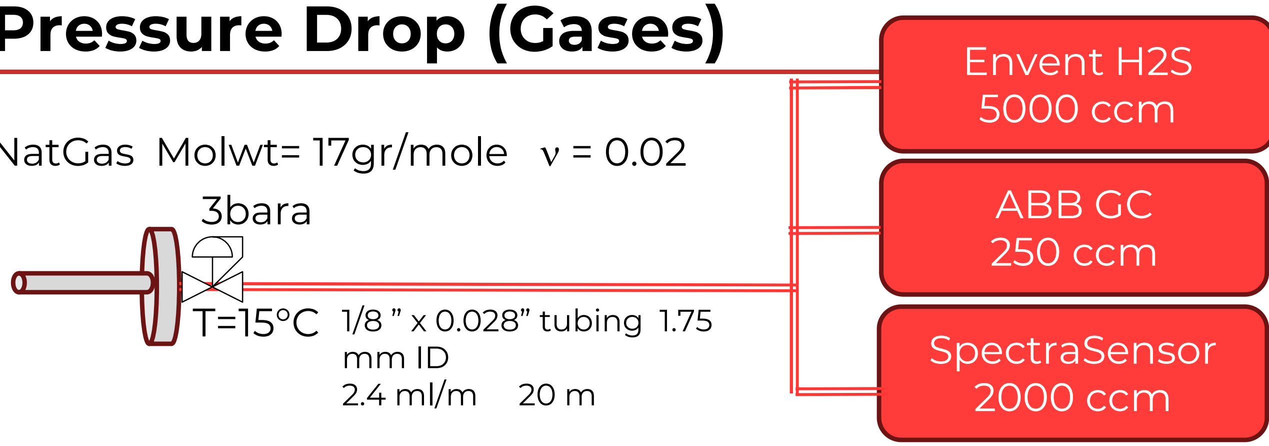
What is the velocity in m/s (distance/time)?

What is the Reynolds # ?

What is the pressure Drop?

Pressure Drop (Gases)

NatGas Molwt= 17gr/mole ν = 0.02



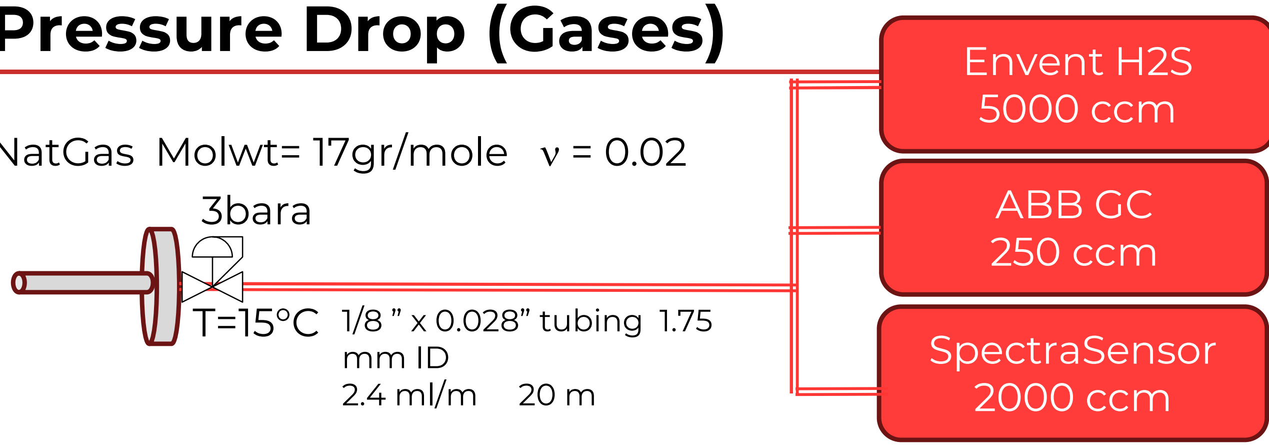
What is the flow in the line? $\boldsymbol{Flow = 5000+2000+250 = 7250\ ccm}$

What is the density of the gas in the line? $\rho = \frac{MW}{22.7} \times \frac{P}{1bara} \times \frac{273}{T} = \frac{17.3}{22.7} \times \frac{3}{1} \times \frac{273}{288} = 2.25\,\frac{kg}{m^3}$

What is the volume in the line? $\boldsymbol{Vol = 20m \times 2.4\ ml/m \times 3/1 \times 273/288 = 136.5\ ml}$

What is the response time in seconds ? $Time = \frac{Vol}{Flow} = 136.5/7250$**=0.019min=1.12 s**

Pressure Drop (Gases)



What is the velocity in m/s (distance/time)? $v = \frac{20m}{1.12s} = 17.86\frac{m}{s}$

What is the Reynolds # ? $Re = \frac{1.75 \times 17.86 \times 2.25}{0.02} = 3,516$

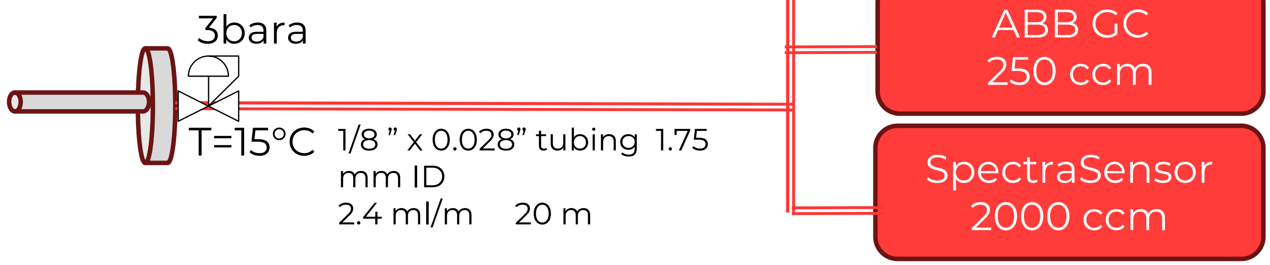
What is the pressure Drop? $\Delta P = \frac{0.032 \times 20 \times 2.25 \times 17.86^2}{2 \times 1.75} = 131\ kPa$ **or about 1.31 bar**

Pressure at inlet to analyzers is 3bara – 1.31 bara = 1.69 bara = 0.69 barg = **10 psig**

HAVE A PROBLEM IF THE ANALYZERS REQUIRE 15 psig at INLET

Pressure Drop (Gases)

NatGas Molwt= 17gr/mole ν = 0.02



Line	ID mm	Volume ml	Time sec	Velocity m/sec	Re	DP kPa
1/8" x0.028"	1.75	136.5	1.12	17.86	3522	131.1
1/8"x0.020"	2.16	210.4	1.74	11.49	2790	44.0
1/4" x 0.049"	3.86	665.4	5.51	3.63	1577	2.5

Darcy Friction Factor

- The Darcy friction factoris a dimensionless quantity used to describe the amount of energy loss due to friction in a fluid flowing through a pipe.
- To estimate it, we need to know the relative roughness (ε/D) of the tubing and the Reynold's number (Re).
- Can be calculated by any number of approximations :
  - For Re < 2320   f = 64/Re
  - For Re > 2320 can use Jains' Equation

$$f = \frac{1.325}{\left[\ln\left(\frac{\epsilon}{3.7D} + \frac{5.75}{Re^{0.9}}\right)\right]^2}$$

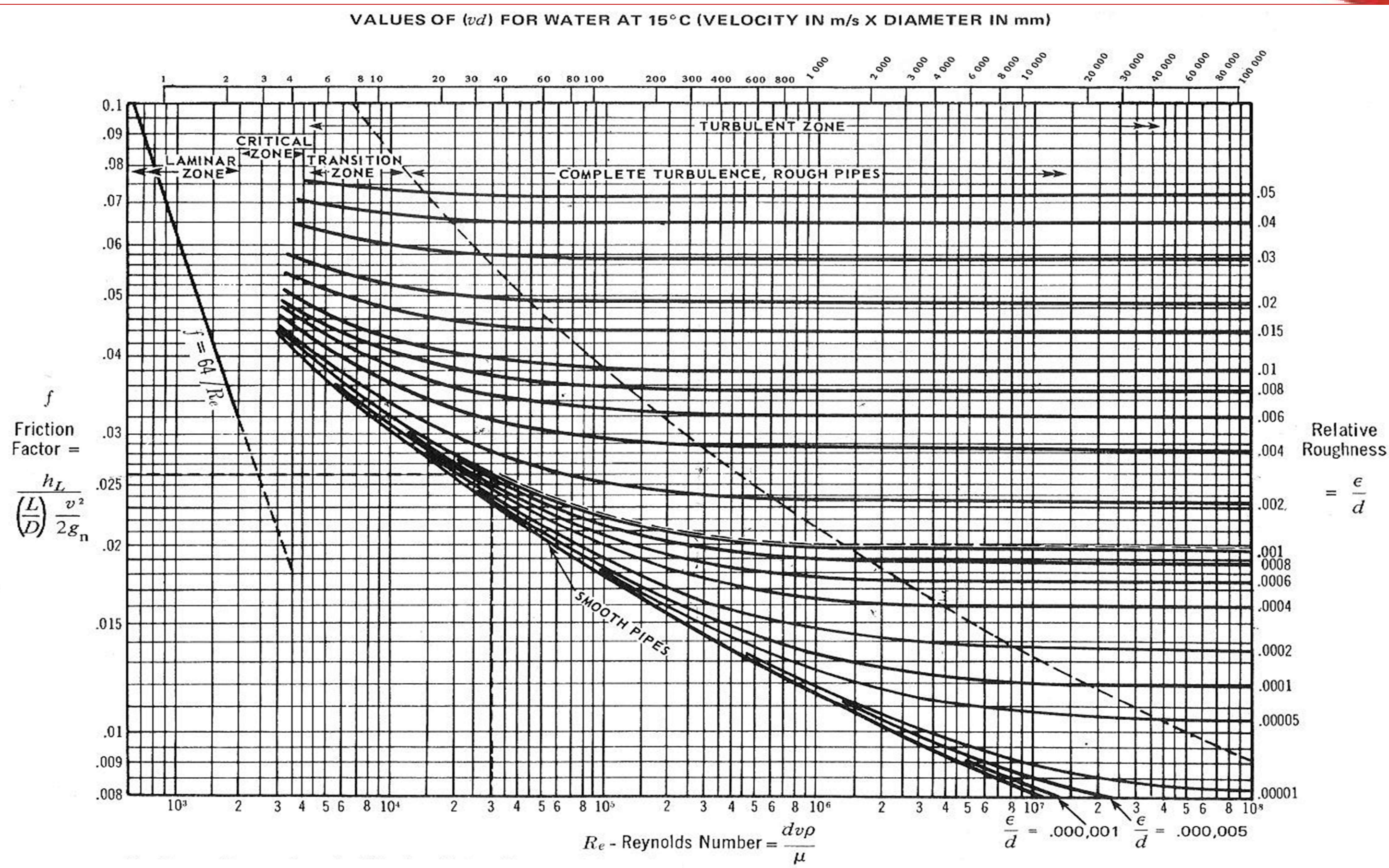
Using Moody Charts

- Relative Roughness
  - In turbulent flow, the friction factor can be retrieved from the Moody Charts in Crane. To look up a value, we need the relative roughness of the tube or pipe walls.
  - The actual irregularity of tube and pipe walls does not change much with diameter and is known as the absolute roughness (ε):
    - for drawn tubing; ε is about 0.0015 mm
    - for commercial pipe; ε is about 0.05 mm
  - Relative roughness is calculated from:

$$rr = \frac{\text{absolute roughness } (\varepsilon)}{\text{line internal diameter (d)}}$$

Eg: for ½" pipe Sch 80 (ID=13.8mm)

$$rr = \frac{0.05\ mm}{13.8\ mm} = 0.0036$$



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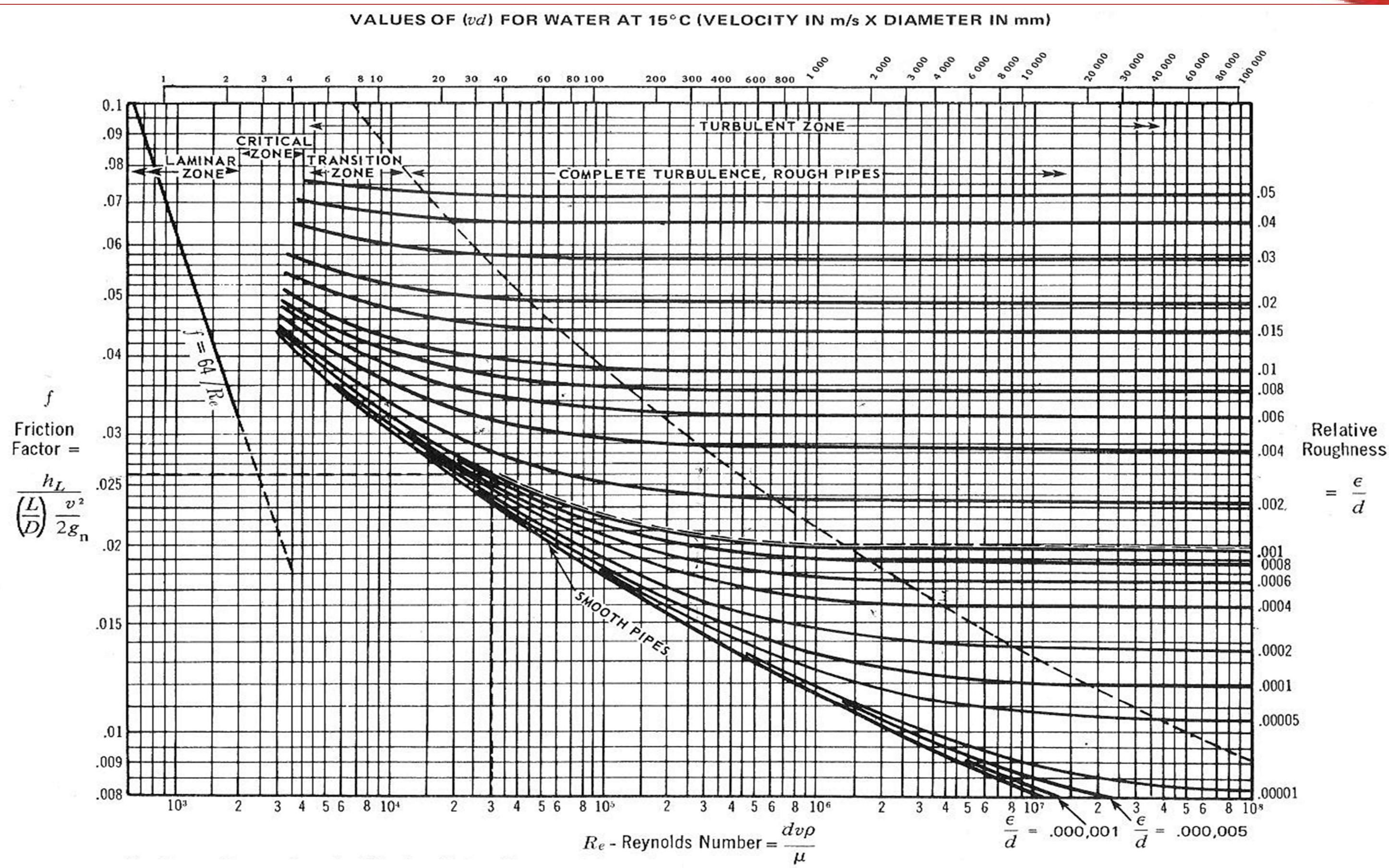

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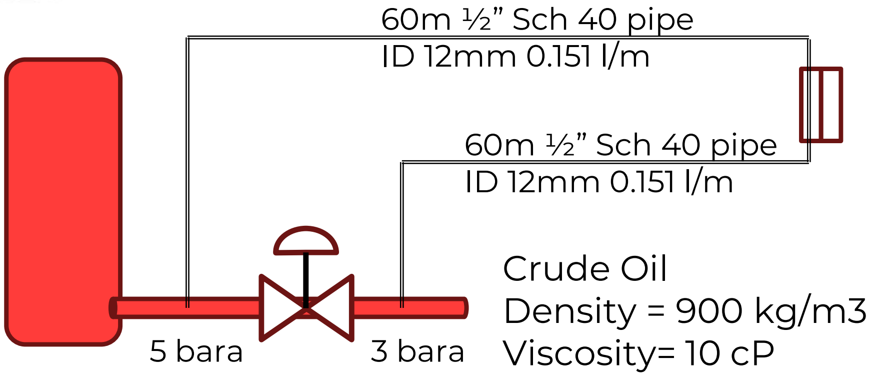
Liquid Fast Loop Example



Crude Oil
Density = 900 kg/m3
Viscosity= 10 cP

Desired Response Time – 1 minute

What velocity is needed ?

What is the volume in the transport line ?

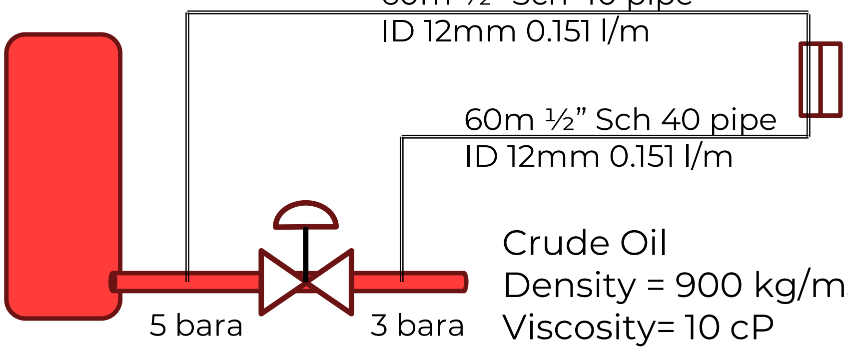
What is the relative roughness ?

What is the Reynolds # ?

Using Moody Chart- What is friction factor?

How much is the pressure drop ?

Liquid Fast Loop Example



Crude Oil
Density = 900 kg/m3
Viscosity= 10 cP

But does it work ?

Desired Response Time – 1 minute

What velocity is needed ? $v = \frac{distance}{time} = \frac{60m}{60s} = 1\frac{m}{s}$

What is the volume in the transport line ? $Vol = 60m \times 0.151\frac{l}{m} = 9.06\ liters$

How much flow is needed ? $Flow = 9.06\ \frac{liters}{min}$

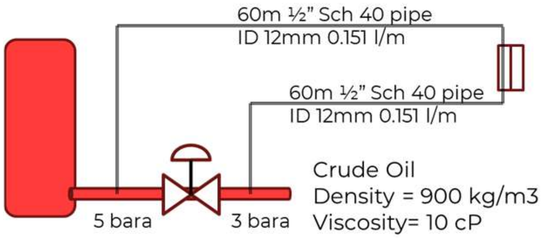
What is the Reynolds # ? $Re = \frac{d \times \rho \times v}{\mu} = \frac{13.8 \times 900 \times 1}{10} = 1240\ (laminar)$

What is the relative roughness ? $rr = \frac{0.05}{13.8} = 0.0036$

Using Moody Chart- What is friction factor? ~ **0.06**

How much is the pressure drop ? $\Delta P = \frac{fL\rho v^2}{2d} = \frac{0.06 \times 60 \times 900 \times 1^2}{2 \times 13{,}8} = 117\ kPa$

Liquid Fast Loop



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What is the relative roughness ? $rr = \frac{0.05}{13.8} = 0.0036$

Using Moody Chart- What is friction factor? ~ **0.06**

How much is the pressure drop ? $\Delta P = \frac{fL\rho v^2}{2d} = \frac{0.06 \times 60 \times 900 \times 1^2}{2 \times 13{,}8} = 117\ kPa$

Are we good ? How do we get back to the process ?

We need 2.35 bar differential !

Possible Solutions:

1) Pump → Expensive
2) Accept 2 minute response time – v drops by ½ v² ¼
   But friction factor goes up- sucks being laminar
3) Shorter sample lines (move the shelter closer)
4) **Go to a larger return line !**
   We don’t care about slow response in the return line
   For example we could go to a ¾” Sch 40 line
   (0.279 l/m 18.85 mm ID)

$$Vol = 60m \times 0.279\frac{l}{m} = 16.7\ liters$$

$$time = \frac{vol}{flow} = \frac{16.7}{9} = 110s$$

$$velocity = \frac{60m}{110s} = \frac{0.55m}{s}$$

$$\Delta P = \frac{0.06 \times 60 \times 900 \times .55^2}{2 \times 18.8} = 26\ kPa$$

Analyzing a system

- Identify major components (significant volumes)
- Identify what you think you want for flow rates
- Estimate number of purges (N) for each object
- Estimate physical volume of each object
- Calculate effective volume for each object
  - Liquids $Vol_{eff} = N \times Vol_{phys}$
  - **Gases** $\boldsymbol{Vol_{eff} = N \times Vol_{phys} \times \left(\frac{P_{obj}}{P_{Flow}}\right) \times \left(\frac{T_{Flow}}{T_{obj}}\right)}$ **← Ideal Gas Law Correction**
- Calculate time in each object ($Time = \frac{Vol_{Eff}}{Flow}$)
- Calculate speed in transport lines ($v = Speed = \frac{Distance}{Time}$)
- Add all the times up for objects before the analyzer
- Calculate time delay and speed for fast loop return

Analyzing a system (more)

- Determine fluid density and viscosity
- Calculate / determine Reynolds numbers from
- Determine / estimate relative roughness
- Determine Darcy friction factor
- Calculate pressure drops for both the supply and the return line
- Evaluate system to see if it meets desired response time and to see if there is sufficient differential pressure
- Optimize as necessary

Summary

- Detailed calculations should be done to evaluate system response, including
  - Flow meter corrections
  - Estimation of volumes
  - Estimation of flow rates
  - Estimation of physical properties
  - Calculation of estimated time delays and velocities
  - Calculation of Reynolds numbers
  - Estimates of friction factors
  - Calculation of pressure drops
  - System optimization

Next Session Summary

- ~~Inputs to Design~~
- ~~General Requirements~~
  - ~~Useful numbers~~
  - ~~Compatibility~~
  - ~~Response time~~
  - Time delay calculations
    - ~~More complex systems~~
    - ~~Fast loops~~
    - ~~Gas laws and compressibility~~
    - ~~Improving system performance~~
- ~~Time delay calculations for gas systems~~
- ~~Calculating Velocities~~
- ~~Viscosity~~
- ~~Laminar and Turbulent Flow~~
- ~~Pressure drops~~
- Generalized Procedure
- Spreadsheet template and worked examples

Questions ?