Introduction to Sample Systems

Session 7

Reboot & Review

Time Delay

SCAN ME

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

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Introduction to Sample Systems

- ~~Inputs to Design~~
- ~~General Requirements~~
  - ~~Useful numbers~~
  - ~~Safe and reliable~~
  - ~~Response time~~
- Flow & Time Delay
  - ~~Fundamentals~~
  - Delay Calculations
  - Pressure Drops
  - Flow & Pressure Control
- 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

- **Review of last three sessions**
- **Get us back on track**
- **Lay the foundations**

What is an Analyzer Sample System?

A process analyzer sample system is a comprehensive arrangement designed to extract, transport, condition, and deliver a representative sample from a process stream to an analyzer. The system ensures that the sample's physical and chemical properties are maintained to be compatible with the analyzer, ensuring accurate and reliable measurements.

Functions of a Sample System

- Take a “Representative” sample
  - Representative →Useful and meeting the needs of the application
- Transport the sample to the analyzer or grab sampler
  - Transport → ensure flow conditions meet timeliness and pressure drop requirements
- Condition the sample to be “compatible” with the needs of the sample system components, the analyzer and the application
  - Compatible → adjust chemical, physical state as necessary, as well as mitigate risks of corrosion, temperature and pressure
- Switch sample streams as necessary
  - Switch → multi-stream applications but also calibration / validation
- Dispose of the sample fluid to a safe location
  - Dispose → deal with analyzer vents, bypass flows etc without influencing performance

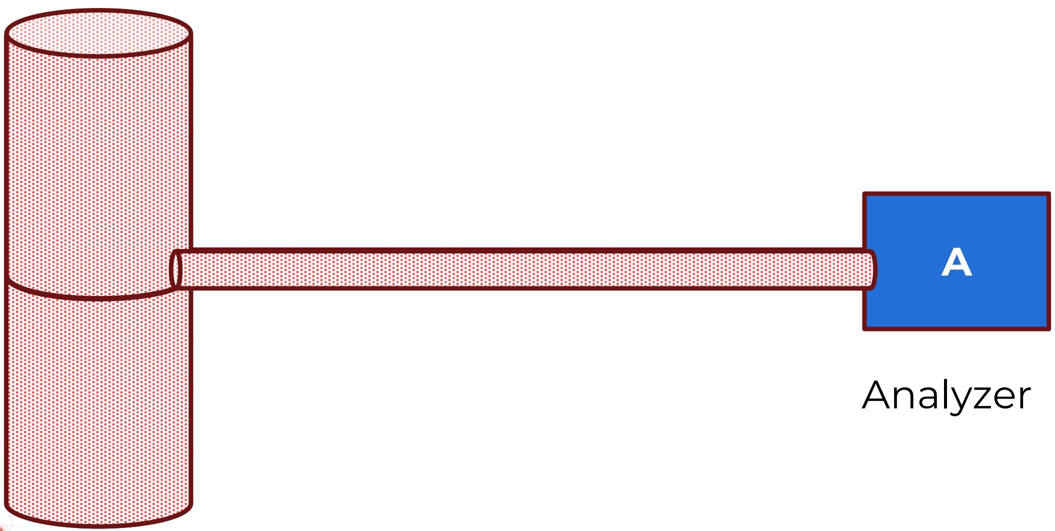
Why is Time Delay Important ?

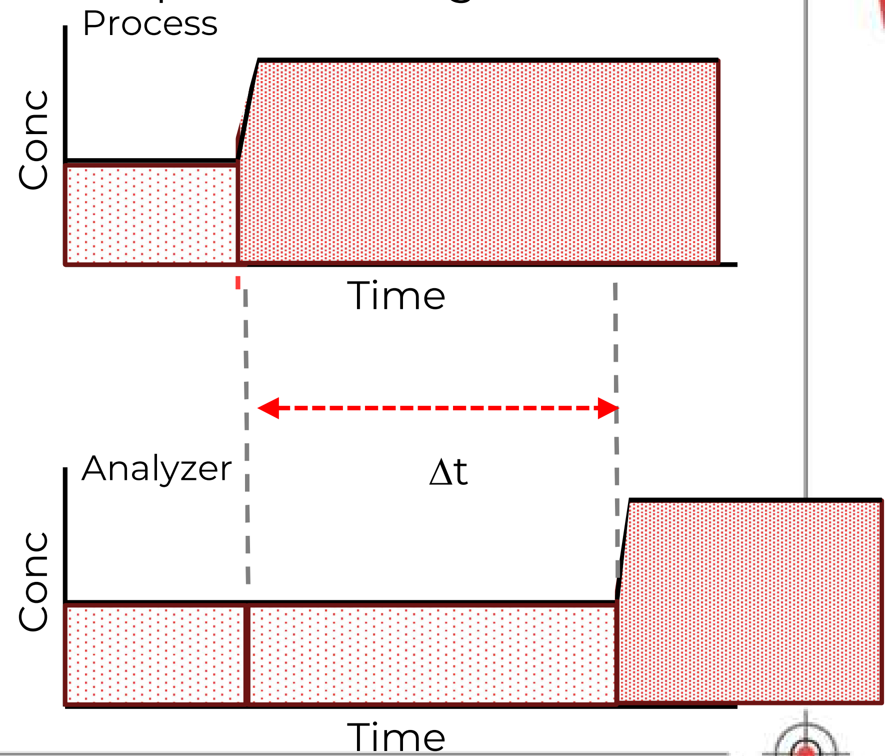
Although all systems have delays, the system responds quickly enough that the USER of the information provided can achieve their goals (process control, emissions monitoring etc)

- For Grab Samples
  - How long will it take all the lines to the grab sample station to purge out
- During calibrations
  - How much calibration fluid is going to be needed and how much offline time
- For process control
  - Can my analyzer respond fast enough to give me the control that I want / need

What do we mean by Time Delay

Assume a sudden change in concentration in the process, how long before we see it at the analyzer. The time difference between the process change and the measurement change is the time delay



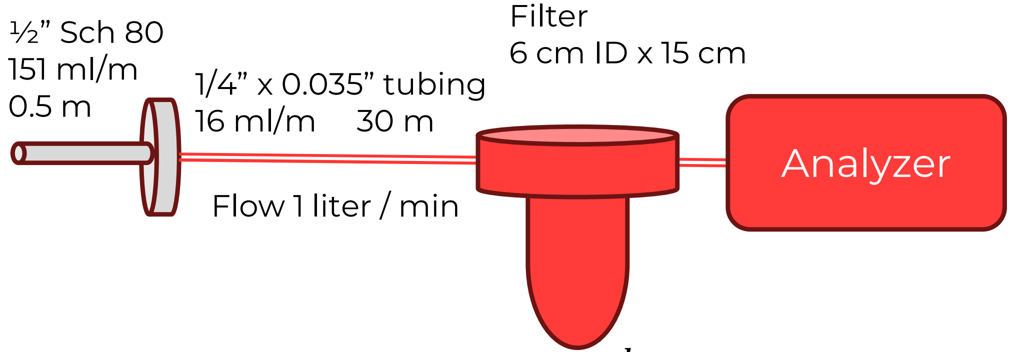


Time Delay in Mixing Volumes

Mixing sows the response time, and it takes at least three volume changes to get to 95% response, five changes to 99%

In our sample system design we generally assume filters, knockout pots, and other similar volumes will need to purged three times

$$Time = {}^{3 \times Volume}/_{Flow\ Rate}$$



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

$$Vol_{line} = 30m \times 16 \frac{ml}{m} = 480\ ml$$

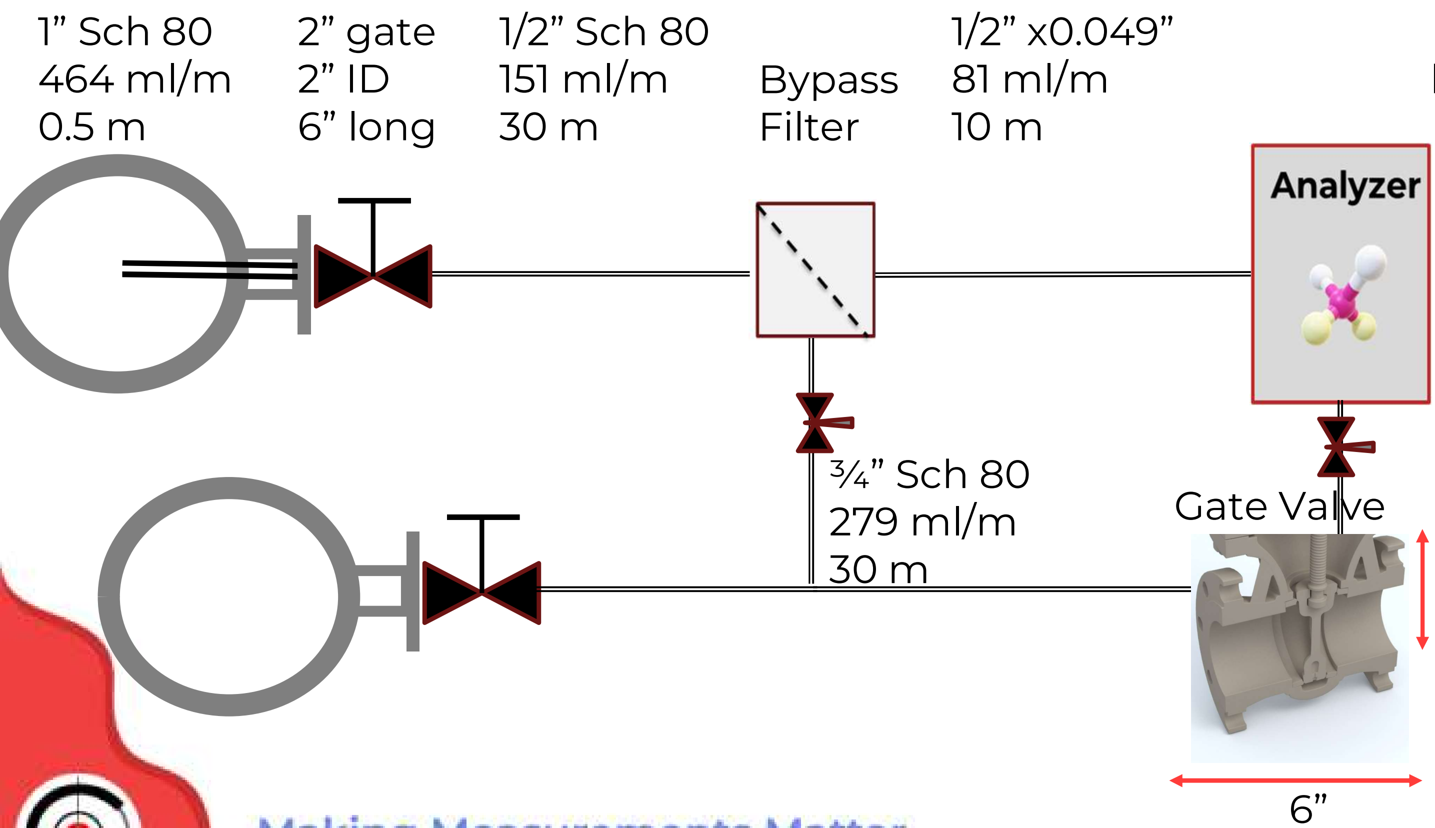
$$Vol_{Filter} = \pi \times 3^2 \times 15 = 423\ ml$$

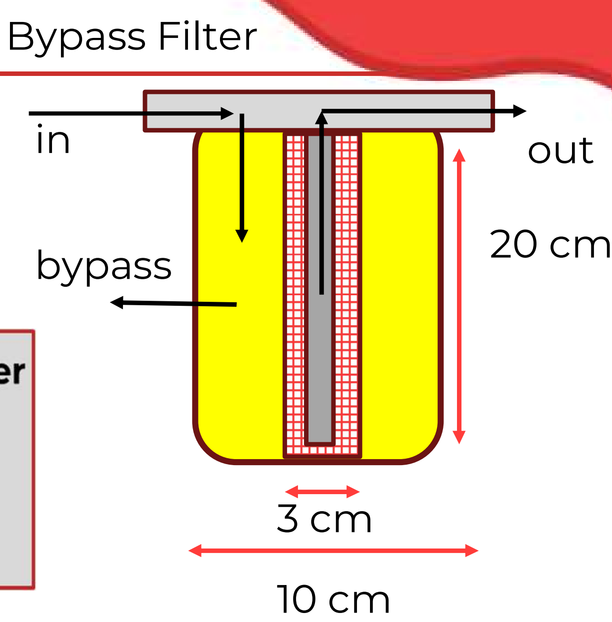
$$Purge_{Filter} = 3 \times 423ml = 1270\ ml$$

$$Delay = \frac{1270ml + 480\ ml + 75ml}{1000\ \frac{ml}{min}} = 1.8\ minutes$$

Analyzing a system

4. Estimate volume in each object





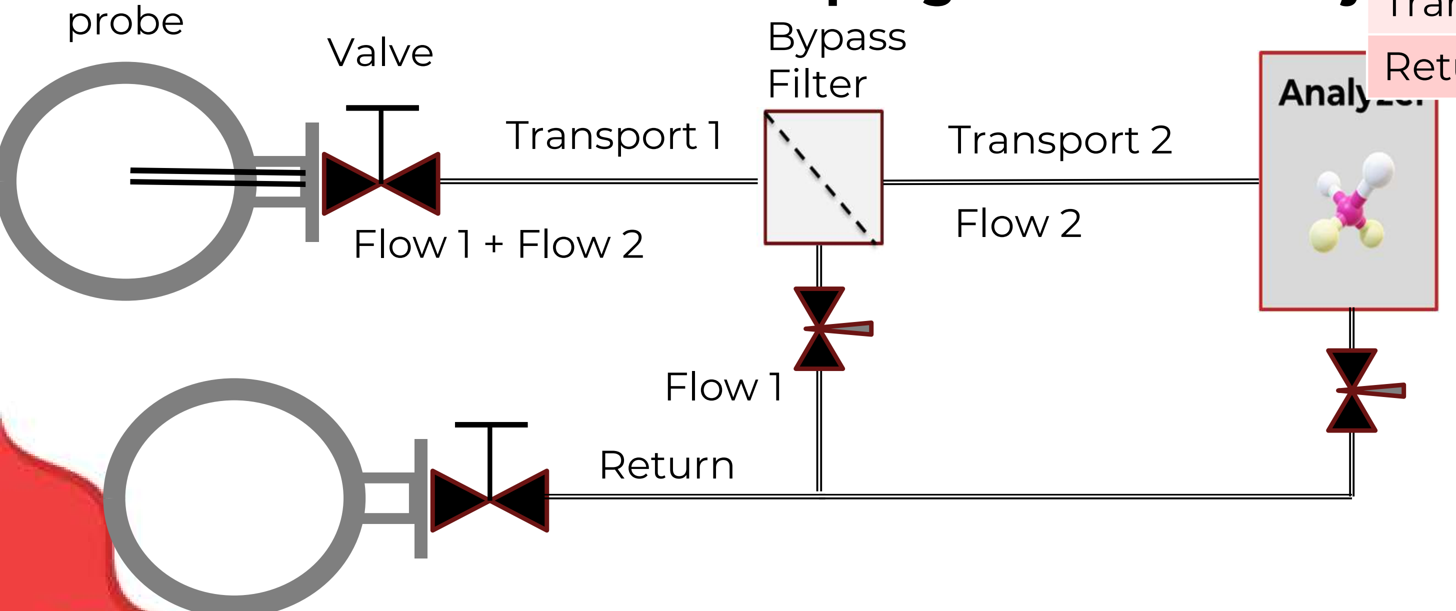
$V_{inner} = \pi \times 1.5^2 \times 20 = 141\ ml$

$V_{outer} = \pi \times 5^2 \times 20 - 141\ ml = 1426\ ml$

Analyzing a system

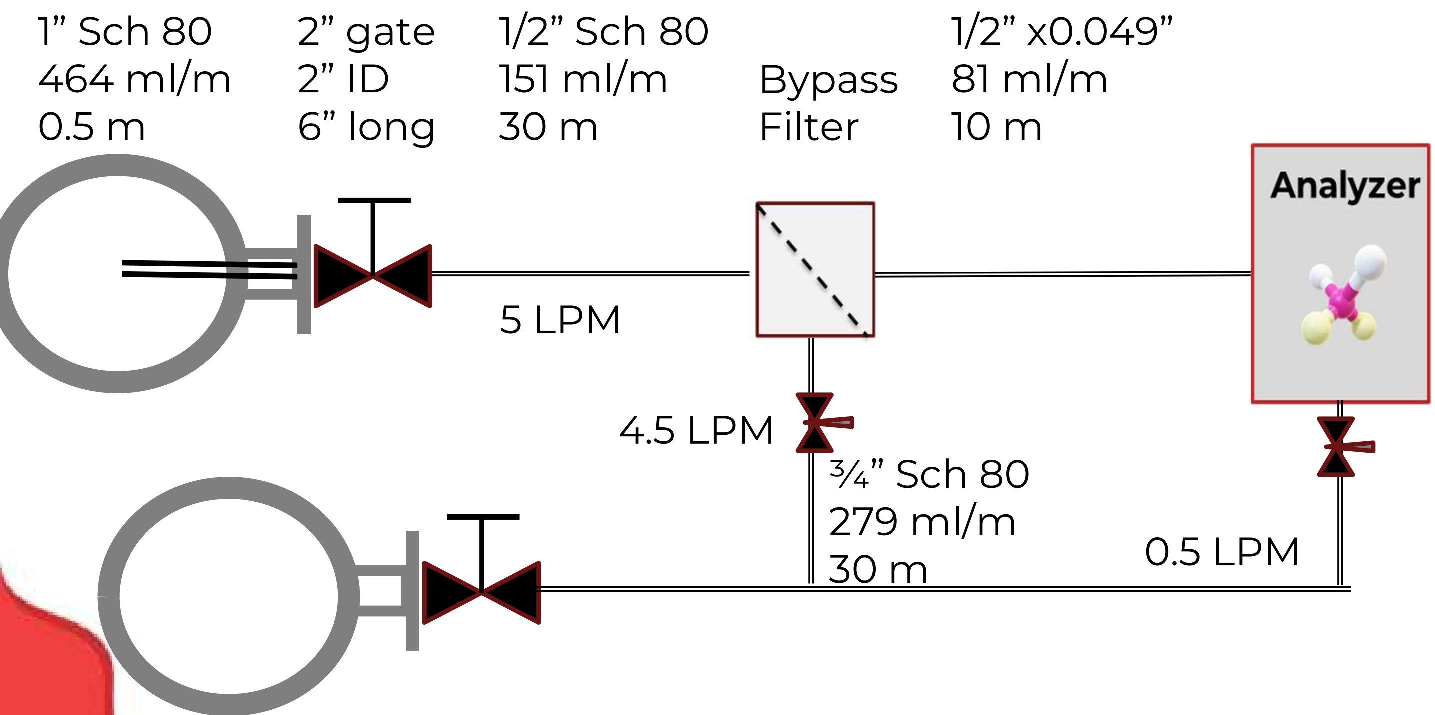
1. **Identify major components**
2. **Identify flows through each object**
3. **Estimate number of purges for each obj**

Object	Flow	N
Probe	Flow1+Flow2	1
Valve	Flow1+Flow2	3
Transport 1	Flow1+Flow2	1
Filter Front	Flow1+Flow2	3
Filter Back	Flow2	3
Transport 2	Flow2	1
Return Line	Flow1+Flow2	1



Analyzing a system

4. Estimate Physical Volume in each object



$$Probe = 0.5m \times 464\frac{ml}{m} = 262\ ml$$

$$Gate = \pi \times 2.5^2 \times 15 = 295\ ml$$

$$Trans1 = 30m \times 151\frac{ml}{m} = 4530\ ml$$

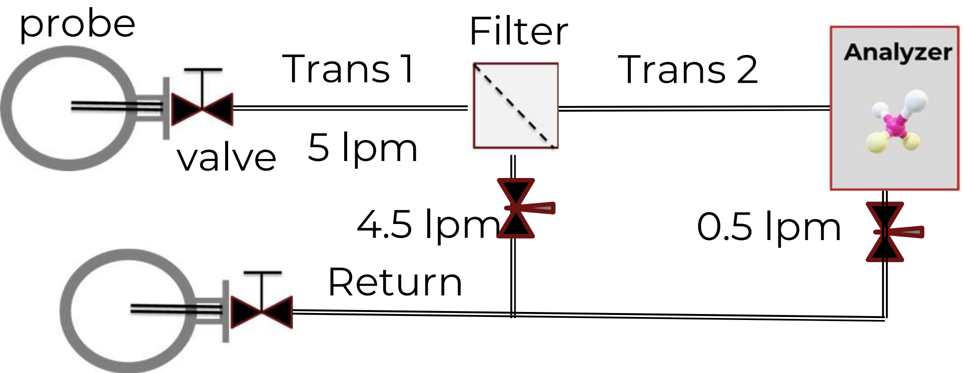
$$V_{inner} = \pi \times 1.5^2 \times 20 = 141\ ml$$

$$V_{outer} = \pi \times 5^2 \times 20 - 141\ ml = 1426\ ml$$

$$Trans2 = 10m \times 81\frac{ml}{m} = 810ml$$

$$Return = 30m \times 279\frac{ml}{m} = 8370\ ml$$

Analyzing a system



5. **Calculate Effective Volume**
6. **Calculate Time Delay**
7. **Add Up time to get to analyzer**

$$Eff.Vol = N\ x\ Phys.Vol$$

Object	N	Phys. Vol.(ml)	Eff. Vol. (ml)	Flow (ccm)	Time (seconds)
Probe	1	262	262	5000	3.1
Valve	3	295	885	5000	10.6
Transport 1	1	4530	4530	5000	54.3
Filter Front	3	1426	4278	5000	51.3
Filter Back	3	141	423	500	51
Transport 2	1	810	810	500	97.2
Return Line	1	8370	8370	5000	100

$$Total\ Time\ to\ Analyzer = 3.1s + 14.1s + 54.3s + 51.3s + 51s + 97.2s = 268\ seconds$$

Sample line < 1 min

Total ~= 5 min

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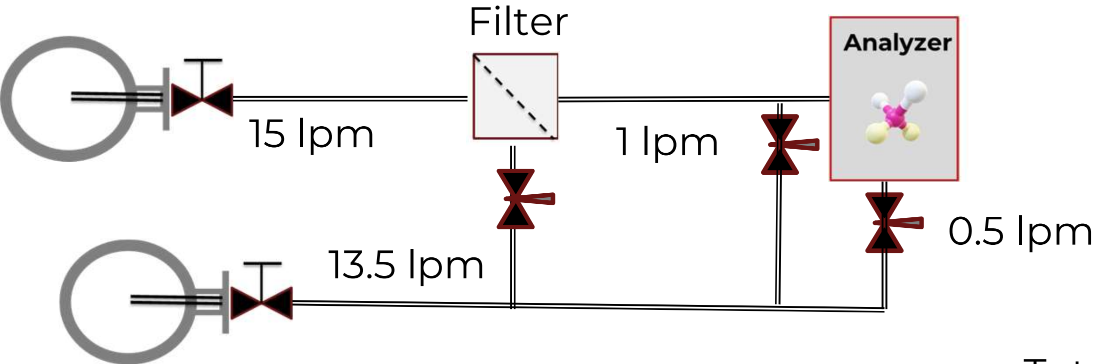
Analyzing a system - Optimize



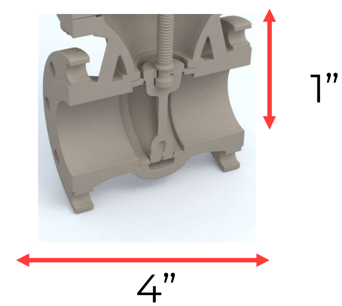
Higher fast loop flow 15 LPM

Smaller valve 1" Gate

Add bypass Tee and flow 1.5 lpm through filter

Total Time 86.2 seconds

Object	N	Phys. Vol.(ml)	Eff. Vol. (ml)	Flow (ccm)	Time (seconds)
Probe	1	262	262	15000	1
Valve	3	48	144	15000	0.6
Transport 1	1	4530	4530	15000	18.1
Filter Front	3	1426	4278	15000	17.1
Filter Back	3	141	423	1500	17
Transport 2	1	810	810	1500	32.4
Return Line	1	8370	8370	15000	33.5



$$Gate = \pi \times 1.27^2 \times 10 = 48\ ml$$

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 =N x Vol_{Phys})
- Calculate time in each object ($Time = \frac{Vol_{Eff}}{Flow}$)
- Add all the times up for objects before the analyzer
- Calculate time delay for fast loop return because it will be useful!

Ideal Gas Law

- If the pressure and temperature of a gas changes, we can predict its change in volume by: $\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$
- This is important since we measure and deal with volumetric flow rates in our time delay calculations, and the changes in pressure and temperature affect how fast the gas is moving
- We use this to figure out how much the gas is compressed or expanded in different parts f our sample system!

Rotameters for Gas- Gas Law Effects

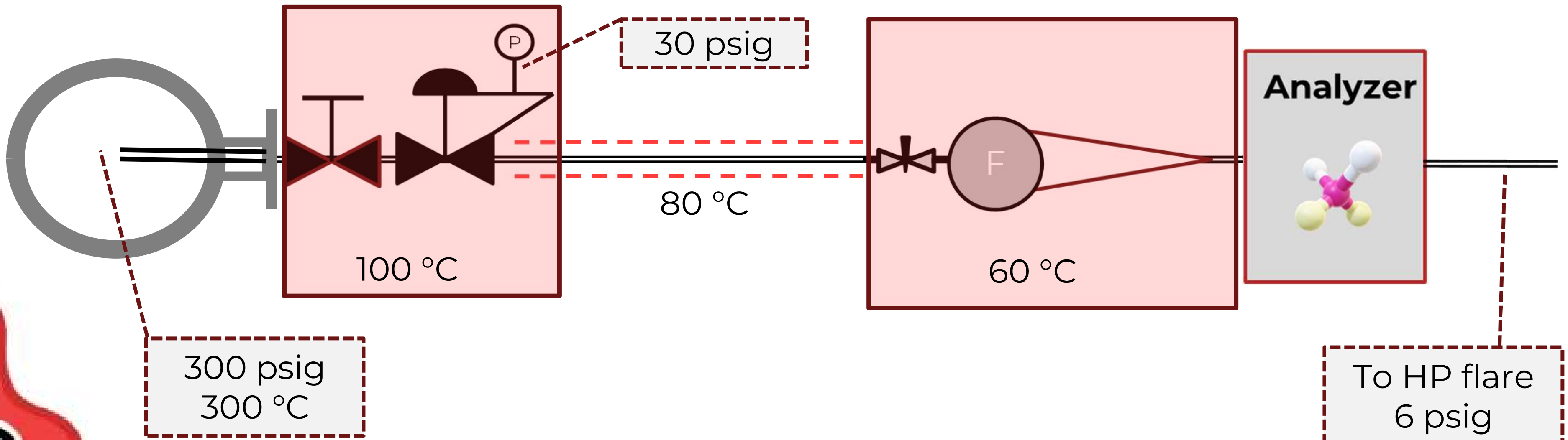
Actual Flow Rates

- Where the ball sits is dependant on operating conditions
  - Molecular Weight of the actual gas vs gas calibrated for
  - Actual operating pressure versus calibration pressure
  - Actual operating temperature versus calibration temperature

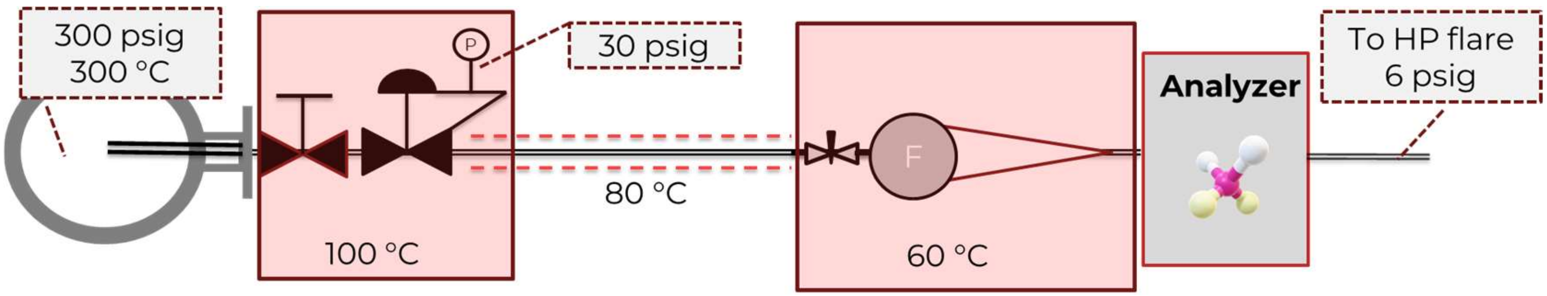
$$Flow_{Actual} = Flow_{Reading} \times \sqrt{\frac{MW_{cal}}{MW_{actual}}} \times \sqrt{\frac{P_{actual}}{P_{cal}}} \times \sqrt{\frac{T_{cal}}{T_{actual}}}$$

Time Delay in Gas Phase Systems

- Will need to do gas law corrections $\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$
- These corrections are done at every object in the system (transport lines, filters, regulators, knockouts etc.)
- All corrections made to the flow meter conditions (not across each object)



1 Identify major components (significant volumes)



Probe (0.4m ½"Sch 80 – 151ml/m)

Valve (1" gate 2.5cm ID, 10cm long)

<u>Assume</u> Regulator has zero internal volume

Transport line (45m ¼" x 0.035" – 16.4 ml/m)

2 What is our flow?

- Flow meter calibrated for Air @ STP (standard temperature and pressure is 0°C (273K) and 100 kPa) and reads in scfh (standard cubic feet per hour) – assume it is reading 5 scfh.
- Convert to slpm $slpm = scfh \div 2.119$ $slpm = 10 \div 2.119$ =2.36
- Process gas molecular weight =21.88 g/mole (air is 29)
- Flowmeter 60°C (333K) & 6 psig $(6psig = 20.5psia \times \frac{100\ kPa}{14.5\ psia} = 141\ kPa)$

$$Flow_{Actual} = Flow_{Reading} \times \sqrt{\frac{MW_{cal}}{MW_{actual}}} \times \sqrt{\frac{P_{actual}}{P_{cal}}} \times \sqrt{\frac{T_{cal}}{T_{actual}}}$$

$$Flow_{Actual} = 2.36\ slpm \times \sqrt{\frac{29}{21.88}} \times \sqrt{\frac{141}{100}} \times \sqrt{\frac{273}{333}} = 2.92\ slpm = 2920\ \text{sccm}$$

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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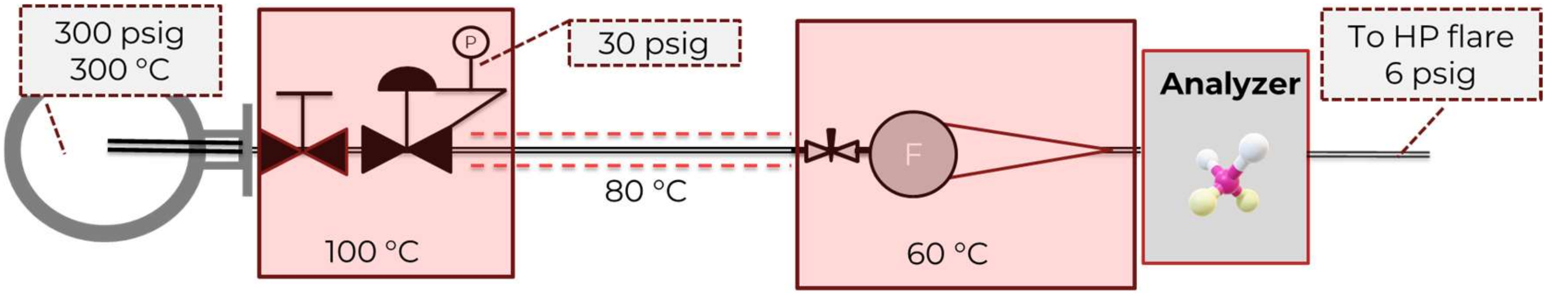
3 Estimate Number of Purges

Identify major components (significant volumes)



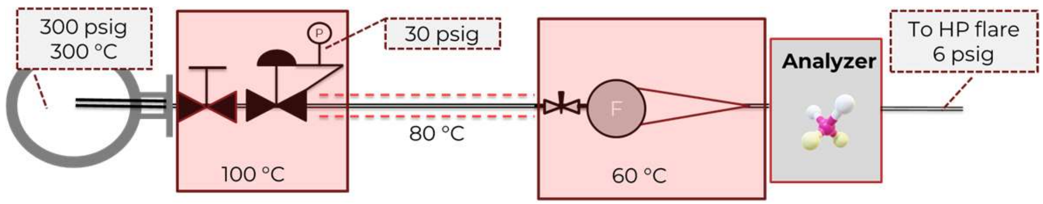
Probe (0.4m ½"Sch 80 – 151ml/m) Purge once

Valve (1" gate 2.5cm ID, 10cm long) Purge three times

Assume Regulator has zero internal volume

Transport line (45m ¼" x 0.035" – 16.4 ml/m) Purge once

4 Estimate Physical Volumes



Probe (0.4m ½"Sch 80 – 151ml/m) $V = 0.4 \times 151 = 60.4\, ml$

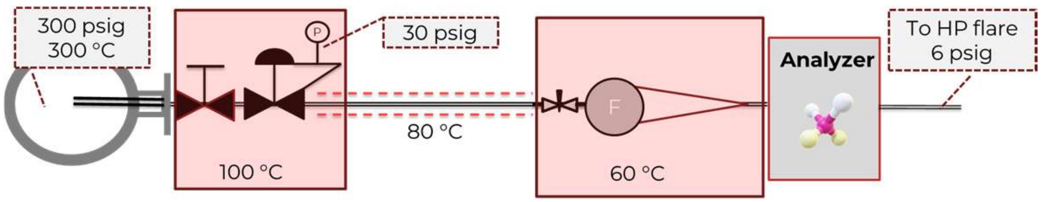
Valve (1" gate 2.5cm ID, 10cm long) $V = \pi \times 1.25^2 \times 10 = 49\, ml$

<u>Assume</u> Regulator has zero internal volume

Transport line (45m ¼" x 0.035" – 16.4 ml/m) $V = 45 \times 16.4 = 738\, ml$

We need to modify our system for Gases !

- 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**



Flow @STP = 2.92 slpm
$P_{Flow} = 100\ kPa\ T_{Flow} = 273K$

$$Probe\ \ \boldsymbol{P_{probe}} = (300\ psig + 14.5 psig) * \frac{100\ kPa}{14.5\ psig} = 2169\ kPa \quad \boldsymbol{T_{probe}} = 300 + 273 = 573K$$

$$Valve\ \ \boldsymbol{P_{Valve}} = (300\ psig + 14.5 psig) * \frac{100\ kPa}{14.5\ psig} = 2169\ kPa \quad \boldsymbol{T_{valve}} = 100 + 273 = 373K$$

$$Line\ \ \boldsymbol{P_{Line}} = (30\ psig + 14.5 psig) * \frac{100\ kPa}{14.5\ psig} = 307\ kPa \quad \boldsymbol{T_{probe}} = 80 + 273 = 353\ K$$

5 Calculate Effective Volume

Probe $1 \times 60.4ml \times \left(\frac{2169}{100}\right) \times \left(\frac{273}{573}\right) = 624\ ml$

Valve $3 \times 49ml \times \left(\frac{2169}{100}\right) \times \left(\frac{273}{373}\right) = 2334\ ml$

Line $1 \times 738 \times \left(\frac{307}{100}\right) \times \left(\frac{273}{353}\right) = 1752\ ml$

Object	N	Phys. Vol.(ml)	Eff. Vol. (ml)	Flow (sccm)	Time (seconds)
Probe	1	60.4	624	2920	
Valve	3	49	2334	2920	
Transport	1	738	1752	2920	

6 Calculate Time in Each Object

Object	N	Phys. Vol.(ml)	Eff. Vol. (ml)	Flow (sccm)	Time (seconds)
Probe	1	60.4	624	2920	13
Valve	3	49	2334	2920	48
Transport	1	738	1752	2920	36

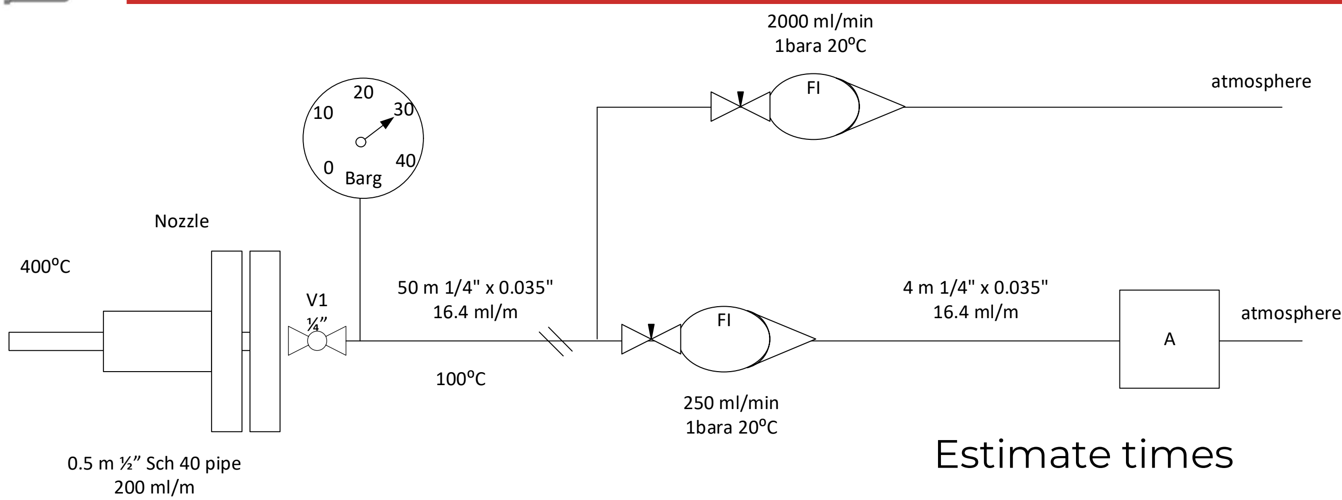
7 Add up total time

$$Time = 13\ s + 48\ s + 36\ s = 97\ seconds$$

Observations of interest

- If we only considered sample line- well under a minute
- Total system almost two minutes
- Largest delay is in the gate valve! And this is only for 3x purge
  - If we wanted 99% response would need 5x purge !

With Gases – Drop Pressure Near Tap



Assume Rotameter calibrated for 1 bara and 20°C and for correct MW

Volumes

$$P = Probe = 0.5m \times \frac{200ml}{m} \times \frac{31bara}{1bara} \times \frac{293K}{673K} = 1349ml$$

$$L1 = Line1 = 50m \times \frac{16.4ml}{m} \times \frac{31bara}{1bara} \times \frac{373K}{293K} = 19968ml$$

$$L2 = 4m \times \frac{16.4ml}{m} \times \frac{1bara}{1bara} \times \frac{293K}{293K} = 65.6ml$$

Estimate times

$$TimeP = \frac{1349mL}{2250\ mL/min} = 0.6min$$

$$TimeL1 = \frac{19968\ mL}{2250\ mL/min} = 8.87min$$

$$TimeL2 = \frac{65.6mL}{250\ mL/min} = 0.26min$$

$$Total = 9.75\ Minutes$$

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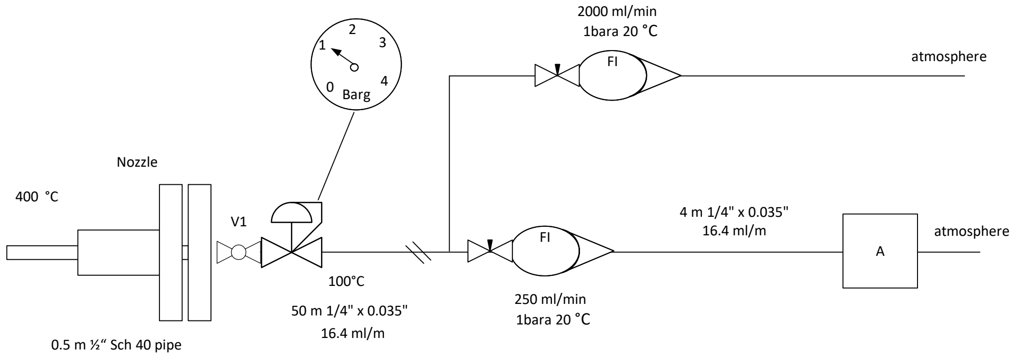
Add a Regulator !



If we are at the design stage and wanted faster response, we could possibly consider a smaller probe, or a narrower ID sample line.
Do calculations before install!
Costly to make changes after!

Estimate volumes

$$P = Probe = 0.5m \times \frac{200ml}{m} \times \frac{31bara}{1bara} \times \frac{293K}{673K} = 1349ml$$

$$L1 = Line1 = 50m \times \frac{16.4ml}{m} \times \frac{2bara}{1bara} \times \frac{293K}{373K} = 1288ml$$

$$L2 = L2 = 4m \times \frac{16.4ml}{m} \times \frac{1bara}{1bara} \times \frac{293K}{293K} = 65.6ml$$

Estimate times

$$TimeP = \frac{1349mL}{2250\ mL/min} = 0.6\text{min}$$

$$TimeL1 = \frac{1288\ mL}{2250\ mL/min} = 0.572min$$

$$TimeL2 = \frac{65.6mL}{250\ mL/min} = 0.26min$$

$$Total = 1.43\ Minutes$$

Add a New Step – Calculate Speed

- To determine pressure drop in transport lines, we need to determine how fast the fluid is moving
- This is pretty simple since we have calculated the times !

$$v = Speed = \frac{Distance}{Time}$$

For our last example

Object	N	Phys. Vol.(ml)	Eff. Vol. (ml)	Flow (sccm)	Time (seconds)	Length (meters)	Speed (m/sec)
Probe	1	100	1349	2250	36	0.5	0.014
Line 1	1	820	1288	2250	34.2	50	1.46
Line 2	1	65.6	65.6	250	15.6	4	0.26

Analyzing a system

- Identify major components (<u>significant volumes</u>)
- 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

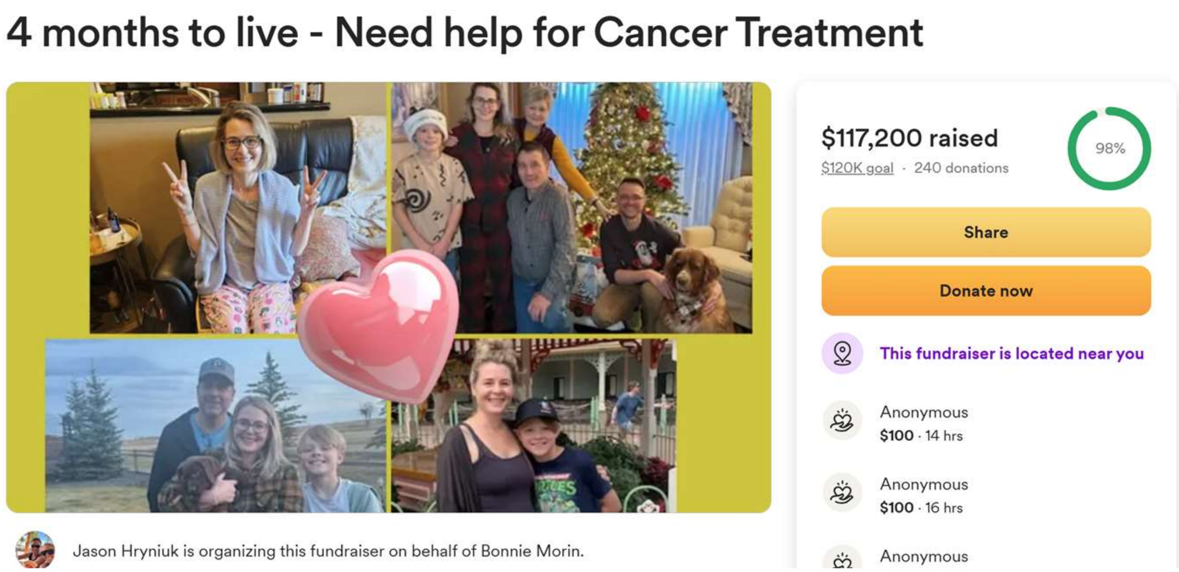
Summary

- Gas phase systems create some complexity in analyzing time delays
- If we know the gas composition, we can estimate the average molecular weight
- We need to know what gas and what conditions the flow meter was calibrated for and apply corrections when evaluating flows
- We need to know the pressures and temperatures everywhere in the flow system and apply ideal gas law corrections
- For tubes and pipes, knowing the time delay and their lengths allows us to calculate how fast the fluid is moving.

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

We don't charge for these classes



Amanda is a friend and an employee

Diagnosed with a potentially terminal cancer

If you feel these classes are valuable, and you are able – please donate

www.gofundme.com/f/4-months-to-live-need-help-for-cancer-treatment

Questions ?