Spring 2003 **10.450 Process Dynamics, Operations, and Control**

Problem Sets - 8

1. You have an 1800 kg h^{-1} stream of hexane at 100°C. Calculate the pressure drop for a fully-open valve of C_v = 17.

estimating pressure drop through fully open valve, given mass flow and Cv

mass flow	1800	kg h-1	0.5	kg s-1
density	580	kg m-3		
Cv	17	gal.in.min-1.lbf-0.5	1.29151E-05	m4 s-1 N-0.5
ref density	999	kg m-3		

calculate volumetric flow

$$F = \frac{w}{r}$$

0.000862 m3 s-1

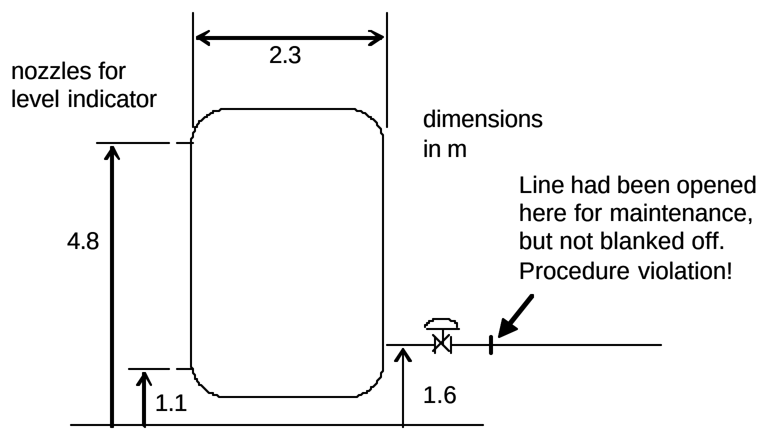
calculate pressure drop

$$\Delta P = \frac{r}{r_r}\left(\frac{F}{C_v}\right)^2$$

2586.731 Pa
0.375076 psi

Of course, you realize that the numbers shown in this calculation sheet would be rounded to a more realistic precision for reporting results: 2590 Pa.

2. Environmental disaster! There was a spill of BaD_4StUF_2 from a tank; you are required to estimate the magnitude of the release. From checking the records, you find that the valve was open at 40% for 17 s, that it is an equal-percentage valve whose characteristics are represented by a rangeability of 40, and C_v is 23. The tank was under nitrogen blanket at 1.2 atm absolute, the temperature was 45°C, liquid level was 80%, ambient temperature was 8°C. Liquid properties are density 926 kg m^{-3}, heat capacity 3270 kJ kg^{-1} K^{-1}, surface tension 15 dynes cm^{-1}.



draining from a tank over an interval. Estimate the total spill.

first, assume that the transient is sufficiently short that the level doesn't change much. Calculate the drain rate from the SS mechanical energy balance, and then check total amount drained with change in level by material balance.

Further difficulty in that pipe size isn't given, so the acceleration can't be calculated. Handle by assuming valve loss coef is much greater than one. The flow calculated will be conservatively high by some unknown amount. Then assume some reasonable pipe sizes, consistent with the given value of Cv, and check the velocity for reasonable values. After picking pipe size, can check the 'large-K' assumption.

conditions at liquid surface

elevation	4.06	m		
pressure	1.2	atm	121590	Pa

conditions at discharge to atmosphere

elevation	1.6	m		
pressure	1	atm	101325	Pa

fluid properties

density	926	kg m-3

valve data

Cv	23	gal.in.min-1.lbf-0.5	1.74734E-05	m4 s-1 N-0.5
rangebility	40			
opening	0.4			
ref density	999	kg m-3		

other data

g	9.807	m s-2
duration	17	s

calculate the ratio (loss coef)/(pipe area squared)

548508643 m-4

$$\frac{K}{A_p^2} = \frac{2}{r_r}\left(\frac{R^{(1-g)}}{C_v}\right)^2$$

calculate the flow based entirely on friction loss

0.0004096 m3 s-1 | 6.492797821 gpm

$$F = A_p v_2 = \sqrt{\frac{2gA_p^2}{K}\left[\frac{P_1 - P_2}{rg} + z_1 - z_2\right]}$$

calculate velocity for different pipe areas

diameter(in)	area (m2)	velocity (m s-1)	K
1	0.00050671	0.808330124	140.8320751
2	0.002026838	0.202082531	2253.313202
3	0.004560386	0.089814458	11407.39809

1" pipe seems most reasonable for velocity and given Cv and the assumption that K dominates is satisfied in any case.

compute spill at this flow rate

6.4477431	kg	14.21727349	lbm
0.006963	m3	1.839626049	gal

this will be a negligible change in liquid level
The flow should vary hardly at all during the spill, justifying the steady-state approximation.

3. You are checking out a flow control loop for instability. You find that the maximum slope on a plot of flow fraction versus valve opening (thoughtfully left for you by your predecessor) is 1.8. If the full installed capacity of this valve is 35 gpm, what is the maximum gain you will encounter in the valve transfer function?

Think of the gain as sensitivity of the output to the input. For the valve, we change flow by changing pressure in the actuator, so that

$$gain = \frac{dF}{dP}$$

We recognize that actuator pressure is related to the opening ?.

$$gain = \frac{dF}{dg}\frac{dg}{dP}$$

Now the installed characteristic is a plot of F/F_{full} vs ?. The maximum slope (given as 1.8) is thus

$$1.8 = \frac{d}{dg}\left(\frac{F}{F_{full}}\right) = \frac{1}{F_{full}}\frac{dF}{dg}$$

We also expect the valve opening to be directly proportional to the actuator pressure

$$\frac{dg}{dP} = \frac{\Delta g}{\Delta P} = \frac{1-0}{(15-12)\,psi}$$

Making the substitutions, we find

$$gain = \frac{dF}{dg}\frac{dg}{dP} = 1.8F_{full}\frac{1}{(12)\,psi}$$

$$= \frac{(1.8)(35)\,gpm}{(12)\,psi} = 5.25\frac{gpm}{psi}$$

Or, you can simply plug into Equation (20.5.3) in the notes…

This gain applies at the opening at which the characteristics have the maximum slope.