Problem 12-14

A spherical carbon-steel tank with an inside diameter of 9 m will be subjected to a working absolute pressure of 310 kPa and a temperature of 27 ºC. All of the welds on the tank are butt-welded with a backing strip. Assuming no corrosion allowance is required, what is the required wall thickness of the tank? Estimate the cost of steel for this tank if the cost of steel sheet is $1.10 per kilogram. On the bases of the data in Figure 12-52, determine the fraction of the purchased cost of the tank that is due to the cost for the steel.

Solution:

Thickness is calculated from the spherical shell equations in Table 12-10 on page 554:

$$t = \frac{P \cdot r}{S \cdot E - 0.2P} + Cc = \frac{209 \cdot 4.5}{94500 \cdot .6 - .2 \cdot 209} + 0 = \underset{\text{ans}}{\underline{\underline{0.0166\ \text{m}}}}$$

t = thickness in meters

P = working pressure in kPa (gauge) = 310-101 = 209 kPa

r = inside tank radius in meters = 4.5 m, given

S = maximum allowable working stress in kPa = 94,500 kPa, Table 12-10, page 555

E = weld efficiency = 0.6, using <u>low estimate</u> for butt-welds, Table 12-10, page 555

Cc = corrosion allowance in m = 0, given

"Limiting conditions" are given in Table 12-10:

$$\text{Thickness Condition: Is } 0.0166\ \text{m} \le 0.356 \cdot 4.5\ \text{m} (= 1.602\ \text{m})?\ \text{Yes}$$

$$\text{Pressure Condition: Is } 209\text{kPa} > 0.665 \cdot S \cdot E (= 0.665 \cdot 94500 \cdot .6 = 37706)?\ \text{Yes}$$

Cost of metal: To determine the cost of the metal in the tank, the mass of the metal must be determined from the density and volume of the metal in the spherical shell. The density of steel is found on page 959 in the PTW text, and is 7830 kg/m^3. The metal volume is the spherical volume based on the outside radius minus the volume based on inside radius:

$$\text{metal volume} = \frac{4}{3} \cdot \pi \cdot (4.5 + 0.0166)^3 - \frac{4}{3} \cdot \pi \cdot (4.5)^3 = 4.240\ \text{m}^3$$

$$\text{metal mass} = \text{density} \times \text{volume} = \frac{7830\,\text{kg}}{\text{m}^3} \times 4.240\ \text{m}^3 = 33{,}199\,\text{kg}$$

$$\text{metal cost} = 33{,}199\ \text{kg} \cdot \$1.10 / \text{kg} = \$36{,}519 \approx \underset{\text{ans}}{\underline{\underline{\$36{,}500}}}$$

Now, determine the fraction of cost due to steel:

The capacity of the vessel is equal to the internal volume:

$$\text{capacity} = \text{volume} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(4.5)^3 = 382\text{m}^3$$

From Figure 12-52 on page 557, the cost of a 382m^3 vessel is \$221,000. Figure 12-52 is shown below with this reading indicated with red lines. This cost along with the cost of the metal is used to calculate the desired fraction.

$$\text{fraction of cost} = \frac{\$36,500}{\$221,000} = \underline{\underline{0.165}}_{\text{ans}}$$

(CE Price index does not need to be used since all prices are in 2002 dollars).

Cadet answers can vary depending on the reading from Figure 12-52 and the value chosen for weld efficiency. The answer shown here is for a tank cost of \$221,000 and weld efficiency of 0.6.

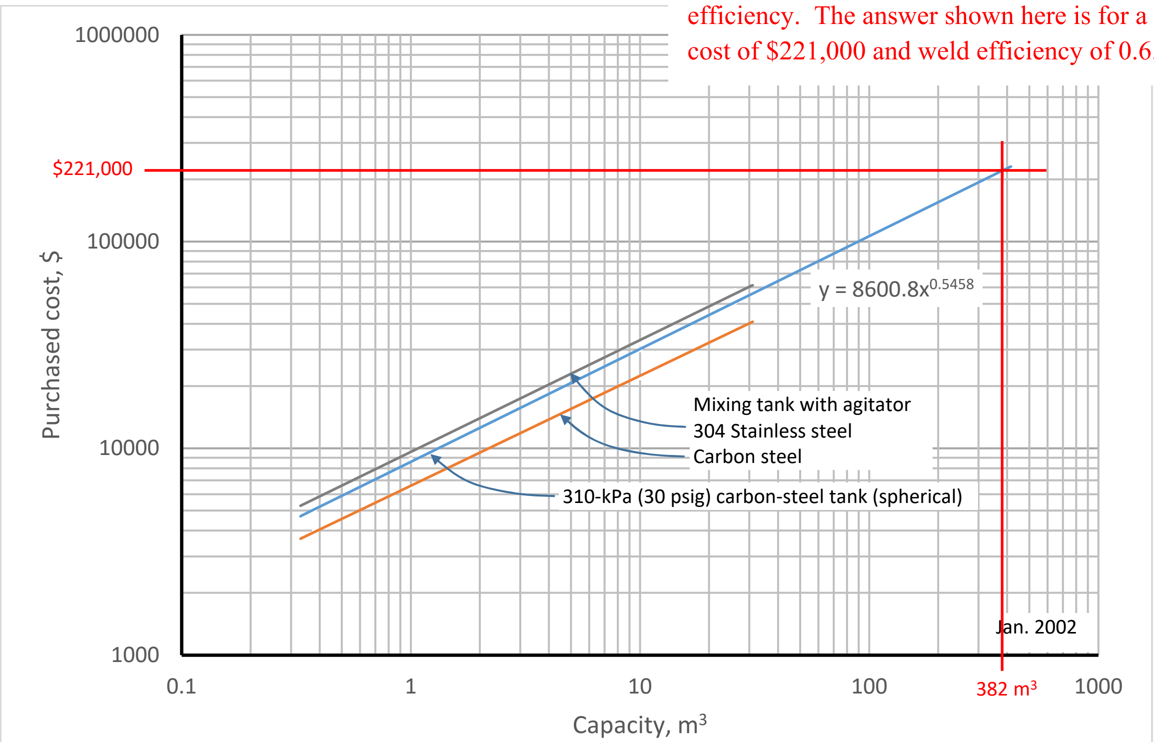

Figure 12-52. Purchased cost of mixing and storage tanks. Price for mixing tank includes the cost of the driving unit.

Limiting conditions are satisfied. Check using Table 12-10

Problem 12-15

Air at 15 ºC and 275 kPa is admitted to the entrance of a horizontal steel pipe with an inside diameter of 0.0779 m. The entering velocity is 15 m/s. Spherical particles with a 60-mesh average particle size are picked up by the airstream immediately downstream from the entrance to the pipe; the weight ratio of solid particles to the air is 4:1, and the density of the particles is 2690 kg/m^3. If the pipe is 50 m in length, what is the pressure loss in the pipe?

Solution

This problem is very similar to Example 12-8 on pages 570-572. Students should use this example as a guide to solving the problem. An excel solution to Example 12-8 is linked to the course web page and was discussed in class. This Excel solution was modified below to solve Problem 12-15.

In using this worksheet and a guide to solving the problem, it is important to realize that Example 12-8 uses a compressor, while Problem 12-15 does not. So the inlet pressure to the compressor in the worksheet must be assumed to be 101 kPa. Also, since the velocity in the pipe is 15 m/s, the entering air velocity needs to be set to ~39.7 m/s to allow the velocity in cell E23 to be 15 m/s. The Excel worksheet is shown below:

	A	B	C	D	E	F	G	H	I
1		**Design tool for pneumatic conveyor**	Problem 12-15		input				
2									
3		**Quantity**	**symbol**	**units**					
4		entering air velocity	v_{feed}	m/s	40				
5		pipe diameter	D	m	0.0779				
6		pipe cross-sectional area	A	m^2	0.004766				
7		air volumetric flow rate	m_v	m^3/s	0.190645				
8		air entering density	ρ_{in}	kg/m^3	1.221	before compressor			
9		air mass flow rate	m_a	kg/s	0.232777				
10		feed air pressure	P_{feed}	kPa	101.325	before compressor			
11		feed air temperature in deg C	T_{feed}	C	15	assume isothermal			
12		feed air temperature in K	T_{feed_K}	K	288.15				
13		molecular weight of air	MW	g/mol	28.88				
14		air pressure after compressor	P_a	kPa	275	at beginning of conveyor			
15		presure drop (assume a value)	ΔP_{est}	kPa	12.21192				
16		air pressure at exit of conveyor (estimate)	P_b	kPa	262.7881	inlet P - P-drop			
17		average pressure in pipe (calculate)	P_{avg}	kPa	268.894				
18		gas constant	R_{gas}	J/molK	8.3144				
19		density of air in pipe (estimate)	ρ_{avg}	kg/m^3	3.241372	ideal gas			
20		density of solid	ρ_{solid}	kg/m^3	2690				
21		mass flow rate of solid	m_s	kg/s	0.931109				
22		density of mixture	ρ_{mix}	kg/m^3	16.12912				
23		average velocity of air in conveyor	v_{avg}	m/s	15.07285				
24		minimum air velocity (lift velocity)	v_{min}	m/s	80.10417	interp from v_min; must be < v_{avg}			

Density of air at 101.3 kPa and 15 °C, calculated.

Entering air velocity adjusted to give 15 m/s in this cell.

Cadets should think about the 80.1 m/s minimum lift velocity versus 15.0 m/s. In this problem, the average air velocity is less than the minimum air velocity needed to provide any vertical lift to the solids. What are the implications of this situation? How can it be corrected?

25					
26	heat capacity at constant pressure	C_p	J/molK	30.2287	looked up in fig D-3, page 957; replace i
27	heat capacity at constant volume	C_v	J/molK	21.9143	=Cp-R
28	heat capacity ratio	k	dimensionless	1.379405	=Cp/Cv
29	*delivered compressor power*	P_c	*kW*	*22.1876*	from Eq 12-22a
30					
31	*frictional loss due to sudden constriction*	F_c	*kW*	*0.00992*	Refer to Table 12-1 on page 490, sectio
32	area ratio, assumed	A_2/A_1	dimensionless	0.75	assumed
33	constriction coefficient	K_c	dimensionless	0.1875	use if/then statement because two forr
34	correction factor for turbulent flow	α	dimensionless	0.5	
35	*frictional loss due to expansion*	F_e	*kW*	*0.05288*	
36	*frictional loss due to straight pipe*	ΣF	*kW*	*0.25458*	use 12-7, Darcy-Weisbach version, FE m
37	friction factor	f	dimensionless	0.015	given on page 569; use Moody Plot fror
38	equivalent length of elbows	L_e	m	0	
39	number of elbows	N_{el}	dimensionless	0	
40	length of stright run pipe	L	m	50	
41	equivalent length of conveyor	$L+L_e$	m	50	
42	*total frictional contributions due to air*	$F_c+F_e+\Sigma F$	*kW*	*0.31738*	
43	*kinetic energy term*	W_{KE}	*kW*	*0.10577*	
44	*gravitational term*	W_L	*kW*	*0.00182*	
45	elevation (rise)	ΔZ	m	0.2	
46	gravitational constant	g	m/s^2	9.8	
47	*sliding friction term*	W_{sf}	*kW*	*0.45624*	given on page 569
48	coefficient of sliding friction	f_s	kW	1	given in problem
49	*centrifugal term due to elbows*	W_{el}	*kW*	*0*	
50	*frictional contributions due to solid*	$W_{KE}+W_L+W_{sf}+W_{el}$	*kW*	*0.56384*	
51	*total frictional losses*	P_f	*kW*	*0.88122*	
52					
53	calculated pressure drop	Δp_{calc}	kPa	12.21193	Iterate:
54	difference between ΔP_{est} and ΔP_{calc}	$\lvert \Delta p_{est}-\Delta p_{calc} \rvert$		1.75E-07	ans Change guess for pressure drop i
55					until difference is minimized to a
56	compressor efficiency	η	dimensionless	1	acceptably small epsilon.
57	***total power requirement***	$P=P_f+P_c/\eta$	*kW*	***23.0688***	

Answer must be indicated!

Iterate cell E15 until this cell (E54) is close to zero.

The average velocity in the pipe is less than the minimum required lift velocity, so this conveyor may not work as specified.

To correct for insufficient lift velocity, I used a feed velocity of 145 m/s and inlet pressure of 275 kPa to get an average velocity of 87.1 m/s.