Problem 12-6

A preliminary estimate of the total cost for a completely installed pumping system is required for a certain design project. In this system, 15.75 kg/s of cooling water at 15.5 ºC is to be provided using a 305-m pipeline. It has been estimated that the theoretical power requirements for the pump will be 7.5 kW. Using the following data, estimate the total cost of the pumping system:

Material of construction – carbon steel	Insulation (85% magnesia) – 0.038 m
Number of fittings (equivalent to tees) – 40	Pump – centrifugal
Number of valves (gate) – 4	Motor – AC, enclosed, 3-phase, 1800 r/min

Cadets are required to calculate purchased price in January of 2025.

Solution

Total cost must be defined. For any piece of equipment, there is a purchased cost and an installed cost, and purchased cost is different from installed cost. Installed cost is normally calculated by multiplying the purchased cost by a known factor. From the "Cost & Evaluation Spreadsheet" posted on the course webpage, the average installation factor is about 2.8. The sum of all the purchased costs (calculated below) is multiplied by 2.8 to get the total installed cost. However, in this assignment, we define "total cost" as total *purchased* cost.

The cost analysis must account for time-value of money using cost indices. The pricing charts in the 3rd Edition of PTW are referenced to 1979, and the 5th Edition of the book is in 2002 dollars. To make the adjustments, use the cost factors found in the "CE Plant Cost Index" linked to the course web page. To simplify the calculations below, everything is referenced to 2002 during the calculations, using the CE Plant Cost Index on numbers taken from 1979 for fittings, and then the index is used to bring the values up to year 2025 at the end of the problem.

The pipe diameter is not given in the problem but is required to determine the cost. It must be calculated using Equation 12-16 or one of the other $D_{i,opt}$ equations presented in Lesson 2. In this solution, we will use Equation 12-15. Start by assuming the Reynolds number is greater than 2100 and that the diameter is greater than 0.0254 m. These assumptions must be verified.

$$D_{i,opt} = 0.363 \cdot \dot{m}_v^{.45} \cdot \rho^{.13} = 0.363 \cdot \left(\frac{15.75 \frac{kg}{s}}{998 \frac{kg}{m^3}} \right)^{.45} \cdot \left(998 \frac{kg}{m^3} \right)^{.13} = 0.1377 m$$

The density of water is found in PTW, p. 959. Viscosity is found on page 953 and is 1.12 cP.

$$D_{i,opt}\left(\text{in inches}\right) = 0.1377 m \cdot \frac{1 \text{ inch}}{0.0254 \text{ m}} = 5.422 \text{ inches}$$

Normally, we would check the standard sizes in Table D-13 on page 962, but 5-inch pipe is not listed there. Use Google to search "pipe sizes and schedules" to find a reference with a table of pipe dimensions, such as engineering toolbox. Searching such a table reveals that the closest standard size is 5-inch Schedule 40 pipe, with an outside diameter of 5.563 inches and a wall thickness of 0.258 inches. The internal diameter is 5.047 inches or 0.1281m.

Now, proceed to calculate the Reynolds number using the actual inside diameter of the 5-inch pipe to verify the assumption.

$$\text{Velocity} = \frac{\left(15.75\,\frac{\text{kg}}{\text{s}}\right)\Big/\left(998\,\frac{\text{kg}}{\text{m}^3}\right)}{\pi\left(0.1281\right)^2 / 4} = 1.22\,\frac{\text{m}}{\text{s}}$$

$$\text{ReynoldsNumber} = \frac{\text{DV}\rho}{\mu} = \frac{0.1281\text{m}\cdot 1.21\,\frac{\text{m}}{\text{s}}\cdot 998\,\frac{\text{kg}}{\text{m}^3}}{0.00112\,\frac{\text{kg}}{\text{m}\cdot\text{s}}} = 139{,}644$$

Since the Reynolds number is well into the turbulent regime, our earlier assumption was justified. Now proceed to the cost calculations.

The cost of the pipe in January 2002 is determined from Figure 12-4 on page 503. Use 5-inch carbon-steel schedule 40 welded pipe:

$$\text{Cost of Pipe} = \frac{\$26}{\text{m}}\cdot 305\text{m} = \$7{,}930$$

The cost of the tees is determined from PTW 3rd edition, Figure 13-4, page 529 (Posted under lesson 2, "1979_Pipe_and_Fitting_Prices"). Use 5-inch nominal diameter. Also, use appropriate cost factors to scale pricing from 1979 to 2002 dollars:

$$\text{Cost of Tees} = 40\text{ tees}\cdot\frac{\$50}{\text{tee}}\cdot\frac{555.8}{300.3} = \$3{,}702$$

The cost of the gate valves in January 2002 is determined from Figure 12-8 on page 505. Use 5-inch nominal diameter with 860 kPa rating:

$$\text{Cost of Gate Valves} = 4\text{ valves}\cdot\frac{\$320}{\text{valve}} = \$1{,}280$$

The cost of the 0.038 m magnesia insulation is determined from Figure 12-12 on page 507:

$$\text{Cost of Insulation} = \frac{\$17}{\text{m}}\cdot 305\text{m} = \$5{,}185$$

To get the pump cost, use Figure 12-20 on page 518 of PTW. The pump power is given as 7.5 kW. *Note carefully that this is the horizontal axis in the figure.* To see this, consider that the pressure increase across the pump can be calculated from the power:

$$\Delta P = 7.5\text{kW} \cdot \frac{998 \frac{\text{kg}}{\text{m}^3}}{15.75 \frac{\text{kg}}{\text{s}}} = 7500 \frac{\text{N} \cdot \text{m}}{\text{s}} \cdot \frac{998 \frac{\text{kg}}{\text{m}^3}}{15.75 \frac{\text{kg}}{\text{s}}} = 475{,}238 \frac{\text{N}}{\text{m}^2} = 475.238 \text{ kPa}$$

$$\text{Capacity Factor} = \frac{15.75 \frac{\text{kg}}{\text{s}}}{998 \frac{\text{kg}}{\text{m}^3}} \cdot 475{,}238 \text{ Pa} = \frac{15.75 \frac{\text{kg}}{\text{s}}}{998 \frac{\text{kg}}{\text{m}^3}} \cdot 475{,}238 \frac{\text{N}}{\text{m}^2} = 7500 \frac{\text{N} \cdot \text{m}}{\text{s}} = 7.5 \text{ kW}$$

Read "7.5" on the horizontal axis of the figure, up to the curve for "cast steel casing up to 1035 kPa." (345 kPa will not work because it is less than 475 kPa.) This gives a pump cost of about \$9,000. The motor orientation was not specified. If cadets read up to "Horizontal in-line, vertical motor," they will get \$7,900.

Now, add all the components together to get the total cost (in 2002):

Piping	\$7,930
Tees	\$3,702
Gate Valves	\$1,280
Insulation	\$5,185
Subtotal	**\$18,097**
Pump & Motor	\$9,000[1]
Total	**\$27,097**

[1]\$7,900 for an in-line vertical motor, giving a total cost of \$25,997.

The cost of the system is \$27,097 in January 2002. To scale this up to January 2025 dollars, use the CE plant cost indices for pipes, valves and fittings and for pumps and compressors. These factors are found in different columns in the table, so they must be scaled separately:

$$\$18{,}097 \cdot \frac{1315.9}{555.8} + \$9{,}000 \cdot \frac{1587.1}{699.2} = \$63{,}274 \approx \underline{\underline{\$63{,}000}}_{\text{ans}}$$

For the in-line vertical motor (note 1 above), this would be \$60,777, or about \$61,000.

Problem 12-13

What power will be required to mix an aqueous solution of 50% NaOH in a baffled tank, 2m in diameter? The mixing will be performed in the vertical tank filled to a height of 2 m by a disk turbine with six flat blades. The turbine is 0.67 m in diameter and is positioned 0.67 m above the bottom of the tank. The turbine blades are 0.134 m wide and turn at 90 r/min. The solution has a viscosity of 0.012 Pa·s and a density of 1500 kg/m^3.

Solution

Method 2: The notation used below is found in the PTW text, pp. 540-541 and 587-588.

$$N_r = 90\,\tfrac{\text{rotations}}{\text{minute}} \cdot \tfrac{1\text{ min}}{60\text{ seconds}} = 1.5\,\tfrac{\text{rotations}}{\text{second}}$$

$$\text{Reynolds number} = \frac{D_a^2 N_r \rho}{\mu} = \frac{(0.67\text{m})^2 \cdot (1.5\,\tfrac{\text{rotations}}{\text{second}}) \cdot 1500\,\tfrac{\text{kg}}{\text{m}^3}}{0.012\,\tfrac{\text{kg}}{\text{m}\cdot\text{sec}}} = 84{,}169$$

Since the Reynolds number is greater than 10,000, use Equation 12-44 on page 542:

$$N_{Po} = K_T = 6.30$$

where K_T is found in Table 12-9 for a six-bladed turbine and N_{Po} is on p. 540 below Eq. 12-39.

$$N_{Po} = \frac{P}{N_r^3 D_a^5 \rho} = 6.30$$

$$\therefore P = 6.3 \cdot (90/60)^3 \cdot (0.67)^5 \cdot 1500 = \underline{\underline{4306\text{ W}}}_{\text{ans}}$$

$$\theta = 12{,}000 \cdot \left(\frac{\mu \cdot V}{P}\right)^{.5} \cdot \left(\frac{V}{1 \cdot \text{m}^3}\right) = 12{,}000 \cdot \left(\frac{0.012\,\tfrac{\text{kg}}{\text{m}\cdot\text{sec}} \cdot 6.28\text{m}^3}{4306\,\tfrac{\text{kg}\cdot\text{m}^2}{\text{sec}^3}}\right)^{.5} \cdot \left(\frac{6.28\text{m}^3}{1 \cdot \text{m}^3}\right) = \underline{\underline{72.5\text{ sec}}}_{\text{ans}}$$

where $$V = \frac{\pi}{4}(2\,\text{m})^2 \cdot 2\text{m} = 6.28\text{ m}^3$$

Method 1: This method uses Figure 12-40 and follows below:

$$F_r = \frac{D_a N_r^2}{g} = \frac{0.67^2 \cdot (90/60)^2}{9.8} = 0.154$$

ϕ = 6.0 from Figure 12-40, page 541.

$$m = \frac{1 - \mathrm{Log}(\mathrm{Re})}{40} = \frac{1 - \mathrm{Log}(84169)}{40} = -0.0981$$

$$N_{Po} = \phi Fr^{m} \quad \text{(Eq 12-40)}$$

$$P = 6 \cdot (.154)^{-0.0981} \cdot (90/60)^3 \cdot .67^5 \cdot 1500 = \underline{\underline{4928\ \mathrm{W}}}_{\text{ans}}$$

$$\theta = 12,000 \cdot \left(\frac{\mu \cdot V}{P}\right)^{.5} \cdot \left(\frac{V}{1 \cdot m^3}\right) = 12,000 \cdot \left(\frac{0.012 \frac{kg}{m \cdot sec} \cdot 6.28 m^3}{4928 \frac{kg \cdot m^2}{sec^3}}\right)^{.5} \cdot \left(\frac{6.28 m^3}{1 \cdot m^3}\right) = \underline{\underline{67.8\ \mathrm{sec}}}_{\text{ans}}$$