

Unit Operations and Processes in Environmental Engineering (2nd Edition)

Chapter 8, Problem 4P

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Problem

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A flocculation basin is to be designed for a water coagulation plant, and the design flow is 49,200 m³/d. The basin is to be a cross-flow horizontal-shaft, paddle-wheel type with a mean velocity gradient of 26.7 s⁻¹ (at 10°C), a detention time of 45 min and a G τ value from 50,000 to 100,000. Tapered flocculation is to be provided, and three compartments of equal depth in series are to be used, as shown in Figure 8.19(b). The compartments are to be separated by slotted, redwood baffle fences, and the basin floor is level. The G values are to be 50, 20, and 10 s⁻¹. The flocculation basin is to have a width of 27.43 m to adjoin the settling basin. The paddle wheels are to have blades with a 150-mm width and a length of 3.05 m. The outside blades should clear the floor by 305 mm and be 305 mm below the water surface. There are to be six blades per paddle wheel, and the blades should have a clear spacing of 305 mm. Adjacent paddle wheels should have a clear spacing of 760 to 915 mm between blades. The wall clearance is 305 to 460 mm. Determine:

- The basin dimensions.
- The paddle-wheel design.
- The power to be imparted to the water in each compartment and the total power required for the basin.
- The range in rotational speed for each compartment if 1:4 variable-speed drives are employed.

Step-by-step solution

Step 1 of 20

a)

Calculate the volume using the formula,

$$V = Qt$$

Here, Q is the flowrate and t is detention time.

Substitute 49,200 m³/d for Q and 45 min for t and apply conversion factors to obtain V in m³.

$$V = \left(\frac{49,200 \text{ m}^3}{\text{d}} \right) \left(\frac{1 \text{ d}}{86,400 \text{ s}} \right) \left(\frac{1}{45 \text{ min}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right) = 1537.5 \text{ m}^3$$

Divide the volume by the "basin width" to obtain the basin "side" area (A).

$$A = \frac{V}{W}$$

Here, W is the basin width.

Substitute 1537.5 m³ for V and 27.43 m for W.

$$A = \frac{1537.5 \text{ m}^3}{27.43 \text{ m}} = 56.05 \text{ m}^2$$

Comments (1)

Step 2 of 20

Because three square chambers are used in series, the side area will have a length that is three times its depth. Represent the proportionality of length and depth.

$$L = 3D$$

Here, L is length and D is depth

Area is equal to length multiplied by depth. Write the formula for area.

$$A = LD$$

Substitute 3D for L.

$$A = 3D \times D$$

$$= 3D^2$$

$$D = \sqrt{\frac{A}{3}}$$

Substitute 56.05 m² for A.

$$D = \sqrt{\frac{56.05 \text{ m}^2}{3}} = 4.32 \text{ m}$$

Multiply this by 3 to obtain L.

$$L = 3 \times (4.32 \text{ m})$$

$$= 12.96 \text{ m}$$

Therefore, the basin dimensions are given by a depth of 4.32 m, a length of 12.96 m, and a width of 27.43 m.

Comment

Step 3 of 20

b)

The paddle wheel design constraints are as follows: 7 wheels are to be used, the minimum wall spacing is 305 mm (which is 0.305 m), and the maximum wheel spacing is 915 mm (which is 0.915 m). The overall tank width is 27.43 m.

Calculate the space per wheel.

$$(\text{space per wheel}) = \frac{(\text{basin width}) - 2(\text{wall spacing}) - 6(\text{wheel spacing})}{7}$$

Substitute 27.43 in for basin width, 0.305 mm for wall spacing (the minimum value), and 0.915 m for the wheel spacing (the maximum value).

$$(\text{space per wheel}) = \frac{(27.43 \text{ m}) - 2(0.305 \text{ m}) - 6(0.915 \text{ m})}{7} = 3.047 \text{ m}$$

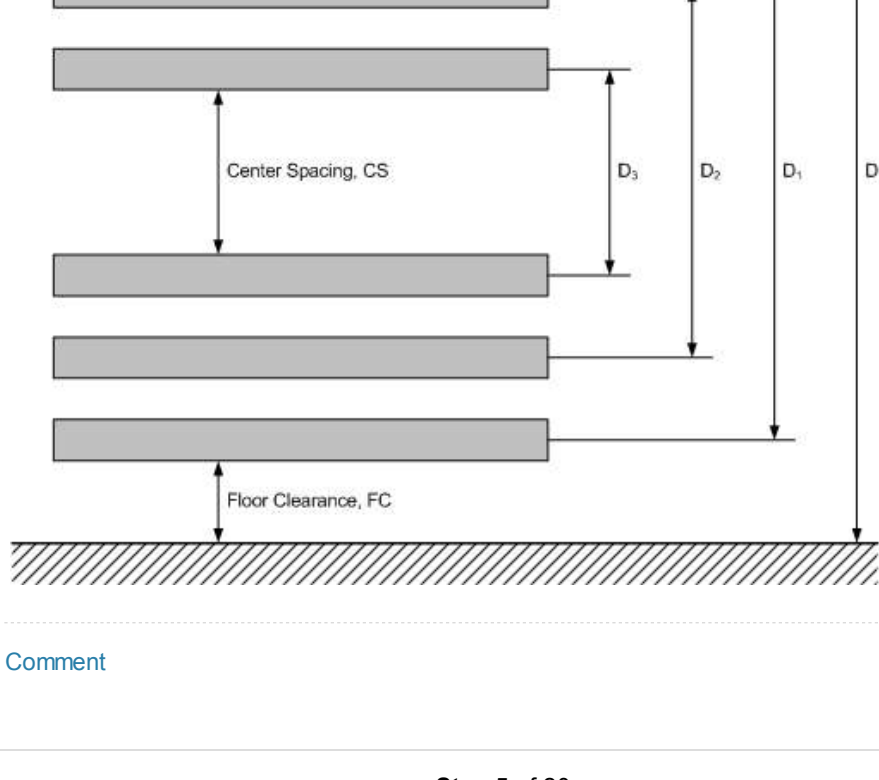
This agrees with the 3.05 m blade width given for each wheel.

Therefore, the horizontal dimensions are defined by a wall spacing of 0.305 m and a wheel spacing of 0.915 m.

Comment

Step 4 of 20

Six blades are to be used in each paddle wheel. The paddle wheel vertical design is explained by the following drawing.



Comment

Step 5 of 20

List the design constraints.

- The tank depth, D, was found in part (a) to be 4.32 m.
- The floor clearance, FC, must be 305 mm (which is 0.305 m).
- The water surface clearance, WSC, must be 305 mm (0.305 m).
- The blade width, BW, is 150 mm (0.150 m).
- The blade clearance, BC, must be 305 mm (0.305 m) or more. This is the key design parameter that will be varied to achieve the overall design.
- The center spacing, CS, must be 305 mm (0.305 m) or more.

The distances D₁, D₂, and D₃ are from blade center to blade center for each pair of blades from outside to inside of paddle wheel.

Comment

Step 6 of 20

Calculate the distance between the outside row of blades.

$$D_1 = D - \left(FC + WSC + 2 \times \frac{BW}{2} \right)$$

$$D_1 = D - FC - WSC - BW$$

Substitute 4.32 m for D, 0.305 m for FC, 0.305 m for WSC, and 0.150 m for BW.

$$D_1 = (4.32 \text{ m}) - (0.305 \text{ m}) - (0.305 \text{ m}) - (0.150 \text{ m}) = 2.950 \text{ m}$$

Calculate the distance between the middle row of blades.

$$D_2 = D_1 - \left(2 \times \frac{BW}{2} + 2 \times BC + 2 \times \frac{BW}{2} \right)$$

$$= D_1 - 2BW - 2BC$$

Substitute 2.950 m for D₁ and 0.150 m for BW.

$$D_2 = (2.950 \text{ m}) - 2(0.150 \text{ m}) - 2BC = (2.650 \text{ m}) - 2BC$$

Comments (1)

Step 7 of 20

Calculate the distance between the inner row of blades.

$$D_3 = D_2 - \left(2 \times \frac{BW}{2} + 2 \times BC + 2 \times \frac{BW}{2} \right)$$

$$= D_2 - 2BW - 2BC$$

Substitute 0.150 m for BW and (2.650 m) - 2BC for D₂.

$$D_3 = [(2.650 \text{ m}) - 2BC] - 2(0.150 \text{ m}) - 2BC = (2.350 \text{ m}) - 4BC$$

Calculate the center spacing.

$$CS = D_1 - 2 \times \frac{BW}{2} = D_1 - BW$$

Substitute 0.150 m for BW and (2.350 m) - 4BC for D₁.

$$CS = (2.350 \text{ m}) - 4BC - (0.150 \text{ m}) = (2.200 \text{ m}) - 4BC$$

Comment

Step 8 of 20

The procedure outlined in these steps creates a system of equations that establishes the design distances for the paddle wheels and calculates the provided center spacing (CS). Any value of BC can be selected that provides CS greater than 0.305 m.

Any value of BC between 0.305 m and 0.473 m will satisfy the design constraints. For example, substituting 0.450 m for BC in the system of equations gives the following distances.

$$D_1 = 2.950 \text{ m}$$

$$D_2 = (2.950 \text{ m}) - 2(0.450 \text{ m}) = 1.750 \text{ m}$$

$$D_3 = (2.650 \text{ m}) - 4(0.450 \text{ m}) = 0.550 \text{ m}$$

$$CS = (2.350 \text{ m}) - 4(0.450 \text{ m}) = 0.400 \text{ m}$$

Because 0.400 m > 0.305 m, the design is acceptable. Therefore, a suggested design is given by a blade width of 0.450 m. Values between 0.305 m and 0.473 m are acceptable.

Comment

Step 9 of 20

c)

Write the formula for the power delivered to each blade.

$$P = \mu G^2 V$$

The volume for each compartment is equal to one-third of the total volume of 1537.5 m³. This is equal to 1537.5/3 = 512.5 m³.

For the first tank, substitute 0.00131 N-s/m² for μ , 50 s⁻¹ for G, and 512.5 m³ for V into the power equation.

$$P_1 = \left(\frac{0.00131 \text{ N} \cdot \text{s}}{1 \text{ m}^2} \right) \left(\frac{50}{\text{sec}} \right)^2 \left(\frac{512.5 \text{ m}^3}{1} \right) \left(\frac{1 \text{ W}}{1 \text{ N} \cdot \text{m/s}} \right) = 1678.4 \text{ W}$$

For the second tank, substitute 0.00131 N-s/m² for μ , 20 s⁻¹ for G, and 512.5 m³ for V for V into the power equation.

$$P_2 = \left(\frac{0.00131 \text{ N} \cdot \text{s}}{1 \text{ m}^2} \right) \left(\frac{20}{\text{sec}} \right)^2 \left(\frac{512.5 \text{ m}^3}{1} \right) \left(\frac{1 \text{ W}}{1 \text{ N} \cdot \text{m/s}} \right) = 268.6 \text{ W}$$

Comment

Step 10 of 20

For the second tank, substitute 0.00131 N-s/m² for μ , 10 s⁻¹ for G, and 512.5 m³ for V for V into the power equation.

$$P_3 = \left(\frac{0.00131 \text{ N} \cdot \text{s}}{1 \text{ m}^2} \right) \left(\frac{50}{\text{sec}} \right)^2 \left(\frac{512.5 \text{ m}^3}{1} \right) \left(\frac{1 \text{ W}}{1 \text{ N} \cdot \text{m/s}} \right) = 67.1 \text{ W}$$

Calculate the total power imparted to the water is found by summing the power in each compartment.

$$P_{\text{TOTAL}} = P_1 + P_2 + P_3$$

Substitute 1678.4 W for P₁, 268.6 W for P₂, and 67.1 W for P₃.

$$P_{\text{TOTAL}} = (1678.4 \text{ W}) + (268.6 \text{ W}) + (67.1 \text{ W}) = 2014.1 \text{ W}$$

Thus, the total power imparted to the water is 2014.1 W. The power imparted in the first compartment is 1678.4 W, the power imparted in the second compartment is 268.6 W, and the power imparted in the third compartment is 67.1 W.

Comment

Step 11 of 20

d)

First, compute the horizontal velocity for each pair of blades. Write the formula first.

$$v = (\text{rps}) \times \frac{\pi D}{(\text{rev})} \times 0.75$$

In part (b), the three diameters were determined based on a blade clearance of 0.450 m.

Substitute 2.950 m for D₁, 1.750 m for D₂, and 0.550 m for D₃.

For the outside pair of blades, substitute 2.950 m for D.

$$v_1 = (\text{rps}) \pi (2.950) \times 0.75 = 6.951 \text{ rps}$$

For the middle pair of blades, substitute 1.750 m for D.

$$v_2 = (\text{rps}) \pi (1.750) \times 0.75 = 4.123 \text{ rps}$$

For the inner pair of blades, substitute 0.550 m for D.

$$v_3 = (\text{rps}) \pi (0.550) \times 0.75 = 1.296 \text{ rps}$$

Comment

Step 12 of 20

Write the formula for power per blade (let i represent the blade number).

$$P_i = C_D A_i \rho v_i^3$$

In this formula, C_D is the drag coefficient; A_i is the area of ith blade, ρ is the density of water, and v_i is the horizontal velocity of the ith blade.

Substitute 999.7 kg/m³ for ρ and simplify the constant.

$$P_i = C_D A_i (999.7)^3 v_i^3$$
$$P_i = 499.9 C_D A_i v_i^3$$

Comment

Step 13 of 20

Use the formula for power per blade, write the formula for the power per wheel, P. In writing this equation, each pair of blades can be considered as one blade with twice the area of each individual blade.

$$P = 499.9 C_D A_1 v_1^3 + 499.9 C_D A_2 v_2^3 + 499.9 C_D A_3 v_3^3$$

Because A₁, A₂, and A₃ are the same, simplify the formula to

$$P = 499.9 C_D A (v_1^3 + v_2^3 + v_3^3)$$

Here, A is the blade area. The blade dimensions are given as 0.150 m wide and 3.05 m long. From this, the blade area can be found. Include a factor of 2 because there are two blades in each pair of blades in the paddle wheel.

$$A = 2 \times (0.150 \text{ m}) \times (3.05 \text{ m})$$

$$A = 0.915 \text{ m}^2$$

Next, find the value for C_D. From the blade dimensions, find the length-width ratio (LWR).

$$LWR = \frac{0.150 \text{ m}}{3.05 \text{ m}} = 20.333 \approx 20$$

Use LWR in Table 8.3 to find the appropriate C_D value of 1.5.

Comment

Step 14 of 20

Substitute 1.5 for C_D, 0.915 m² for A, 6.951 rps for v₁, 4.123 rps for v₂, and 1.296 rps for v₃.

$$P = 499.9 (1.5) (0.915) [(6.951 \text{ rps})^3 + (4.123 \text{ rps})^3 + (1.296 \text{ rps})^3] = (\text{rps})^3 (499.9) [(1.5) (0.915) [(6.951)^3 + (4.123)^3 + (1.296)^3]] = (\text{rps})^3 (559999)$$

Solve for (rps).

$$(\text{rps}) = \left(\frac{P}{559999} \right)^{1/3}$$

This establishes a formula for deriving the rotational speed.

For the first compartment, find the power per wheel by taking the total power imparted and dividing by the number of wheels, 7. Recall that the power in the first compartment was 1678.4 W.

$$P = \frac{1678.4 \text{ W}}{7} = 239.8 \text{ W}$$

Comment

Step 15 of 20

Apply the rotational speed formula.

$$(\text{rps}) = \left(\frac{P}{559999} \right)^{1/3}$$

Substitute 239.8 W for P.

$$(\text{rps}) = \left(\frac{239.8}{559999} \right)^{1/3} = 0.0754 \text{ rps}$$

Convert this to rpm by multiplying by 60.

$$0.0612 \text{ rps} \times 60 = 4.52 \text{ rpm}$$

Find the minimum rotational speed by dividing by 4, based on the 1:4 drive ratio.

$$4.52 \text{ rpm} / 4 = 1.13 \text{ rpm}$$

Comment

Step 16 of 20

Finally, check the outside horizontal velocity to ensure that it falls beneath 0.91 m/s.

Write the formula for horizontal velocity.

$$v = 0.75 \pi D (\text{rps})$$

Substitute 0.0754 for (rps) and 2.950 m for D.

$$v = 0.75 \pi (2.950 \text{ m}) (0.0754) = 0.524 \text{ m/s}$$

Because this is less than 0.91 m/s, the design is acceptable.

Therefore, for the first compartment, the power is equal to 1678.4 W, the nominal rotational speed is 4.52 rpm with a range of 1.13 to 4.52 rpm, and the outside horizontal velocity is 0.524 m/s.

Comment

Step 17 of 20

For the second compartment, find the power per wheel by taking the total power imparted and dividing by the number of wheels, 7. Recall that the power in the second compartment was 268.6 W.

$$P = \frac{268.6 \text{ W}}{7} = 38.4 \text{ W}$$

Apply the rotational speed formula.

$$(\text{rps}) = \left(\frac{P}{559999} \right)^{1/3}$$

Substitute 38.4 W for P.

$$(\text{rps}) = \left(\frac{38.4}{559999} \right)^{1/3} = 0.0409 \text{ rps}$$

Convert this to rpm by multiplying by 60.

$$0.0409 \text{ rps} \times 60 = 2.46 \text{ rpm}$$

Find the minimum rotational speed by dividing by 4, based on the 1:4 drive ratio.

$$2.46 \text{ rpm} / 4 = 0.61 \text{ rpm}$$

Comment

Step 18 of 20

Finally, check the outside horizontal velocity to ensure that it falls beneath 0.91 m/s.

Write the formula for horizontal velocity.

$$v = 0.75 \pi D (\text{rps})$$

Substitute 0.0409 for (rps) and 1.750 m for D.

$$v = 0.75 \pi (1.750 \text{ m}) (0.0409) = 0.284 \text{ m/s}$$

Because this is less than 0.91 m/s, the design is acceptable.

Therefore, for the second compartment, the power is equal to 268.6 W, the nominal rotational speed is 2.46 rpm with a range of 0.61 to 2.46 rpm, and the outside horizontal velocity is 0.284 m/s.

Comment

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Step 19 of 20

For the third compartment, find the power per wheel by taking the total power imparted and dividing by the number of wheels, 7. Recall that the power in the third compartment was 67.1 W.

$$P = \frac{67.1 \text{ W}}{7}$$
$$= 9.6 \text{ W}$$

Apply the rotational speed formula.

$$\left(\text{rps} \right) = \left(\frac{P}{559999} \right)^{1/3}$$

Substitute 9.6 W for P.

$$\left(\text{rps} \right) = \left(\frac{9.6}{559999} \right)^{1/3}$$
$$= 0.0258 \text{ rps}$$

Convert this to rpm by multiplying by 60.

$$0.0258 \text{ rps} \times 60 = 1.55 \text{ rpm}$$

Find the minimum rotational speed by dividing by 4, based on the 1:4 drive ratio.

$$1.55 \text{ rpm} / 4 = 0.37 \text{ rpm}$$

Comment

Step 20 of 20

Finally, check the outside horizontal velocity to ensure that it falls beneath 0.91 m/s.

Write the formula for horizontal velocity.

$$v = 0.75\pi D \left(\text{rps} \right)$$

Substitute 0.0258 for (rps) and 0.550 m for D.

$$v = 0.75\pi \left(0.550 \text{ m} \right) \left(0.0258 \right)$$
$$= 0.179 \text{ m/s}$$

Because this is less than 0.91 m/s, the design is acceptable.

Therefore, for the third compartment, the power is equal to $\left[\frac{67.1 \text{ W}}{7} \right]$, the nominal rotational speed is $\left[1.55 \text{ rpm} \right]$ with a range of $\left[0.37 \text{ to } 1.55 \text{ rpm} \right]$, and the outside horizontal velocity is $\left[0.179 \text{ m/s} \right]$.

Comment

Was this solution helpful?

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Chapter 8, Problem 5P

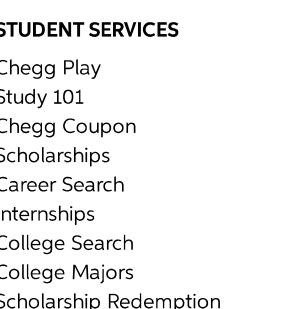
A pneumatic flocculation basin is to be designed for a tertiary treatment plant having a flow of 5.0 MGD. The plant is to employ high-pH lime coagulation, and pertinent data for the flocculation basin are as follows: detention time = 5 min, G =...

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Chapter 8, Problem 9P

A lime-soda softening plant treats a flow of 150 MGD, and the water has 86 mg/l Ca+2, 35 mg/l Mg+2, and 6 mg/l CO2. The

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