

$$\textcircled{1} V_T = 15\text{ m} \times 10.3\text{ m} \times 5\text{ m} = 772.5\text{ m}^3$$

$$V_{\text{STAGE}} = 772.5\text{ m}^3 \div 3 = 257.5\text{ m}^3 \approx 257.2\text{ m}^3$$

Assuming  $Q$  is for one basin

$$G = 40\text{ s}^{-1}$$

$$\text{motor efficiency} = 80\%$$

$$\text{Paddle velocity} = 0.5\text{ m/s, taken as being relative to water}$$

$$\text{Temperature} = 15^\circ\text{C}; \mu = 0.00139\text{ Pa}\cdot\text{s}; \rho = 999.103\frac{\text{kg}}{\text{m}^3}$$

$$C_D = 1.8$$

$$\text{For first stage: } W = 10.3\text{ m}; H = 5.0\text{ m}, L = 5.0\text{ m}$$

Find paddle width (m), motor power (W)  
and rotational speed (rpm)

$$G = \sqrt{\frac{P}{\mu V}}; \quad P = G^2 \mu V$$

$$P = (40\text{ s}^{-1})(40\text{ s}^{-1})(0.00139\text{ Pa}\cdot\text{s})(257.2\text{ m}^3)$$
$$= 572\text{ W}$$

$$P_{\text{motor}} = \frac{572\text{ W}}{0.80} = 715\text{ W} \quad (\text{taking account of motor efficiency})$$

$$(715\text{ W} \times 1.5) = \underline{\underline{1072.5\text{ W}}} \quad (\text{applying safety factor of } 1.5)$$

$$\text{Paddle length} = 2.5\text{ m}$$

$$C_D = 1.8 \quad \text{so} \quad L/W > 20.$$

$$\frac{L}{W} = 20 = \frac{250\text{ cm}}{W\text{ cm}}; \quad W = 12.5$$

$\textcircled{1}$

For  $L/W > 20$ ;  $W < 12.5$  cm

$$\text{Try } W = 10 \text{ cm} \quad A_p = (0.1 \text{ m})(2.5 \text{ m}) = 0.25 \text{ m}^2$$

$$P = \frac{C_d A_p \rho v^3}{2} = \frac{C_d A_p (2\pi k r n)^3}{2}$$

$$\text{No. of paddles}_{\text{stage}} = \left( \frac{4 \text{ paddles}}{\text{wheel}} \right) \left( \frac{3 \text{ wheels}}{\text{stage}} \right) = \frac{12 \text{ paddles}}{\text{stage}}$$

$$v_p = 2\pi k r n = 0.5 \text{ m/s}$$

$$\text{For paddle } W = 10 \text{ cm}; \quad r = (4.2 \text{ m}/2) - 0.05 \text{ m} = 2.05 \text{ m}$$

$$n = \frac{v_p}{2\pi k r} = \frac{0.5 \text{ m/s}}{2\pi (0.75)(2.05 \text{ m})} \left( \frac{60 \text{ s}}{1 \text{ min}} \right) = 3.105 \text{ rpm}$$

$$P = \frac{C_d A_p \rho v^3}{2}; \quad A = \frac{P(2)}{(C_d)(\rho)(v^3)}$$
$$= \frac{(572 \text{ W})(2)}{(1.8)(999.103 \text{ kg/m}^3)(0.5 \text{ m/s})^3}$$
$$= 5.089 \text{ m}^2$$

$$A_p = \frac{5.089 \text{ m}^2}{12} = 0.424 \text{ m}^2$$

$$A_p = L \times W; \quad W = \frac{A_p}{L} = \frac{0.424 \text{ m}}{2.5 \text{ m}} = 0.170 \text{ m}$$

Assuming the relationship of  $L/W$  to  $C_d$  given in Table 3-7 does not work. Use  $W_p = 17$  cm.

(2)

$$r = (4.20 \text{ m} / 2) - (0.17 / 2) = 2.1 \text{ m} - 0.085 \text{ m} \\ = 2.015 \text{ m}$$

$$n = \frac{V_p}{2\pi Kr} = \frac{0.5 \text{ m/s}}{2\pi (0.75)(2.015 \text{ m})} \left( \frac{60 \text{ s}}{1 \text{ min}} \right) \\ = \underline{\underline{3.16 \text{ rpm}}}$$

In equation:  $P = \frac{C_d A_p v^3}{2}$

A is the area of all paddles at the same radius

(2) Given:  $Q = 36 \times 10^3 \text{ m}^3/\text{d}$  assuming  $Q$  is per basin.  
 $t = 23 \text{ min}$   
 $G = 40 \text{ s}^{-1}$  for 1<sup>st</sup> compartment  
 $L = W$   
 $T = 10^\circ\text{C}$   
 Use Table 7-3 design criteria  
 3 compartments

Find: basin dimensions  
 paddle configuration  
 power requirement  
 motor power  
 rotation speed

$$\begin{aligned}
 V &= Qt = \frac{(36000 \text{ m}^3/\text{d}) (23 \text{ min}) (1 \text{ d.})}{(24 \times 60 \text{ min})} \\
 &= 575 \text{ m}^3
 \end{aligned}$$

$$575 \text{ m}^3 / 3 \text{ compartments} = 191.7 \text{ m}^3 / \text{compartment}$$

Let wheel diameter  $D = 3.5 \text{ m}$

$$\text{Try } L = W = H ; \sqrt[3]{191.7 \text{ m}^3} = 5.766 \text{ m}$$

To meet  $V$  requirement and clearance requirements use  $D = 4.0 \text{ m}$

Use max clearance of  $0.7 \text{ m}$  between wheel and walls.

$$L = W = 4.0 \text{ m} + 2(0.7 \text{ m}) = 5.4 \text{ m}$$

$$H = \frac{191.7 \text{ m}^3}{(5.4 \text{ m})(5.4 \text{ m})} = 6.57 \text{ m}, \text{ use } 6.6 \text{ m}$$

(4)

$$V = (5.4\text{m})(5.4\text{m})(6.6\text{m}) = 192.4\text{m}^3 \text{ O.K.}$$

$$H = D + 1\text{m or more} \text{ O.K.}$$

Max paddle length = 3.5 m. so use 2 units

To get in greatest paddle lengths we  
min. clearances.

$$\frac{5.4\text{m} - 1\text{m (between units)} - 2(0.3\text{m})}{2} = 1.9\text{m}$$

Use 2.0 m long paddles and extend w to 5.6 m.

$$\frac{191.7\text{m}^3}{(5.6\text{m})(6.6\text{m})} = 5.19 \approx 5.20\text{m}$$

Compartment is 5.6 m W x 5.2 m L x 6.6 m H

$$T = 10^\circ\text{C}; \rho = 999.703 \text{ kg/m}^3; \mu = 0.001307 \text{ Pa}\cdot\text{s}$$

$$G = \sqrt{\frac{P}{\mu V}}; P = G^2 \mu V$$

$$P = (40\text{s}^{-1})(40\text{s}^{-1})(0.001307 \text{ Pa}\cdot\text{s})(5.6 \times 5.2 \times 6.6 \text{ m}^3) \\ = 401.9 \text{ W}$$

$$\text{For 80\% efficient motor } P = \frac{401.9}{0.8} = 502.4 \text{ W}$$

$$\text{and providing a safety factor } P = (502.4 \text{ W})(1.5) \\ = \underline{\underline{754 \text{ W}}}$$

Try 3 paddles/arm, each paddle 0.15 m x 2.0 m

$$\text{Wheel } R = 2.0 \text{ m}$$

$$\frac{1}{3} \text{ spacings} = 2.0/3 = 0.66\text{m}; 1.33 \text{ and } 2.0 \text{ m} \\ \text{to outside edges.}$$

(5)

$$r_1 = 0.667 \text{ m} - 0.075 \text{ m} = 0.592 \text{ m}$$

$$r_2 = 1.333 \text{ m} - 0.075 \text{ m} = 1.258 \text{ m}$$

$$r_3 = 2.0 \text{ m} - 0.075 \text{ m} = 1.925 \text{ m}$$

$$P = \frac{C_d A P \rho^3}{2}$$

A paddle at each radius

$$= (2 \text{ m}) (0.15 \text{ m}) \left( \frac{4 \text{ paddles}}{\text{wheel}} \right) \left( \frac{2 \text{ wheels}}{\text{shaft}} \right) = 2.4 \text{ m}^2$$

$$L/W = 2.0 \text{ m} / 0.15 \text{ m} = 13.3 \quad C_D \approx 1.35$$

$$n = \left( \frac{2P}{\rho C_d A [2\pi k]^3 [r_1^3 + r_2^3 + r_3^3]} \right)^{1/3}$$

$$= \left[ \frac{2(401.9) \text{ W}}{\left( 999.703 \frac{\text{kg}}{\text{m}^3} \right) (1.35) (2.4 \text{ m}^2) (104.65) (0.2075 + 1.991 + 7.133)} \right]^{1/3}$$

9.3315

$$= (2.541 \times 10^{-4})^{1/3} = 0.0633 \text{ rps} = 3.80 \text{ rpm}$$

$$\begin{aligned} \text{Outermost paddle tip speed} &= 2\pi r n \\ &= 2\pi (2.0 \text{ m}) (0.0633 \text{ rps}) \\ &= 0.795 \text{ m/s. (OK, 0.15-1.0 m/s)} \end{aligned}$$

$$A_{\text{paddles}} / A_{\text{x-sect}} = \frac{(2.4 \text{ m}^2) (3)}{(5.6 \text{ m} \times 6.6 \text{ m})} = 0.194 \quad (\text{OK, } 0.1-0.25)$$

For Basin  $H = 6.6 \text{ m}$ ;  $W = 5.6 \text{ m}$ ;  $L = 3 \times 5.2 \text{ m} = 15.6 \text{ m}$

Paddles are  $2.0 \text{ m} \times 0.15 \text{ m}$ , 2 units/shaft, 4 arms/wheel, 3 paddles/arm.

(6)

Flow through velocity  $V_H = 0.15 - 0.45$  m/min recommended.

$$A_H V_H = Q$$

$$V_H = \frac{Q}{A_H} = \frac{36,000 \text{ m}^3/\text{d}}{6.6 \text{ m} \times 5.6 \text{ m}} \times \frac{1 \text{ d}}{24 \times 60 \text{ min}}$$

$$= 0.676 \text{ m/min. too high}$$

Assume  $Q = 36,000 \text{ m}^3/\text{d}$  is for 2 basins

or  $Q = 18,000 \text{ m}^3/\text{d}$  for 1 basin.

$$V = Q t = (18,000 \text{ m}^3/\text{d} \times 23 \text{ min}) \left( \frac{1 \text{ d}}{24 \times 60 \text{ min}} \right)$$
$$= 287.5 \text{ m}^3$$

$$287.5 \text{ m}^3 / 3 \text{ compartments} = 95.83 \text{ m}^3 / \text{compartment}$$
$$\approx 96 \text{ m}^3$$

Let wheel  $D = 3.5 \text{ m}$

$$\text{Try } L = W = H; \sqrt[3]{95.83 \text{ m}^3} = 4.57$$

Max. paddle length = 3.5 m

$$\sqrt[3]{4.5 \text{ m} \times 4.5 \text{ m} \times 4.75 \text{ m}} = 4.57 \approx 4.6 \text{ m} \text{ is close}$$

$\begin{matrix} W & L & H \end{matrix}$

The above will satisfy clearance requirements

Try 3 paddles/arm, each paddle 3.5 m x 0.12 m

$$R = 1.75 \text{ m}$$

$$1/3 \text{ spacings} = 1.75 \text{ m} / 3 = 0.583 \text{ m}$$

and 1.167 m and 1.75 m to outside edges

(7)

$$r_1 = 0.583 \text{ m} - 0.06 \text{ m} = 0.523 \text{ m}$$

$$r_2 = 1.167 \text{ m} - 0.06 \text{ m} = 1.107 \text{ m}$$

$$r_3 = 1.75 \text{ m} - 0.06 \text{ m} = 1.690 \text{ m}$$

A paddle at each radius

$$(3.5 \text{ m} \times 0.12 \text{ m}) \left( \frac{4 \text{ paddles}}{\text{wheel}} \right) \left( \frac{1 \text{ wheel}}{\text{shaft}} \right) = 1.68 \text{ m}^2$$

$$L/W = 3.5/0.12 = 29.2 \quad C_D \approx 1.8$$

For one basin:

$$P = G^2 \mu V = (40 \text{ s}^{-1})^2 (40 \text{ s}^{-1}) (0.001307 \text{ Pa}\cdot\text{s}) (96.2 \text{ m}^3) \\ = 201.2 \text{ W}$$

$$n = \left( \frac{2P}{\rho C_D A [2\pi K]^3 [r_1^3 + r_2^3 + r_3^3]} \right)^{1/3}$$

$$= \left( \frac{(2 \times 201.2 \text{ W})}{(999.703 \frac{\text{kg}}{\text{m}^3}) (1.8) (1.68 \text{ m}^2) (104.65) [0.143 + 1.357 + 4.807]} \right)^{1/3}$$

6.327

$$= (2.0103 \times 10^{-4})^{1/3} = 0.0586 \text{ rps} = 3.51 \text{ rpm}$$

$$\text{Outermost paddle tip speed} = 2\pi r n \\ = 2\pi (1.75) (0.0586 \text{ rps}) \\ = 0.644 \text{ m/s} \quad (\text{OK } 0.15 - 1.0 \text{ m/s})$$

$$\frac{A_{\text{paddle}}}{A_{x\text{-sect}}} = \frac{(1.68 \text{ m}^2)(3)}{(4.5 \text{ m} \times 4.75 \text{ m})} = 0.236 \quad (\text{OK } 0.1 - 0.25)$$

Flow through velocity  $V_H = 0.15 - 0.45 \text{ m/min}$  is good

$$V_H = \frac{Q}{A_x} = \frac{18,000 \text{ m}^3/\text{d}}{(4.5 \text{ m} \times 4.75 \text{ m})} \times \frac{1 \text{ day}}{24 \times 60 \text{ min}} = 0.58 \text{ m/min}$$

(B) too high!



Try 3 basins  $Q = 36,000 \text{ m}^3/\text{d} = 12,000 \text{ m}^3/\text{d}$

$$V = Qt = \frac{12,000 \text{ m}^3/\text{d}}{3} \left( 23 \text{ min} \right) \left( \frac{1 \text{ d}}{24 \times 60 \text{ min}} \right)$$
$$= 191.6 \text{ m}^3$$

$191.6 \text{ m}^3 / 3 \text{ compartments} = 63.8 \text{ m}^3/\text{compartment}$

$$\sqrt[3]{63.8} = 3.998 \approx 4.0 \text{ m} \quad \text{if } L = W = H$$

$$V_H = \frac{Q}{A_x} = \frac{12,000 \text{ m}^3/\text{d}}{4 \text{ m} \times 4 \text{ m}} \times \frac{1 \text{ day}}{24 \times 60 \text{ min}} = 0.520 \text{ m}/\text{min}$$

$A_x$  still too large and  $H$  cannot be reduced so use 2 basins but set  $L \neq W$  and try 2 units per compartment.

$$V \approx 96 \text{ m}^3; \quad \text{Try } H = 4.2 \text{ m} \quad W = 96 \text{ m}^3 = 6.35, \\ L = 3.6 \text{ m} \quad 3.6 \text{ m} \times 4.2$$

$W = 6.35 \text{ m}$  still makes  $A_x$  too small so increase  $W$  to  $6.60 \text{ m}$

$$V_H = \frac{Q}{A_x} = \frac{12,000 \text{ m}^3/\text{d}}{4.2 \text{ m} \times 6.6 \text{ m}} \times \frac{1 \text{ day}}{24 \times 60 \text{ min}} = 0.451 \text{ m}/\text{min}$$

Will accept!

Basin and detention time have been increased slightly which is conservative (safe) though more expensive.

Use paddle wheel  $D = 3.0 \text{ m}$

$R = 1.50 \text{ m}$ ; Try 3 paddles/arm;

Try 2 units / compartment

$$\text{Wallowane} = 1.0 \text{ m} + 2(0.3 \text{ m}) = 1.6 \text{ m}$$

$$W - \text{Wallance} = 6.6 \text{ m} - 1.6 \text{ m} = 5.0 \text{ m}$$

$$5.0 \text{ m} / 2 = 2.5 \text{ m} = \text{length each paddle}$$

$$\text{Paddle spacing on arm} = 1.50 / 3 = 0.50 \text{ m}$$

and 1.0 m and 1.50 to outer edges.

$$\text{Let paddle} = 2.5 \text{ m} \times 0.10 \text{ m}$$

$$r_1 = 0.45 \text{ m}; \quad r_2 = 0.95 \text{ m}; \quad r_3 = 1.45 \text{ m}$$

8 paddles at each radius

$$A = (8 \times 2.5 \text{ m} \times 0.10 \text{ m}) = 2 \text{ m}^2$$

$$\frac{A_{\text{paddle}}}{A_{x\text{-sect}}} = \frac{(2 \text{ m}^2)(3)}{4.2 \text{ m} \times 6.6 \text{ m}} = 0.216 \quad (\text{O.K. } 0.1 - 0.25)$$

$$W/w = 2.5 / 0.10 = 25 \quad \text{Let } C_D = 1.70$$

For 1 basin:

$$P = G^2 \mu V = (40 \text{ s}^{-1})(40 \text{ s}^{-1})(0.001307 \text{ Pa}\cdot\text{s}) \times (3.6 \text{ m} \times 4.2 \text{ m} \times 6.6 \text{ m})$$
$$= 208.7 \text{ W}$$

$$n = \left( \frac{2P}{\rho C_D A [2\pi K]^3 [r_1^3 + r_2^3 + r_3^3]} \right)^{1/3}$$

$$= \left( \frac{(208.7)(2)}{(999.703 \frac{\text{kg}}{\text{m}^3})(1.70)(2 \text{ m}^2)(104.65)[0.0911 + 0.8574 + 3.0486]} \right)^{1/3}$$

3.9971

$$= (2.936 \times 10^{-4})^{1/3} = 0.06646 \text{ rps} = 3.99 \text{ rpm}$$

$$\text{Outermost paddle tip speed} = 2\pi r n$$
$$= 2\pi (1.5 \text{ m})(0.06646 \text{ rps})$$
$$= 0.626 \text{ m/s} \quad (\text{OK } 0.15 - 1.0 \text{ m/s})$$

(10)

## Final Design:

First compartment:  $H = 4.2 \text{ m}$   
 $L = 3.6 \text{ m}$   
 $W = 6.6 \text{ m}$

Paddle wheels:  $D = 3.0 \text{ m}$   
 $L = 2.5 \text{ m}$   
 $r_1 = 0.45 \text{ m}$ ;  $r_2 = 0.95 \text{ m}$ ;  $r_3 = 1.45 \text{ m}$   
2 wheels / compartment

$$n = 0.06646 \text{ rps} = 3.99 \text{ rpm}$$

Each paddle:  $2.5 \text{ m} \times 0.10 \text{ m}$

Motor power calculation:

Power needed,  $P = 208.7 \text{ W}$

For 80% efficient motor  $P = \frac{208.7}{0.8} = 260.9 \text{ W}$

Providing a safety factor  $P = (260.9 \text{ W})(1.5)$   
 $\approx \underline{\underline{391 \text{ W}}}$

This is power for each motor.

