① $\forall_T$ = 15 m × 10.3 m × 5 m = 772.5 m³

$\forall_{STAGE}$ = 772.5 m ÷ 3 = 257.5 m³ ≈ 257.2 m³

Assuming Q is for one basin

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

motor efficiency = 80%

Paddle velocity = 0.5 m/s, taken as being relative to water

Temperature = 15°C ; μ = 0.00139 Pa·s ; ρ = 999.103 $\frac{kg}{m^3}$

$C_D = 1.8$

For first stage W = 10.3 m; H = 5.0 m, L = 5.0 m

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

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

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

= 572 W

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

(715 W)(1.5) = **1,072.5 W** (applying safety factor of 1.5)

Paddle length = 2.5 m

C_D = 1.8 so L/W > 20.

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

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

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

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

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

$\nu_p = 2\pi k r n = 0.5\ m/s$

For paddle $W = 10$ cm, $r = (4.2m/2) - 0.05\ m = 2.05\ m$

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

$$P = \frac{C_d A \rho \nu^3}{2}\ ;\quad A = \frac{(P)(2)}{(C_d)(\rho)(\nu^3)}$$

$$= \frac{(572\ W)(2)}{(1.8)(999.103\ kg/m^3)(0.5\ m/s)^3}$$

$$= 5.089\ m^2$$

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

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

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

$r = (4.20\,m/2) - (0.17/2) = 2.1\,m - 0.085\,m$
$= 2.015\,m$

$$n = \frac{v_p}{2\pi k r} = \frac{0.5\,m/s}{2\pi\,(0.75)(2.015\,m)}\left(\frac{60\,s}{1\,min}\right)$$

$= \underline{\underline{3.16\ rpm}}$

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

A is the area of all paddles at the same radius.

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

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

$$\forall = Qt = \frac{(36{,}000 \text{ m}^3/d)(23 \text{ min})(1 \text{ d})}{(24 \times 60 \text{ min})}$$

$$= 575 \text{ m}^3$$

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

Let wheel diameter $D = 3.5$ m

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

To meet $\forall$ requirement and clearance requirements use $D = 4.0$ m

Use max clearance of 0.7 m between wheel and walls.

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

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

$\forall = (5.4 m)(5.4 m)(6.6 m) = 192.4 m^3$ O.K.

$H = D + 1 m$ or more O.K.

Max paddle length = 3.5 m so use 2 units

To get in greatest paddle lengths use min. clearances.

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

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

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

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

$T = 10°C$; $\rho = 999.703 kg/m^3$; $\mu = 0.001307 Pa \cdot s$

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

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

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

and providing a safety factor $P = (502.4 W)(1.5)$

$= \underline{\underline{754 W}}$

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

Wheel R = 2.0 m

1/3 spacings = 2.0/3 = $0.6\dot{6}$ m ; $1.3\dot{3}$ and 2.0 m to outside edges.

$r_1 = 0.667\ m - 0.075\ m = 0.592\ m$

$r_2 = 1.333\ m - 0.075\ m = 1.258\ m$

$r_3 = 2.0\ m - 0.075\ m = 1.925\ m$

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

A paddles at each radius

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

$L/W = 2.0\ m / 0.15\ m = 13.3 \qquad C_D \cong 1.35$

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

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

9.3315

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

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

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

(OK, 0.1-0.25)

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

Paddles are 2.0 m × 0.15 m, 2 units/shaft, 4 arms/wheel, 3 paddles/arm

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

$A_x V_H = Q$

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

$= 0.676$ 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

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

$= 287.5 \text{ m}^3$

$287.5 \text{ m}^3 / 3$ compartments $= 95.8\bar{3} \text{ m}^3$/compartment

$\approx 96 \text{ m}^3$

Let wheel $D = 3.5$ m

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

Max. paddle length $= 3.5$ m

4.5 m ×	4.5 m ×	4.75 m	$= 96.2 \approx 96 \text{ m}^3$ is close
W	L	H	

The above will satisfy clearance requirements

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

$R = 1.75$ m

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

and 1.167 m and 1.75 m to outside edges

$r_1 = 0.583\ m - 0.06\ m = 0.523\ m$
$r_2 = 1.167\ m - 0.06\ m = 1.107\ m$
$r_3 = 1.75\ m - 0.06\ m = 1.690\ m$

A paddle at each radius

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

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

For one basin:

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

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

$$= \left(\frac{(2)(201.2\ W)}{(999.703\ \frac{kg}{m^3})(1.8)(1.68\ m^3)(104.65)[0.143 + 1.357 + 4.827]}\right)^{1/3}$$

6.327

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

Outermost paddle tip speed $= 2\pi r n$
$= 2\pi\,(1.75)(0.0586\ rps)$
$= 0.644\ m/s$ (OK, 0.15–1.0 m/s)

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

Flow through velocity $V_H = 0.15 - 0.45$ m/min is good

$$V_H = \frac{Q}{A_x} = \frac{18{,}000\ m^3/d}{(4.5\,m \times 4.75\,m)} \times \frac{1\ day}{24 \times 60\ min} = 0.584\ m/min$$

too high !

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

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

$= 191.\dot{6} \text{ m}^3$

$191.6 \text{ m}^3 / 3 \text{ compartments} = 63.\dot{8} \text{ m}^3/\text{compartment}$

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

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

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.

$\forall \cong 96 \text{ m}^3$; Try $H = 4.2$ m, $L = 3.6$ m $W = \frac{96 \text{ m}^3}{3.6 \text{ m} \times 4.2} = 6.35$

W = 6.35 m still makes A_x too small so increase W to 6.60 m

$V_H = \frac{Q}{A_x} = \frac{18{,}000 \text{ m}^3/d}{4.2 \text{ m} \times 6.6 \text{ m}} \times \frac{1 \text{ day}}{24 \times 60 \text{ min}} = 0.451 \text{ m/min}$

Will accept!

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

Use paddle wheel D = 3.0 m

R = 1.50 m ; Try 3 paddles/arm ;

Try 2 units / compartment

Wallowance = 1.0 m + 2(0.3 m) = 1.6 m

$W - W_{allowance} = 6.6\,m - 1.6\,m = 5.0\,m$

$5.0\,m / 2 = 2.5\,m$ = length each paddle

Paddle spacing on arm = 1.50/3 = 0.50 m
and 1.0 m and 1.50 to outer edges.

Let paddle = 2.5 m x 0.10 m

$r_1 = 0.45\,m$; $r_2 = 0.95\,m$; $r_3 = 1.45\,m$

8 paddles at each radius

$A = (8)(2.5\,m \times 0.10\,m) = 2\,m^2$

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

$L/w = 2.5/0.10 = 25$ Let $C_D = 1.70$

For 1 basin:

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

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

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

3.9971

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

Outermost paddle tip speed $= 2\pi r n$
$= 2\pi (1.5\,m)(0.06646\,rps)$
$= 0.626\,m/s$ (OK 0.15–1.0 m/s)

Final Design:

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

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

$n = 0.06646\ rps = 3.99\ rpm$

Each paddle: $2.5\ m \times 0.10\ m$

Motor power calculation:

Power needed, $P = 208.7\ W$

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

Providing a safety factor $P = (260.9\ W)(1.5)$

$\approx \underline{391\ W}$

This is power for each motor