Flocculator Model - Miramar WTP

Density and Viscosity Functions

$$\mu_{H2O}(T) := 2.414 \cdot 10^{-5} Pa \cdot s \cdot 10^{\frac{247.8 \cdot K}{T - 140K}}$$

$$WaterDensityTable = \begin{pmatrix} 0 & 999.9 \\ 5 & 1000 \\ 10 & 999.7 \\ 20 & 998.2 \\ 30 & 995.7 \\ 40 & 992.2 \\ 50 & 988.1 \\ 60 & 983.2 \\ 70 & 977.8 \\ 80 & 971.8 \\ 90 & 965.3 \\ 100 & 958.4 \end{pmatrix}$$

$$cubicspline(xarray, yarray, x) := interp(cspline(xarray, yarray), xarray, yarray, x)$$

$$\rho_{H2O}(T) := cubicspline\left(WaterDensityTable^{\langle 0 \rangle}, WaterDensityTable^{\langle 1 \rangle} \cdot \frac{kg}{m^3}, \frac{T}{K} - 273.15\right)$$

$$\nu_{H2O}(T) := \frac{\mu_{H2O}(T)}{\rho_{H2O}(T)}$$

Average Shear and Energy Dissipation Rate

$$\boxed{T_{design} := \begin{pmatrix} 15\,°C \\ 25\,°C \end{pmatrix}}$$

$$\boxed{G_{Floc} := \frac{50}{s}}$$ range of 20-70/s

$$\boxed{\theta_{Floc} := 30min}$$

$$G\theta_{Floc} := G_{Floc} \cdot \theta_{Floc}$$ $$G\theta_{Floc} = 90000$$

$$\varepsilon_{Floc.Avg} := G_{Floc}^{\ 2} \cdot \nu_{H2O}(T_{design})$$ $$\varepsilon_{Floc.Avg} = \begin{pmatrix} 2.8 \\ 2.2 \end{pmatrix} \cdot \frac{mW}{kg}$$

Motor Power

$\boxed{Q_{Basin56} := 110\text{mgd}}$

$$P_{FlocShaft}(T) := G_{Floc} \cdot Q_{Basin56} \cdot G\theta_{Floc} \cdot \overrightarrow{\left(\nu_{H2O}(T) \cdot \rho_{H2O}(T)\right)}$$

$$P_{FlocShaft}\left(T_{design}\right) = \begin{pmatrix} 24.6 \\ 19.3 \end{pmatrix} \cdot \text{kW}$$

The actual power of the motors in basin 5,6 is

$$hp_{Basin56} := (2 \cdot 7.5\text{hp} + 4 \cdot 5\text{hp}) \cdot 2 = 52 \cdot \text{kW}$$

Each basin has the same line of 6 stages and 6 motors

The design apparently assumed that only the first stage would be at 70/s

Maximum Energy Dissipation Rate at Propeller Tip

$\boxed{N_{Paddle} := 3.5 \cdot \frac{1}{\text{min}}}$ $\boxed{D_{Paddle} := 12\text{ft}}$ $\boxed{H_{Propeller} := 1.12\text{ft}}$

Paddle speed (measured); paddle wheel diameter and paddle board height (scaled from record dwgs)

Plate ratio (from CFD data for baffled flocculators):

$H_{Plate} := 100\text{cm}$ $V_{Plate} := 1\frac{\text{m}}{\text{s}}$ $\varepsilon_{PlateMax} := 0.043\frac{\text{W}}{\text{kg}}$

$$\Pi_{Plate} := \frac{H_{Plate}^{\frac{1}{3}} \cdot \varepsilon_{PlateMax}^{\frac{1}{3}}}{V_{Plate}} = 0.4$$

$$V_{Propeller} := \pi \cdot D_{Paddle} \cdot N_{Paddle}$$

$$V_{Propeller} = 2.2 \cdot \frac{\text{ft}}{\text{s}}$$

$$\varepsilon_{PropellerTip} := \frac{\left(\Pi_{Plate} \cdot V_{Propeller}\right)^3}{H_{Propeller}} = 38 \cdot \frac{\text{mW}}{\text{kg}}$$

$$\varepsilon_{PropellerTip} = 37.9 \cdot \frac{\text{mW}}{\text{kg}}$$

$$G_{PropellerTip} := \sqrt{\frac{\varepsilon_{PropellerTip}}{\nu_{H2O}\left(T_{design_1}\right)}} = 206.1\,\text{s}^{-1}$$

$$G_{PropellerTip} = 206.1\,\text{s}^{-1}$$

$$\alpha_{\varepsilon} := \frac{\varepsilon_{PropellerTip}}{\varepsilon_{Floc.Avg}}$$

$$\alpha_{\varepsilon} = \begin{pmatrix} 13 \\ 17 \end{pmatrix}$$

Pilot System Flocculator Configuration

$\boxed{D_{Paddle.Pilot} := 19.3in}$ $\boxed{H_{Paddle.Pilot} := 4in}$ Paddle dimensions

$$A_{Paddle.Pilot} := D_{Paddle.Pilot} \cdot H_{Paddle.Pilot} = 77.2 \cdot in^2$$

$\boxed{W_{Pilot} := 22.5in}$ $\boxed{L_{Pilot} := 22.5in}$ Length and width of each floc basin

$\boxed{Vol_{Pilot} := 60.9gal}$ Water volume and depth

$$HW_{Pilot} := \frac{Vol_{Pilot}}{W_{Pilot} \cdot L_{Pilot}} = 27.8 \cdot in$$

$\boxed{C_D := 1.8}$ Appoximate drag coefficient.
(*Mixing in Coag. and Floc.* p. 412)

Calculated Pilot Speed to Match Maximum Energy Dissipation Rate

$$\varepsilon_{FlocJarTip} = \frac{\left(\Pi_{Plate} \cdot V_{Tip.Pilot}\right)^3}{H_{Paddle.Pilot}} = \frac{\left[\Pi_{Plate} \cdot \left(\pi \cdot D_{Paddle.Pilot} \cdot N_{Floc.Pilot}\right)\right]^3}{H_{Paddle.Pilot}}$$

If we solve for an rpm that matches the energy dissipation rate of the full scale flocculator we get:

$$N_{Floc.Pilot.Scaled} := \frac{H_{Paddle.Pilot}^{\frac{1}{3}} \cdot \varepsilon_{PropellerTip}^{\frac{1}{3}}}{\pi \cdot D_{Paddle.Pilot} \cdot \Pi_{Plate}}$$

$$N_{Floc.Pilot.Scaled} = 17.4 \cdot \frac{1}{min}$$

$$\varepsilon_{Floc.Pilot.Scaled} := \frac{C_D \cdot A_{Paddle.Pilot}}{Vol_{Pilot}} \cdot \frac{\left(\frac{\pi}{2} \cdot D_{Paddle.Pilot} \cdot N_{Floc.Pilot.Scaled}\right)^3}{2} = 2.2 \cdot \frac{mW}{kg}$$

Average Pilot Test Energy Dissipation Rate

$\boxed{N_{Floc.Pilot} := 17.5 \frac{1}{min}}$ Pilot apparatus speed setting

$$V_{Tip.Pilot} := \pi \cdot D_{Paddle.Pilot} \cdot N_{Floc.Pilot} = 1.5 \cdot \frac{ft}{s}$$

$$V_{Avg.Pilot} := \left(\frac{\pi}{2} \cdot D_{Paddle.Pilot} \cdot N_{Floc.Pilot}\right) = 0.7 \cdot \frac{ft}{s}$$

For a single continuous paddle, the average velocity along the paddle is half the tip velocity.

$$\varepsilon_{Floc.Pilot.Tip} := \frac{\left(\Pi_{Plate} \cdot V_{Tip.Pilot}\right)^3}{H_{Paddle.Pilot}}$$

$$\varepsilon_{Floc.Pilot.Tip} = 38.4 \cdot \frac{mW}{kg}$$

Estimate power based on Reynolds and Richards (1996) eq. 8.16 or *Mixing in Coag. and Floc.* (1991) eq. 11-29.

$$P_{Floc.Pilot} := C_D \cdot A_{Paddle.Pilot} \cdot \rho_{H2O}\left(T_{design_1}\right) \cdot \frac{\left(\frac{\pi}{2} \cdot D_{Paddle.Pilot} \cdot N_{Floc.Pilot}\right)^3}{2} = 506.3 \cdot mW$$

$$\varepsilon_{Floc.Pilot.Avg} := \frac{P_{Floc.Pilot}}{Vol_{Pilot} \cdot \rho_{H2O}\left(T_{design_1}\right)}$$

$$\varepsilon_{Floc.Pilot.Avg} = 2.2 \cdot \frac{mW}{kg}$$

$$\alpha_{Floc.Pilot} := \frac{\varepsilon_{Floc.Pilot.Tip}}{\varepsilon_{Floc.Pilot.Avg}}$$

$$\alpha_{Floc.Pilot} = 17.4$$

Pilot Test Average Shear and Gθ

$$\boxed{Q_{Pilot} := 2gpm}$$

Pilot system flow rate

$$\boxed{N_{Basins.Pilot} := 3} \qquad \boxed{N_{Basins.Pilot.Online} := 1}$$

Number of floc basins in the pilot system.

$$\theta_{Pilot} := \frac{N_{Basins.Pilot.Online} \cdot Vol_{Pilot}}{Q_{Pilot}}$$

$$\theta_{Pilot} = 30.5\,min$$

$$G_{Floc.Pilot} := \sqrt{\frac{\varepsilon_{Floc.Pilot.Avg}}{\nu_{H2O}\left(T_{design_1}\right)}}$$

$$G_{Floc.Pilot} = 49.7\,s^{-1}$$

$$G\theta_{Floc.Pilot} := G_{Floc.Pilot} \cdot \theta_{Pilot}$$

$$G\theta_{Floc.Pilot} = 90740$$