Multi-level Water Storage System

Calculating the efficiency of the model

Firstly, let us calculate the total energy consumed using **the Multi-level Water Storage Method.**

Let us consider water before and after being pumped up to a certain height z.

For a given pump of specified dimensions, let N_c be the coupling power, N_c the hydraulic power and ϑ be the overall efficiency.

$$\vartheta = \frac{N}{N_c}$$

$$N = \dot{m}W_{sp}$$

$$W_{sp} = g * H_{total}$$

where W_{sp} denotes the specific work done, $\dot{m}$ is the mass flow-rate and H the corresponding head.

$$H_{total} = H_{static} + H_{friction} + H_{other}$$

$$H_{friction} = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

where f is Darcy friction factor, L is the length of the pump, D is the diameter and v is the average velocity of the water.

$$H_{static} = \Delta(enthalpy) + \Delta z$$

where $\Delta(z)$ is the change in height (potential head). We assume that the change in enthalpy of water is negligible (zero reaction power).

$$H_{total} = \Delta z + f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right) + k_f\left(\frac{v^2}{2g}\right)$$

Using the above equations and ignoring H_{other} as it is lesser in values than the others, we get

$$N_c = \left(\frac{Q\rho g}{\vartheta}\right)\left(\Delta z + f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)\right)$$

where Q is the volumetric flow-rate and ρ is the density of the liquid flowing. **Assumption:** Q is held constant while Power is varied.

We can also observe that taking minor losses into considerations doesn't affect the energy consumption in our systems at all, and they get cancelled out in the process.

Tank for the $\boldsymbol{i^{th}}$ floor is located on the $\boldsymbol{(i+1)^{th}}$ floor. Let be the h height of each floor and N_{Ci} denote the power required to pump the liquid to the floor.

$$N_{Ci} = \left(\frac{Q\rho g}{\vartheta}\right)\left((i+1)h + \left(\frac{f}{D}\right)\left(\frac{(i+1)h}{2g}\right)\left(\frac{Q^2}{A^2}\right)\right)$$

$$N_{Ci} = \left(\frac{Q\rho g}{\vartheta}\right)\left(1 + \left(\frac{f}{D}\right)\left(\frac{1}{2g}\right)\left(\frac{Q^2}{A^2}\right)\right)(i+1)h$$

Let E_i be the energy consumed to pump the liquid to the i^{th} floor, V_i is the volume of water required and t_i is the time taken to fill the tank

$$E_i = N_{Ci} \times t_i$$

$$t_i = \frac{V_i}{Q}$$

$$E_{ci} = \left(\frac{\rho g}{\vartheta}\right)\left(1 + \left(\frac{f}{D}\right)\left(\frac{1}{2g}\right)\left(\frac{Q^2}{A^2}\right)\right)(i+1)hV_i$$

$$E_{ci} = k(i+1)hV_i$$

Assuming the requirement is the same for all the floors, we get

$$E_{total} = \sum_{i=0}^{N} k(i+1)hV$$

$$E_{total} = (khV)\left(\frac{(N+1)(N+2)}{2}\right)$$

Now, considering the energy requirements in the conventional method of pumping all the water to the overhead tank,

$$N_{CN} = \left(\frac{Q\rho g}{\vartheta}\right)\left(1 + \left(\frac{f}{D}\right)\left(\frac{1}{2g}\right)\left(\frac{Q^2}{A^2}\right)\right)(N+1)h$$

$$E_N = N_{CN} \times t_N$$

$$t_N = \frac{V_N}{Q}$$

$$V_N = (N+1)\,V$$

$$E_N = (khV)(N+1)^2$$

Calculating percentage energy saved:

$$\Delta E = E_N - E_{total}$$

$$\Delta E = (khV)\left(\frac{N(N+1)}{2}\right)$$

$$\boldsymbol{\frac{\Delta E}{E_N} = \frac{N}{2(N+1)}}$$

For our given case of $N = 5$,

$$\frac{\Delta E}{E_N} = 0.416$$

We can calculate the percentage of energy saved to be equal to 41.6%.

Even taking into minor losses, we can observe that $\boldsymbol{\Delta E}$ remains the same as the minor losses cancel out.