Problem of the Day

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In their quest to be energy neutral, the operations team at the Green Meadows Resource Recovery Facility is evaluating a hydroelectric station on the effluent pipe line. Over the last twelve months the flow at the plant averaged 7.8 MGD. There is a 32-ft drop from the chlorine contact chamber to the river when the river is at its highest elevation that is usable for power generation. For purposes of the evaluation, the team is assuming the overall efficiency of the power generation equipment is 80% with 2.5 feet of head loss due to friction. Calculate how many kWh the system would produce per day.

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Introduction

Hydroelectric power generation is essentially the opposite of a pumping system. Instead of doing work lifting the water from point A to point B, water does work when it falls from point B to point A. If I could flip our pump graphic upside down, the discharge piping would become what is known as the penstock which delivers the water to the power generating equipment. The pump in our graphic would be some device that converts the falling water to mechanical energy. Lester Allan Pelton invented the Pelton wheel in the 1870s for this purpose and it is still widely used today. The motor in our graphic would be the generator that converts the mechanical energy to electrical energy. Instead of indicating how much energy (kWh) we're using to pump water, the meter in our graphic would indicate how much energy we're producing. As we all know, water to our plants flows 24/7, so the hydroelectric station would be online 24 h/d. The one super big difference in the two systems (pumping versus power generation) is that moving from right to left in our graphic we'll multiply, rather than divide, by the overall efficiency.

We're still going to use the two conversion factors we've been using. The first is used to convert ft·lb/min to HP and vice versa, and the second is used to convert HP to kW and vice versa.

$$\frac{33{,}000\ \text{ft·lb}}{\text{min·HP}} \quad \text{or} \quad \frac{\text{min·HP}}{33{,}000\ \text{ft·lb}}$$

and

$$\frac{0.746\ \text{kW}}{\text{HP}} \quad \text{or} \quad \frac{\text{HP}}{0.746\ \text{kW}}$$

Solution

Here is the list of information given in the problem:

1. Overall efficiency = 80% = 0.8
2. Elevation change = 32 ft
3. Friction head = 2.5 ft
4. Available head = (32 − 2.5) = 29.5 ft
5. Effluent flow = 7.8 Mgal/d
6. Density of effluent = 8.34 lb/gal (assumed since not given)

As in pumping problems, we will calculate the power delivered by the falling water (flow × available head), adjust it because the energy conversion is not 100% efficient, multiply by the number of "connected" hours per day, and convert it to the units wanted, kWh/d. These units are put between heavy vertical lines, as always, followed by an equals sign and the blank solution bridge.

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$$\left|\frac{\textbf{kWh}}{\textbf{d}}\right| = \underline{\hspace{10cm}}$$

So this is a totally different kind of problem than we're used to and, likely, will never be asked on a certification exam. Because it is so different, I'm just going to let the units do the work for me. Nowhere in our list do we have the units kW, so I'm going to start the solution bridge with one of the conversion factors given above to get these units needed in the answer on the solution bridge as shown in bold.

$$\frac{\mathbf{kW}\text{h}}{\text{d}} = \frac{0.746\ \mathbf{kW}}{\text{HP}}$$

Now I need h/d on the solution bridge. Knowing that the hydroelectric plant will produce power 24 h/d, this is the next entry on the solution bridge.

$$\frac{\mathbf{kWh}}{\mathbf{d}} = \frac{0.746\ \mathbf{kW}}{\text{HP}} \cdot \frac{24\ \mathbf{h}}{\mathbf{d}}$$

All the units needed in the answer are now on the solution bridge so we proceed by canceling unwanted units until they're all gone. The only units now on the solution bridge needing cancelation are HP. Again, nothing in our list has these units so we enter yet another conversion factor, canceling like units in the denominator and numerator.

$$\frac{\mathbf{kWh}}{\mathbf{d}} = \frac{0.746\ \mathbf{kW}}{\cancel{\text{HP}}} \cdot \frac{24\ \mathbf{h}}{\mathbf{d}} \cdot \frac{\text{min}\cdot\cancel{\text{HP}}}{33{,}000\ \text{ft}\cdot\text{lb}}$$

To cancel ft in the denominator, the available head (No. 4) is entered next in the numerator.

$$\frac{\mathbf{kWh}}{\mathbf{d}} = \frac{0.746\ \mathbf{kW}}{\cancel{\text{HP}}} \cdot \frac{24\ \mathbf{h}}{\mathbf{d}} \cdot \frac{\text{min}\cdot\cancel{\text{HP}}}{33{,}000\ \cancel{\text{ft}}\cdot\text{lb}} \cdot \frac{29.5\ \cancel{\text{ft}}}{}$$

To cancel lb in the denominator, the density of water (effluent, No. 6) is entered next with 8.34 lb in the numerator.

$$\frac{\mathbf{kWh}}{\mathbf{d}} = \frac{0.746\ \mathbf{kW}}{\cancel{\text{HP}}} \cdot \frac{24\ \mathbf{h}}{\mathbf{d}} \cdot \frac{\text{min}\cdot\cancel{\text{HP}}}{33{,}000\ \cancel{\text{ft}}\cdot\cancel{\text{lb}}} \cdot \frac{29.5\ \cancel{\text{ft}}}{} \cdot \frac{8.34\ \cancel{\text{lb}}}{\text{gal}}$$

There is nothing in the list that has units of gal, but there is Mgal. Another conversion factor is entered (one of my favorites).

$$\frac{\mathbf{kWh}}{\mathbf{d}} = \frac{0.746\ \mathbf{kW}}{\cancel{\text{HP}}} \cdot \frac{24\ \mathbf{h}}{\mathbf{d}} \cdot \frac{\text{min}\cdot\cancel{\text{HP}}}{33{,}000\ \cancel{\text{ft}}\cdot\cancel{\text{lb}}} \cdot \frac{29.5\ \cancel{\text{ft}}}{} \cdot \frac{8.34\ \cancel{\text{lb}}}{\cancel{\text{gal}}} \cdot \frac{10^6\ \cancel{\text{gal}}}{\text{Mgal}}$$

Now the flow (No. 5) can be entered to cancel Mgal.

$$\frac{\mathbf{kWh}}{\mathbf{d}} = \frac{0.746\ \mathbf{kW}}{\cancel{\text{HP}}} \cdot \frac{24\ \mathbf{h}}{\mathbf{d}} \cdot \frac{\text{min}\cdot\cancel{\text{HP}}}{33{,}000\ \cancel{\text{ft}}\cdot\cancel{\text{lb}}} \cdot \frac{29.5\ \cancel{\text{ft}}}{} \cdot \frac{8.34\ \cancel{\text{lb}}}{\cancel{\text{gal}}} \cdot \frac{10^6\ \cancel{\text{gal}}}{\cancel{\text{Mgal}}} \cdot \frac{7.8\ \cancel{\text{Mgal}}}{\text{d}}$$

The units min and d are canceled with yet another conversion factor.

kWh	=	0.746 **kW**	24 **h**	~~min·HP~~	29.5 ~~ft~~	8.34 ~~lb~~	10^6 ~~gal~~	7.8 ~~Mgal~~	~~d~~	
d		~~HP~~	**d**	33,000 ~~ft·lb~~		~~gal~~	~~Mgal~~	~~d~~	1,440 ~~min~~	

While all the units have canceled except those needed in the answer, we’re not done. We have to account for the fact that the conversion of the falling water to electrical energy is not 100% efficient. Here is where we have to multiply by the overall efficiency being assumed by the operations team (No. 1).

kWh	=	0.746 **kW**	24 **h**	~~min·HP~~	29.5 ~~ft~~	8.34 ~~lb~~	10^6 ~~gal~~	7.8 ~~Mgal~~	~~d~~	0.8
d		~~HP~~	**d**	33,000 ~~ft·lb~~		~~gal~~	~~Mgal~~	~~d~~	1,440 ~~min~~	

Since all the units have now canceled except those needed in the answer, **kWh/d**, and we’ve accounted for the efficiency of the system, we know the solution bridge is complete. The arithmetic gives the answer.

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kWh	=	0.746 **kW**	24 **h**	~~min·HP~~	29.5 ~~ft~~	8.34 ~~lb~~	10^6 ~~gal~~	7.8 ~~Mgal~~	~~d~~	0.8
d		~~HP~~	**d**	33,000 ~~ft·lb~~		~~gal~~	~~Mgal~~	~~d~~	1,440 ~~min~~	

$0.746 \times 24 \times 29.5 \times 8.34 \times 1{,}000{,}000 \times 7.8 \times 0.8 \div 33{,}000 \div 1{,}440 =$ **578 kWh/d**.

Discussion

There is much to consider before constructing a hydroelectric facility as described, but if the cost of electricity usage averages $0.075/kWh, this amounts to $15,823/year. Not huge but in our operator quest to be as sustainable and cost effective as possible, every little bit helps.

Happy calculating! Let us know, by leaving a comment, if you want us to do a specific problem, if you see a mistake, or if you have a question on any of the Problems of the Day you are looking at.