Problem of the Day

2014.Nov.16

Introduction

The Water Environment Federation is the trade organization for water professionals, including wastewater treatment operations professionals (http://wefcom.wef.org/home). Individual states, or groups of states, sponsor local chapters. On October 29, 2014, I gave a 6-hour Math for Operators Workshop at the annual conference of the Pacific Northwest Clean Water Association (PNCWA). PNCWA represents Idaho, Oregon and Washington (http://www.pncwa.org/). All operators should seriously consider joining their local association. In California it is the California Water Environment Association (http://www.cwea.org/).

Long story short: I randomly covered a series of math problems in the PNCWA workshop, and I have been requested by several attendees to send them the problems. Instead, I am going to post them here (starting with the 2014.Nov.04 Problem of the Day). They are good practice for all visitors to WWTT's Problem of the Day.

For those of you who may be new to WWTT's Problem of the Day, we insert a page break before and after the problem statement so you can print it without looking at the solution. **See what you can do to solve the problem before looking at the solution**.

We are continuing today and focusing on pumping problems. I remember when I was studying for my Colorado Wastewater Treatment Plant Operator Certification exams and **hating** pumping problems. They are really not that bad, especially if you set them up the same way every single time, as WWTT suggests. **And**, if you remember two important conversion factors.

Most, but not all, of these problems start with calculating the water power by multiplying the flow rate of the pump by the total dynamic head. In many instances, the ultimate calculation that is required is the cost of running the pump. Therefore, the water power has to first be divided by the pump efficiency, expressed as a decimal, to get the brake power. The brake power is then divided by the motor efficiency, expressed as a decimal, to get the motor power which is what is passing through the electric meter. The usage charge is determined by the local power company by multiplying the motor power by the number of hours per billing cycle that the motor/pump is running. Today's, like yesterday's, Problem of the Day demonstrates. Today's problem, however, looks at the cost of electricity to operate a pump over 40 years, a calculation one might do when conducting a **business case evaluation**.

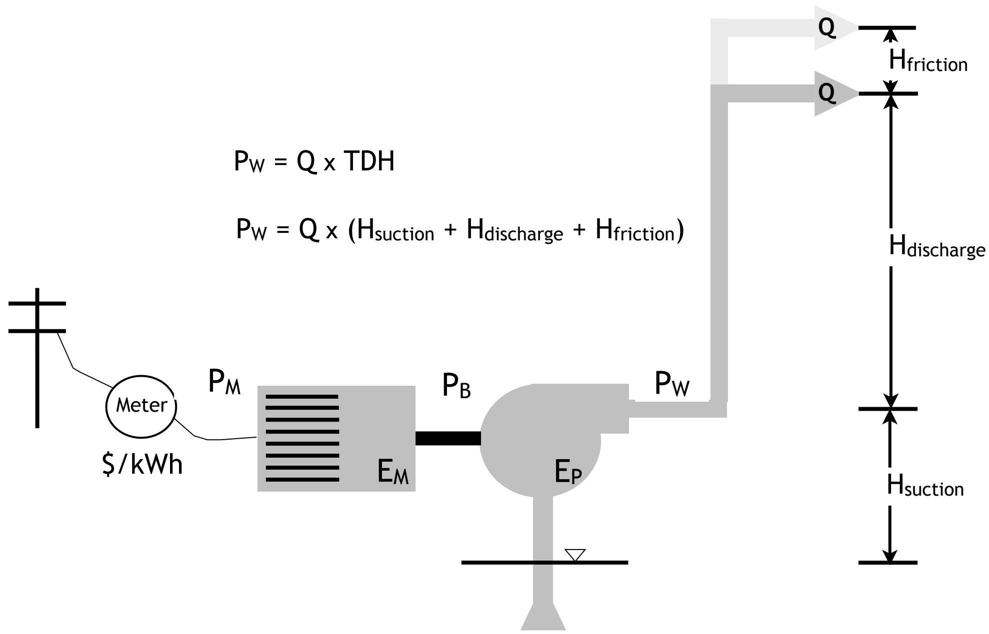
Problem of the Day

Given a proposed primary effluent pumping station (PEPS) and the following information, calculate the cost of electricity to run the pump for 40 years.

- Pumped flow, average = 181 MGD
- Total dynamic head = 10 feet
- Pump efficiency = 86%
- Motor efficiency = 94%
- Pump operation, continuous = 24 hours/day
- Cost of electricity = $0.0725/kWh
- **Calculate: cost of electricity over 40 years**.

Solution

WWTT puts **every** pumping problem in terms of the following graphic:



*Generic graphic for all pumping problems. From left to right: telephone pole, electric meter, motor (complete with air-cooling fins), pump, pump suction (negative suction shown), and pump discharge. Abbreviations: kWh = kilowatt hours (**kilowatts times hours NEVER kilowatts per hour**), P_M = input power to motor, P_B = brake power (output power from motor same as input power to pump), P_W = output power from pump = power delivered to the water), Q = pumping flow rate, $H_{suction}$ = suction head, $H_{discharge}$ = discharge head, $H_{friction}$ = friction head, and TDH = total dynamic head = $H_{suction}$ + $H_{discharge}$ + $H_{friction}$.*

This schematic shows a typical pumping system. Definitions of terms and need-to-know information are as follows [**note: power can be expressed in either horsepower (HP) or kilowatts (kW)**]:

- **Motor power** (P_M) is the **input** power to the motor. The electric meter (Meter) records the connected power and the duration that power is consumed (power times time = energy). When calculating electrical cost, the motor power is always expressed in kW which is then multiplied by the number of connected hours over a billing cycle. Electrical usage is determined by the amount of kWh used.
- **Brake power** (P_B) is the **output** power of the motor, which is the same as the **input** power to the pump.
- **Water power** (P_W) is the **output** power of the pump and is equal to the amount of power actually delivered to the water.
- The water power, P_W, is determined by multiplying the flow rate of the pump discharge (Q) by the **total dynamic head** (TDH) which is the sum of the suction head ($H_{suction}$), the discharge head ($H_{discharge}$), and, when provided, the friction head ($H_{friction}$).
- The efficiency of all mechanical equipment is calculated by dividing the output power by the input power; efficiency is often expressed as a percentage. **Motor efficiency** (E_M) is calculated by dividing brake power (P_B) by motor power (P_M) and multiplying by 100.
- **Pump efficiency** (E_P) is calculated by dividing water power (P_W) by brake power (P_B) and multiplying by 100.

The equation given in the graphic for calculating the water power (P_W) is very straightforward and is used over and over again (for example, in today's Problem of the Day):

$$P_W = Q \times TDH$$

While ft·lb/min are units of power, in water and wastewater problems power is expressed in either **HP** or **kW**; the two are **interchangeable** because they are **both units of power**. The two most important conversion factors for doing these problems are (WWTT suggests you memorize these):

$$\frac{33{,}000\ \text{ft}\cdot\text{lb}}{\text{min}\cdot\text{HP}}$$

and

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

All of us tied to the electrical grid pay the local power company by how many kilowatt·hours we use over a billing period. This is the **usage fee** paid to the power company and is **different from the demand charge** that WWTPs and other large users of electricity pay power companies (the demand charge is **not** part of today's Problem of the Day). Electricity is typically the second greatest cost (after labor) for WWTPs, so **it's a really big deal**. Because our ratepayers pay for the construction and operation of our WWTPs—yes, the ones that give us our paychecks—cost containment should be on every operator's mind. I am reminded here of the Mission Statement of Cascade Energy (https://cascadeenergy.com/): **make energy conservation happen**. This should be the mindset of all water and wastewater operators.

We are going to calculate the electricity cost over 40 years so we need to take into account leap years. Instead of adding one day to the calendar every four years, we will add a quarter of a day (0.25) to every year and use the following conversion factor:

$$\frac{365.25\ \text{d}}{\text{yr}}$$

Problem of the Day. Given a proposed primary effluent pumping station (PEPS) and the following information, calculate the cost of electricity to run the pump for 40 years.

- Pumped flow, average = 181 MGD
- Total dynamic head = 10 feet
- Pump efficiency = 86% = 0.86
- Motor efficiency = 94% = 0.94
- Pump operation, continuous = 24 h/d, 365.25 d/yr
- Cost of electricity = $0.0725/kWh
- **Calculate: cost of electricity over 40 years.**

First calculate P_W = Q x TDH and express in kW:

P_W, kW	=	181 ~~Mgal~~	10 ~~ft~~	~~min·HP~~	10^6 ~~gal~~	8.34 ~~lb~~	~~d~~	0.746 **kW**
		~~d~~		33,000 ~~ft·lb~~	~~Mgal~~	~~gal~~	1,440 ~~min~~	~~HP~~

All units have canceled except **kW** so the arithmetic gives the interim answer:

P_W = 181 x 10 x 1,000,000 x 8.34 x 0.746 ÷ 33,000 ÷ 1,440 = **237 kW**.

To calculate **P_B**, **P_W is divided by the pump efficiency expressed as a decimal**:

P_B, kW	=	237 **kW**	
			0.86

P_B = 237 ÷ 0.86 = **276 kW**.

To calculate **P_M**, **P_B is divided by the motor efficiency expressed as a decimal**:

P_M, kW	=	276 **kW**	
			0.94

P_M = 276 ÷ 0.94 = **294 kW**.

Now that the meter power, P_M, is known, the cost of the electricity, $, over 40 years is calculated. Let the units tell you what to do. Start with the units you want ($) between heavy vertical lines on the left-hand side of the equals sign, and then start the railroad track with the units you need in the answer. Here, there is only one other place that $ shows up: the cost of electricity: $0.0725/kWh.

$	=	$0.0725	24 ~~h~~	365.25 ~~d~~	40 ~~yr~~	294 ~~kW~~
		~~kWh~~	~~d~~	~~yr~~		

Only the dollar sign, $, remains on the right-hand side of the equals sign, so the math is done. The arithmetic completes the calculation:

0.0725 x 24 x 365.25 x 40 x 294 = **<u>$7,480,000</u>** (rounded).

Pretty amazing! This is a low-head but high volume pumping example. Still, over 40 years, electricity alone is going to cost $7.5M! And this was assuming there would be no change in the price of electricity over those 40 years. What's the chance of that happening? Yeah, right.

Happy calculating!

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