Problem of the Day

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A flow of 1,500 gpm is pumped against a total head of 95 feet. The pump is 84% efficient and the motor is 92% efficient. Calculate the motor input power in kilowatts.

18030 Brookhurst Street, PMB 573 · Fountain Valley, California 92708 · 866-773-WWTT
www.wastewatertechnologytrainers.com

Introduction

Pumping is a major expense at wastewater treatment plants, so operators need to know how to calculate what it costs to operate pumps. While not specifically asking to calculate cost, today's problem is a precursor to a cost calculation since the power utility charges wastewater treatment plants based on the amount of power delivered to the motor, not the pump or the water, and how much of the time that power is being used.

The amount of power the pump delivers to the water, the water power (P_W), moving it up from point A to point B is a very simple equation:

$$P_W = Q \times TDH$$

where Q is the flow rate of the pump and TDH is the total dynamic head against which the pump is pumping. While this equation is simple enough, what tends to trip operators up is the unit conversions that are needed to express P_W in meaningful units, either horsepower (HP) or kilowatts (kW). TDH will almost always be in units of feet but, as operators well know, Q can be in many different units; for example ft^3/s, gal/min, gal/hr, gal/d or Mgal/d. There is a version of this equation that many operators are taught that has the number 3,960 in it. WWTT doesn't advocate the use of the "3,960-equation" because, in order to use it, Q **must** be in units of gal/min and TDH **must** be in units of ft. If you forget to put Q in units of gal/min and use that equation, you will get the wrong answer.

"Power" to me brings to mind going to the gym to work out. In fact, power is defined as "work per unit time," where "work" is strictly defined as well. So when I go to the gym I don't lift gallons, I lift pounds; I don't work out with gallon weights, I work out with pound weights. For this reason, WWTT uses the equation above with this conversion factor:

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

We will see the use of this demonstrated below.

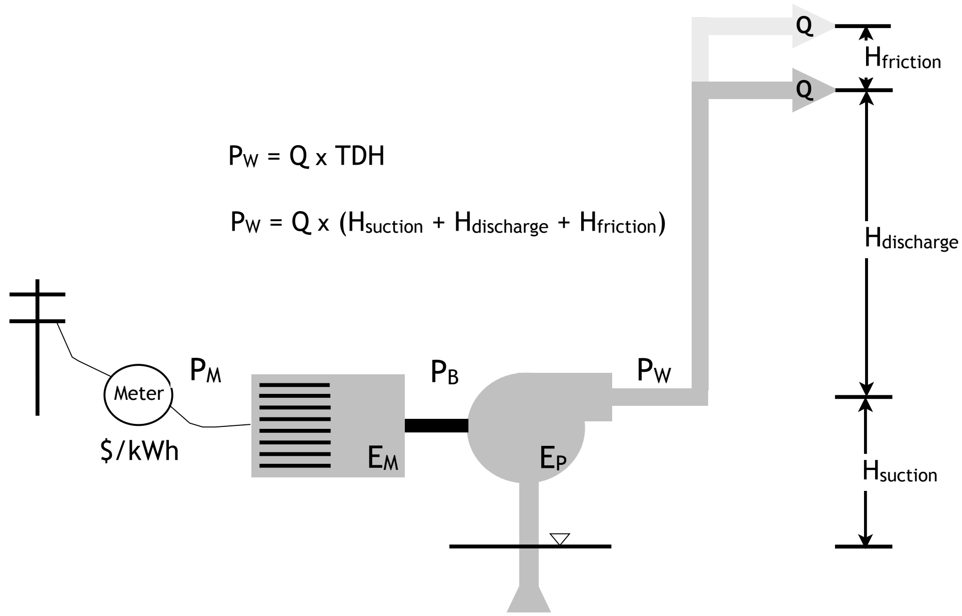
Horsepower (HP) and kilowatts (kW) are both units of power. All operators should master converting HP to kW and kW to HP. The conversion factor to use is:

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

This conversion is important because electric use meters are always in kWh. That's kilowatts times hours **not** kilowatts per hour. All operators need to keep this straight. Note also that power times time, like kWh, is a unit of energy. To repeat: kW (and HP) is a unit of power and kWh is a unit of energy. Power and energy are different.

Finally, the graphic on the next page shows the figure WWTT always uses when doing pumping problems. Yes, it starts with a telephone pole on the far left. If you get in the habit of drawing this picture the same way for all pumping problems, the problems will make a lot more sense and cause a lot less angst.

A few things to note about the graphic and pumping problems. The total dynamic head (TDH) is, strictly speaking, the sum of the suction, discharge and friction heads. The friction head is frequently not given so the TDH has to be assumed equal to the suction and discharge heads, which is also known as the static head. Also, there are many instances in wastewater collection and treatment systems where the suction head is positive, meaning the water surface elevation of the reservoir on the suction side of the pump (e.g., a wet well) is above the pump. However, the graphic shown is the way many certification exam questions are structured. Finally, the efficiencies of the motor and pump are best expressed as decimals. To calculate brake power (P_B), water power (P_W) is divided by the decimal pump efficiency (E_P). To calculate motor power (P_M), brake power (P_B) is divided by the decimal motor efficiency (E_M) **or** the water power (P_W) is divided by the decimal pump efficiency (E_P) and the decimal motor efficiency (E_M).



Pumping schematic (P_M = motor power; P_B = brake power; P_W = water power; E_M = motor efficiency; E_P = pump efficiency; $H_{suction}$ = suction head; $H_{discharge}$ = discharge head; $H_{friction}$ = friction head; Q = pump flow rate and TDH = total dynamic head).

Solution

The question asks for the motor power (P_M) in kW so these units are entered between heavy vertical lines, an equals sign and the equation, and another equals sign and the blank solution bridge.

Problem of the Day: A flow of 1,500 gpm is pumped against a total head of 95 feet. The pump is 84% efficient and the motor is 92% efficient. Calculate the motor input power in kilowatts.

P_M, kW	=	Q x TDH	=							
		E_P x E_M								

When given flow and head in a pumping problem, you know you will be calculating the water power. Again, this is always Q x TDH, so this is how the solution bridge is started.

P_M, kW	=	Q x TDH	=	1,500 gal	95 ft					
		E_P x E_M		min						

Don't worry about the units, just enter Q and TDH as given in the problem. As stated above, TDH will almost always be in ft. To understand what conversions are needed, the next entry on the solution bridge is always 33,000 ft·lb/min·HP entered so that ft cancel in the numerator and denominator as shown. Note, also, in this particular case, that min cancel in the numerator and denominator.

P_M, kW	=	Q x TDH	=	1,500 gal	95 ~~ft~~	~~min~~·HP				
		E_P x E_M		~~min~~		33,000 ~~ft~~·lb				

The density of water is then entered to cancel both gal and lb in the numerator and denominator as shown.

P_M, kW	=	Q x TDH	=	1,500 ~~gal~~	95 ~~ft~~	~~min~~·HP	8.34 ~~lb~~			
		E_P x E_M		~~min~~		33,000 ~~ft·lb~~	~~gal~~			

The factor to convert HP to kW is entered so the unwanted units (HP) cancel in the numerator and denominator.

P_M, kW	=	Q x TDH	=	1,500 ~~gal~~	95 ~~ft~~	~~min·HP~~	8.34 ~~lb~~	0.746 kW		
		E_P x E_M		~~min~~		33,000 ~~ft·lb~~	~~gal~~	~~HP~~		

While all the unwanted units have canceled and the solution bridge has only the units needed in the answer, the decimal efficiencies of the pump and motor need to be entered.

P_M, kW	=	Q x TDH	=	1,500 ~~gal~~	95 ~~ft~~	~~min·HP~~	8.34 ~~lb~~	0.746 kW		
		E_P x E_M		~~min~~		33,000 ~~ft·lb~~	~~gal~~	~~HP~~	0.84	0.92

The solution bridge is now complete and the arithmetic gives the answer:

1,500 x 95 x 8.34 x 0.746 ÷ 33,000 ÷ 0.84 ÷ 0.92 = **34.8 kW**.

Discussion

These problems are very straightforward but seem to always give operators angst. The conversion factor 33,000 ft·lb/min·HP is way outside most operators' comfort zones. I understand that. But if your can memorize and easily use the conversion factor 7.48 gal/ft^3, you can just as easily memorize and get used to using the conversion factor 33,000 ft·lb/min·HP. The sooner you do so, the easier these problems will be! And remember to draw the same picture (on previous page) every time. It really 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.