Problem of the Day

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The operations staff is putting an anaerobic digester back in service after a rehab project. They have filled the 60-ft diameter digester with primary effluent to a depth of 32 ft. The temperature of the digester contents is currently 63°F, which they have to raise to an operating temperature of 98°F before they can start adding raw sludge from the primary clarifiers and digesting sludge from another digester. Calculate how many BTUs are needed to raise the temperature in the digester.

Introduction

As discussed in yesterday's Problem of the Day, it is very energy intensive and, therefore, expensive to heat water. This is why it is so important to maximize the solids concentration, by minimizing the amount of water, in raw and biological sludges to anaerobic digesters, which are typically operated at 98-100°F. In today's Problem of the Day we have to calculate how much energy it will take to heat the water (primary effluent) in an anaerobic digester up to the operating temperature so the digester can be put back in service.

As in yesterday's problem. we need to know what a BTU is: **One BTU is the amount of energy needed to raise one pound of water (1 lb) one degree Fahrenheit (1°F)**. So, the conversion factor used is:

$$\frac{BTU}{lb \cdot °F} \quad \text{or} \quad \frac{lb \cdot °F}{BTU}$$

In order to calculate how many BTUs we need to supply, we need to know how many pounds (lb), not gallons, of water we're heating and how many degrees Fahrenheit (°F) we're raising those pounds.

Solution

The question asks to calculate BTU. These units, as always, are entered between heavy vertical lines followed by an equals sign and the blank solution bridge.

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$$\left| BTU \right| = \_\_\_\_\_$$

I have recently been working with an operator who struggles terribly with "word problems." A lot of people do. He was telling me it's hard for him to even extract the "givens" out of the problem statement. I suggest that you underline each **number**, with units, given in the problem statement. So today's problem would look like this:

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Since these are math problems, the numbers in the problem statement are what are important to us. Although we all know problems sometimes give us numbers we don't need, let's not worry about that now. Each of the numbers has to be described in our list of givens. Here I say describe them anyway you want to but take as much out of the problem statement as you can. This is what I see:

1. Digester diameter = 60 ft
2. Depth of water (primary effluent) in digester = 32 ft
3. Current temperature of digester contents = 63°F
4. Digester operating temperature = 98°F
5. Temperature increase = (98 − 63)°F = 35°F (calculated based on BTU definition)

What I see in this list is a lot of ft and °F. I know that I can calculate the volume in ft^3 given the dimensions of the digester, and I know I can convert ft^3 to gal. Looking at the definition of a BTU, though, I know I need lb of water not gal of water, so I have to add one item to the list:

6. Density of water = 8.34 lb/gal

As we have done many times here, we start the solution bridge with the units needed in the numerator of the answer. Since there is nothing in the list with units of BTU, we start with our BTU conversion factor with BTU in the numerator as shown in bold.

BTU	=	**BTU**	
		lb·°F	

We now have the units in the solution bridge needed in the answer. Proceeding, we cancel unwanted units until only BTU remains. There are two units to be canceled, lb and °F. I'm going to cancel lb with the density of the water, No. 6 in our list.

BTU	=	**BTU**	8.34 ~~lb~~	
		~~lb~~·°F	gal	

Now I want to cancel gal but have none in the list. I see a bunch of ft and °F. I know I can calculate the volume of the digester, but it will be in ft^3. So I enter another conversion factor to cancel the gal.

BTU	=	**BTU**	8.34 ~~lb~~	7.48 ~~gal~~	
		~~lb~~·°F	~~gal~~	ft^3	

The volume of the digester is calculated by multiplying the area of the circle (0.785 × $diameter^2$ or 0.785 × diameter × diameter) by the water depth. The diameter is No. 1 in our list; water depth is No. 2. Notice ft^3 in the denominator. In order to cancel these units, the volume must be entered in the numerator so ft^3 cancels with ft × ft × ft.

BTU	=	**BTU**	8.34 ~~lb~~	7.48 ~~gal~~	0.785	60 ~~ft~~	60 ~~ft~~	32 ~~ft~~
		~~lb~~·°F	~~gal~~	~~ft^3~~				

The only unit remaining, in the denominator, is °F. This is canceled by entering the number of degrees we have to raise the temperature, No. 5 in our list.

BTU	=	**BTU**	8.34 ~~lb~~	7.48 ~~gal~~	0.785	60 ~~ft~~	60 ~~ft~~	32 ~~ft~~	35~~°F~~
		~~lb~~·~~°F~~	~~gal~~	~~ft^3~~					

Because all the units have canceled except those needed in the answer, **BTU**,we know the solution bridge is complete and the arithmetic gives the answer.

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$$\mathbf{BTU} = \frac{\mathbf{BTU}\ \ 8.34\ \cancel{\text{lb}}\ \ 7.48\ \cancel{\text{gal}}\ \ 0.785\ \ 60\ \cancel{\text{ft}}\ \ 60\ \cancel{\text{ft}}\ \ 32\ \cancel{\text{ft}}\ \ 35\ \cancel{^\circ\text{F}}}{\cancel{\text{lb}}\cdot\cancel{^\circ\text{F}}\ \ \cancel{\text{gal}}\ \ \cancel{\text{ft}^3}}$$

8.34 × 7.48 × 0.785 × 60 × 60 × 32 × 35 = **197,450,314 BTU**.

Discussion

As we said, heating water takes a lot of energy. While reading up on BTUs online, several websites made mention of the fact that 1 BTU is approximately equivalent to energy from completely burning a 4-inch, wooden kitchen match. We're talking nearly 200 million kitchen matches to warm the water in that digester!

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.