# Problem of the Day
# 2014.Oct.23

## Discussion

The Problem of the Day of the last two days has looked at calculating and using percent solids recovery (PSR) when dealing with thickening and dewatering process units. Today's Problem of the Day continues that focus.

More to the point, today's problem is yet another example of how powerful the use of units are in solving wastewater treatment math problems; indeed, all kinds of problems. In the certification and math review classes that WWTT does, many operators are reluctant to embrace the use of units because it seems tedious and time consuming. While this is most certainly true when just starting to use "the railroad track," with continuing patience and practice (practice, practice, practice!!!), the use of units will become second nature and, ultimately, proven failsafe and foolproof.

## Problem

Using the railroad track to solve today's problem demonstrates how amazing it is.

**Problem of the Day**: The cake from a dewatering centrifuge is discharged into a 9-$yd^3$ hopper before being emptied into a dump truck. Typically, the centrifuge achieves a percent solids recovery (PSR) of 95.6%. The anaerobically digested sludge, with a TS concentration of 4.5%, is fed to the centrifuge at 145 gpm. The cake discharged from the centrifuge has a TS concentration of 24.5% and a density of 69 $lb/ft^3$. Calculate how long it will take, in hours, to fill the hopper.

## Solution

It is very important to remember and get the hang of how WWTT expresses the PSR if given in a problem. In the current problem, a PSR of 95.6% is given. WWTT express this as:

$$95.6\%\ \text{PSR} = \left| \frac{95.6\ \text{lb TS}_c}{100\ \text{lb TS}_s} \right|$$

where $TS_c$ is the TS in the cake ("c" for "cake") and $TS_s$ is the TS in the sludge ("s" for "sludge") even though the TS in the cake are the same TS in the sludge, only some water has been removed by centrifugation.

Here is what we know from the problem statement, specifically labeled in the manner WWTT recommends:

- Sludge flow = 145 gal sldg/min
- Sludge TS = 4.5% = 4.5 lb $TS_s$/100 lb sldg
- Sludge density = 8.34 lb sldg/gal sldg (assumed since not given)
- PSR = 95.6% = 95.6 lb $TS_c$/100 lb $TS_s$
- Cake TS = 24.5% = 24.5 lb $TS_c$/100 lb cake
- Cake density = 69 lb cake/$ft^3$ cake
- Cake hopper volume = 9 $yd^3$ cake

As always, the units needed in the answer are identified from the problem statement. The problem specifically asks for "...how long it will take, in **hours**,..." This unit (hr), then, is entered between thick vertical lines followed by an equals sign and the blank track.

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$$\left| \text{hr} \right| = \_\_\_\_\_$$

This railroad can't be started like previous railroad tracks because nowhere in the list above does the unit, hr, occur. Mmmmmmm....what to do?

Hours (hr) is a unit of time. Looking closely at the list above, there is only one piece of information given that has a unit of time associated with it: 145 gal sldg/**min**. Again, let the units talk to you: while hours and minutes aren't the same units, we can easily converted one to the other and vice versa. More importantly, as discussed in a previous Problem of the Day, if, for example, a unit of time is in the numerator on the left-hand side of the equals sign, as in the current problem, and a unit of time is entered, incorrectly, in the denominator on the right-hand side of the equals sign, there is no conversion factor known to human kind that is going to change the position of the time unit from the denominator to the numerator. Therefore, the unit of minutes in the sludge flow rate must be entered into the numerator of the railroad track as shown.

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$$\text{hr} = \frac{\text{min}}{\frac{145 \text{ gal sldg}}{}}$$

Now we convert the min to hr needed in the answer, which are now shown in **bold** on both sides of the equals sign.

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$$\textbf{hr} = \frac{\cancel{\text{min}} \quad \textbf{hr}}{145 \text{ gal sldg} \quad 60 \cancel{\text{min}}}$$

The railroad track now has the unit in it needed in the answer, **hr**. From this point all that is necessary is to cancel out unwanted units, currently **gal sldg**. From the list above, there is only one other instance where the units, gal sldg, show up, 8.34 lb sldg/gal sldg. Therefore, this needs to be "flipped upside down," or inverted, when entering it into the railroad track so the units, gal sldg, cancel.

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$$\textbf{hr} = \frac{\cancel{\text{min}} \quad \textbf{hr} \quad \cancel{\text{gal sldg}}}{145 \cancel{\text{gal sldg}} \quad 60 \cancel{\text{min}} \quad 8.34 \text{ lb sldg}}$$

Now the units, lb sldg, need to be canceled. There is only one other instance in the list above where these units appear, 4.5 lb $TS_s$/100 lb sldg, which is how WWTT expresses 4.5% TS in the sludge. Again, this needs to be flipped upside down when entering it into the railroad track so the units, lb sldg, cancel.

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$$\textbf{hr} = \frac{\cancel{\text{min}} \quad \textbf{hr} \quad \cancel{\text{gal sldg}} \quad 100 \cancel{\text{lb sldg}}}{145 \cancel{\text{gal sldg}} \quad 60 \cancel{\text{min}} \quad 8.34 \cancel{\text{lb sldg}} \quad 4.5 \text{ lb } TS_s}$$

Now the units, lb $TS_s$, need to be canceled. There is only one other instance in the list above where these units appear, 95.6 lb $TS_c$/100 lb $TS_s$, which is how WWTT expresses 95.6% PSR. Again, this needs to be flipped upside down when entering it into the railroad track so the units, lb $TS_s$, cancel.

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **hr** | = | ~~min~~ | **hr** | ~~gal~~ sldg | 100 ~~lb~~ sldg | 100 ~~lb $TS_s$~~ | | |
| | | 145 ~~gal~~ sldg | 60 ~~min~~ | 8.34 ~~lb~~ sldg | 4.5 ~~lb $TS_s$~~ | 95.6 lb $TS_c$ | | |

I can't help but reflect here how amazing this problem-solving approach is! There is no need to memorize a bunch of formulas or remember to divide or multiply by some conversion factor because the units tell you what you need to do.

Now the units, lb $TS_c$, need to be canceled. There is only one other instance in the list above where these units appear, 24.5 lb $TS_c$/100 lb cake, which is how WWTT expresses 24.5% TS in the cake. This is entered into the railroad track so the units, lb $TS_c$, cancel.

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **hr** | = | ~~min~~ | **hr** | ~~gal~~ sldg | 100 ~~lb~~ sldg | 100 ~~lb $TS_s$~~ | 24.5 ~~lb $TS_c$~~ | | |
| | | 145 ~~gal~~ sldg | 60 ~~min~~ | 8.34 ~~lb~~ sldg | 4.5 ~~lb $TS_s$~~ | 95.6 ~~lb $TS_c$~~ | 100 lb cake | | |

Now the units, lb cake, need to be canceled. There is only one other instance in the list above where these units appear, 69 lb cake/$ft^3$ cake, which is how WWTT expresses the density of the cake. This is entered into the railroad track so the units, lb cake, cancel.

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|---|---|---|---|---|---|---|---|---|---|---|
| **hr** | = | ~~min~~ | **hr** | ~~gal~~ sldg | 100 ~~lb~~ sldg | 100 ~~lb $TS_s$~~ | 24.5 ~~lb $TS_c$~~ | 69 ~~lb cake~~ | | |
| | | 145 ~~gal~~ sldg | 60 ~~min~~ | 8.34 ~~lb~~ sldg | 4.5 ~~lb $TS_s$~~ | 95.6 ~~lb $TS_c$~~ | 100 ~~lb cake~~ | $ft^3$ cake | | |

Now the units, $ft^3$ cake, need to be canceled. As it turns out, these units don't show up in the list above. However, $yd^3$ cake show up in the hopper volume, 9 $yd^3$ cake. Both of these units, $ft^3$ and $yd^3$, are units of volume and can be easily converted one way or the other. So, the hopper volume is entered into the railroad track. When doing so, note the unit, cake, cancels in the denominator and numerator. This is more fun than a video game!

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **hr** | = | ~~min~~ | **hr** | ~~gal sldg~~ | 100 ~~lb sldg~~ | 100 ~~lb $TS_s$~~ | 24.5 ~~lb $TS_c$~~ | 69 ~~lb cake~~ | 9 $yd^3$ ~~cake~~ | |
| | | 145 ~~gal sldg~~ | 60 ~~min~~ | 8.34 ~~lb sldg~~ | 4.5 ~~lb $TS_s$~~ | 95.6 ~~lb $TS_c$~~ | 100 ~~lb cake~~ | $ft^3$ ~~cake~~ | | |

Because there are 3 feet in a yard, there are 27 $ft^3$ (3 x 3 x 3 = 27) in a $yd^3$. This is entered into the railroad track so the units, $ft^3$ and $yd^3$, cancel.

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **hr** | = | ~~min~~ | **hr** | ~~gal sldg~~ | 100 ~~lb sldg~~ | 100 ~~lb $TS_s$~~ | 24.5 ~~lb $TS_c$~~ | 69 ~~lb cake~~ | 9 ~~$yd^3$ cake~~ | 27 ~~$ft^3$~~ |
| | | 145 ~~gal sldg~~ | 60 ~~min~~ | 8.34 ~~lb sldg~~ | 4.5 ~~lb $TS_s$~~ | 95.6 ~~lb $TS_c$~~ | 100 ~~lb cake~~ | ~~$ft^3$ cake~~ | | ~~$yd^3$~~ |

Since all the units have canceled except the one needed in the answer, **hr**, the math is done and the arithmetic gives the answer:

100 x 100 x 24.5 x 69 x 9 x 27 ÷ 145 ÷ 60 ÷ 8.34 ÷ 4.5 ÷ 95.6 ÷ 100 = **1.32 hr**.

Does this take some practice?

You bet!

Is it worth it?

Absolutely!