Problem of the Day

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An anaerobic digester is being put back in service after cleaning and refurbishing. Digesting sludge from two operating primary digesters will be used for seed. 45,000 gallons/day of digested sludge is available during the startup period. The digesting sludge has a specific gravity of 1.011 and a total solids concentration of 3.8%, 52% of which is volatile. The raw sludge is 75% volatile with a total solids concentration of 5.8%. The VS loading ratio to be maintained to the startup digester is 0.05 pounds of feed volatile solids per pound of seed volatile solids. Calculate how many gallons per day of raw sludge should be pumped to the startup digester.

Introduction

WasteWater Technology Trainers has received multiple requests from California Grades IV and V operators of recent to work through a "digester feed problem." Today's and yesterday's Problems of the Day were "inspired" by a problem provided by another California certification review trainer. Although the numbers have been changed, I think it is important to repeat exactly how the problem was presented by the other trainer:

> "At a new plant, it is expected that 14,512 lbs/day of primary sludge will be pumped to the digester. The sludge is 4.4% solids with a volatile content of 72%. The volatile solids loading ratio to be used is 0.07 lbs of new volatile solids/lb of volatile solids under digestion. If the seed sludge to be used has a 12% solids concentration which is 55% volatile, determine how may [sic] pounds of seed sludge are required? At 8.66 lbs/gallon, how many gallons are required?"

While I'm a pretty smart guy, I find this problem statement to be extremely confusing. For starters, how does one have "solids under digestion" at a "new plant"? It is very unclear that the "solids under digestion" (where are they under digestion?) are going to be used as the seed solids. Why is the concentration of solids in the seed sludge so high? Finally, does the question mean to ask how many pounds **per day** of seed sludge are required since so many pounds of primary sludge **per day** are being pumped to the digester? As stated, this question is just plain awful; it's embarrassing really. No wonder operators hate math! Many operators whom I have heard from say of this question, "I don't even know what it's asking." I agree.

I have to tried rewrite the question, different questions yesterday and today, so it makes more sense. I have done a little research into anaerobic digester startup and have seen several documents recommend that approximately 20 pounds of digested or digesting sludge VS should be used for every pound of raw sludge VS fed to the digester. This is where "The VS loading ratio to be maintained to the startup digester is 0.05 pounds of feed volatile solids per pound of seed volatile solids," comes from. In other, mathematical words, 1 lb feed VS/20 lb seed VS = 0.05 lb feed VS/ lb seed VS.

Solution

The following information is given or assumed, expressed in very specific units in order to keep the "feed" solids separate from the "seed" solids. Note the use of the subscripts "f" and "s" to designate total and volatile solids in the feed and seed sludges, respectively. This is a little "accounting" trick used by WWTT in other problems. As you will see, it works really well.

1. Seed sludge available = 45,000 gal seed/d
2. Feed sludge TS concentration = 5.8% TS = 5.8 lb TS_f/100 lb feed
3. Feed sludge density = 8.34 lb feed/gal feed (assumed since not given)
4. Feed sludge VS concentration = 75% VS = 75 lb VS_f/100 lb TS_f
5. Volatile loading ratio = 0.05 lb VS_f/lb VS_s
6. Seed sludge TS concentration = 3.8% TS = 3.8 lb TS_s/100 lb seed
7. Seed sludge specific gravity = 1.011
8. Seed sludge density (calculated) = 1.011 x 8.34 lb/gal = 8.43 lb seed/gal seed
9. Seed sludge VS concentration = 52% VS = 52 lb VS_s/100 lb TS_s

Today's problem asks to calculate "How many gallons per day of raw sludge should be pumped to the startup digester." "Translated" into the units WWTT uses in the list above, we must calculate **gal feed/d**. These units, then, are put between heavy vertical lines, as always, followed by an equals sign and the blank solution bridge.

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gal feed	=	
d		

The only place the units gal feed appear in the list is in the denominator of No. 3. This, then, is entered "upside down" to start the solution bridge to get the units needed in the numerator of the answer.

gal feed	=	**gal feed**	
d		8.34 lb feed	

At WWTT's Grades IV & V Operator Certification and Math Review class held at Orange County Sanitation District recently, one of the students suggested getting all of the units needed in the answer on the solution bridge before starting to cancel unwanted units. I do this already in some problems, so I thought it would be a good, guiding strategy to implement. The only place the units d appear in the list is in the denominator of No. 1. This, then, is entered next to get the units needed in the denominator of the answer .

gal feed	=	**gal feed**	45,000 gal seed	
d		8.34 lb feed	**d**	

We have all the units on the solution bridge needed in the answer, gal feed/d, so now the "solution" is to cancel unwanted units. We start by canceling lb feed that only appears again in the list above in the denominator of No. 2, entered upside down so like units cancel denominator and numerator.

gal feed	=	**gal feed**	45,000 gal seed	100 ~~lb feed~~	
d		8.34 ~~lb feed~~	**d**	5.8 lb TS_f	

The only other place the units lb TS_f appear is in the denominator of No. 4. It is entered upside down, too, so like units cancel denominator and numerator.

gal feed	=	**gal feed**	45,000 gal seed	100 ~~lb feed~~	100 ~~lb TS_f~~	
d		8.34 ~~lb feed~~	**d**	5.8 ~~lb TS_f~~	75 lb VS_f	

The only other place the units lb VS_f appear is in the denominator of No. 5, the volatile solids "loading ratio." It is entered so like units cancel denominator and numerator.

gal feed	=	**gal feed**	45,000 gal seed	100 ~~lb feed~~	100 ~~lb TS_f~~	0.05 ~~lb VS_f~~	
d		8.34 ~~lb feed~~	**d**	5.8 ~~lb TS_f~~	75 ~~lb VS_f~~	lb VS_s	

The only other place the units lb VS_s appear is in the numerator of No. 9. It is entered so like units cancel denominator and numerator.

gal feed	=	**gal feed**	45,000 gal seed	100 ~~lb feed~~	100 ~~lb TS_f~~	0.05 ~~lb VS_f~~	52 ~~lb VS_s~~	
d		8.34 ~~lb feed~~	**d**	5.8 ~~lb TS_f~~	75 ~~lb VS_f~~	~~lb VS_s~~	100 lb TS_s	

The only other place the units lb TS_s appear is in the numerator of No. 6. It is entered so like units cancel

denominator and numerator.

gal feed	=	**gal feed**	45,000 gal seed	100 ~~lb feed~~	100 ~~lb TS_f~~	0.05 ~~lb VS_f~~	52 ~~lb VS_s~~	3.8 ~~lb TS_s~~	
d		8.34 ~~lb feed~~	**d**	5.8 ~~lb TS_f~~	75 ~~lb VS_f~~	~~lb VS_s~~	100 ~~lb TS_s~~	100 lb seed	

The only other place the units lb seed appear is in the numerator of No. 8. It is entered so like units cancel denominator and numerator. This entry also cancels gal seed, numerator and denominator.

gal feed	=	**gal feed**	45,000 ~~gal seed~~	100 ~~lb feed~~	100 ~~lb TS_f~~	0.05 ~~lb VS_f~~	52 ~~lb VS_s~~	3.8 ~~lb TS_s~~	8.43 ~~lb seed~~
d		8.34 ~~lb feed~~	**d**	5.8 ~~lb TS_f~~	75 ~~lb VS_f~~	~~lb VS_s~~	100 ~~lb TS_s~~	100 ~~lb seed~~	~~gal seed~~

Since all the units have now canceled except those needed in the answer, gal seed/d, we know the solution bridge is complete. The arithmetic gives the answer.

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gal feed	=	**gal feed**	45,000 ~~gal seed~~	100 ~~lb feed~~	100 ~~lb TS_f~~	0.05 ~~lb VS_f~~	52 ~~lb VS_s~~	3.8 ~~lb TS_s~~	8.43 ~~lb seed~~
d		8.34 ~~lb feed~~	**d**	5.8 ~~lb TS_f~~	75 ~~lb VS_f~~	~~lb VS_s~~	100 ~~lb TS_s~~	100 ~~lb seed~~	~~gal seed~~

45,000 x 100 x 100 x 0.05 x 52 x 3.8 x 8.43 ÷ 8.34 ÷ 5.8 ÷ 75 ÷ 100 ÷ 100 = **1,033 gal feed/d**.

Discussion

It is interesting to note the ratio of the digested **seed** sludge flow rate to the raw **feed** sludge flow rate is 44 (45,000 ÷ 1,033 = 44), which means you're putting a lot more already digested sludge in a digester during start up then raw sludge. Again, this emphasizes the need to start anaerobic digesters up slowly. In addition, great caution is required because of the potential to develop an explosive mixture of methane and air in the headspace above the liquid surface as the digester is filling. You really have to have a plan!

This is really kind of a cool problem and solution. It demonstrates, once again, the power of the solution-bridge approach to problem solving. Being able to label the different pieces of information given in the problem in a consistent and intuitive way is obviously key. This labeling step, in fact, demonstrates your understanding of what the problem is about and how you're going to solve it. Setting up the solution bridge is pretty straightforward once you've identified the units needed in the answer (i.e., what the problem is asking you to solve for) and everything is labeled correctly. The understanding is in the labeling so this is where you need to practice.

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.