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PART 3 C FACT SHEETS

The following pages present fact sheets for specific topics and calculations needed to determine compliance with 40 CFR Part 503. Each topic will be presented with a narrative description**C**the calculation or conversion used is discussed first, then an example and a blank calculation for practice, if applicable. Please note that the calculations do not represent the entire approved analytical method; they are only mathematical calculations, which are components of the entire method. Therefore, preliminary calculations that may also be required are not shown.

The following is a list of the topics that are presented in this section:

Section **Topic** **Page**

SECTION 3.1 C POLLUTANT LIMITS

The 40 CFR Part 503 regulation regarding land application establishes different numeric limits for nine metals depending on the final use/disposal option for the biosolids. Previous versions of the regulation established numeric limits for 28 inorganic and organic pollutants, as well as total hydrocarbons. "However, in the final rule, the Agency determined that certain pollutants should not be regulated because they either are not present in biosolids, or if present, the potential for exposure was small."[1]

No biosolids can be land applied if they exceed the ceiling concentrations listed in Table 1 of 40 CFR 503.13. The remainder of the limits apply to specific use or disposal options. Table 3.1.1 provides a comprehensive listing of all of the pollutant limits currently regulated under 503.13.

When examining the limits, you will notice that metric units are provided. To help in your conversion of these limits, Section 3.15 provides many of the conversions needed throughout Part 503.

Table 3.1.1. Pollutant Limits.
40 CFR Part 503.13, Tables 1 - 4

Pollutant	Table 1 Ceiling Concentrations (mg/kg)*	Table 2 Cumulative Pollutant Loading Rates (kg/ha)	Table 3 Pollutant Concentrations (mg/kg)*	Table 4 Annual Pollutant Loading Rates (kg/ha/365 day period)
As	75	41	41	2.0
Cd	85	39	39	1.9
Cu	4,300	1,500	1,500	75
Pb	840	300	300	15
Hg	57	17	17	0.85
Mo	75	**	**	**
Ni	420	420	420	21
Se	100	100	100	5.0
Zn	7,500	2,800	2,800	140

*Dry weight basis

**Molybdenum pollutant limits deleted from regulation pending reconsideration of plant uptake rates

[1] 40 CFR Part 503, Preamble, pages 350-351.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.2 C PERCENT TOTAL SOLIDS

Total solids is the term applied to material residue left in a vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature of 103 to 105°C. This temperature range is important to ensure that no water content is measured and volatile solids are not driven off. Total solids are comprised of the following:

$Suspended solids = the portion of total solids retained by a filter.
$Dissolved solids = the portion of total solids that pass through a filter.

$$\% \text{ Total Solids} = \frac{\text{weight of sample dry}}{\text{weight of sample wet}} \times 100$$

In determining what percentage of a biosolids sample is the total solids, the following ratio applies:

However, the laboratory technician would use the following equation from Method 2540 G of Standard Methods because he/she must take into account the weight of the dish used in the drying process:

$$\% \text{ Total Solids} = \frac{(A - B) \times 100}{(C - B)}$$

Where
A = weight of dried residue + dish, g
B = weight of dish, g
C = weight of wet sample + dish, g

Please note that the parameters, A, B, and C, are determined from Method 2540 G of Standard Methods, 18th Edition. The method's protocols specify drying temperature and test duration.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Percent Total Solids

To determine percent total solids follow Standard Method 2540 G and use the following equation:

$$\% \text{ Total Solids} = \frac{(A - B) \times 100}{(C - B)}$$

Where

A = weight of dried residue + dish, g
B = weight of dish, g
C = weight of wet sample + dish, g

Example #1: Determine the percent total solids from the following:

wet weight of sample + dish = 1.56 g
dry weight of sample + dish = 1.43 g
weight of dish = 1.4 g

$$\frac{(1.43\text{ g} - 1.4\text{ g}) \times 100}{1.56\text{ g} - 1.4\text{ g}} = 18.7 \% \text{ total solids}$$

$$\frac{((\quad)\text{g} - (\quad)\text{g}) \times 100}{(\quad)\text{g} - (\quad)\text{g}} = \underline{\quad\quad} \% \text{ total solids}$$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.3 C DRY WEIGHT BASIS

Laboratory results for biosolids are typically reported in one of two forms, wet weight (*i.e.*, mg/L) or a dry weight (*i.e.*, mg/kg). You should request your laboratory to provide the results on a dry weight basis. In the event that the laboratory results are reported on a wet weight basis, the results for each pollutant in each sample must be converted to determine the dry weight concentration for recordkeeping/reporting purposes and for comparison with 40 CFR Part 503 Pollutant Limits. To accomplish this conversion, the percent total solids in the biosolids sample must be known (see Section 3.2 Percent Total Solids).

The following equation can be used to determine the dry weight concentration because the equation uses the assumption that the specific gravity of water and biosolids are both equal to one. However, this assumption holds true only when the solids concentration in the biosolids is low. The calculated dry weight concentration may vary slightly from the actual concentration as the solids content increases because the density of the biosolids may no longer be equal to that of water. Typically, this concern is unrealized as the solids content of biosolids is usually low. EPA is aware of this potential problem and may make a determination regarding this matter at a later date.

$$\frac{\text{A mg/L(wet)}}{\text{\% Total Solids}} = \text{B mg/kg(dry)}$$

Determine the pollutant concentration on a dry weight basis using the following abbreviated conversion:[1]

Where A = the concentration of the pollutant in the biosolids on a wet weight basis in mg/l
B = The concentration of the pollutant in the biosolids on a dry weight basis in mg/kg
% Total Solids = the percentage of solids in the biosolids sample expressed as a decimal

A unit conversion is incorporated into the equation.

[1] *Land Application of Sewage Sludge - A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503.* December 1994. U.S. EPA Office of Enforcement and Compliance Assurance, Washington, D.C.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Dry Weight Basis

$$\frac{A\ mg/l}{\%\ Total\ Solids} = B\ mg/kg$$

Determine the pollutant concentration on a dry weight basis using the following equation:

Example #1: Determine the dry weight concentrations of the pollutants.

- The laboratory analysis of your biosolids yielded the following results:

As - 6.6 mg/L
Cd - 5.5 mg/L
Cu - 374 mg/L
Hg - 0.22 mg/L
Ni - 44 mg/L
Pb - 44 mg/L
Se - 2.2 mg/L
Zn - 330 mg/L

- The percent total solids of the biosolids was determined to be 22%. Remember to convert the percent total solids to a decimal by multiplying by 100 before placing it into the equation.

$$\frac{6.6\ mg/L(As,\ Wet)}{0.22} = 30\ mg/kg(As,\ dry)$$

Therefore, using the given equation, the dry weight concentration of As can be determined as follows:

The remainder of the converted results are:

$$\frac{(\quad)\ mg/L(wet)}{0.\_} = \_\quad mg/kg(dry)$$

Cd=25mg/kg, Cu=1,700mg/kg, Pb=200mg/kg, Hg=1mg/kg, Ni=200mg/kg, Se=10mg/kg, Zn=1,500mg/kg

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.4 C ANNUAL WHOLE SLUDGE APPLICATION RATE (AWSAR)

The annual whole sludge application rate (AWSAR) is the maximum amount of biosolids in metric tons, dry weight, that can be applied to a hectare of land in a 365-day period. This requirement is specific to biosolids sold or given away in a bag or other container for application to land. If the biosolids are subject to annual pollutant loading rates (APLR), then it cannot be applied at greater than the AWSAR to ensure that the APLRs are not exceeded. The AWSAR limits the total amount of biosolids applied while the APLR limits the amount of pollutant applied.

To determine the AWSAR for each regulated pollutant, use the following three step procedure:[1]

Step 1: Analyze the biosolids and determine the dry weight concentration for all pollutants listed in 503.13, Table 4.

Step 2: Using the pollutant concentrations from Step 1 and the APLRs from 503.13, Table 4, calculate the AWSAR for each pollutant using the following equation:

$$\mathbf{AWSAR} = \frac{\mathbf{APLR}}{\mathbf{C * 0.001}}$$

where: C = the concentration of pollutant in biosolids, mg/kg, dry weight
0.001 = conversion factor converting mg/kg units to metric tons
APLR = the 503.13, Table 4 value for that specific pollutant, kg/ha per 365-day period

Step 3: The AWSAR for the biosolids is the lowest AWSAR calculated in Step 2.

[1] 40 CFR Part 503, Appendix A.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Annual Whole Sludge Application Rate (AWSAR)

Use the following equation to calculate the AWSAR:

$$\text{AWSAR} = \frac{\text{APLR}}{\text{C} * 0.001}$$

Example #1: Determine the AWSAR for your biosolids

- Determine the dry weight pollutant concentrations for all metals.

As=30mg/kg, Cd=25mg/kg, Cu=1,700mg/kg, Pb=200mg/kg, Hg=1mg/kg, Ni=200mg/kg, Se=10mg/kg, Zn=1,500mg/kg

- Using the pollutant concentrations from above and the APLRs from 503.13 Table 4, calculate an AWSAR for each pollutant using the given equation.

$$\text{Cd Y} \quad \frac{1.9\ \text{(kg/ha)}}{25\ \text{(mg/kg)} \times .001} = 76 \text{ metric tons/ha/365 day period}$$

The remaining metals are as follows:

As = 66 mt/ha/365, Cu = 44 mt/ha/365, Pb = 75 mt/ha/365,
Hg = 850 mt/ha/365, Ni = 105 mt/ha/365, Se = 500 mt/ha/365,
Zn = 424 mt/ha/365

Determine the lowest AWSAR calculated. In this example, the lowest AWSAR is 44 mt/ha/365 day period for Cu. Therefore, if the biosolids are applied to the land at a rate greater than 44 metric tons per hectare per 365 day period, the APLR for Cu will be exceeded. The AWSAR for this particular biosolid is limited to 44 metric tons per hectare per year.

Please note: Since the dry weight concentration for Cu (1,700 mg/kg) exceeds the 503.13 Table 3 limit of 1,500 mg/kg, the management practices requirement 503.14 (d) is applicable. This citation requires that bulk biosolids must be applied at a whole sludge application rate that is equal to or less than the agronomic rate. Therefore, in this example, the agronomic rate may determine the application rate and not the AWSAR. If all of the pollutant concentrations were below 503.13, Table 3 limits, than the bulk biosolids could be applied at the calculated AWSAR.

Pollutant Y __ (kg/ha)/365 days) (__ mg/kg * 0.001) = ___ mt/ha/365 days

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.5 C AGRONOMIC RATE FOR (N)

The agronomic rate is the amount of biosolids that is needed in order to supply the recommended amount of nitrogen (*N*) for a particular type of crop without allowing excess *N* to migrate below the root zone and into the ground water. Part 503.14.d states, "Bulk sewage sludge shall not be applied at rates above agronomic rates, with the exception of reclamation projects when authorized by the permitting authority." The agronomic rate is the ratio of the biosolids nitrogen used for the crop (dry weight per unit area) divided by the available nitrogen in the biosolids (dry weight):[1]

$$\text{Agronomic Rate} = \frac{\text{BIOSOLID } N \text{ NEEDED FOR CROP}}{\text{AVAILABLE } N \text{ IN BIOSOLIDS}}$$

It was the intention of EPA that this handbook provide simplified and easy to use calculations for help in determining compliance with Part 503. Unfortunately, many steps are required to determine the agronomic application rate of biosolids. The steps are explained on the following pages.

When evaluating the calculations for agronomic rate, note that soil data is required to determine the amount of additional nitrogen needed for the specific crop. Therefore, for dry land farming, deep soil monitoring should be conducted once every five years with samples collected at one foot intervals for a total of five feet. For irrigated farm land, samples should be collected within the plow zone on an annual basis. If soil data is not available, residual nitrogen can be calculated based on previous biosolids applications using the mineralization rate of organic nitrogen. However, annual soil tests will provide you with a more accurate estimate of the nitrogen content of the soil. Be advised that one individual soil sample may not provide an accurate determination for an entire area of land. Therefore, multiple soil samples from different locations within the field are recommended to provide a more accurate determination of residual nitrogen content. Additional information regarding this subject is presented on the following page.

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[1] *Guidance for Writing Permits for the Use and Disposal of Sewage Sludge.* September 1995. U.S. EPA Office of Wastewater Management, Permits Division. Washington, D.C.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

AGRONOMIC RATE

Prior to conducting the calculations, several points must be noted:

Step Number 2 of Worksheet 1, "Nitrogen available in the soil," indicates that you should use the greater value of either the "background nitrogen in the soil" or the "available nitrogen from previous biosolids applications." The distinction is made so that you do not account for residual nitrogen in the soil twice, and therefore overestimate the actual N content of the soil.

The mineralization rates presented in Table 3.5.4 are generalized values. Your biosolids may exhibit a different rate depending upon the receiving soils and agricultural practices used. To compensate for these estimates, model biosolids management programs have their soil tested on an annual basis and at a minimum of once every two years. By conducting the tests you can determine the actual N content of your soil at that point in time. Annual soil tests eliminate the need for mineralization rate determinations and automatically account for residual nitrogen from previous biosolids applications.

If you choose not to conduct the soil tests on an annual basis and instead determine the residual nitrogen from previous biosolids applications, you may wish to have a mineralization rate test conducted on your biosolids to determine the actual mineralization rate. Be aware that the costs associated with mineralization tests may be much higher than an annual soil test. For assistance in obtaining information regarding soil tests, fertilizer recommendations, and mineralization tests, a listing of agricultural extensions is provided at the end of this fact sheet. The list includes regional universities, phone numbers, and document numbers, if available.

Prior to determining the agronomic rate, you will need to obtain all of the information listed below:

Biosolids (Data from analysis)

- Percent solids
- Total Kjeldahl Nitrogen (TKN)
- NH_4-N (ammonium nitrogen)
- NO_3-N (nitrate)
- Organic N (TKN minus NH_4-N)

Soil (Data from soil test laboratory)

- pH
- Cation-Exchange-Capacity (CEC)
- Residual N (this is either measured soil N or the residual N estimated from previous biosolids applications)

Crop (Information obtained from farmer, farm advisor, or fertilizer guides)

- Type
- Expected yield
- Total fertilizer N recommendation
- Supplemental fertilizer N (*i.e.*, commercial fertilizer, irrigation water, etc.)

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Helpful Hint: The following conversions may be helpful in determining the agronomic rate

lb/ton x 500 = mg/kg
lbs/acre x 1.1218 = kg/ha
tons/acre x 2242.15 = kg/ha
tons/acre x 2.2421 = mt/ha

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

WORKSHEET 1C Agronomic Loading Rate Summary

Key to Symbols and Abbreviations

NH_4^+-N = Ammonium nitrogen content of the biosolids obtained from analytical testing of the biosolids, kg/mt (dry weight basis).

Kv = Volatilization factor estimating ammonium nitrogen remaining after atmospheric losses.

Org-N = Organic nitrogen content of the biosolids obtained from analytical testing, kg/mt (dry weight basis).

F_{01} = Mineralization rate for the biosolids during the first year of application, in percent of organic nitrogen expressed as a fraction (*i.e.*, 20% = 0.2).

1. Total available nitrogen from biosolids.

a. Ammonium nitrogen ______ **kg/mt**
Calculated with the following formula:
NH_4^+-N(kg/mt) x Kv(Kv obtained from Table 3.5.3)

b. Mineralized organic nitrogen for first year of application ______ **kg/mt**
Calculated with the following formula:
Org-N x F_{01} (F_{01} obtained from Table 3.5.4)

c. Nitrate nitrogen ______ **kg/mt**

d. Total available nitrogen from biosolids ______ **kg/mt**
Add a, b, and c

2. Nitrogen available in the soil (Use the greater of a. or b.)

a. Background nitrogen in soil (From soil test results) ___ **kg/ha**

OR

b. Available nitrogen from previous biosolids applications
(From Worksheet 2) ___ **kg/ha**

3. Nitrogen supplied from other commercial sources

kg/ha

(*i.e.*, fertilizer or irrigation water)

4. Total nitrogen available from existing sources ______ **kg/ha**
Add 2a **or** 2b (whichever is greater) and 3

5. Total nitrogen requirement of crop ______ **kg/ha**

6. Supplemental nitrogen needed from biosolids ______ **kg/ha**
Subtract 4 from 5

7. Agronomic loading rate (Divide 6 by 1) ___ **mt/ha**

OR

mt/ha) 2.2421 ______ **tons/acre**

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

WORKSHEET 2CCalculating Mineralized Organic Nitrogen

The organic nitrogen in biosolids continues to decompose and release mineral nitrogen through the mineralization process for several years following its initial application. This residual nitrogen from the previously applied biosolids must be accounted for as part of the overall nutrient budget when determining the agronomic rate for biosolids. The following procedures calculate mineralized organic nitrogen. These calculations must be done for each yearly biosolids application (see example calculations).

Table 3.5.1

1. Year	2. Starting N (kg/ha)	3. Mineralization Rate (Table 3.5.4)	4. Mineralized Org-N (kg/ha)	5. Org-N Remaining (kg/ha)
0-1 (first application)				
1-2				
2-3				
3-4				
4-5				

Summary of steps needed to complete the table:
(the numbers correspond to the columns in the table)

1. Number of years after initial application.

2. In the first year, this equals the amount of N initially applied. In subsequent years, it represents the amount of Org-N remaining from the previous year (*i.e.*,column 5).

3. The Org-N content of the applied biosolids continues to be mineralized, at decreasing rates, for years after initial application. See Table 3.5.4 for mineralization rates.

4. Multiply column 2 times column 3.

5. Subtract column 4 from column 2.

A detailed example of the above table is presented on the following page.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Example

Assume biosolids were applied to the site at a rate of 5 mt/ha with a 3% org-N content (dry weight basis) in 1986. The following year, 1987, 3 mt/ha of biosolids (same org-N contents as 1986) was applied to the same site. No biosolids were applied to the site after 1987. It is now 1990 and you want to calculate the available nitrogen from previous biosolids applications.

1986 - org-N in biosolids applied = (0.03) (5 mt/ha) (1,000 kg/mt) = 150 kg/ha

1987 - org-N in biosolids applied = (0.03) (3 mt/ha) (1,000 kg/mt) = 90 kg/ha

Calculate the residual nitrogen from 1986 and 1987 in the following manner (assume biosolids are anaerobically digested and use corresponding Table 3.5.4 value):

Table 3.5.2

Year*	Starting N (kg/ha)	Mineralization Rate (Table 3.5.4)	Mineralized Org-N (kg/ha)	Org-N Remaining (kg/ha)
1986 Biosolids				
0-1 (first application - 1986)	150	0.2	30	120
1-2 (1987	120	0.1	12	108
2-3 (1988)	108	0.05	5.40	102.60
3-4 (1989)	102.60	0.03	3.08	99.52
4-5 (1990)	99.52	0.03	2.99	96.53
1987 Biosolids				
0-1 (first application - 1987)	90	0.2	18	72
1-2 (1988)	72	0.1	7.2	64.80
2-3 (1989)	64.8	0.05	3.24	61.56
3-4 (1990)	61.56	0.03	1.85	59.71

To determine the total org-N remaining from the biosolids applied in 1986 and 1987, add the last value in the last column of the table for the 1986 biosolids to the last value in the last column of the table for the 1987 biosolids (*i.e.*, 96.53 + 59.71 = 156.24 kg/ha). Total org-N remaining in 1990 is 156.24 kg/ha.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Table 3.5.3. Volatilization Factors (Kv).

If Biosolids are:	Factor Kv Is:
Liquid and surface applied	.50
Liquid and injected into the soil	1.0
Dewatered and applied in any manner	1.0

Table 3.5.4. Mineralization Rate*

Time after biosolids application (Year)	% of Org-N Mineralized from Aerobically Digested Biosolids	% of Org-N Mineralized from Anaerobically Digested Biosolids	% of Org-N Mineralized from Composted Biosolids
0-1	30	20	10
+-1-2	15	10	5
2-3	8	5	3
3-4	4	3	3
4-5	3	3	3

* Percentage of Org-N present mineralized during the time interval shown

We have described above a typical method of calculating agronomic rate. You may wish to contact your State Extension Service to request the recommended method for your geographic area. The following table contains Extension Services in some States; a complete listing can be found at http://www.penickgroup.com/exts.phtml.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Listing of Agricultural Extensions

Table 3.5.5

University	Phone Number*	Document Number**
Colorado State	(303)-491-6198	XCM-37
Utah State	(801) 750-2251	AGWM-02
Wyoming	(307) 766-2115	Not Available
South Dakota State	(605) 688-4601	EC-750
North Dakota State	(701) 231-7882	SF-882
Montana State	(406) 994-3273	MTEB 104

*Number provided is usually for the extension service document room but if not, have your call directed towards the Agricultural Extension Service.

**If a document number is not provided, please ask for the general catalog as the extension service has different documents for different crop types. You may want the entire catalog so as to choose which document(s) is right for you.

In general, when contacting your regional agricultural extension, ask for the fertilizer guide or fertilizer recommendation document. Some extension services have different guides for different plants so you may want to obtain the catalog of available guides. Most of the extension services will charge a fee for these documents. For soil tests, you should contact the soil lab through the numbers provided above.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.6 C ANNUAL POLLUTANT LOADING RATE (APLR)

The annual pollutant loading rate ($APLR_{503}$) is the maximum amount of a pollutant that can be applied to a unit area of land during a 365 day period. The $APLRs_{503}$ are established standards and are presented in Part 503.13 Table 4. By using the following equation, you can calculate the actual annual pollutant loading rate ($APLR_A$) that occurred during a given 365 day period. These calculated values can then be compared to the $APLRs_{503}$ in Table 4 to determine if the $APLRs_{503}$ for the given area of land have been exceeded. To determine the actual annual whole sludge application rate (AWSAR) which will allow you to meet the $APLR_{503}$ see Section 3.4. $APLRs_{503}$ applies only to biosolids that are sold or given away in a bag or other container.

To determine the actual annual pollutant loading rate ($APLR_A$) to an area of land use the following equation:

$$APLR_A = C * AWSAR * 0.001$$

where **$APLR_A$ = the actual annual pollutant loading rate (kg/ha)/365 days,**
C = the pollutant concentration (mg/kg),
AWSAR = the annual whole sludge application rate (mt/ha)/365 days,
and 0.001 = a conversion factor.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Annual Pollutant Loading Rate

To determine the actual annual pollutant loading rate ($APLR_A$) to an area of land use the following equation:

$$APLR_A = C * AWSAR * 0.001$$

where **$APLR_A$ = the actual annual pollutant loading rate (kg/ha)/365 days,**
C = the pollutant concentration (mg/kg),
AWSAR = the annual whole sludge application rate (mt/ha)/365,
and 0.001 = a conversion factor

Example #1: Determine the actual annual pollutant loading rates ($APLR_A$) of your biosolids.

The laboratory results of your biosolids yielded the following dry weight results:

As=30 mg/kg, Cd=25 mg/kg, Cu=1,700 mg/kg, Pb=200 mg/kg, Hg=1 mg/kg, Ni=200 mg/kg, Se=10 mg/kg, Zn=1,500 mg/kg

As determined in Section 3.4, the annual whole sludge application rate (AWSAR) is (44 mt/ha)/365 days.

Now use the $APLR_A$ equation presented above to calculate the annual pollutant loading rates (APLR) for each pollutant.

Cd Y 25 mg/kg * 44 (mt/ha)/365 days * 0.001 = 1.1 kg/ha/365 days

The remainder of the calculated values are (in yearly rates):

As = 1.32 kg/ha, Cu = 74.8 kg/ha, Pb = 8.8 kg/ha, Hg = 0.044 kg/ha, Ni = 8.8 kg/ha,
Se = 0.44 kg/ha, Zn = 66 kg/ha

$APLR_A$ for Cd=___ mg/kg *___ (mt/ha)/365 days * 0.001 = ___ kg/ha/365 days

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.7 C CUMULATIVE POLLUTANT LOADING RATE (CPLR)

The cumulative pollutant loading rate ($CPLR_{503}$) is the maximum amount of a pollutant that can be applied to an area of land as specified in the regulations at 40 CFR Part 503. In other words, the $CPLR_{503}$ is the total mass of a particular pollutant (on a dry weight basis) that may be applied to a unit area of land during the entire life of the application site. When the established CPLRs for any one of the nine heavy metals listed in 503.13, Table 2 is reached at a site, no additional bulk biosolids subject to CPLR limits may be applied to the site. The $CPLR_{503}$ applies to bulk biosolids applied to agricultural land, forest, and a public contact site, or a reclamation site. In order to ensure that you do not exceed the any of the $CPLRs_{503}$, you will need to track the actual loadings of each pollutant on a site. To calculate pollutant loadings applied to a site, you can use an equation similar to that used to calculate the actual annual pollutant loading rate ($APLR_A$) in Section 3.6. This equation, however, calculates the pollutant loading for each application of biosolids to a site instead of the annual loading. Once you have determined the pollutant loading for each application of biosolids, you can sum the pollutant loadings using another equation to determine the actual measured cumulative pollutant loading rate ($CPLR_A$).

An equation to calculate the pollutant loading to a site for a single application is as follows:

$$PL = C * AR * 0.001$$

where **PL = Pollutant Loading (kg/ha)**
C = Concentration of Pollutant (mg/kg)
AR = Application Rate to a site (mt/ha)
0.001 = Conversion factor

To then calculate the $CPLR_A$ on the site you use the following equation to sum the application pollutant loadings:

$$3_e^b PL = PL_b + PL_n ... + PL_e = CPLR_A$$

where **Ó = summation**
PLb = pollutant loading first
PLe = pollutant loading at last
PL_n = pollutant loadings for intermediate applications (2 through n)
PL = pollutant loading (kg/ha)
$CPLR_A$ = actual measured CPLR (kg/ha)

To develop an overall picture of the how the CPLR affects your application site, you can predict the estimated site life of your application site provided the biosolids characteristics remain the same.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
The site life is determined with the use of the following equation:

$$\text{Site Life, yr} = \frac{CPLR_{503}}{APLR_{A}}$$

where **$CPLR_{503}$ = the Part 503.13, Table 2 value for a specific pollutant**
$APLR_{A}$ = the actual annual sludge pollutant loading (kg/ha)/365 days

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Cumulative Pollutant Loading Rate

Example #1: Determine the $CPLR_A$ for a given land application site:

The laboratory results of your biosolids yielded the following dry weight results:

As=30 mg/kg, Cd=25 mg/kg, Cu=1,700 mg/kg, Pb=200 mg/kg, Hg=1 mg/kg, Ni=200 mg/kg, Se=10 mg/kg, Zn=1,500 mg/kg

Using the $APLR_A$ calculation from Section 3.6, the 1993 pollutant loading for zinc was determined to be = 66 kg/ha/365 day period.

Use the following table to determine the $CPLR_A$ for zinc for the land application site. Similar tables would need to be developed for the remaining pollutants.

Table 3.7.1. Tracking Cumulative Pollutant Loading for Zinc (Example).

Application Number	Pollutant Concentration (mg/kg)	Biosolids Application Rate (AWSAR) (mt/ha/yr)	Zinc Pollutant Loading (kg/ha)	Cumulative Pollutant Loading at End of Year (kg/ha)
1	1,500	44	66	66
2	1,500	44	66	66+66 = 132
3	1,500	44	66	132+66 = 198
4	1,500	44	66	198+66 = 264
5	1,500	44	66	264+66 = 330

Therefore, after 5 years of applying biosolids to the land application site, the actual cumulative loading for zinc was determined to be 330 kg/ha. This example assumes that the quality of your biosolids remains the same over the five year period. Changes in pollutant concentrations or changes in the application rate will alter your cumulative pollutant loadings.

The calculated CPLR for zinc listed in the above table is identical to the calculated value using the given equation:

$$\Sigma_e^b PL = PL_b + PL_{m....} + PL_e = CPLR_A$$

$$\Sigma_1^5 PL = 66 + 66 + 66 + 66 + 66 = 330 \text{ kg/ha}$$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
Cumulative Pollutant Loading RateCContinued

Example #2: Determine the site life of your land application site.

The $APLR_A$ for the biosolids had been previously determined in Section 3.6:

As = 1.32 kg/ha, Cd = 1.1 kg/ha, Cu = 74.8 kg/ha, Pb = 8.8 kg/ha, Hg = 0.044 kg/ha,
Ni = 8.8 kg/ha, Se = 0.44 kg/ha, Zn = 66 kg/ha

Calculate the years an inorganic pollutant can be land applied by utilizing the following equation:

$$\text{Site Life, yr} = \frac{CPLR_{503}}{APLR_A}$$

Using the given equation, the site life for arsenic can be determined as follows:

$$As = \frac{41\ (kg/ha)}{1.32\ (kg/ha)/yr} = 31\ years$$

Site life for the remaining metals are: Cd= 35 yr, **Cu= 20 yr**, Pb= 34 yr, Hg= 386 yr, Ni= 48 yr,
Se= 227 yr, Zn= 42 yr

Determine the lowest number of years calculated, which is 20 years for Cu. This is the period that biosolids can be applied to the land without causing any of the cumulative loading rates in 503.13 Table 2 to be exceeded if pollutant concentrations remain the same.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.8 C SPECIFIC OXYGEN UPTAKE RATE (SOUR)

Specific Oxygen Uptake Rate (SOUR) is the mass of oxygen consumed per unit time per unit mass of total solids (dry weight basis) in the biosolids. The vector attraction potential of biosolids treated in an aerobic process can be shown to be adequately reduced if the SOUR determined at 20EC is equal to or less than the established standard of 1.5 mg of oxygen per hour per gram of total solids. The SOUR test is limited to those biosolids which have been aerobically digested at temperatures between 10°C (50°F) and 30°C (86°F) and has not yet been evaluated for use with biosolids that contain more than 2% solids.

Since the established standard of 1.5 mg of oxygen per hour per gram of total biosolids is only appropriate for those aerobic biosolids digested at 20°C (68°F), a calculation is needed to adjust the SOUR determined at one temperature to the SOUR for another temperature. To adjust the results of the test taken at a temperature other than 20°C (68EF) (the test should be performed at the temperature at which aerobic digestion is occurring in the treatment unit) use the following equation[1]:

$$\mathbf{SOUR_{20} = SOUR_{T} * Ø^{(20-T)}}$$

Where T = Temperature of aerobic digestion
Ø = 1.05 if T is above 20EC (68EF)
1.07 if T is below 20EC (68EF)

The following calculation can be used to determine the SOUR of a specific biosolids sample:[2]

$$\mathbf{SOUR_{T}, (mg/g)/hr = \frac{O_2 \text{ consumption rate } (mg/L)/min}{\text{Total solids, } g/L} * \frac{60 \text{ min}}{hr}}$$

The oxygen consumption rate is determined by Method 2710 B of Standard Methods, 18th Edition. Total solids is determined using method 2540G.

---

[1] *Environmental Regulations and Technology - Levels of Pathogens and Vector Attraction in Sewage Sludge*. December, 1992. U.S. EPA Office of Research and Development. Washington, D.C.

[2] Method 2710 B, Standard Methods, 18th Edition.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
Specific Oxygen Uptake Rate (SOUR)

Example 1: Calculate the SOUR when aerobic digestion is occurring at 20EC (68EF).

The following information was determined using Methods 2710 B and 2540 G of Standard Methods, 18th Edition, respectively:

- Oxygen consumption rate = .025 (mg/L)/min
- Total solids = 1 g/L

Use the given equation to calculate the SOUR:

$$\mathbf{SOUR_T\ (mg/g)/hr = \frac{.025\ (mg/L)/min}{1\ g/L} \times \frac{60\ min}{hr} = 1.5\ (mg/g)/hr}$$

The calculated SOUR of 1.5 (mg/g)/hr indicates that the vector attraction reduction accomplished through digestion was adequate for compliance.

Example 2: Calculate the SOUR when aerobic digestion is occurring at 15EC.

Assume the same oxygen consumption rate and total solids as in Example 1 above.

Use the given equation to calculate the SOUR at 15EC:

$$\mathbf{SOUR_{15}\ (mg/g)hr = \frac{.025\ (mg/L)/min}{1\ g/L} \times \frac{60\ min}{hr} = 1.5\ (mg/g)/hr}$$

To adjust the results of the SOUR taken at 1.5 (mg/g)/hr at 15EC to a SOUR which can be compared to the SOUR standard to 1.5 (mg/g)/hr at 20EC use the conversion equation given:

$$\mathbf{SOUR_{20} = 1.5\ (mg/g)/hr * 1.07^{(20-15)}}$$

Converting the $SOUR_{15}$ to a $SOUR_{20}$ gives 2.1 (mg/g)/hr which is above the standard and means the biosolids have not been stabilized sufficiently to reduce vector attraction and meet the 40 CFR Part 503 standard.

A. $SOUR_{\_\_}\ (mg/g)/hr = \frac{(\ \ )(mg/L)/min}{(\ \ \ )g/L} * \frac{60\ min/hr}{} = \_\_\_\ (mg/g)/hr$

B. $SOUR_{20}\ (mg/g)/hr = \frac{(\ \ )(mg/L)/hr}{(\ \ \ )g/L} * \frac{\_\_\_^{(20-\_)}}{hr} = \_\_\_\ (mg/g)/hr$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.9 C DENSITY OF MICROORGANISMS

The density of microorganisms is defined as the number of microorganisms per unit mass of total solids (dry weight). Density is expressed differently for various organisms:

- Helminth ova are observed and counted as individuals under a microscope.
- Viruses are usually counted in plaque-forming units (PFUs)
- Bacteria are counted in colony-forming units (CFUs) or most probable number (MPN). A CFU is a count of colonies on an agar plate or filter disk. MPN is a statistical estimate of numbers in an original sample.

The density of helminth ova, enteric viruses, and Salmonella sp. is expressed as numbers, PFUs, and CFUs per 4 grams of biosolids, dry weight. This terminology is used because most of the tests started with 100 ml of biosolids which typically contained 4 grams of solids. The MPN number, based on certain probability formulae, is an estimate of the mean density of coliforms in the sample and is presented per gram of biosolids, dry weight.

For detailed examples of how to calculate numbers, PFUs, CFUs, and MPN, please refer to the following pages which were provided by Doug Rice of the Colorado State University Environmental Quality Laboratory.

(NOTE: Total solids should always be determined when measuring microorganism densities in biosolids.)

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Microbiological Calculations for 503 Biosolids Analysis

I. Dry Weight Calculation:

The dry weight calculation is the most important step in biosolids analysis since all results are based on this

$$Percent\ of\ Dry\ Weight = \frac{Dry\ weight\ - Tare\ weight}{Wet\ weight\ - Tare\ weight}\ x\ 100$$

number. Step one is to determine how much of the total weight of the biosolids is due to the solid portion. The tare or empty weight of the drying dish must be subtracted from both the wet and dry weights:

Step two is to determine the multiplication factor to be used for all of the results. This factor tells us what the

$$Multiplication\ factor = \frac{Wet\ weight\ - Tare\ weight}{Dry\ weight\ - Tare\ weight}$$

result will be if all the analyte came from the solids. Low moisture biosolids will have small multiplication factors and high moisture biosolids will have large multiplication factors:

II. Most Probable Number Calculation:

The Most Probable Number (MPN) is a statistical estimate of microbial populations. By counting the number of Apositive@ tubes at each dilution a result can be calculated from a standard table. This result must then be modified by the Amultiplication factor@ to obtain the population per gram dry weight.

$$MPN/g\ Wet = \frac{MPN\quad table}{100}\ x\ Middle\ tube\ Dilution\ factor$$

Step 1:

$$MPN/g\ Dry\ Weight = MPN/g\ wet\ x\ Multiplication\ factor$$

Step 2:

$$Salmonella/4\ g = 4\ x\ MPN/g\ dry\ weight$$

Step 3: For Salmonella, the results must be reported per 4 grams.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

III. Membrane Filtration Calculation:

The Membrane Filtration (MF) calculation is a direct count of the viable population. The result is obtained by counting the number of colonies on the membrane and multiplying by the dilution factor of the plate that was counted. Again the result must be modified by the multiplication factor to obtain the population per gram dry weight.

$$\text{Colony Forming Units (CFU)/g wet} = \text{CFU x Dilution factor}$$

Step 1:

$$\text{CFU/g dry weight} = \text{CFU/g wet x Multiplication Factor}$$

Step 2:

Examples of these calculations can be seen on the following data sheets.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

503 Biosolids Calculations Worksheet

$$Percent\ Dry\ Weight = \frac{3.7015 - 1.4012}{11.3925 - 1.4012} x\ 100 = 23.02\%$$

$$Multiplication\ \ factor = \frac{11.3925 - 1.4012}{3.7015 - 1.4012} = 4.35 = \frac{1}{.2302}$$

$$Salmonella/g\ wet = \frac{4}{100} x\ 1 (diln.\ of\ \ Middle\ tube) = 0.04$$

$$Salmonella/g\ Dry\ Weight = 0.04/g\ wet\ x\ 4.34 = 0.17\ MPN/g\ dry$$

$$Salmonella/4\ g\ Dry\ Weight = 4\ x\ MPN/g\ dry\ weight = \underline{0.69\ MPN/4\ g\ dry}$$

$$Percent\ Dry\ Weight = \frac{6.8392 - 1.4095}{12.1015 - 1.4095} x\ 100 = 50.78\%$$

$$Multiplication\ \ factor = \frac{12.1015 - 1{,}4095}{6.8392 - 1.4095} = 1.97 = \frac{1}{.5078}$$

$$Fecal\ colif./g\ wet = \frac{110}{100} x\ 1000 (diln.\ of\ \ Middle\ tube) = 1{,}100/g\ wet$$

$$Fecal\ colif./g\ \ Dry\ Weight = 1{,}100/g\ wet\ x\ 1.97 = \underline{1.87\ MPN/g\ dry}$$

Salmonella Example A:

MPN Fecal Coliform Example B:

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

$$\text{Percent Dry Weight} = \frac{2.0915 - 1.4000}{11.0132 - 1.4000} \times 100 = 7.19\%$$

$$\text{Multiplication factor} = \frac{11.0132 - 1.4000}{2.0915 - 1.4000} = 13.9 = \frac{1}{.0719}$$

$$\text{Colony Forming Units (CFU)/g wet} = 35 \times 10{,}000 = 350{,}000\text{/g wet}$$

$$\text{Fecal colif./g dry weight} = 350{,}000 \times 13.9 = \underline{4{,}865{,}000 \text{ FC/g dry}}$$

MF Fecal Coliform Example C:

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
DRY WEIGHTS - Biosolids ANALYSIS
SOURCE:
DATE REPORTED:

Sample ID	Pan #	Tare Weight	Wet Weight	Dry Weight	% Solids	X
A Salmonella	12	1.4012	11.3925	3.7015	23.02	4.34
B MPN-Fecal	20	1.4095	12.1015	6.8392	50.78	1.97
C MF-Fecal	18	1.400	11.0132	2.0915	7.19	13.9

Biosolids ANALYSIS
SOURCE: The Plant
DATE RECEIVED: 7/14/93
DATE RUN: 7/15/93
DATE REPORTED: 7/21/93

Sample ID	Sample Date	Composition	Dilution	# Positive Fecal Coliforms	# Positive Salmonella	m-FC
A Salmonella ex.	7/22/93	semi-solid	10 1 -1 -2		1 0 1 0 (1-0-1)	
B MPN-Fecal ex	7/22/93	solid	-1 -2 -3 -4	5 5 3 1 (5-3-1)		
C MF-Fecal ex	7/22/93	liquid	-3 -4 -5 -6			TNTC 35 3 0

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Standard MPN Table

0-0-0	<2	4-1-2	26
0-0-1	2	4-2-0	22
0-1-0	2	4-2-1	26
0-2-0	4	4-3-0	27
1-0-0	2	4-3-1	33
1-0-1	4	4-4-0	34
1-1-0	4	5-0-0	23
1-1-1	6	5-0-1	31
1-2-0	6	5-0-2	43
2-0-0	4	5-1-0	33
2-0-1	7	5-1-1	46
2-1-0	7	5-1-2	63
2-1-1	9	5-2-0	49
2-2-0	9	5-2-1	70
2-2-1	11	5-2-2	94
2-3-0	12	5-3-0	79
3-0-0	8	5-3-1	110
3-0-1	11	5-3-2	140
3-0-2	13	5-3-3	180
3-1-0	11	5-4-0	130
3-1-1	14	5-4-1	170
3-1-2	16	5-4-2	220
3-2-0	14	5-4-3	280
3-2-1	17	5-4-4	350
3-2-2	19	5-5-0	240
3-3-0	17	5-5-1	350
4-0-0	13	5-5-2	540
4-0-1	17	5-5-3	920
4-1-0	17	5-5-4	1600
4-1-1	21	5-5-5	>1600

If a series of dilutions are made, select the highest dilution in which all tubes are positive, then also use the two next

$$MPN/g\ wet = \frac{MPN\ see\ table}{100}\ x\ Middle\ tube\ Dilution\ \ factor$$

higher dilutions.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Environmental Health Services Laboratory
B-226 Microbiology Building
(303) 491-6729 of 491-4837

MEMORANDUM

DATE: 05 March 1993

TO: Wayne Ramey
City of Louisville
749 Main St.
Louisville, Colorado 80027

FROM: Douglas Rice
Laboratory Director

Samples of biosolids were tested for Fecal coliform and Salmonella populations. The fecal coliform population was determined by the MPN method (Part 9221 E). The Salmonella species population was determined by the MPN/Streak plate method (Part 9260D). The biosolids samples were received on 2/19/93. Lab analysis occurred on 2/19/93.

RESULTS: (per gram dry weight)

Sample	Fecal Coliform MPN/gm	Salmonella MPN/4 gm	Solids
A: 1st Quarter 1992	<6	<0.3	31.2%
B: 2nd Quarter 1992	<7	<0.3	28.9%
C: 3rd Quarter 1992	1,120	<0.3	31.2%
D: 4th Quarter 1992	>4,464	<0.2	35.8%
E: Composite 1991	72	<0.2	45.9%

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.10 C ANNUAL APPLICATION RATE FOR DOMESTIC SEPTAGE

The maximum rate at which domestic septage can be land applied in any 365-day period must not exceed the agronomic rate. Thus, the annual application rate for domestic septage depends on the amount of nitrogen required by the vegetation grown on the application site. This equation is only slightly different than the equation for agronomic rate for biosolids because available nitrogen in domestic septage is assumed to be constant rather than a calculated number. Due to the similarities between this equation and the equation for agronomic rate, the steps to determine the amount of nitrogen needed by the vegetation have not been included in this fact sheet. These steps can be found in the Agronomic Rate Fact Sheet in Section 3.5 (use Steps 2 through 6).

The annual application rate for domestic septage is determined using the following equation:[1]

$$AAR = \frac{N}{0.0026}$$

Where

AAR = Annual application rate in gallons per acre per 365-day period

N = Amount of nitrogen in pounds per acre per 365-day period needed by the crop or vegetation grown on the land

0.0026 = Constant, based on assumed amount of nitrogen and solids content in domestic septage.

[1] 40 CFR Part 503.13(c).

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Annual Application Rate for Domestic Septage

Example #1: Determine the annual application rate of domestic septage needed for corn.

It was previously determined from a local agricultural school's soil suitability guide, that corn needs approximately 250 lbs of N/acre/365-day period. Therefore, calculate the AAR using the given equation:

$$\textbf{AAR for corn} = \frac{\textbf{250lbs./acre/365-day period}}{\textbf{0.0026}} = \textbf{96,153 gal/acre/365 days}$$

The calculated value indicates that the corn crop will require approximately 96,153 gallons of domestic septage per acre per 365-day period to supply the required nitrogen.

$$\textbf{AAR for \_\_\_\_\_} = \frac{\textbf{\_\_\_ lbs. per acre per 365-day period}}{\textbf{0.0026}}$$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.11 C VOLATILE SOLIDS REDUCTION (VSR)

Volatile solids reduction (VSR) is typically achieved by either anaerobic or aerobic digestion which degrades most of the biodegradable material in biosolids to lower activity forms. The material remaining after digestion degrades so slowly that vectors, such as insects and rodents, are not attracted to it. Therefore, achieving a suitable level of VSR helps to ensure that pathogens and diseases are not readily spread by vectors.

Although 40 CFR Part 503 requires a 38% reduction of volatile solids, the regulation does not specify a method for calculating volatile solids reduction. A complete description of the available methods for calculating volatile solids reduction is presented in *Environmental Regulations and Technology - Control of Pathogens and Vector Attraction in Sewage Sludge*, December 1992, U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C. EPA/625/R-99/006, Appendix C. The document can be obtained from EPA's National Service Center for Environmental Publications, at 1-800-490-9198. The document lists the following four methods for calculating VSR:

- Full mass balance method
- Approximate mass balance method
- Constant ash method
- Van Kleeck method

For small to medium sized POTWs, the full mass balance method is unsuitable because it requires more information than is typically collected at a wastewater treatment plant; the constant ash method is roughly equivalent to the Van Kleeck method, but is generally more complex. Therefore, the approximate mass balance (AMB) method and the Van Kleeck method are the most suitable.

The AMB method assumes steady state conditions within the digester, in which the volumetric inputs and outputs are relatively constant on a daily basis and there is no substantial accumulation of volatile solids in the digester over a period of time. The method is accurate in all cases provided that the composition of all streams and the quantities of decant and digested biosolids are known. The Van Kleeck method also assumes steady state conditions but is not accurate when there is grit accumulation. Volatile solids reduction is measured across the digester. However, when appreciable volatile solids reduction occurs after digestion, it is appropriate to measure the loss from just before the digester to the point where the biosolids leave the treatment works.

The remainder of this reference sheet describes the differences between the AMB and Van Kleeck methods and highlights the strengths and weaknesses of each. It is important to note that the VSR calculation is only as accurate as the measurement of volatile solids content in the biosolids. The analytical method to determine the volatile solids content is Method 2540 G of Standard Methods, 18th Edition.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Volatile Solids Reduction

Volatile solids reduction can be determined by using either of the two following method equations:

VAN KLEECK METHOD:

$$\% \ VSR = \frac{(VS_f - VS_b)}{VS_f - (VS_f \times VS_b)} \times 100$$

where VS_f = Fractional volatile solids of raw biosolids fed to the digester, kg/kg

VS_b = Fractional volatile solids of digested biosolids, kg/kg

Note that in this equation fractional volatile solids are the mass of volatile solids per unit mass of total solids.

APPROXIMATE MASS BALANCE METHOD (AMB):

$$\% \ VSR = \frac{(F*Y_f)-(B*Y_b)-(D*Y_d)}{(F*Y_b)} \times 100$$

where F = Volume of raw biosolids fed to digester, m^3/day
Y_f = Volatile solids concentration of raw biosolids, kg/m^3
B = Volume of digested biosolids, m^3/day
Y_b = Volatile solids concentration of digested biosolids, kg/m^3
D = Volume of decant, m^3/day
Y_d = Volatile solids concentration of decant, kg/m^3

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Volatile Solids Reduction

The following table shows how variations in the physical condition of the digester alter the calculated VSR using both methods.

Method/Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
AMB	0.4	0.4	0.4	0.46
Van Kleeck	0.4	0.32	0.4	0.4

Where: **Scenario 1 - No decant removed, no grit accumulation**
Both methods valid
Scenario 2 - No decant removed, grit accumulation
AMB method valid
VK method invalid
Scenario 3 - Decant removed, no grit accumulation
AMB method valid
VK method valid only if volatiles solids in digested biosolids = volatile solids in decantate
Scenario 4 - Decant removed, grit accumulation
AMB method valid if volumetric flow rate of digested biosolids and decantate are measured
VK method invalid

Scenarios 1 - 4 indicate that the most ideal condition within the digester for accurately calculating VSR occurs when decant is not removed from the digester and grit is not accumulating. If those conditions occur, either method produces accurate and valid results. Variations of those physical conditions reduce the viability of using either method. The AMB method can be reliable in many situations, while the Van Kleeck method is useless under some conditions.

As noted above, determining whether grit is accumulating is a key step in deciding which method is most suitable for a particular POTW. This can be determined using the following method:

If: $F*X_f = (B*X_b)$ + fixed solids loss
Then: Fixed solids loss = $(F*X_f) - (B*X_b)$
Where: F = Volume of raw biosolids fed to the digester, m^3/day
X_f = Fixed solids concentration of raw biosolids, kg/m^3
B = Volume of digested biosolids, m^3/day
X_b = Fixed solids concentration of digested biosolids, kg/m^3

If the fixed solids loss is greater than zero it can be concluded that they are accumulating in the digester.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Volatile Solids Reduction

Once it is determined whether grit is accumulating, the following may help in determining which method to use:

Which Method to Use?	
Use AMB	Use Van Kleeck
If grit is accumulating	If there is no grit accumulating
If decant is withdrawn daily and if VS_b ... VS_d	If decant is withdrawn daily and if the $VS_b = VS_d$

*Where: VS_b = Volatile solids of the digested Biosolids
VS_d = Volatile solids of the decantate

After determining which method to use, you are ready to calculate the VSR. No matter which method is used, an average volatile solids concentration must be calculated (Y in the AMB method and VS in the Van Kleeck method). For these methods the averages should be weighted averages according to the mass of the biosolids stream in question. The weighted average based on mass is calculated using the following equation:

$$VS_{av} = \frac{(V_1*TS_1*VS_1)+(V_2*TS_2*VS_2)+(V_3*TS_3*VS_3)+ \ldots}{(V_1*TS_1)+(V_2*TS_2)+(V_3*TS_3)+ \ldots}$$

Where: V_n = Volume of biosolids added to disgester (m^3)
TS_n = Total solids concentration of either the raw biosolids going into the digester or coming out of the digester, Kg/m^3

The following example demonstrates how to calculate volatile solids averages based on mass. The problem is to average the volatile solids concentration for four consecutive biosolids additions to a digester.

Addition	Volume m^3	Total Solids Conc. kg/m^3	Volatile Solids (Y) or (VS)
1	12	72	0.75
2	8	50	0.82
3	13	60	0.80
4	10	55	0.77

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Weighted by Mass

$$VS_{av} = \frac{(12 \times 72 \times 0.75) + (8 \times 50 \times 0.82) + (13 \times 60 \times 0.80) + (10 \times 55 \times 0.77)}{(12 \times 72) + (8 \times 50) + (13 \times 60) + (10 \times 55)} = \mathbf{0.780}$$

The average weighted by mass should be used as the Y variable in the AMB method and the VS variable in the Van Kleeck method. Use of averages weighted by volume or arithmetic averages may not be sufficiently accurate.

Calculations to determine volatile solids reductions for each method are provided below:

VAN KLEECK METHOD:

$$\% \; VSR = \frac{VS_f - VS_b}{VS_f - (VS_f * VS_b)} * 100$$

where VS_f = Fractional volatile solids of raw biosolids fed to the digester, kg/kg
VS_b = Fractional volatile solids of digested biosolids, kg/kg

Example for Van Kleeck Method:

$$\% \; VSR = \frac{0.77 - 0.65}{0.77 - (0.77 * 0.65)} * 100 = 45\%$$

where VS_f = 0.77 kg/kg
VS_b = 0.65 kg/kg

APPROXIMATE MASS BALANCE METHOD (AMB):

$$\% \; VSR = \frac{FY_f - BY_b - DY_d}{FY_f} * 100$$

where F = Volume of raw biosolids fed to digester, m^3/day
Y_f = Volatile solids concentration of raw biosolids, kg/m^3
B = Volume of digested biosolids, m^3/day
Y_b = Volatile solids concentration of digested biosolids, kg/m^3
D = Volume decant, m^3/day
Y_d = Volatile solids concentration of decant, kg/m^3

Please note that the values for B and D must be field measured where decant is withdrawn and grit is accumulating. Additional simplified equations for situations where grit is not accumulating and/or where decant is not withdrawn are provided in the above referenced document.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Example for AMB Method:

$$\% \ VSR = \frac{(100)(50) - (60)(41.42) - (40)(12.76)}{(100)(50)} * 100 = 40\%$$

where $F = 100 \ m^3/day$
$Y_f = 50 \ kg/m^3$
$B = 60 \ m^3/day$
$Y_b = 41.42 \ kg/m^3$
$D = 40 \ m^3/day$
$Y_d = 12.76 \ kg/m^3$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.12 C ASSESSMENT DOCUMENT FOR COMPLIANCE WITH BIOSOLIDS QUALITY REQUIREMENTS FOR POTWs WHICH UTILIZE AEROBIC DIGESTION AND LAND APPLICATION OF BIOSOLIDS

EPA Regulation 40 CFR Part 503 on "Standards for the Use and Disposal of Sewage Sludge" has established new requirements for such practices. This is a simplified document which is designed to assist POTW personnel in the assessment of biosolids quality requirements for POTWs under the regulations. This guidance specifically applies to *aerobic digestion* facilities which practice *land application* of biosolids. These are common practices in EPA Region 8 POTWs. The document is not only simplified for plants of this type, but it also only applies to biosolids quality considerations and not to other considerations such as biosolids management, site considerations, monitoring, recordkeeping, and reporting. Most of the requirements other than those relating to biosolids quality are easier to modify or change and are not as rigidly related to the physical facilities at the POTW as biosolids quality.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

LAND APPLICATION BIOSOLIDS QUALITY ASSESSMENT FOR AEROBICALLY DIGESTED SLUDGE

I. Assess biosolids quality with respect to pollutants

It is recommended that the first step in this assessment be that of assessing biosolids quality with respect to pollutants. There are nine substances or pollutants which have concentration limits. It is assumed that personnel at this POTW have sampled the biosolids on at least one or more occasions to determine the concentration of these pollutants. If not, such testing will have to be done to assess compliance.

There is a schematic diagram below that shows the process of assessing compliance with the pollutant requirement. In addition, Worksheet No. 1 will help you through the process of assessment.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

LAND APPLICATION SLUDGE QUALITY ASSESSMENT AEROBICALLY DIGESTED SLUDGE

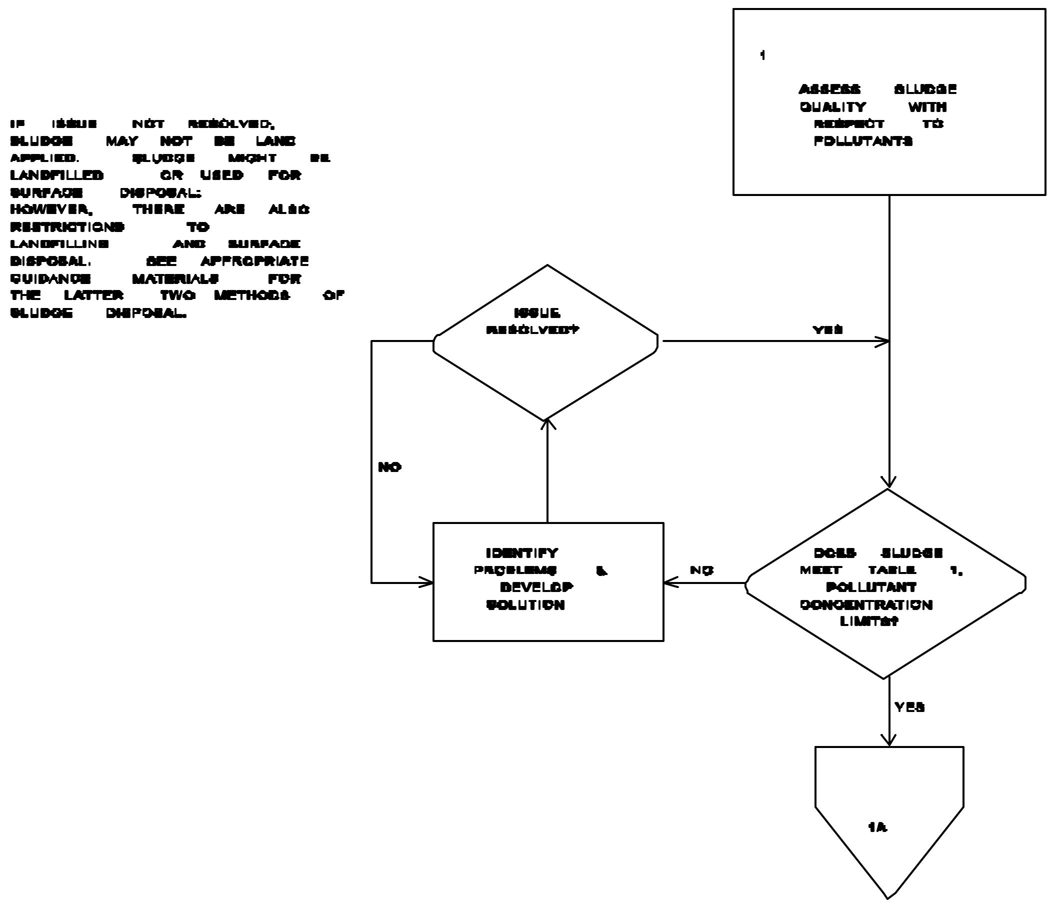


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Worksheet No. 1: Assess Biosolids Quality With Respect To Pollutants

(Note: Use this worksheet to assess compliance with biosolids pollutant ceiling concentration limits for *land application* of biosolids stabilized by aerobic digestion processes.)

1. Compare the quality of your POTW biosolids to the following limits.

Pollutant Ceiling Concentration Limits			
Pollutant	Ceiling Conc. Limit (units:mg/kg)*	Your POTW's Biosolids Quality (units:mg/kg)*	Check Each Box Where Biosolids Pollutant Conc. Is Greater Than The Ceiling (Col.3 > Col.2)
Column: 1	Column: 2	Column: 3	Column: 4
As	75		
Cd	85		
Cu	4,300		
Pb	840		
Hg	57		
Mo	75		
Ni	420		
Se	100		
Zn	7,500		

Table Footnote:

* These units are in terms of mg of the pollutant per kg of dry solids, *i.e.*, solids dried by evaporation at 103 degrees Centigrade for 12 hours, see *Standard Methods*.

2. How many check marks are located in Column 4 of the above table?

3. If "0" is the correct response to the previous question check this line.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
If the correct response is "0," your biosolids meet "Table 1 Pollutant Concentration Limits" and you may proceed to assess your POTW's capability with respect to Class B Pathogens.

4. If you did not check item 3 above, check this line.

If you checked line 4 your biosolids do not meet "Table 1 Pollutant Concentration Limits" and you may not dispose of your POTW's biosolids by "Land Application." Before disposal by "Land Application" the quality of the biosolids must comply with the Table 1 Pollutant Concentration Limits. Retest biosolids immediately and/or determine source of the pollutant(s) which exceed the biosolids quality standard. Please understand that the biosolids may be disposed of by "Surface Disposal" or "Landfilled." However, prior to disposing of your biosolids by either of these methods you should review your plan with your State officials to ensure that all requirements are met.

II. Assess POTW capability with respect to Class B Pathogen requirements.

The Class B Pathogen requirements can be met by (1) utilization of treatment processes that meet requirements for Processes to Significantly Reduce Pathogens (PSRP); Processes to Further Reduce Pathogens (PFRP); other accepted processes equivalent to PSRP or PFRP; or (2) by testing the biosolids to determine the coliform density per gram. This assessment will only address the PSRP process of aerobic digestion, which is a biosolids digestion process often used in Region 8 POTWs, and coliform testing.

The schematic diagram does not show the option of meeting PSRP by other processes that are accepted as equivalent to the identified PSRP processes merely to ensure that it is not overlooked as a possibility. Process equivalency is discussed in Chapter 11 of the document entitled *Environmental Regulations and Technology - Control of Pathogens and Vector Attraction in Sewage Sludge*, EPA/625/R-99/006, September 1999. All POTWs should have this document available for reference. This document should be available from EPA's National Service Center for Environmental Publications, at 1-800-490-9198. Equivalency designations are difficult to obtain and any POTW personnel who feel that they have an equivalent process should discuss their ideas with State or EPA personnel before making application for equivalency.

Shown below is a continuation of the schematic diagram which covers assessment of biosolids quality with respect to pathogens and a worksheet, Worksheet No. 2, to assist in this process. The worksheet first addresses the monitoring of the biosolids coliform density and, secondly, compliance with the PSRP requirements. **Keep in mind that compliance can be met by either approach, depending on which is preferred by your POTW.** Consequently some POTWs may wish to address compliance with PSRP either without further need for consideration of coliform monitoring or at least prior thereto.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

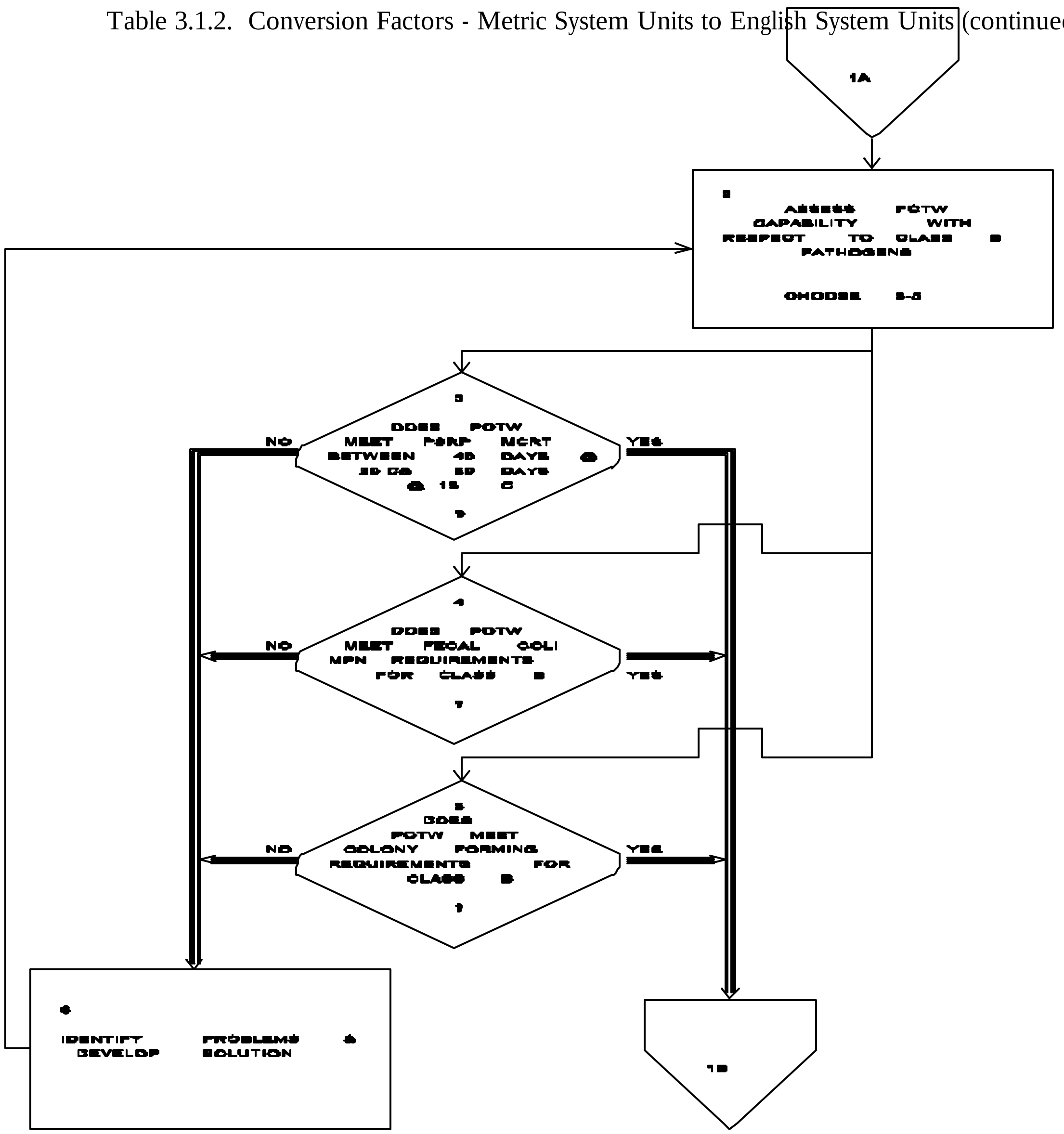


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Worksheet No. 2: Assess POTW Capability with respect to Class B Pathogen Requirements

1. Monitoring Fecal Coliform Density.

Testing for fecal coliform density requires that a minimum of 7 samples of treated biosolids be collected at or near the time of use or disposal of the biosolids. The geometric mean fecal coliform density of these samples must be less than 2 million CFU (Colony Forming Units) or MPN (Most Probable Number) per gram of sludge solids (Total Solids, dry weight basis).

The seven samples should be collected over a 2-week period during each monitoring event. For small plants (those in which there are less than 290 dry metric tons of biosolids produced per year), Region 8 requires that the biosolids be monitored during the most severe time of the year, from a cold temperature standpoint, to ensure meeting the regulations year-round.

Please note that the coliform density is expressed in terms of CFU or MPN per gram of sludge solids (Total Solids, dry weight basis). Therefore an aliquot of each sample must be dried and the solids content determined in accordance with procedure 2540 of *Standard Methods for the Examination of Water and Wastewater*, 18th Edition.

Please read the AWhite House document@ (EPA document EPA/625/R-99/006 entitled *Environmental Regulations and Technology - Control of Pathogens and Vector Attraction in Sewage Sludge*) carefully for more detailed recommendations for sampling and analysis of biosolids for compliance with Part B Pathogen requirements.

Biosolids samples can be analyzed for MPN or CFU according to either of two procedures as follows:

a. Standard Methods procedure 9221. This is a procedure using dilution tubes which results in a Most Probable Number of fecal coliform organisms per gram of sludge solids (Total Solids).

b. Standard Methods procedure 9222. This is a procedure using membrane filters which results in numbers of Colony Forming Units per gram of sludge solids (Total Solids).

To determine the Geometric Mean Coliform Density, list in the table below the coliform density per gram of biosolids for each of the 7 or more samples collected over the sampling period. Determine the logarithm to Base 10 for each density listed and with this data calculate the geometric mean Fecal Coliform density per gram of sludge solids.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Sample Number	Coliform Density per gram of biosolids	Log (Base 10)
	Sum (1)	

Geometric Mean = Antilog of Average of Log
Coliform Density (Base 10) Numbers, where (2) is number
Per Gram * of samples

= Antilog of [(1)) (2)]

= Antilog (________)
( )

= _______ CFU or MPN
(circle correct unit)

* The Geometric Mean will be in either CFU or MPN units depending on the type of tests performed.

Please keep in mind that there are many chances for error in these calculations, so check your procedures and calculations carefully. Keep all records and calculations. After checking your calculations and procedures, do the biosolids from your POTW meet Class B pathogen requirements? If the geometric mean coliform density is less than 2,000,000 (2 million) MPN or CFU per gram of sludge solids (dry weight) you have met the requirement.

Do the biosolids meet this requirement? ___ Y/N

If the answer is "Yes," you may proceed to assess compliance with the Vector Attraction Reduction requirements, below.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

If the biosolids do not meet the coliform density criterion, you must either retest biosolids coliform density or assess compliance with Class B Pathogen requirements by means of Processes to Significantly Reduce Pathogens (PSRP); see Item 2 below. Once your biosolids have failed the Coliform density test on two consecutive sampling events (2 two-week sampling periods) you should proceed to assess compliance with requirements presented under Item 2.

2. Meeting Class B Pathogen requirements by means of Processes to Significantly Reduce Pathogens (PSRP).

Since your plant has aerobic digestion facilities, this procedure is to determine whether you meet PSRP for aerobic digesters.? Aerobic digestion processes which meet PSRP requirements are processes in which the biosolids are agitated with air or oxygen to maintain aerobic conditions for a mean cell residence time and temperature between 40 days at 20EC and 60 days at 15EC.

a. Temperature.

If your aerobic digester has temperatures within the digestion facilities less than 15EC. for any significant length of time,

---

? It should be pointed out that alternative processes that are equivalent to PSRP can also be used to meet Class B requirements. Table 5-2 on page 24 of the White House document lists some of the processes that the EPA Pathogen Equivalency Committee has determined to be equivalent. In addition, it is possible to have other biosolids treatment processes classified as "Processes to Significantly Reduce Pathogens." Chapter 11 of the White house document discusses how pathogen equivalency is established. However, such determinations are difficult to obtain and any POTW personnel who feel they have an equivalent process to the identified PSRP processes should discuss their ideas with State or EPA personnel before making application for equivalency.

If your facility does not comply with the requirements for PSRP, certain measures, including heating, insulation and covering of digesters can be undertaken; however, they should be carefully evaluated before adding such facilities to try to meet minimum temperature requirements.

List below the aerobic digester temperature data covering the last year of operation. Do not include temperature data collected for biosolids holding facilities, *i.e.*, processes following the aerobic digester.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Minimum Digester Mixed Liquor Temperatures - Four Coldest Months

Month/Year	Average Min. Temp 1st Stage	Average Min. Temp 2nd Stage	Average Min. Temp Other Stages

Select the coldest of the average minimum temperatures in the digestion facilities over a 2-months or 60-day period. List that temperature as follows _____ EC. Is this value $ 15EC?
____ (Y/N). If the answer is no, your aerobic digester does not meet the requirements for PSRP as indicated earlier. If the answer is yes proceed with the assessment.

b. Mean Cell Residence Time (MCRT).

As indicated previously the MCRT for aerobic digesters must be between 40 days at 20EC and 60 days at 15EC. (Longer values would be permitted.) To evaluate MCRT values please show in the space below or on an attached sheet, by means of a schematic drawing, how the aerobic digestion facilities are arranged and the process and flow sequence used through the digesters. This will permit review of your calculations and procedures.

With the coldest average temperature recorded over a 60 day period, determined under Item "a" above, use the attached "Aerobic Digestion Temperature / MCRT" graph (page 11) to determine the required MCRT for your system. The required MCRT from the graph is _____ days.

Now determine the MCRT or the HRT for your aerobic digestion facilities. Since the Hydraulic Residence Time (HRT) is usually easier to calculate, we suggest that you first calculate the HRT using the following formula:

$$HRT = V/q$$

where V is the volume of the aerobic digester and q is the rate of flow of biosolids into the digester. An example is as follows:

V = 100 cubic meters and q = 2.5 cubic meters per day

$$HRT = \frac{100 \text{ cubic meters}}{2.5 \text{ cu. meters/day}} = 40 \text{ days}$$

The HRT is usually an acceptable value for MCRT in aerobic digestion where the digester approximates a complete

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

mix reactor, the volume remains reasonably constant from day to day, there is biosolids discharge to the digester essentially each day and a similar withdrawal of supernatant or exiting digested biosolids. Do you operate your digester in this manner? __ (Y/N) If yes calculate the HRT of your digester as indicated. If no, skip the HRT calculation and proceed to the MCRT determination.

The value of q should be determined for the same 60-day period that was used in the temperature determination. The value of q should be in cubic meters per day if the volume is in cubic meters per day so that the unit of time comes out in days.

The value of q can be determined by flow measurement (provided that such facilities are available in your POTW) over a given period of time, or it can be estimated from piston pump volumes and the number of strokes of the pump which occur over a given time period. It might also be estimated by pumping into a measuring container or into the aerobic digester if the depth and subsequent volume could be calculated with reasonable accuracy by raising the liquid level a significant amount over a fairly lengthy period of time. However, keep in mind that most pumps other than piston pumps have changes in rate of flow with differing head conditions. So if the latter type of estimate is being made and the pump is discharging against less head than in actual practice, the rate of flow could be inaccurate. If you have difficulty with this calculation, we suggest you consult your consulting engineer or your State or EPA contact.

Use the space below to show your calculations in computing the HRT for your plant.

My calculation for HRT is _____ days.

MCRT

If the HRT does not meet the required number of days or the parameters indicated above for its use are not valid, the MCRT may be calculated using the White House document for assistance. Calculation of MCRT would be required if the digester is operated as a batch process, if the feed biosolids concentration and/or flow varies substantially from day to day, and if the digester volume does not remain reasonably constant.

Please see Appendix E, pages 99 - 102 of the White House document for different examples on determination of MCRT for aerobic digesters. In addition, please see the attached sheet entitled "Calculation of MCRT" (page 13) which is an example of Case 4 on page 101 of the White House document. This example covers a mode of operation of aerobic digesters frequently used in small plants. The example, Case 4 in the White House document makes use of Equation 3 of that document as listed on page 99. The equation is as follows:

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

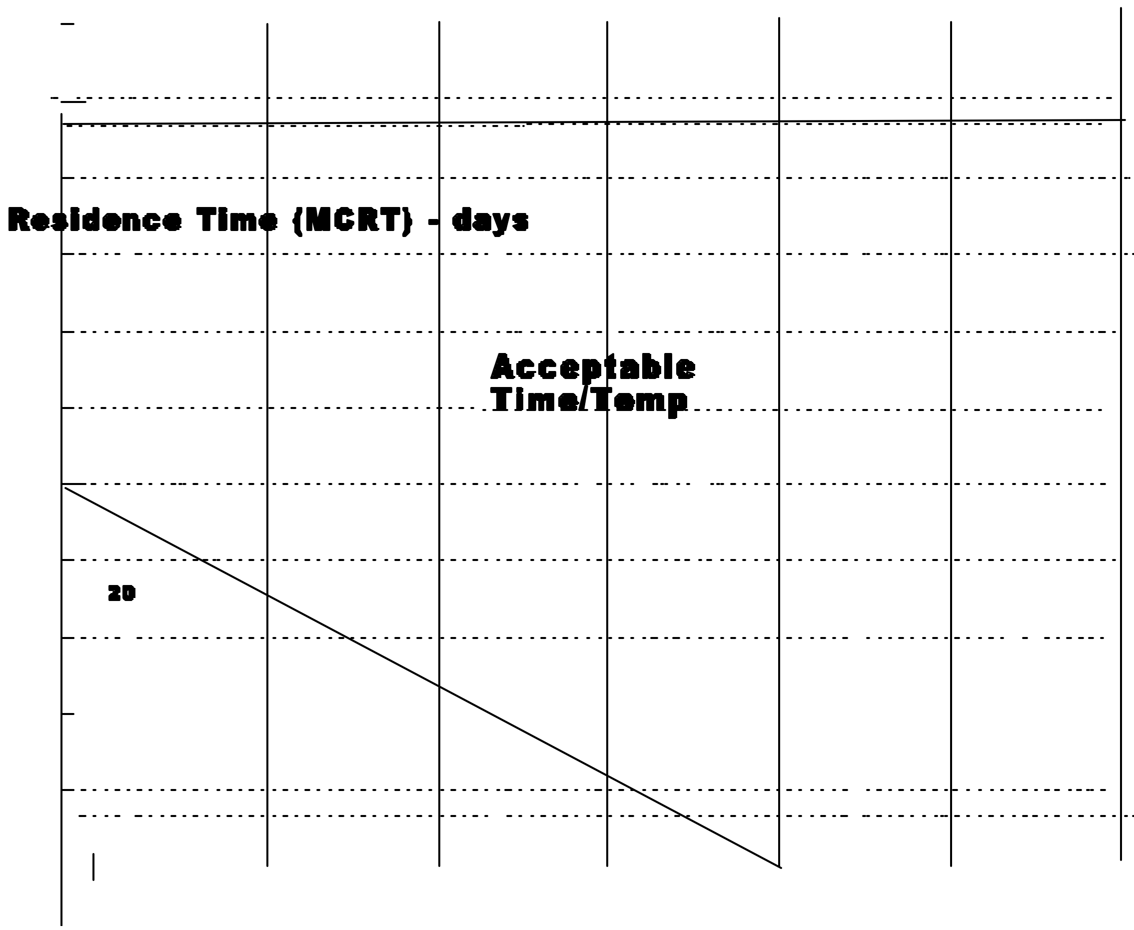


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

$$\text{Nominal average solids residence time or MCRT} = \frac{V\,(Cv)}{q\,(Cq)}$$

where V = reactor volume, q = flow rate leaving, Cv = concentration of solids in the reactor, and Cq = concentration of solids in exiting biosolids.

An average (arithmetic mean) for a specific time period is one method of determining the data to use for an MCRT calculation. Another method might be to use a 60-day moving average. A 60-day moving average, for example, is where you take the last 60 days of data, add all the values, and divide by 60 days. Then as you move on from day to day you subtract the data from day one (the data for the earliest day) and add the data for the current day to the sum of all the daily values. As you calculate the sum each day and divide it by 60 days, you have a 60-day moving average.List the HRT and/or the MCRT value that was obtained from the above calculation(s). HRT ____days MCRT ___days. Does your facility meet the required number of days for MCRT? _____(Y/N) Please show the data and calculations involved in these determinations in the space below.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Calculation of MCRT

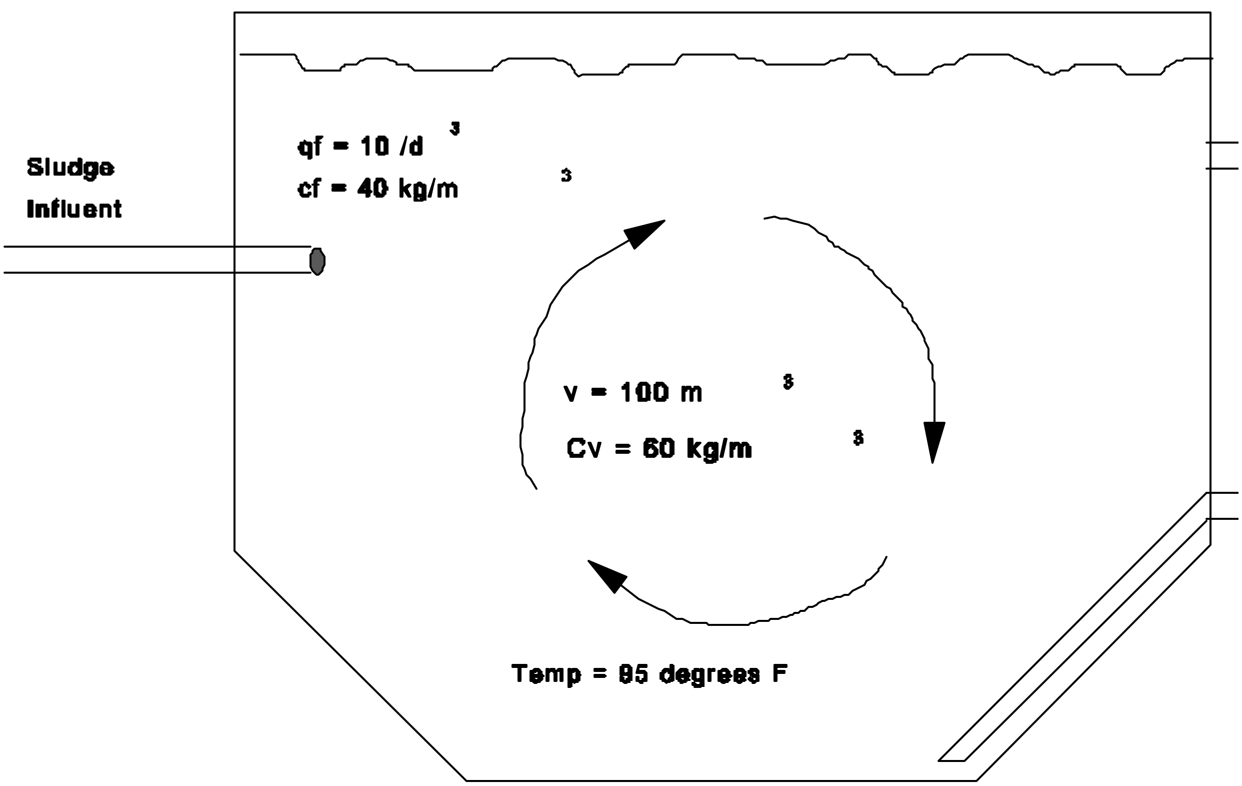


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

c. Dissolved Oxygen Concentration.

The PSRP for aerobic digestion requires that aerobic conditions be maintained in the aerobic digester. This has been considered to mean maintenance of dissolved oxygen concentrations between 1.0 and 2.0 mg/L except perhaps when allowing the biosolids to settle for short periods of time prior to decanting as a means of concentrating the biosolids in the digester. The critical time for meeting the D.O. level is probably when the biosolids in the digester are most concentrated and when the temperature in the digester is at or near its highest level. This is true provided that oxygen is continuously being supplied to the digester which is probably necessary, with the exception mentioned above, in order to maintain aerobic conditions.

List the minimum Dissolved Oxygen concentrations measured in the aerobic digester during the two month period used to calculate the HRT or MCRT period in the digester.

Month	Min. D.O. 1st Stage	Min. D.O. 2nd State	Min. D.O. Other Stages

d. Mixing

In addition to the above requirements, adequate mixing in aerobic digesters is an important part of the adequacy of such facilities, but not a specific requirement for conformance with the Part 503 regulations. It is mentioned here so that you do not overlook an important item in aerobic digestion treatment. Although some deposition of settleable solids often occurs in the corners and on the bottom of aerobic digesters, settled solids accumulation should not be excessive, and the biosolids density should be fairly uniform throughout the aerobic digester.

Are the contents of your digester adequately mixed? __(Y/N)

3. Conclusion

You have now determined if your POTW meets the Class B Pathogen requirements either by means of Fecal Coliform sampling or by meeting the requirements of Processes to Significantly Reduce Pathogens (PSRP).

Does your POTW meet the Class B Pathogen Requirements? ___ (Y/N) If Class B Pathogen requirements are not met, your biosolids may not be land applied.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

III. Assess POTW with Respect to Vector Attraction Reduction

On the following page there is a continuation of the schematic diagram covering this overall biosolids assessment. This portion covers the assessment of your POTW and the biosolids produced with respect to vector attraction requirements. With reference to the schematic you might first note that the assessment covers three land application-related practices: (1) the surface application of biosolids in a land application program; (2) the subsurface injection of biosolids in a land application program; and (3) the incorporation of biosolids into the soil in a land application program.

Since more biosolids are surface applied than land applied by means of subsurface injection or incorporation into the soil, the schematic (and the worksheet which follows it) first address the situation in which biosolids are surface applied. *Any* of the seven alternatives listed may be used to verify or show conformance with the vector attraction reduction requirements. These are the alternatives listed as "a" through "g" under Item 1 in the worksheet. Consequently it is important that you <u>not</u> try to use all of the alternatives to show compliance. Instead you should use the alternative or alternatives that are most applicable and most practical for your plant and the processes which are available, if any, in addition to aerobic digestion. It is only necessary to meet one of the seven alternatives.

The alternatives for surface applied biosolids are not addressed in the same sequence in Worksheet No. 3 as they are listed in the schematic. This has no significance other than that the SOUR test, for instance, might be easier to use than some of the others for an aerobic digestion plant. All seven alternative will not be practical or even possible for most plants.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

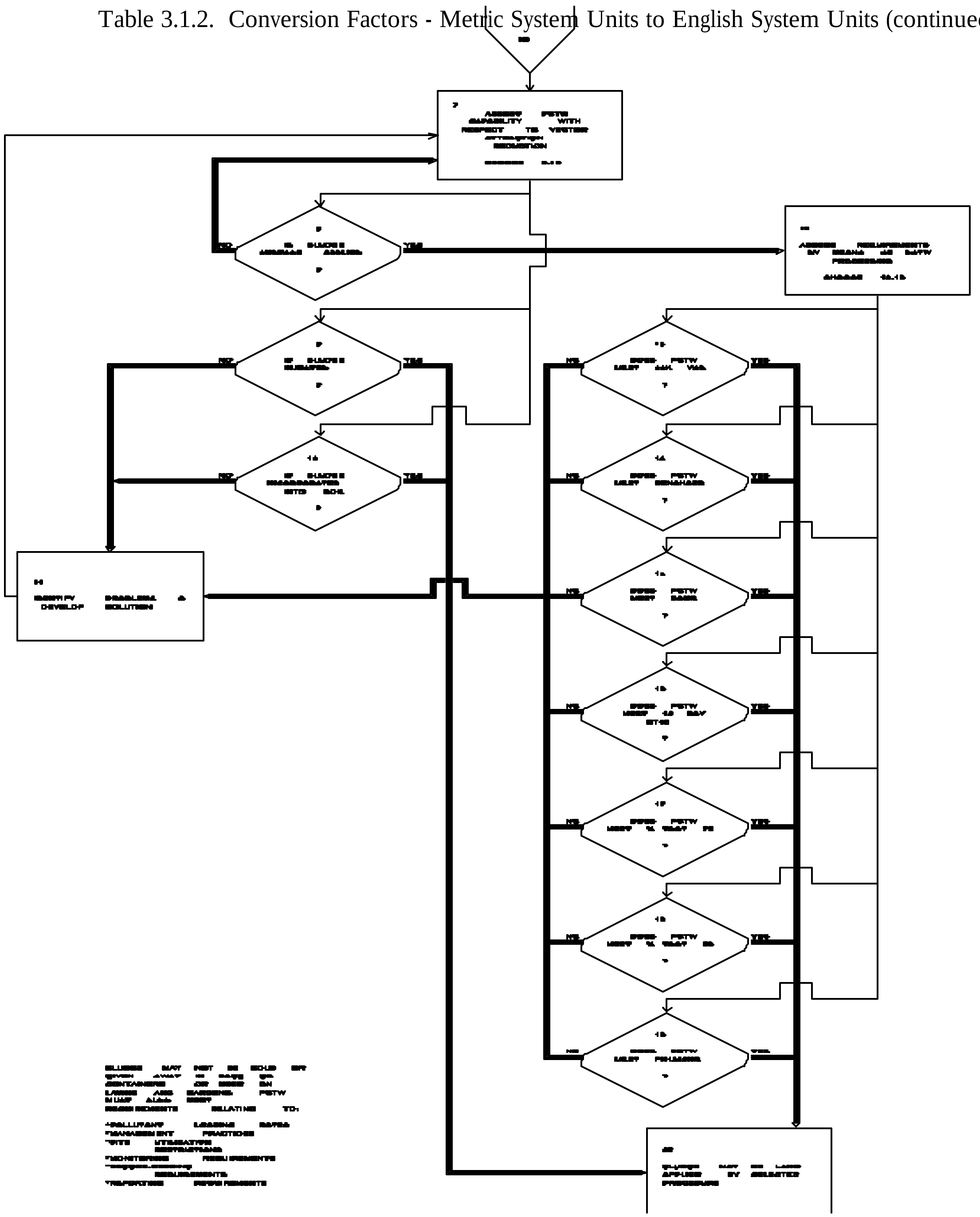


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Worksheet No. 3: Assess POTW with Respect to Vector Attraction Reduction

1. Assess biosolids that are surface applied

This portion of the worksheet covers biosolids which are land applied to the land surface and which are not injected or otherwise incorporated into the soil to keep the biosolids from contact with potential vectors.

a. Specific Oxygen Uptake Rate (SOUR) for aerobically digested biosolids (SOUR)

This is one of several methods for assessment of biosolids with respect to Vector Attraction Reduction. Adequate vector attraction reduction is obtained if the SOUR of the biosolids (*i.e.*, biosolids from the final biosolids treatment process) to be used or disposed is determined to be equal to or less than 1.5 mg of oxygen per hour per gram of total sludge solids (dry weight basis) at 20EC. The oxygen uptake rate depends on the conditions of the test and, to some degree, on the nature of the original biosolids before aerobic treatment. The SOUR method may be unreliable at solids content above 2% and it requires a poorly defined temperature correction at temperatures differing substantially from 20EC. Guidance on performing the SOUR test and on biosolids-dependent factors are provided in Appendix D of the White House document. If you use this alternative for Vector Attraction Reduction, please provide details in the space provided below to describe the process used and to show your calculations.

List below your calculated SOUR value. Please list the value in the indicated terms. SOUR = ___ mg O5/ hr-gram of Total Solids at 20EC. Does this alternative show compliance with Vector Attraction Reduction requirements? (Y/N) If the answer is yes, you should be ready to draw final conclusions as to compliance by your biosolids and POTW with the biosolids quality requirements for land application of biosolids. If the answer is no, you should proceed to one of the other 6 Vector Attraction Reduction alternatives for land application of aerobically digested biosolids to the land surface to assess compliance.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

b. Thirty-eight % or greater Volatile Solids Reduction

Ordinarily, Volatile Solids Reduction (VSR) is calculated through the aerobic digestion process; however, it is acceptable to calculate the reduction across all biosolids treatment processes where there is treatment following digestion, *i.e.* through biosolids holding tanks or lagoons, biosolids drying beds, etc. Examples in this worksheet and in the White House document are based on calculation of VSR across the aerobic digestion process.

To calculate the percentage reduction in VS (Volatile Solids) through the digestion facilities at your POTW, you will need to collect the following data on digester operation. The symbols used are the same as those used in the White House document, Appendix C, except for TS (Total Solids Concentration). This is added since it is also data that should be collected and records kept. For example, the total solids concentration may be needed to weight average values in the determination of volatile solids reduction (See "Average Values" on page 89 of the White House document).

Feed Biosolids
F = Volumetric Flow Rate, say in m^3/d
Yf = Volatile solids concentration, say in kg/m^3
Xf = Fixed solids concentration, say in kg/m^3
VSf = Fractional volatile solids, say in kg/m^3
TSf = Total solids, say in kg/m^3

Digested Biosolids
B = Volumetric Flow Rate, say in m^3/d
Yb = Volatile solids concentration, say in kg/m^3
Xb = Fixed solids concentration, say in kg/m^3
VSb = Fractional volatile solids, say in kg/m^3
TSb = Total solids, say in kg/m^3

Decantate (Supernatant)
D = Volumetric Flow Rate, say in m^3/d
Yd = Volatile solids concentration, say in kg/m^3
Xd = Fixed solids concentration, say in kg/m^3
VSd = Fractional volatile solids, say in kg/m^3
TSd = Total solids, say in kg/m^3

If it is determined that the calculation of VSR in your POTW can be done without some of the above data (such as through use of the Van Kleeck equation? where there is no grit accumulation and VSb = VSd) an adjustment can be made in some of the data needed. When the above data are used in the equations for calculation of percent reduction of VS, averages need to be used. It is recommended that averages obtained from data over at least a 60-day period should be used. For the smaller POTWs where VSR may be calculated only once a year, it is important that the data utilized be collected during the coldest period of the year to help ensure that the VSR would be met all year long. The average values should be weighted (preferably on the basis of mass of solids in the different streams) as explained on pages 89 and 90 of the White House document. This requires use of the Total Solids concentration in the biosolids stream.

To check the VSR achieved by your POTW a data sheet is attached (as page 34) that can be used to list data to be

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
used in the VSR calculations. This is the sheet titled "Calculation of VSR and Grit Accumulation."

In calculating the Volatile Solids Reduction (VSR) through your POTW digestion facilities, reference is made to sheets VSR1, VSR2, VSR3, VSR4 and VSR5, which are attached. These reference sheets were developed by Bob Brobst, EPA Region 8 to summarize and use with the information presented in Appendix C of the White House document.

? See pages 88 and 89 of the White House document and/or the sheet identified as "VSR 1," attached.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

It is suggested that POTW personnel first calculate the percentage volatile solids reduction using the Van Kleeck method with the formula on Sheet VSR1. Please note that the fractional volatile solids are determined by dividing the mass of volatile solids in kg/m^3 by the total solids in kg/m^3.

The formula is as follows:

$$\% \text{ VSR} = 100 * \frac{\text{VSf - VSb}}{\text{VSf - (VSf * VSb)}}$$

(The standard formula is multiplied by 100 to put the answer in a percentage form, *e.g.*, 38.3% instead of 0.383)

VS, is the mass of volatile solids per unit mass of total solids, kg/kg.

VSf = Fractional volatile solids of raw biosolids fed to the digester, kg/kg

VSb = Fractional volatile solids of digested biosolids, kg/kg

Example: Based on data from Table C-1 page 87 of White House document. Problem 2. Values for Volatile Solids and Total Solids are weighted averages for a 60-day period. In the table below, Y is used as the symbol for Volatile Solids Concentration.

Basic Data:	Feed Biosolids	Digested Biosolids
Y	50,000 mg/L	30,000 mg/L
TS	67,000 mg/L	45,00 mg/L

$$\text{VSf} = \frac{50{,}000 \text{ mg/L}}{67{,}000 \text{ mg/L}} = \frac{50 \text{ kg/m}^3}{67 \text{ kg/m}^3} = 0.746$$

$$\text{VSb} = \frac{30{,}000 \text{ mg/L}}{45{,}000 \text{ mg/L}} = \frac{30 \text{ kg/m}^3}{45 \text{ kg/m}^3} = 0.667$$

$$\% \text{ VSR} = 100 * \frac{0.746 - 0.667}{0.746 - (0.746 * 0.667)} = 31.8 \%$$

Note: mg/L is converted to kg/m^3 as follows:

1,000,000 mg = 1 kg

1 mg = .000001 kg

28.32 L = 1 ft^3

27 ft^3 = 1 yd^3

1 yd^3 = .765 m^3

$$1 \text{ L} = \frac{1}{28.32} * \frac{1}{27} * .765 \text{ m}^3 = .001 \text{ m}^3$$

$$\text{mg/L} = \underline{.000001} \text{ kg/m}^3 = .001 \text{ kg/m}^3$$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
.001

Now please make your calculation of %VSR using the Van Kleeck equation listed above. Please show the data used and your calculations in the space provided below or on an attached sheet.

____
____
____
____
____

The % VSR using the above method was ____%. Is the value greater than the needed 38% VSR, thereby indicating compliance with this requirement? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions as to compliance by your biosolids and POTW with the biosolids quality requirements for land application of biosolids. If the answer is no, your digester may be affected by the accumulation of grit. In that case proceed to Sheet VSR1 again and determine the volatile solids reduction using the Approximate Mass Balance Method (AMB). The formula for this determination is as follows:

$$\%\ VSR = 100 * \frac{FYf - BYb - DYd}{FYf}$$

(Here again the standard formula is multiplied by 100 to put the answer in a percentage form.)

F = Volume of raw biosolids fed to digester, m^3/day
Yf = Volatile solids concentration of raw biosolids, kg/m^3
B = Volume of digested biosolids, m^3/day
Yb = Volatile solids concentration of digested biosolids, kg/m^3
D = Volume of decantate, m^3/day
Yd = Volatile solids concentration of decantate, kg/m^3

Example: Based on data in Table C-1 page 87 of White House document. Problem 4. Values for Volatile Solids and Total Solids are weighted averages for a 60 day period. Volumes of biosolids per day are measured and are also average values.

Basic Data:	Feed Biosolids	Digested Biosolids	Decantate
Vol/day	26,400 gpd	13,086 gpd	13,314 gpd

$$F = 26{,}400\ \text{gal/d} = \frac{26{,}400\ \text{gal/d}}{264\ \text{gal/}\ m^3} = 100\ m^3/\text{d}$$

VS conc.	50,000 mg/L	41,420 mg/L	12,760 mg/L

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

$$Yf = 50{,}000 \text{ mg/L} * \frac{1}{1{,}000} = 50 \text{ kg/ m}^3$$

(Note that there is an explanation of the above conversion on pages 22 and 23.)

$$B = 13{,}086 \text{ gal/d} = \frac{13{,}086 \text{ gal/d}}{264 \text{ gal/ m}^3} = 49.57 \text{ m}^3\text{/d}$$

$$Yb = 41{,}420 \text{ mg/L} * \frac{1}{1{,}000} = 41.42 \text{ kg/ m}^3$$

$$D = 13{,}314 \text{ gal/d} = \frac{13{,}314 \text{ gal/d}}{264 \text{ gal/ m}^3} = 50.43 \text{ m}^3\text{/d}$$

$$Yd = 12{,}760 \text{ mg/L} * \frac{1}{1{,}000} = 12.76 \text{ kg/ m}^3$$

$$\%\ VSR = 100\ \frac{(100)\ (50) - (49.57)\ (41.42) - (50.43)\ (12.76)}{(100)\ (50)}$$

$$\%\ VSR = 100 * \frac{2{,}304}{5{,}000} = 100 * .461 = 46.1\%$$

As indicated on Sheet VSR3, there is a formula to determine if grit is accumulating. This formula (see Problem No. 4 on page 88 of the White House document) is as follows:

$$\text{Fixed Solids Loss} = \frac{FXf - BXb - DXd}{FXf} \text{ where,}$$

F = Volume of raw biosolids fed to digester in m^3/d

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
Xf = Fixed solids concentration of raw biosolids in kg/m^3

B = Volume of digested biosolids in m^3/day

Xb = Fixed solids concentration of digested biosolids in kg/m^3

D = Volume of decantate biosolids in $m^{3/d}$

Xd = Fixed solids concentration in decantate biosolids in kg/m^3

Example:

Basic Data:	Feed Biosolids	Digested Biosolids	Decantate
Biosolids Vol.	100 m^3/d	49.57 m^3/d	50.43 m^3/d
Fixed Solids Concentration	17 kg/m^3	23.50 kg/m^3	7.24 kg/m^3

(Please note that the above data comes from Table G-1 on page 87 of the White House document for

$$\frac{\text{Fixed Solids Loss}}{\text{(as a fraction)}} = \frac{(100)\,(17) - (49.57)\,(23.50) - (50.43)\,(7.24)}{(100)\,(17)}$$

$$= \frac{170}{1700} = 0.1 \text{ or } 10\%$$

Problem 4.)

If you utilized the Approximate Mass Balance (AMB) Method to calculate the % Volatile Solids Reduction, please show the data used and your calculations in the space provided below or on an attached sheet.________________

____
____
____
____
____
____
____

The % VSR using the AMB method was as follows ____ %. Is the value greater than the needed 38% VSR, thereby indicating compliance with this requirement? ____ (Y/N) If the answer is yes, you should be ready to draw final conclusions as to compliance by your biosolids and POTW with the biosolids quality requirements for land application of biosolids. Did you calculate the Fixed Solids Loss in your aerobic digester? ____ (Y/N) Did this calculation show a significant accumulation of grit? ___ (Y/N)
If the % VSR using the AMB method was not greater than 38%, you have not met the requirement for Vector Attraction Reduction by means of this assessment and you should proceed to assess compliance by means of one of

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
the other 6 Vector Attraction Reduction test alternatives. If you have a concern about the correctness of the calculations using % Volatile Solids Reduction, you should check them with State or EPA personnel with whom you have contact.

c. Additional digestion of aerobically digested (BENCHAER).

This is an option that may be used with aerobically digested biosolids. Aerobically digested biosolids with 2% or less solids are considered to have achieved satisfactory vector attraction reduction if they lose less than 15% additional volatile solids when aerobically batch-digested in a laboratory in a bench-scale unit at 20EC. (68EF.) higher for an additional 30 days. Procedures for this test are presented in Appendix D of the White House document. Biosolids with greater than 2% solids can be diluted to 2% solids with effluent, and the test can then be run on the diluted biosolids. If you use this alternative to assess Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet. Did the biosolids being tested have less than 2% solids? __ (Y/N) Was it necessary to dilute the biosolids to achieve less than 2% solids? ___ (Y/N) Did the biosolids lose less than 15% additional volatile solids, thus meeting the requirements of this test for compliance with the Vector Attraction Reduction requirements? __ (Y/N)

If the above test and calculations indicate a yes answer to compliance with this test, you should be ready to draw final conclusions as to compliance by your biosolids and POTW with the biosolids quality requirements for land application.

If the answer to the above question was no, you have not met the requirement for Vector Attraction Reduction by means of this assessment and you should proceed to assess compliance by means of one of the other 6 Vector Attraction Reduction test alternatives.

d. Meeting Vector Attraction Reduction by aerobically composting the biosolids for 14 days or longer with the temperature over 40EC., and with the average temperature higher than 45EC **(14DAYGT40)**.

This option is discussed in greater detail in the White House document. Most aerobic digestion plants are not also equipped for composting biosolids, so few plants will be able use this option or alternative to achieve compliance with Vector Attraction Reduction requirements. The guidance does indicate that the option can be applied to processes such as aerobic digestion, but other options are more likely to meet the requirements.

If you utilize this alternative for Vector Attraction Reduction, please provide details and data in the space provided below or on an attached sheet.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for the land application. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

e. Meeting Vector Attraction Reduction by drying to remove water or moisture so that the solids content of the biosolids is at least 75% and no unstabilized primary treatment solids are included **(%TSGT75)**.

Please read the additional details regarding this option in paragraph 6.8 on page 29 of the White House document. If you utilize this alternative for Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet.

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for land application. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

f. Meeting Vector Attraction Reduction by drying to removed water or moisture so that the solids content of the biosolids is at least 90% when unstabilized primary treatment solids are included **(%TSGT90)**.

This alternative is discussed in the White House document. If you utilize this alternative for Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet.

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for the land application of biosolids. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

g. Meeting Vector Attraction Reduction by means of Alkaline Stabilization in which the pH is raised to at least 12 by alkali addition and, without the addition of more alkali, the pH remains at 12 or higher for 2 hours and then 11.5 or higher for an additional 22 hours **(PH1222HR)**.

If you utilize this alternative for Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet.

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for the land application of biosolids. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

2. Assess biosolids that are subsurface injected or incorporated into the soil.

a. Subsurface Injection: If biosolids are not surface applied, but are injected into the soil beneath the soil surface, meeting the Vector Attraction Reduction (VAR) requirements can be accomplished by this procedure. It must be properly done as explained on pages 29 and 30 of the White House document. If injected into the soil it must be done in such a manner that no significant amount of biosolids is present on the land surface within one hour after injection. This places a barrier of earth between the biosolids and possible vectors. Odors should dissipate quickly following injection. It is suggested that POTW personnel utilizing this practice use photographs to show the condition of the soil before and after injection, and maintain information regarding the equipment used to accomplish injection.

b. Incorporation into the Soil: Under this practice the biosolids applied to the land surface must be incorporated into the soil within 6 hours after placement on the land. As indicated in the White House document, if mixing with the soil is reasonably good, odors and any appearance of biosolids will be virtually eliminated after mixing occurs. It may be wise to accomplish the mixing or incorporation quickly (much less than 6 hours) if the soil has considerable clay because clay soils tend to become unmanageably slippery and muddy if liquid biosolids are allowed to soak into the first inch or two of topsoil.

Please keep records that include the following information when injecting or incorporating biosolids into the soil.

Date of Inj or Incorp.	Location	Time of Inj or Applic'tn.	Time of Mixing into soil	Weather Conditions

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Date of Inj or Incorp.	Location	Time of Inj or Applic'tn.	Time of Mixing into soil	Weather Conditions

Description of Procedure and Equipment Used.

____
____
____
____
____
____

Has your POTW met the Vector Attraction Reduction Requirement by means of sub-surface injection? __ (Y/N)
Has your POTW met the Vector Attraction Reduction Requirement by means of incorporation into the soil? (Y/N)

3. Conclusion

You now should have determined if your biosolids and POTW meet Vector Attraction Reduction requirements. Does your POTW meet this requirement? __ (Y/N) If the answer is yes, and you have met the requirements for pollutants and for Class B Pathogens, your biosolids meets quality requirements for land application; however, the other requirements of the regulations must also be met. The other requirements include those relating to Pollutant Loading Rates, Management Practices, Site Utilization Restrictions, Monitoring Requirements, Recordkeeping Requirements, and Reporting Requirements. It addition it should be pointed out that biosolids which just meet the requirements of this assessment may not be sold or given away in bags or containers or used on lawns and gardens.

VSR 1

VS - Fractional Volatile Solids - Mass of volatile solids per unit of mass of total solids kg/kg

$$\% \text{ VSR} = \frac{VS_f - VS_b}{VS_f - (VS_f * VS_b)}$$

Van Kleeck Method:

VS_f = Fractional volatile solids of raw biosolids fed to the digester, kg/kg

VS_b = Fractional volatile solids of digested biosolids, kg/kg

Approximate Mass balance Method (AMB)

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

$$\% \, VSR = \frac{FY_f - BY_b - DY_3}{FY_f}$$

F = Volume of raw biosolids fed to digester m^3/day
Y_f = Volatile solids concentration of raw biosolids, kg/m^3
B = Volume of digested biosolids. m^3/day
Y_b = Volatile solids concentration of digested biosolids, kg/m^3
D = Volume of decantate. m^3/day
Y_d = Volatile solids concentration of decantate, kg/m^3

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

VSR 2

	1	2	3	4
AMB	0.4	0.4	0.4	0.46
Van Kleeck	0.4	0.32	0.4	0.4

1. No decant, no grit accumulation
   Both methods valid and correct

2. No decant, grit accumulation
   AMB method valid
   VK method invalid and incorrect

3. Decant, no grit accumulation
   AMB method valid
   VK method valid (if VS_b equals VS_d)

4. Decant, grit accumulation
   AMB method valid (if B and D are measured)
   VK method invalid

VSR 3

To determine whether grit is accumulating:

$FX_f = BX_b$ / Fixed solids loss

Fixed solids loss = $FX_f - BX_b$

F = Volume of raw biosolids fed to digester, m^3/day

Xf = Fixed solids concentration of raw biosolids, kg/m^3

B = Volume of digested biosolids, m^3/day

X_b = Fixed solids concentration of digested biosolids, kg/m^3

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

VSR 4

Y and VS values used should be averages

Averages should be weighted averages

Additional	Volume	TS concentration	VS
1	12 m^3	72 kg/m^3	0.75
2	8 m^3	50 kg/m^3	0.82
3	13 m^3	60 kg/m^3	0.80
4	10 m^3	55 kg/m^3	0.77

Weighted by mass

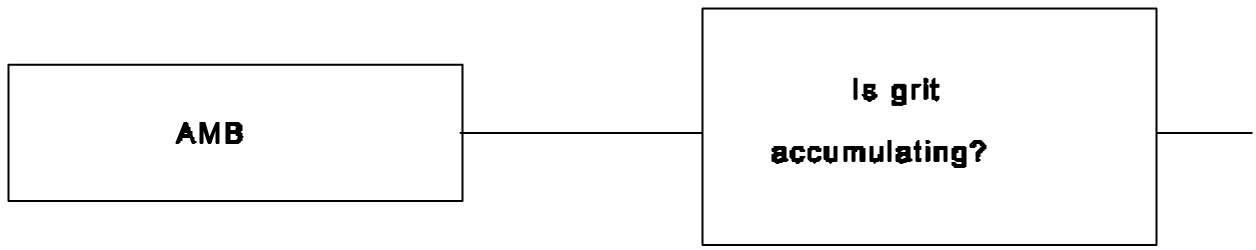
$$VS_{av} = \frac{(12 * 72 * 0.75) + (8 * 50 * 0.82) + (13 * 60 * 0.80) + (10 * 55 * 0.77)}{(12 * 72) + (8 * 50) + (13 * 60) + 10 * 55)} = 0.780$$

$$VS_{av} = \frac{(12 * 0.75) + (8 * 0.82) + (13 * 0.80) + (10 * 0.77)}{12 + 8 + 13 + 10} = 0.783$$

Arithmetic Average

$$VS_{av} = \frac{0.75 + 0.82 + 0.80 + 0.77}{4} = 0.785$$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).



VSR 5

OR

Which Equation to Use?

Use AMB	Use VK
! If grit is accumulating	! If there is no grit accumulating
! If decantate is withdrawn daily and if $VS_d \underline{/} VS_b$	! If decantate is withdrawn daily and if the $VS_b = VS_d$

Note: AMB =Approximate Mass Balance method.
VK =Van Kleeck method.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

CALCULATION OF VSR AND GRIT ACCUMULATION

	Measured Flows			Volatile Solids			Fixed Solids		
Day	F	B	D	Yf	Yb	Yd	Xf	Xb	Xd
	m^3/d	m^3/d	m^3/d	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

SECTION 3.13 C ASSESSMENT DOCUMENT FOR COMPLIANCE WITH BIOSOLIDS QUALITY REQUIREMENTS FOR POTWs WHICH UTILIZE ANAEROBIC DIGESTION AND LAND APPLICATION OF BIOSOLIDS

EPA Regulation 40 CFR Part 503 on "Standards for the Use and Disposal of Sewage Sludge" has established new requirements for such practices. This is a simplified document which is designed to assist POTW personnel in the assessment of biosolids quality requirements for POTWs under the new regulations. This guidance specifically applies to *anaerobic digestion* facilities which practice *land application* of biosolids. These are common practices in EPA Region 8 POTWs. The document is not only simplified for plants of this type, but it also only applies to biosolids quality considerations and not to other considerations such as biosolids management, site considerations, monitoring, recordkeeping, and reporting. Most of the requirements other than those relating to biosolids quality are easier to modify or change and are not as rigidly related to the physical facilities at the POTW as biosolids quality.

Table 3.A.2. Conversion Factors - Metric System Units to English System Units (continued).

LAND APPLICATION SLUDGE QUALITY ASSESSMENT FOR AEROBICALLY DIGESTED BIOSOLIDS

I. Assess biosolids quality with respect to Pollutants

It is recommended that the first step in this assessment be that of assessing biosolids quality with respect to pollutants. There are nine substances or pollutants which have concentration limits. It is assumed that personnel at this POTW have sampled the biosolids on at least one or more occasions to determine the concentration of these pollutants. If not, such testing will have to be done to assess compliance.

There is a schematic diagram below that shows the process of assessing compliance with the pollutant requirement. In addition, Worksheet No. 1 will help you through the process of assessment.

Table 3.1.2: Conversion Factors - Metric System Units to English System Units (continued).

LAND APPLICATION SLUDGE QUALITY ASSESSMENT AEROBICALLY DIGESTED SLUDGE

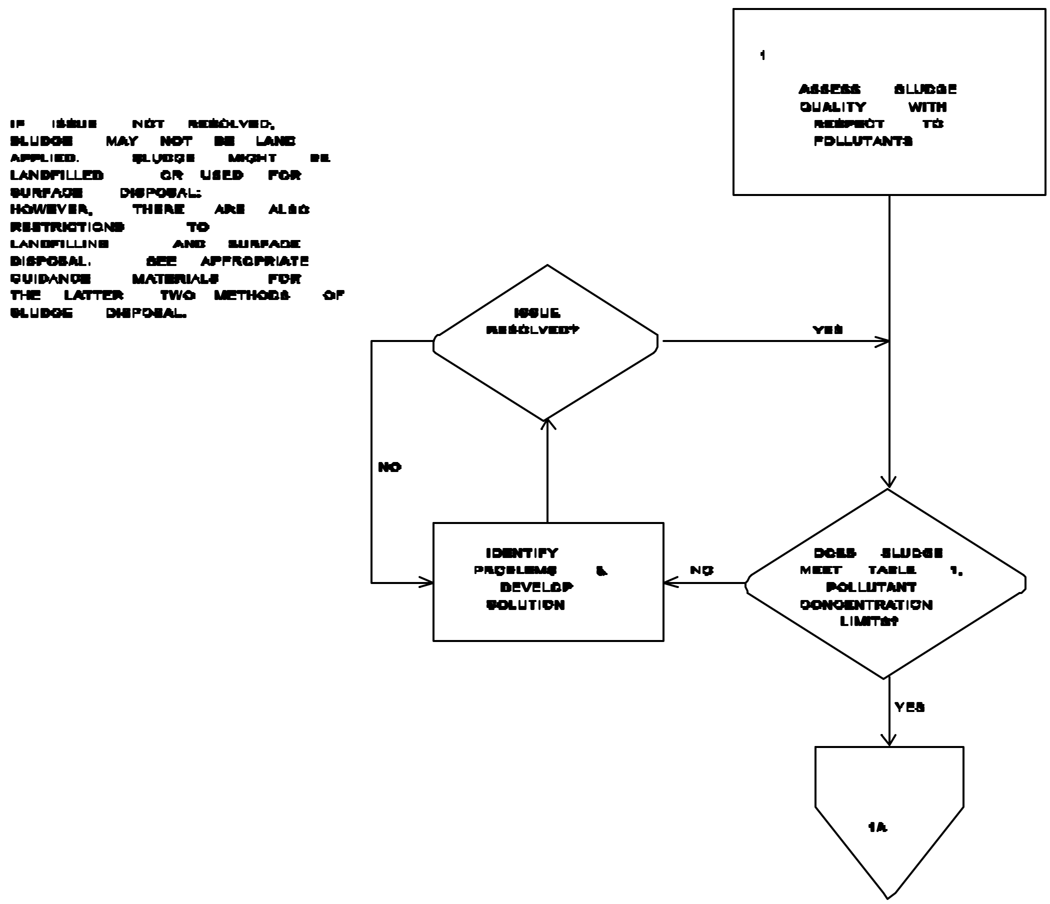


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Worksheet No. 1: Assess Biosolids Quality With Respect To Pollutants

(Note: Use this worksheet to assess compliance with biosolids pollutant ceiling concentration limits for *land application* of biosolids stabilized by anaerobic digestion processes.)

1. Compare the quality of your POTW biosolids to the following limits.

Pollutant Ceiling Concentration Limits			
Pollutant	Ceiling Conc. Limit (units:mg/kg)*	Your POTW's Biosolids Quality (units:mg/kg)*	Check Each Box Where Biosolids Pollutant Conc. Is Greater Than The Ceiling (Col.3 > Col.2)
Column: 1	Column: 2	Column: 3	Column: 4
As	75		
Cd	85		
Cu	4,300		
Pb	840		
Hg	57		
Mo	75		
Ni	420		
Se	100		
Zn	7,500		

Table Footnote:

* These units are in terms of mg of the pollutant per kg of dry solids, *i.e.*, solids dried by evaporation at 103 degrees Centigrade for 12 hours, see *Standard Methods*.

2. How many check marks are located in Column 4 of the above table?

3. If "0" is the correct response to the previous question check this line.

If the correct response is "0," your biosolids meets "Table 1 Pollutant Concentration Limits" and you may

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
proceed to assess your POTW's capability with respect to Class B Pathogens.

4. If you did not check item 3 above, check this line.

If you checked line 4 your biosolids does not meet "Table 1 Pollutant Concentration Limits" and you may not dispose of your POTW's biosolids by "Land Application." Before disposal by "Land Application" the quality of the biosolids must comply with the Table 1 Pollutant Concentration Limits. Retest biosolids immediately and/or determine source of the pollutant(s) which exceed the biosolids quality standard. Please understand that the biosolids may be disposed of by "Surface Disposal" or "Landfilled." However, prior to disposing of your biosolids by either of these methods you should review your plan with your State officials to ensure that all requirements are met.

II. Assess POTW capability with respect to Class B Pathogen requirements.

The Class B Pathogen requirements can be met by (1) utilization of treatment processes that meet requirements for Processes to Significantly Reduce Pathogens (PSRP), or Processes to Further Reduce Pathogens (PFRP), or other accepted processes equivalent to PSRP or PFRP; or (2) by testing the biosolids to determine the coliform density per gram of solids. This assessment will only address the PSRP process of aerobic digestion, which is a biosolids digestion process often used in Region 8 POTWs, and coliform testing of the biosolids.

The schematic diagram does not show the option of meeting PSRP by other processes that are accepted as equivalent to the identified PSRP processes merely to ensure that it is not overlooked as a possibility. Process equivalency is discussed in Chapter 11 of the so-called White House document entitled *Environmental Regulations and Technology - Control of Pathogens and Vector Attraction in Sewage Sludge*, EPA/625/R-99/006, September 1999. All POTWs should have this document available for reference. This document should be available from EPA's National Service Center for Environmental Publications, at 1-800-490-9198. Equivalency designations are difficult to obtain and any POTW personnel who feel that they have an equivalent process should discuss their ideas with State or EPA personnel before making application for equivalency.

Shown below is a continuation of the schematic diagram which covers assessment of biosolids quality with respect to pathogens and Worksheet No. 2 to assist in this process. The worksheet first addresses the monitoring of the biosolids coliform density and, secondly, compliance with the PSRP requirements. **Keep in mind that compliance can be met by either approach, depending on which is preferred by your POTW.** Consequently some POTWs may wish to address compliance with PSRP either without further need for consideration of coliform monitoring or at least prior thereto.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

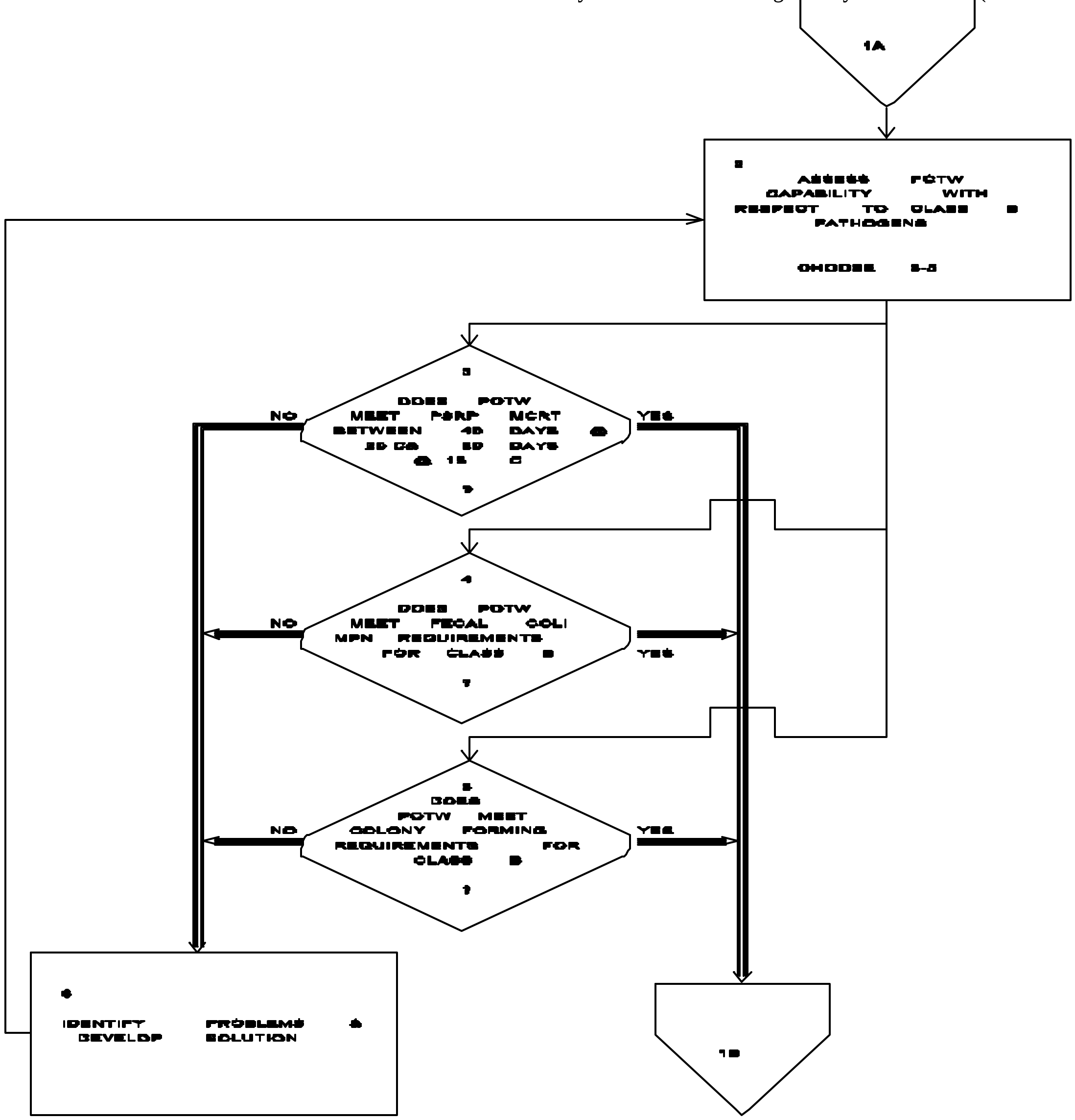


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Worksheet No. 2: Assess POTW Capability with respect to Class B Pathogen Requirements

1. Monitoring Fecal Coliform Density.

Testing for fecal coliform density requires that a minimum of 7 samples of treated biosolids be collected at or near the time of use or disposal. The geometric mean fecal coliform density of these samples must be less than 2 million CFU (Colony Forming Units) or MPN (Most Probable Number) per gram of sludge solids (Total Solids, dry weight basis).

The seven samples should be collected over a 2-week period during each monitoring event. For small plants (those in which there are less than 290 dry metric tons of biosolids produced per year), Region 8 requires that the biosolids be monitored during the most severe time of the year, from a cold temperature standpoint, to ensure meeting the regulations year-round.

Please note that the coliform density is expressed in terms of CFU or MPN per gram of sludge solids (Total Solids, dry weight basis). Therefore an aliquot of each sample must be dried and the solids content determined in accordance with procedure 2540 of *Standard Methods for the Examination of Water and Wastewater*, 18th Edition.

Please read the White House document (EPA document EPA/625/R-99/006 entitled *Environmental Regulations and Technology - Control of Pathogens and Vector Attraction in Sewage Sludge*) carefully for more detailed recommendations for sampling and analysis of biosolids for compliance with Part B Pathogen requirements.

Biosolids samples can be analyzed for MPN or CFU according to either of 2 procedures as follows:

a. Standard Methods procedure 9221. This is a procedure using dilution tubes which results in a Most Probable Number of fecal coliform organisms per gram of sludge solids (Total Solids).

b. Standard Methods procedure 9222. This is a procedure using membrane filters which results in numbers of Colony Forming Units per gram of sludge solids (Total Solids).

To determine the Geometric Mean Coliform Density, list in the table below the coliform density per gram of biosolids for each of the 7 or more samples collected over the sampling period. Determine the logarithm to Base 10 for each density listed and with this data calculate the geometric mean Fecal Coliform density per gram of sludge solids.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Sample Number	Coliform Density per gram of biosolids	Log (Base 10)
	Sum (1)	

Geometric Mean Coliform Density Per Gram * = Antilog of Average of Log (Base 10) Numbers, where (2) is number of samples

= Antilog of [(1)) (2)]

= Antilog (________)
( )

= ______ CFU or MPN
(circle correct unit)

* The Geometric Mean will be in either CFU or MPN units depending on the type of tests performed.

Please keep in mind that there are many chances for error in these calculations, so check your procedures and calculations carefully. Keep all records and calculations. After checking your calculations and procedures, do the biosolids from your POTW meet Class B pathogen requirements? If the geometric mean coliform density is less than 2,000,000 (2 million) MPN or CFU per gram of solids (dry weight) you have met the requirement.

Do the biosolids meet this requirement? ___ Y/N

If the answer is "Yes," you may proceed to assess compliance with the Vector Attraction Reduction requirements, see page 15.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

If the biosolids do not meet the coliform density criterion, you need to either retest biosolids coliform density or assess compliance with Class B Pathogen requirements by means of Processes to Significantly Reduce Pathogens (PSRP), see Item 2 below. Once your biosolids have failed the Coliform density test on 2 consecutive sampling events (2 two-week sampling periods) you should proceed to assess compliance with requirements presented under Item 2.

2. Meeting Class B Pathogen requirements by means of Processes to Significantly Reduce Pathogens (PSRP).

Since your plant has anaerobic digestion facilities, this procedure is to determine whether you meet PSRP for anaerobic digesters.? Anaerobic digestion processes which meet PSRP requirements are processes in which the biosolids are treated in the absence of air or oxygen for a mean cell residence time and temperature between 15 days at 35° to 55°C and 60 days at 20°C.

a. Temperature.

If your anaerobic digester has temperatures within the digestion facilities less than the minimum temperatures indicated above for any significant length of time, your facility does not comply with the requirements for PSRP. You must meet the minimum values for both temperature and MCRT. MCRT values greater than 60 days at less than 20°C are not acceptable and neither are temperatures higher than 35°C for MCRT times less than 15 days.

List below the anaerobic digester temperature data covering the last year of operation. Do not include temperature data collected for biosolids holding facilities, *i.e.*, processes following the anaerobic digester.

?

It should be pointed out that alternative processes that are equivalent to PSRP can also be used to meet Class B requirements. Table 5-2 on page 24 of the White House document lists some of the processes that the EPA Pathogen Equivalency Committee has determined to be equivalent. In addition, it is possible to have other biosolids treatment processes classified as "Processes to Significantly Reduce Pathogens." Chapter 11 of the White house document discusses how pathogen equivalency is established. However, such determinations are difficult to obtain and any POTW personnel who feel they have an equivalent process to the identified PSRP processes should discuss their ideas with State or EPA personnel before making application for equivalency.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).
Minimum Digester Mixed Liquor Temperatures - Four Coldest Months

Month/Year	Average Min. Temp 1st Stage	Average Min. Temp 2nd Stage	Average Min. Temp Other Stages

Select the coldest of the average minimum temperatures in the digestion facilities over a 2-months or 60-day period. List that temperature as follows _____ EC. Is this value $ 15E C?
____ (Y/N). If the answer is no, your aerobic digester does not meet the requirements for PSRP as indicated earlier. If the answer is yes proceed with the assessment.

b. Mean Cell Residence Time (MCRT).

As indicated previously the MCRT for anaerobic digesters must be between 15 days at 35EC to 55°C and 60 days at 20EC. (Longer values would be permitted.) To evaluate MCRT values please show in the space below or on an attached sheet, by means of a schematic drawing, how the anaerobic digestion facilities are arranged and the process and flow sequence used through the digesters. This will permit review of your calculations and procedures.

If your digester is heated a fairly uniform temperature is probably maintained. If it is unheated it will be seriously affected by the weather. With the coldest average temperature recorded over a 60 day period, determined under Item "a" above, use the attached "Anaerobic Digestion Temperature/MCRT" graph (page 11) to determine the required MCRT for your system. The required MCRT from the graph is _______ days.

Now determine the MCRT or the HRT for your anaerobic digestion facilities. Since the Hydraulic Residence Time (HRT) is usually easier to calculate, we suggest that you first calculate the HRT using the following formula:

HRT

$$HRT = V/q$$

where V is the volume of the aerobic digester and q is the rate of flow of biosolids into the digester. An example is as follows:

V = 100 cubic meters and q = 2.5 cubic meters per day

$$HRT = \frac{100 \text{ cubic meters}}{2.5 \text{ cu. meters/day}} = 40 \text{ days}$$

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

The HRT is usually an acceptable value for MCRT in anaerobic digestion where the digester approximates a complete mix reactor, the volume remains reasonably constant from day to day, there is biosolids discharge to the digester each day, and a similar withdrawal of supernatant or exiting digested biosolids. Do you operate your digester in this manner? _ (Y/N) If yes calculate the HRT of your digester as indicated. If no, skip the HRT calculation and proceed to the MCRT determination.

The value of q should be determined for the same 60-day period that was used in the temperature determination. The value of q should be in cubic meters per day if the volume is in cubic meters per day so that the unit of time comes out in days.

The value of q can be determined by flow measurement (provided that such facilities are available in your POTW) over a given period of time, or it can be estimated from piston pump volumes and the number of strokes of the pump which occur over a given time period. It might also be estimated by pumping into a measuring container or into the aerobic digester if the depth and subsequent volume could be calculated with reasonable accuracy by raising the liquid level a significant amount over a fairly lengthy period of time. However, keep in mind that most pumps other than piston pumps have changes in rate of flow with differing head conditions. So if the latter type of estimate is being made and the pump is discharging against less head than in actual practice, the rate of flow could be inaccurate. If you have difficulty with this calculation, we suggest you consult your consulting engineer or your State or EPA contact.

Use the space below to show your calculations in computing the HRT for your plant.

My calculation for HRT is _____ days.

MCRT

If the HRT does not meet the required number of days or the parameters indicated above for its use are not valid, the MCRT may be calculated using the White House document for assistance. Calculation of MCRT would be required if the digester is operated as a batch process, if the feed biosolids concentration and/or flow varies substantially from day to day, and if the digester volume does not remain reasonably constant.

Table 3.13-2. Conversion Factors: Metric System Units to English System Units (continued).

Temperature & Mean Cell Residence Time (MCRT)

Requirements to Meet Processes to Significantly

Reduce Pathogens (PSRP) by Anaerobic Digestion

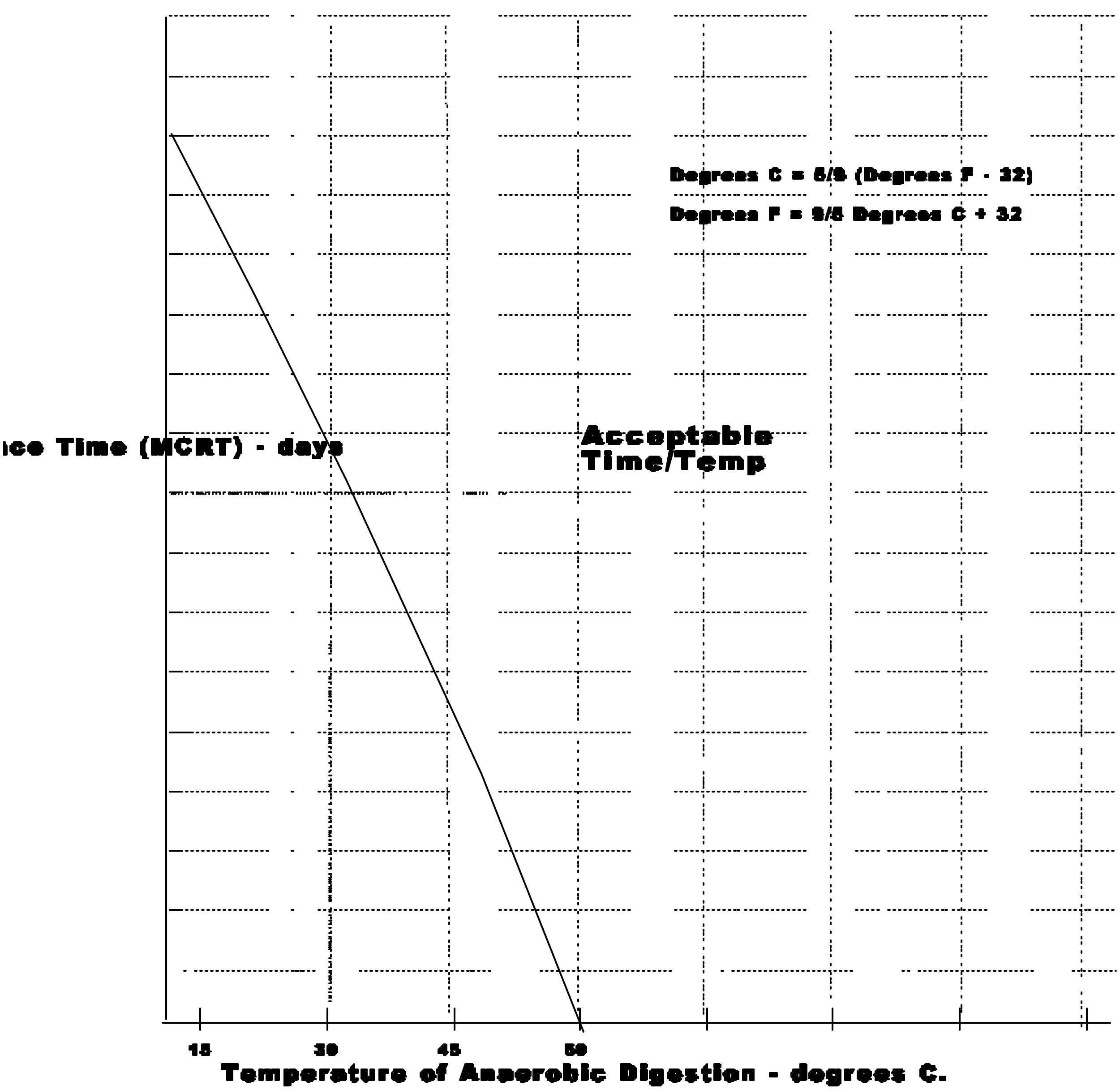


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Please see the Appendix of the White House document for different examples on determination of MCRT for aerobic digesters. In addition, please see the attached sheet entitled "Calculation of MCRT" which is an example of Case 4 on page 101 of the White House document. This example covers a mode of operation of aerobic digesters frequently used in small plants. The example, Case 4 in the White House document, makes use of Equation 3 of that document as listed on page 99. The equation is as follows:

$$\text{Nominal average solids residence time or MCRT} = \frac{V\,(Cv)}{q\,(Cq)}$$

where V = reactor volume, q = flow rate leaving, Cv = concentration of solids in the reactor, and Cq = concentration of solids in exiting biosolids.

An average (arithmetic mean) for a specific time period is one method of determining the data to use for an MCRT calculation. Another method might be to use a 60-day moving average. A 60-day moving average is where you take the last 60 days of data, add all the values, and divide by 60 days. Then as you move on from day to day you subtract the data from day one (the data for the earliest day) and add the data for the current day to the sum of all the daily values. As you calculate the sum each day and divide it by 60 days, you have a 60-day moving average.

List the HRT and/or the MCRT value that was obtained from the above calculation(s). HRT ____days MCRT days. Does your facility meet the required number of days for MCRT? _____(Y/N) Please show the data and calculations involved in these determinations in the space below.

c. Mixing

In addition to the above requirements, adequate mixing in anaerobic digesters is an important part of the adequacy of such facilities, but not a specific requirement for conformance with the Part 503 regulations. It is mentioned here so that you do not overlook mixing as a potentially important item in anaerobic digestion treatment.

Are the contents of your digester adequately mixed? __(Y/N)

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Calculation of MCRT

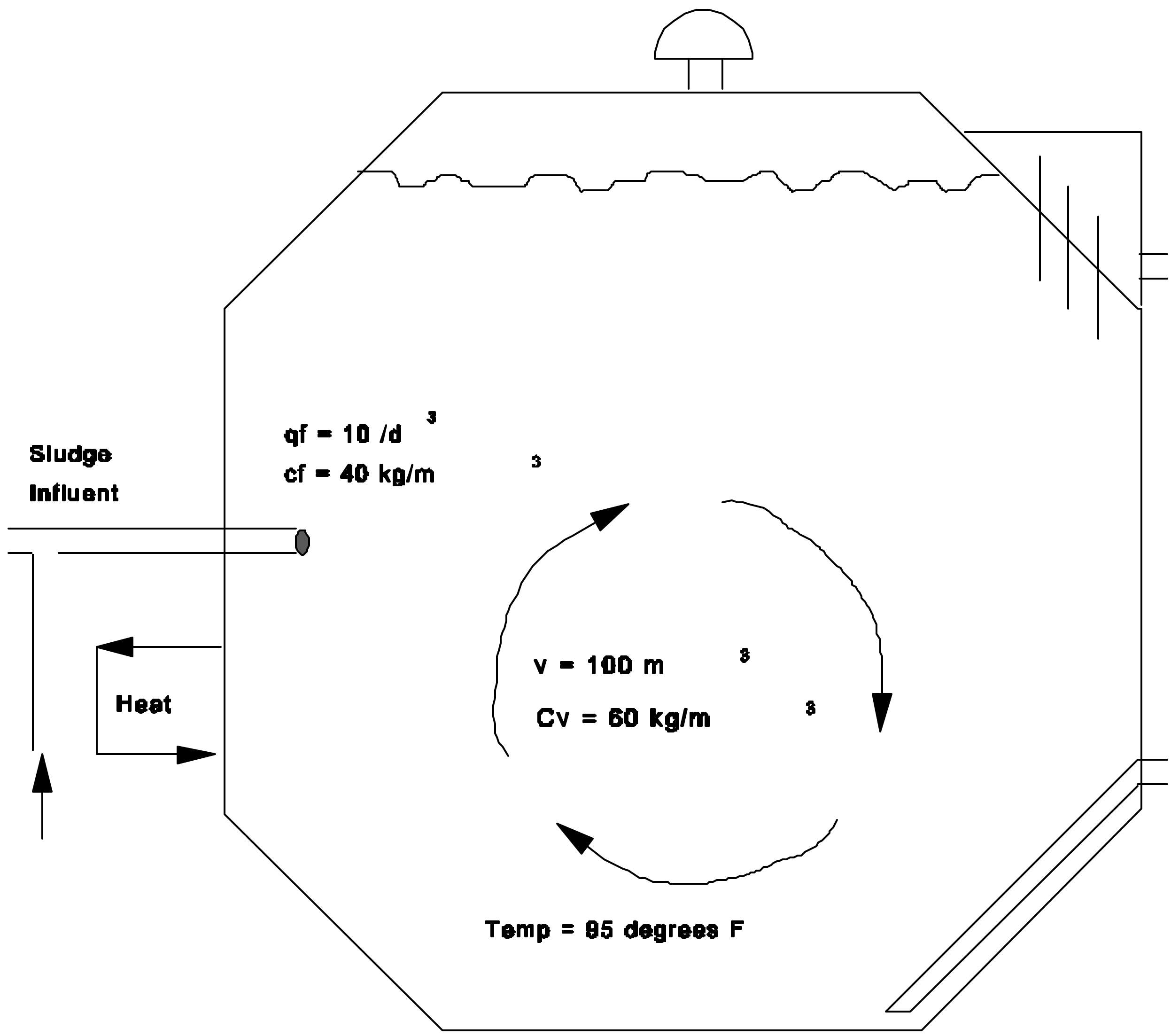


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

3. Conclusion

You have now determined if your POTW meets the Class B Pathogen requirements either by means of Fecal Coliform sampling or by meeting the requirements of Processes to Significantly Reduce Pathogens (PSRP).

Does your POTW meet the Class B Pathogen Requirements? ___ (Y/N) If Class B Pathogen requirements are not met, your biosolids may not be land applied.

III. Assess POTW with Respect to Vector Attraction Reduction

On the following page there is a continuation of the schematic diagram covering this overall biosolids assessment. This portion covers the assessment of your POTW and the biosolids produced with respect to vector attraction requirements. With reference to the schematic you might first note that the assessment covers three land application-related practices: (1) the surface application of biosolids in a land application program; (2) the subsurface injection of biosolids in a land application program; and (3) the incorporation of biosolids into the soil in a land application program.

Since more biosolids are surface applied than land applied by means of subsurface injection or incorporation into the soil, the schematic (and the worksheet which follows it) first address the situation in which biosolids are surface applied. Any of the seven alternatives listed may be used to verify or show conformance with the vector attraction reduction requirements. These are the alternatives listed as "a" through "g" under Item 1 in the worksheet. Consequently it is important that you not try to use all of the alternatives to show compliance. Instead you should use the alternative or alternatives that are most applicable and most practical for your plant and the processes which are available, if any, in addition to aerobic digestion. It is necessary only to meet one of the seven alternatives.

The alternatives for surface applied biosolids are not addressed in the same sequence in Worksheet No. 3 as they are listed in the schematic. This has no significance other than that the SOUR test, for instance, might be easier to use than some of the others for an aerobic digestion plant. All seven alternatives will not be practical or even possible for most plants.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

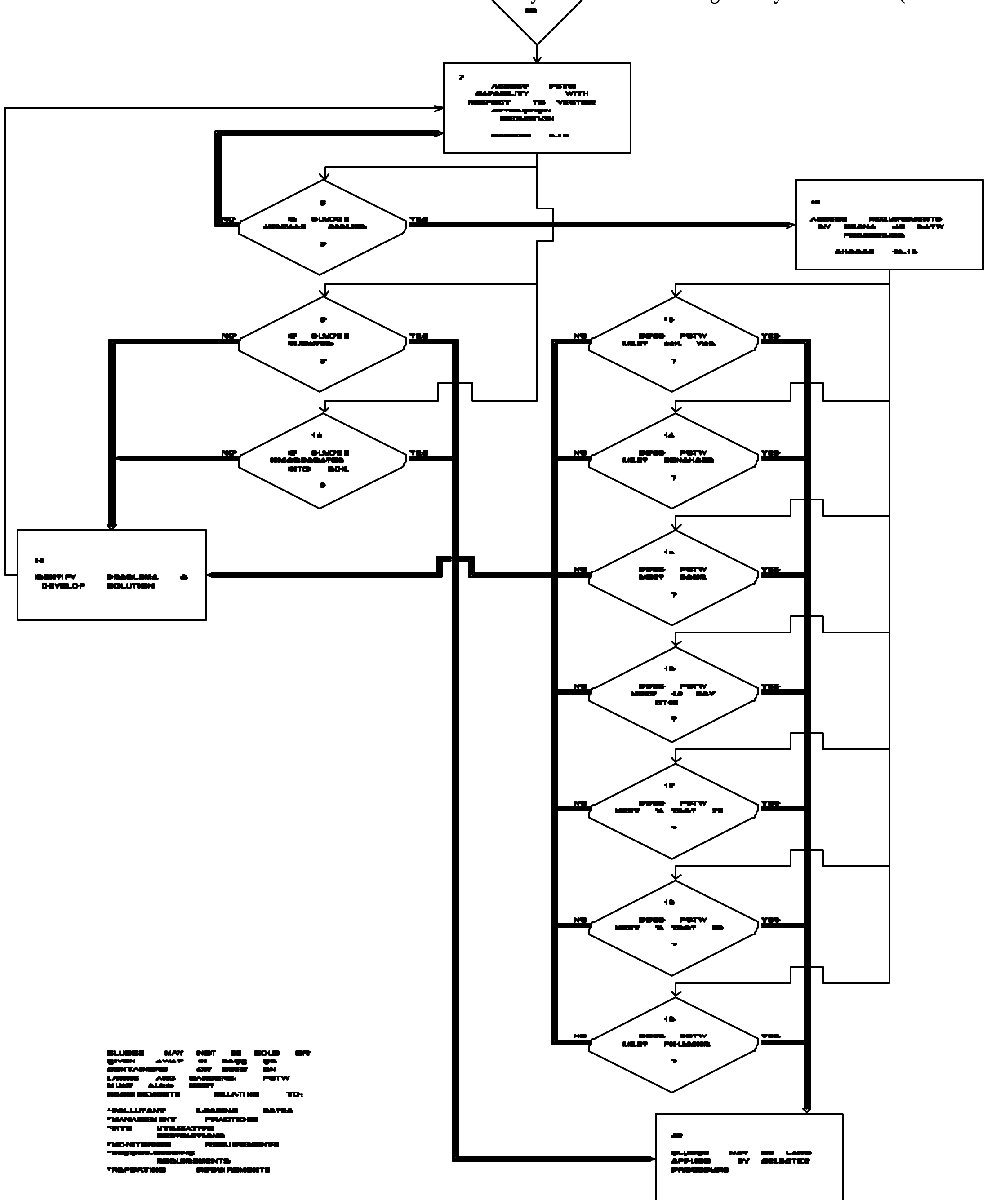


Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Worksheet No. 3: Assess POTW with Respect to Vector Attraction Reduction

1. Assess Biosolids that are surface applied

This portion of the worksheet covers biosolids which are land applied to the land surface and which are not injected or otherwise incorporated into the soil to keep the biosolids from contact with potential vectors.

a. Thirty-eight % or greater Volatile Solids Reduction

Requirements in procedures to calculate volatile solids reduction are found in the previous section and have therefore not been reprinted here.

b. Additional digestion of anaerobically digested biosolids **(BENCHANA)**.

This is an option that may be used with anaerobically digested biosolids. Under this option, anaerobically digested biosolids are considered to have achieved satisfactory vector attraction reduction if they lose less than 17% additional volatile solids when they are anaerobically batch-digested in the laboratory in a bench-scale unit at 30EC to 37EC for an additional 40 days. Procedures for undertaking this test are presented in Appendix D of the White House document.

If you use this alternative to assess Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet. Did the biosolids being tested have less than 17% additional volatile solids reduction when they were anaerobically batch-digested for an additional 40 days? ____(Y/N) Did it therefore meet the requirements for Vector Attraction Reduction? ___ (Y/N)

If the above test and calculations indicate a yes answer to compliance with this test, you should be ready to draw final conclusions as to compliance by your biosolids and POTW with the biosolids quality requirements for land application of biosolids.

If the answer to the above question was no, you have not met the requirement for Vector Attraction Reduction by means of this assessment and you should proceed to assess compliance by means of one of the other 6 Vector Attraction Reduction test alternatives.

c. Meeting Vector Attraction Reduction by means of Alkaline Stabilization in which the pH is raised to at least 12 by alkali addition and, without the addition of more alkali, the pH remains at 12 or higher for 2 hours and then 11.5 or higher for an additional 22 hours **(PH1222HR)**.
If you utilize this alternative for Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for the land application of biosolids. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

d. Meeting Vector Attraction Reduction by drying to remove water or moisture so that the solids content of the biosolids is at least 75% and no unstabilized primary treatment solids are included **(%TSGT75)**.

Please read the additional details regarding this option in the White House document. If you utilize this alternative for Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet.

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for the land application of biosolids. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

e. Meeting Vector Attraction Reduction by drying to remove water or moisture so that the solids content of the biosolids is at least 90% when unstabilized primary treatment solids are included **(%TSGT90)**.

This alternative is discussed in the White House document. If you utilize this alternative for Vector Attraction Reduction, please provide details in the space provided below or on an attached sheet.

Was this option a successful means for meeting the Vector Attraction Reduction requirements? __ (Y/N) If the answer is yes, you should be ready to draw final conclusions regarding the compliance with your biosolids and POTW with the quality requirements for the land application of biosolids. If the answer is no, this option has not been successful in showing compliance with the Vector Attraction Reduction requirements and you should further assess other options that may be available.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

2. Assess biosolids that are subsurface injected or incorporated into the soil.

a. Subsurface Injection: If biosolids are not surface applied, but are injected into the soil beneath the soil surface, meeting the Vector Attraction Reduction (VAR) requirements can be accomplished by this procedure. It must be properly done as explained in the White House document. If injected into the soil it must be done in such a manner that no significant amount of biosolids is present on the land surface within one hour after injection. This places a barrier of earth between the biosolids and possible vectors. Odors should dissipate quickly following injection. It is suggested that POTW personnel utilizing this practice use photographs to show the condition of the soil before and after injection, and maintain information regarding the equipment used to accomplish injection.

b. Incorporation into the Soil: Under this practice the biosolids applied to the land surface must be incorporated into the soil within 6 hours after placement on the land. As indicated on page 30 of the White House document, if mixing with the soil is reasonably good, odors and any appearance of biosolids will be virtually eliminated after mixing occurs. It may be wise to accomplish the mixing or incorporation quickly (much less than 6 hours) if the soil has considerable clay because clay soils tend to become unmanageably slippery and muddy if liquid biosolids are allowed to soak into the first inch or two of topsoil.

Please keep records that include the following information when injecting or incorporating biosolids into the soil.

Date of Inj or Incorp.	Location	Time of Inj or Applic'tn.	Time of Mixing into soil	Weather Conditions

Description of Procedure and Equipment Used.

____

____

____

____

Has your POTW met the Vector Attraction Reduction Requirement by means of sub-surface injection? ___(Y/N)
Has your POTW met the Vector Attraction Reduction Requirement by means of incorporation into the soil? (Y/N)

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

3. Conclusion

You now should have determined if your biosolids and POTW meet Vector Attraction Reduction requirements. Does your POTW meet this requirement? __ (Y/N) If the answer is yes, and you have met the requirements for pollutants and for Class B Pathogens, your biosolids meet quality requirements for land application; however, the other requirements of the regulations must also be met. The other requirements include those relating to Pollutant Loading Rates, Management Practices, Site Utilization Restrictions, Monitoring Requirements, Recordkeeping Requirements, and Reporting Requirements. It addition it should be pointed out that biosolids which just meet the requirements of this assessment may not be sold or given away in bags or containers or used on lawns and gardens.

SECTION 3.14--MANURE SPREADER CALIBRATION

The following are a number of Internet addresses where you can download guidance documents on (1) calculating the spreader application rate, using the Aplastic sheet@ method and the Ayardstick@ method; and (2) calculating spreader capacity.

Table 3.1.2. Conversion Factors - Metric System Units to English System Units (continued).

- http://web1.nsac.ns.ca/nsdam/pt/agron/manure/mancal.htm: *Manure Spreader Calibration*, Nova Scotia Department of Agriculture and Marketing
- http://www.inform.umd.edu:8080/EdRes/Topic/Agr/Env/NDD/WATERMGT/MANURE_SPREADER_CALIBRATION_WORKSHEET.html: *Manure Spreader Calibration Worksheet*, Pennsylvania State University, 1993
- http://www.css.orst.edu/News/Publicat/Sullivan/990629/appratesheet.html: *Spreader Calibration Worksheet for Biosolids Application*, Dan Sullivan, Oregon State University, 1999
- http://hermes.ecn.purdue.edu/server/water/bib/Waste_Management/Equipment.html: A listing of various state publications on manure spreader calibration
- http://poultryweb.tamu.edu/waste/calibrat.html: *Calibration of Manure and Fertilizer Spreaders*, Alabama Cooperative Extension Service
- http://bellnetweb.brc.tamus.edu/res_grid/elementry/PercentofSlope.htm: *Measuring the Percent of Slope* (a simple method using a yardstick and level)

SECTION 3.15--METRIC/ENGLISH CONVERSION TABLES

Table 3.15.1 Conversion Factors - Metric System Units to English System Units

International System of Units (SI)	English System			
Name	Abbreviation	Multiplier	Symbol	Name
Length				
Centimeter	cm	0.3937	in	Inch

International System of Units (SI) English System				
Name	Abbreviation	Multiplier	Symbol	Name
Meter	m	3.2808	ft	Foot
Kilometer	km	0.6214	mi	Mile
		Area		
Square Centimeter	cm^2	0.155	in^2	Square Inch
Square Meter	m^2	10.763	ft^2	Square Foot
Square Kilometer	km^2	.3861	mi^2	Square Mile
Hectare	ha	3.861×10^{-3}	mi^2	Square Mile
Hectare	ha	2.471	ac	Acre
		Volume		
Liter	L	3.531×10^{2}	ft^3	Cubic Foot
Liter	L	0.2642	gal	Gallon
Cubic Meter	m^3	35.3147	ft^3	Cubic Foot
Cubic Meter	m^3	2.641×10^{-4}	Mgal	Million Gallons
Cubic Meter	m^3	8.1071×10^{-4}	acre-ft	Acre-foot
		Pressure		
Kilograms per Square Centimeter	kg/cm^2	14.22	lbs/in^2	Pounds per Square Inch
		Mass		
Gram	gm	2.20×10^{-3}	lb	Pound
Kilogram	kg	2.205	lb	Pound
Metric Tonne	mt	1.103	T	Ton (short)
		Density		
Kilograms per Cubic Meter	kg/m^3	0.0624	lbs/ft^3	Pounds per Cubic Foot
Kilograms per Hectare	kg/ha	4.46×10^{-4}	T/acre	Tons per Acre
Metric Tonnes per Hectare	mt/ha	0.446	T/acre	Tons per Acre
		Discharge (flow rate, volume/time)		
Liters per Second	L/sec	3.531×10^{-2}	ft^3/sec	Cubic Feet per Second

International System of Units (SI)	English System			
Name	Abbreviation	Multiplier	Symbol	Name
Liters per Second	L/sec	15.85	gal/min	Gallons per Minute
Liters per Second	L/sec	22.824.5	gal/day	Gallons per Day
Liters per Second	L/sec	2.28×10^{-2}	Mgal/day	Million Gallons per Day
Cubic Meters per Day	m^3/day	2.6417×10^{-4}	Mgal/day	Million Gallons per Day
		Power		
Kilowatt	kW	1.341	hp	Horsepower
		Temperature		
Degrees Celsius	°C	1.8°C 32	°F	Degrees Fahrenheit
		Miscellaneous		
Milligrams per Liter	mg/L	1.0	ppm	Parts per Million
Micrograms per Liter	ug/L	1.0	ppb	Parts per Billion
Cubic Meters per Hectare	m^3/ha	1.069×10^{-4}	Mgal/acre	Million Gallons per Acre

Table 3.15.2. Conversion Factors - English System Units

English System		International System of Units (SI)		
Name	Abbreviation	Multiplier	Symbol	Name
Length				
Inch	in	2.54	cm	Centimeter
Foot	ft	0.3048	m	Meter
Mile	mi	1.609	km	Kilometer
Area				
Square Inch	in^2	6.4516	cm^2	Square Centimeter
Square Foot	ft^2	9.29×10^{-2}	m^2	Square Meter
Square Mile	mi^2	2.59	km^2	Square Kilometer
Square Mile	mi^2	259	ha	Hectare
Acre	acre	0.4047	ha	Hectare
Volume				
Cubic Foot	ft^3	28.32	L	Liter
Cubic Foot	ft^3	2.832×10^{-2}	m^3	Cubic Meter
Gallon	gal	3.785	L	Liter
Million Gallons	Mgal	3.7854×10^{3}	m^3	Cubic Meter
Acre Foot	acre-ft	1233	m^3	Cubic Meter
Pressure				
Pounds per Square Inch	lbs/in^2	7.031×10^{-2}	kg/cm^2	Kilograms per Square Centimeter
Mass				
Pound	lb	4.539×10^{2}	gm	Gram
Pound	lb	0.4536	kg	Kilogram
Ton (short)	T	0.9072	mt	Metric Tonne
Density				
Pounds per Cubic Foot	lbs/ft^3	16.02	kg/m^3	Kilograms per Cubic Meter

English SystemInternational System of Units (SI)				
Name	Abbreviation	Multiplier	Symbol	Name
Tons per Acre	T/acre	2242.15	kg/ha	Kilograms per Hectare
Tons per Acre	T/acre	2.2421	mt/ha	Metric Tonnes per Hectare
Discharge (flow rate, volume/time)				
Cubic Feet per Second	ft^3/sec	28.32	L/sec	Liters per Second
Gallons per Minute	gal/min	6.39×10^{-2}	L/sec	Liters per Second
Gallons per Day	gal/day	4.3813×10^{-5}	L/sec	Liters per Second
Million Gallons per Day	Mgal/day	43.8126	L/sec	Liters per Second
Million Gallons per Day	Mgal/day	3.7854×10^{3}	m^3/day	Cubic Meters per Day
Power				
Horsepower	hp	0.7457	kW	Kilowatt
Temperature				
Degrees Fahrenheit	°F	0.555(°F-32)	°C	Degrees Celsuis
Miscellaneous				
Parts per Million	ppm	1.0	mg/L	Milligrams per Liter
Parts per Billion	ppb	1.0	ug/L	Micrograms per Liter
Million Gallons per Acre	Mgal/acre	9354.537	m^3/ha	Cubic Meters per Hectare