TEXAS OPTIMIZATION PROGRAM (TOP)
DIRECTED ASSISTANCE MODULE (DAM) 2A

ESTABLISHING APPROPRIATE CHEMICAL FEED RATES FOR A PUBLIC WATER SYSTEM

STUDENT GUIDE

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DAM 2a. Evaluation Form 1

Conventions in this Workshop

Multiplied by:

In this Handout, the sign for performing multiplication may be "×" or "*". Both of these symbols represent the same thing in any equation. For example:

The equation: $6 \times 6 = 36$

means exactly the same as

This equation: $6 * 6 = 36$

Divided by:

In this Handout, the sign for performing division may be "÷", "/", or a horizontal line. Both of these symbols represent the same thing in any equation. For example:

The equation: $36 \div 6 = 6$

means exactly the same as

This equation: $36 / 6 = 6$

means exactly the same as

This equation: $\frac{36}{6} = 6$

Also, when using variables, one does not have to use the multiplier sign:

The equation: $A \times B = AB$

and

Equation: $AB = A \times B$

Concentration (Conc.):

In this Handout, the term "concentration" (sometimes abbreviated, "Conc.") refers to the weight of an active ingredient in a chemical mixture divided by the total unit weight of the mixture expressed as a decimal fraction or as a percentage.

Residual (Res.)

In this Handout, the term "residual" (sometimes abbreviated, "Res.") refers to the mg/L, or ppm, of an active chemical in the "treated" water.

Flow Rates versus Feed Rates

In this Handout, the term "flow rate" is normally used to describe the raw water flow or the treatment water flow. Typically it will be expressed in terms of millions of gallons per day (MGD) or gallons per minute (gpm). However, for some dose and feed rate calculations, the flow rate may need to be converted to milliliters per minute as an intermediate step in the calculation.

In this Handout, the term “feed rate” is normally used to describe the rate at which a chemical is applied to the water being treated. Typically it will be expressed in terms of pounds per day (ppd, or lbs/day), milliliters per minute (ml/min), or gallons per minute (gpm).

Milligrams per Liter (mg/L) and parts per million (ppm):

In this Handout, for convenience, the terms “mg/L” and “ppm” are used describe a weight or volume based dose.

- When describing a weight based dose, the “ppm” is equal to mg/L.
- When calculating a volume based dose, the term ppm does not mean mg/L.

Use of Exponents:

- Dose and feed rate calculations often use a unitless factor of 10^6, which is also called 10 to the 6^{th} power.

  When used, it means:

  $$10^6 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1{,}000{,}000$$

- When using an Excel spreadsheet to do some conversions from one unit of measure to another, the converted number is very small, and Excel resorts to a scientific notation which includes 10 to a negative power. For example, when converting one gallon per minute to millions of gallons per day (gpm to MGD) the answer in the spreadsheet is “6.944E-04”. This term means:

$$6.944\text{E}-04 \ = \ 6.944 \times 10^{-4} \ = \ \frac{6.944}{(10 \times 10 \times 10 \times 10)}$$

Order of Execution in Equations:

In this Handout, the normal algebraic rules apply:

- Multiplication and division are performed first.
- Addition and subtraction are performed last.
- Like units in the numerator and the denominator of an algebraic expression cancel each other out.

Order of Presentation:

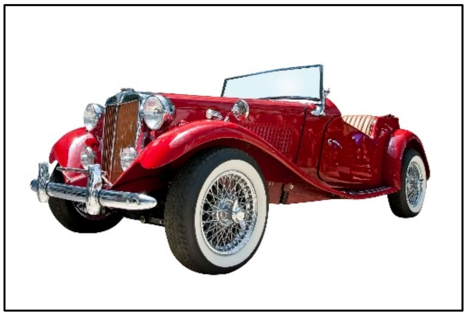
In this Handout, the equations the operator will normally use are presented first, followed by an example. The example may be followed by the explanation of how the equation was built from the most basic starting point and the adjustments necessary to include the important conversion factors.

Basic Background Information

In the treatment of raw water to produce drinking water, we deal with large volumes of water and chemicals. The math we use to calculate how much of a chemical we add to the water has to do with the ratios of chemicals to the water we add the chemicals to.

Away from the plant we deal ratios all the time. For example, with miles per gallon (mpg), miles per hour (mph), and 15% of the dinner check for a tip.

Ratios:



Even though the ratios are quite different for water treatment, the principles for calculating the ratios are exactly the same as the more common calculations we have been doing for years.

For example:

We fill up our tank and we find that it takes 10 gallons to fill it up. We also note that we have traveled 210 miles since the last time we filled up. Then:

Using this formula:

MPG Calcs: $Miles\ per\ gallon\ (mpg) = \text{Miles traveled} \div \text{Volume of gasoline (gal)}$

Therefore:

$$Miles\ per\ gallon\ (mpg) = 210 \text{ miles} \div 10 \text{ gal} = 21.0\ \frac{miles}{gal} = 21.0 \text{ mpg}$$

The calculation of the ratio of miles to the number of gallons used is very simple, can be clearly understood, and most people can do the calculation in their heads when we choose 10 gallons of gasoline for the example.

We may do the same thing to calculate miles per hour (mph). If we traveled that 210 miles in 2 hours, we know (and the DPS helicopter patrol officer knows), we were traveling at 105 mph.

MPH Calcs: $Miles\ per\ hour\ (mph) = 210 \text{ miles} \div 2 \text{ hours} = 105\,\frac{miles}{hour} = 105 \text{ mph}$

(By the way, that was pretty good gas mileage for traveling at that speed.)

Dose calculations are just ratios: if we are adding 10 pounds of gaseous chlorine to 1,000,000 pounds of water, the ratio is:

Weight Ratios: Lbs of chlorine per lb of water = lbs of chlorine ÷ lbs of water (gal)

Substituting in our pounds of chlorine and pounds of water into the weight ratio equation:

$$Lbs\ of\ chlorine\ per\ lb\ of\ water = 10\ lbs \div\ 1{,}000{,}000\ lbs\ =\ 0.00001 \frac{lbs\ Cl_2}{lb\ of\ H_2O}$$

But this number from this ratio calculation is so small. In water treatment, we most often calculate these weights in units of measure without so many zeros. We will talk about this more later.

Let's, suppose that instead of adding 10 pounds of chlorine to 1,000,000 lbs of water, we were adding it to 1,000,000 gallons of water.

First we would have to calculate how much a million gallons of water weighs:

Weight of Water $One\ gallon\ of\ water =\ 8.34\ lbs\ of\ water$

Therefore:

$$1{,}000{,}000\ gal\ \times 8.34 \frac{lbs}{gal}\ =\ 8{,}340{,}000\ lbs\ of\ water.$$

Using the Weight Ratios equation, again:

$$Lbs\ of\ chlorine\ per\ lb\ of\ water = 10\ lbs \div\ 8{,}340{,}000\ lbs\ =\ 0.0000012 \frac{lbs\ Cl_2}{lb\ of\ H_2O}$$

This number has even more zeros than the first calculation we did for weight ratios, and we still don't like it.

Volumetric doses, liquid weight doses, and dry weight doses:

Typically, doses compare the flow rate of the chemical applied to the flow rate of the receiving water. One of the biggest issues in calculating doses is deciding what type of flow ratio we are wanting using to calculate the dose. This issue is central to performing dose calculations. The major types of doses are volume based, liquid weight based, and dry weight based dose calculations.

An important element of each type of calculation is that the active chemical and the receiving water must be measured in the same units.

If the calculation is volume based, the flow rate of the chemical and the flow rate of the receiving water are measured in the same volumetric units per unit time: milliliters-per-minute (ml/min), gallons-per-minute (gpm), millions of gallons per day (MGD), etc. The same is true for weight based dose calculations: both the chemical applied and the receiving water must be measured in the same weight units per unit time.

The practice of calculating chemical feed rates and doses comes down to being able to convert the chemical feed rate and the receiving water flow rate into the same units of measure.

The most commonly used types of dose calculations are presented in Figure 1.

Volume Based Doses	$\frac{\text{Volume of chemical per unit time}}{\text{Volume of receiving water per unit time}} =$	Volume based dose
Liquid Weight Based Doses	$\frac{\text{Weight of liquid chemical per unit time}}{\text{Weight of receiving water per unit time}} =$	Liquid weight based dose
Dry Weight Based Doses	$\frac{\text{Weight of dry chemical in the liquid mixture per unit time}}{\text{Weight of receiving water per unit time}} =$	Dry weight based dose of a liquid chemical
	$\frac{\text{Weight of dry chemical per unit time}}{\text{Weight of receiving water per unit time}} =$	Dry weight based dose of a dry chemical

Figure 1: Volumetric, Liquid Weight, and Dry Weight Dose Calculations

Terms and Abbreviations:

Several terms are important in performing dose calculations. The definitions we use here may not be exactly as found in a science book, but we will use definitions that make dose calculations easier. Table 1 contains a listing of terms often used in dose calculations. We often have to convert from one unit of measure to another and Table 2, located at the end of this handout has many of the more commonly used conversion factors.

Some of terms in the Table 1 require a larger explanation.

Several terms are important in performing dose calculations. The definitions we use here may not be exactly as found in a science book, but we will use definitions that make dose calculations easier. Table 1 contains a listing of terms often used in dose calculations. We often have to convert from one unit of measure to another and Table 2, located at the end of this handout has many of the more commonly used conversion factors.

Table 1: Common Abbreviations

Symbol		Unit of Measure
Doses and Ratios		
Concentration	=	The percentage of weight of a chemical in a mixture to the weight of the total mixture (%)
gpg	=	grains per gallon
mg/L	=	milligrams per Liter
ppm	=	part(s)-per-million
Volumes		
ft^3	=	cubic foot (also, cf)
gal	=	gallon(s)
in^3	=	cubic inch(es)
L	=	Liter(s)
MG	=	million(s) of gallons
ml	=	milliliter(s)

Table 1: Common Abbreviations (continued)		
Symbol		**Unit of Measure**
Flow Rates and Feed Rates		
cfm (also ft^3/min)	=	cubic feet per minute
gpd	=	gallons per day
gph	=	gallons per hour
gpm	=	gallons per minute
ml/min	=	milliliters per minute
MGD	=	million(s) of gallons per day
ppd (also lbs/day)	=	pounds per day

Some of terms in the Table 1 require more explanation.

Concentration: There are several different ways that the term "concentration" is commonly used in chemistry. For example, we may buy a treatment chemical and then dilute it with makeup water in a day tank. We must know the original concentration, but we must also know the diluted concentration in the day tank. The definitions of concentration most useful in dosage calculations are:

1. The percentage, or decimal fraction, of dry chemical, by weight, mixed with a liquid, and used as a chemical feedstock. (See Figure 2.) For example liquid alum is typically 48 to 50 percent (%) alum, depending on the supplier.

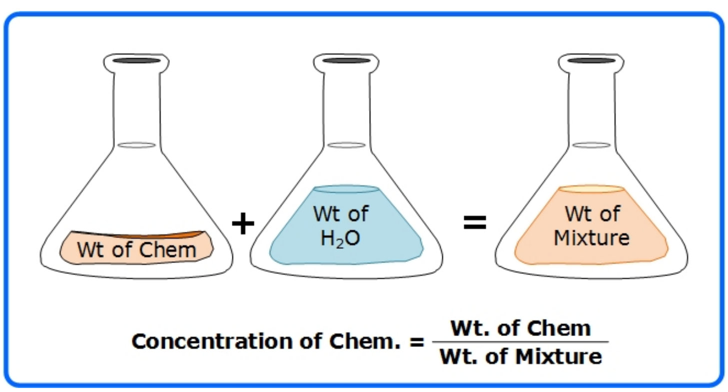
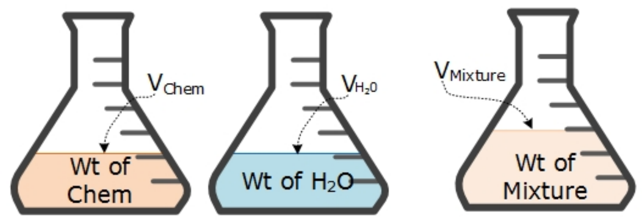


Figure 2: Chemical Concentration of Dry Chemical in Water

2. The percentage, or decimal fraction, of the active component of a dry chemical. For example, HTH is normally 65% calcium hypochlorite, by weight. We often say that HTH is 65% chlorine. The concentration is important because we know that adding a pound of HTH to a day tank will result in only 0.65 pounds of chlorine being added to the tank.



$$\text{Concentration of Chem} = \frac{\text{Wt. of Chem}}{\text{Wt. of Mixture}}$$

$$\text{Volume of Mixture} \neq \text{Vol. of Chem} + \text{Vol. of } H_2O$$

Figure 3: Concentration of Liquid Chemcal in Water

3. The percentage, or decimal fraction, of liquid chemical, by volume or by weight, mixed with water in a day tank and used as a chemical feedstock. Be on guard, some liquid mixtures may partially or completely dissolve in the makeup water. (See Figure 3.)

Parts-per-million (ppm):

Sometimes people use the term “ppm” for the concentration of a chemical in water. It is important to understand what this means.

1 KG	=	1,000 g
1 g	=	1,000 mg
1,000 g	=	1,000,000 mg
1,000,000 mg	=	1 KG

Figure 4: Metric Units

A part-per-million may be based on a ratio of volumes, a ratio of weights, or a ratio of weight to volume (though no one using a reasonable measure of common sense would regularly use this last option).

Metric weights are commonly used in water treatment because of the convenient ratios between the kilogram, gram, and milligram. The ratios between these metric weights are shown in Figure 4.

- One kilogram = 1,000 grams,
- One gram = 1,000 milligrams,
- So, one kilogram = 1,000,000 milligrams.

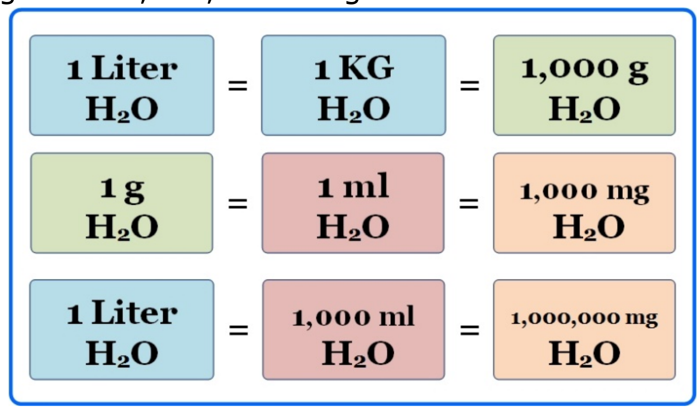


Figure 5: Ratios of Weights and Volumes of Water

We also know that one liter of water weighs 1 kilogram. This makes for some other ratios that are easy to work with. The most commonly used weights and volumes of water ratios are shown in Figure 5.

- One liter of water = one kilogram of water = 1,000 grams of water;
- One gram of water = one milliliter of water = 1,000 milligrams of water;
- So, one liter of water = 1,000 ml of water = 1,000,000 milligrams of water.

Because there are 1,000,000 mg of water in a liter, the number of mgs of chemical added to one liter of water are equal to the number of ppm for that chemical. We have just demonstrated that one milligram of chemical per one liter of water = 1 ppm, by weight.

NOTE: Some people prefer the term "mg/L" to "ppm," but operators find "ppm" to be convenient. The only thing one has to be on guard about is that ppm could also be a volume ratio rather than a weight ratio.

The reason "mg/L" and "ppm" are such convenient terms is because, when you measure the weight of chemical added to a weight of water, you can obtain an accurate ratio no matter what units you use.

The following equations are true:

$$A: \quad (Weight\ of\ chemical\ \div\ Weight\ of\ water)\ in\ \frac{lbs}{lbs} \times\ 1{,}000{,}000 =\ \text{ppm} =\ \text{mg/L}$$

$$B: \quad (Weight\ of\ chemical\ \div\ Weight\ of\ water)\ in\ \frac{kgs}{kgs} \times\ 1{,}000{,}000 =\ \text{ppm} =\ \text{mg/L}$$

$$C: \quad (Weight\ of\ chemical\ \div\ Weight\ of\ water)\ in\ \frac{mgs}{mgs} \times\ 1{,}000{,}000 =\ \text{ppm} =\ \text{mg/L}$$

The key to doing the calculation correctly is that we use the same units to measure for the weight of chemical and the weight of water. But we also know that one liter of water weighs one kilogram. This lets us do the following:

$$D: \quad (weight\ of\ chemical\ \div\ volume\ of\ water)\ in\ \frac{kgs}{Liters} \times\ 1{,}000{,}000 =\ \text{ppm} =\ \text{mg/L}$$

And:

$$E: \quad (weight\ of\ chemical\ \div\ volume\ of\ water)\ in\ \frac{mgs}{Liters} =\ \text{ppm} =\ \text{mg/L}$$

Specific Gravity (Sp.Gr.): The formal definition from the AWWA Dictionary is, "The ratio of the density of a substance to a standard density. For solids and liquids, the density is compared to the density of water at 4° Celsius (39.2° Fahrenheit) (i.e., 1 kilogram per liter). For gases the density is compared to the density of air at standard temperature and pressure (i.e., 1.2 grams per liter)."

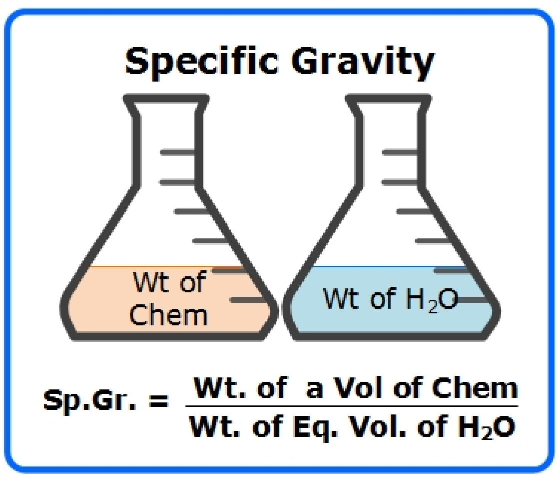


Figure 6: Specific Gravity Calculations

For drinking water calculations, the difference in the density of water at different temperatures is normally ignored. More basically, the Sp.Gr. for a liquid is the ratio of the weight of a certain volume of liquid divided by the weight of the same volume of water at 4° Celsius. The Sg.Gr. is expressed as a decimal fraction of that ratio. (See Figure 6.)

The specific gravity of a chemical is important because we want to accurately calculate the weight of the liquid chemicals we are adding to the treatment process.

Using Specific Gravity in dose calculations:

If a chemical is not diluted (it has a concentration of 100%) the weight of a volume of chemical is calculated using the following equation:

Sp. Gr. Conversions: *Weight of liquid chemical = Volume (gal) x Sp.Gr. x 8.34 lb/gal*

This formula uses the specific gravity and the weight of water to calculate the weight of the liquid chemical. For example, if liquid alum has a specific gravity of 1.3, then the weight of one gallon of liquid alum is calculated as follows:

Substituting our values into the Sp.Gr. conversions equation:

$$\text{Weight of one gallon of liquid alum} = 1 \text{ gal} \times 1.3 \times 8.34 \text{ lb-Water/gal-Water}$$

Then:

$$\text{Weight of one gallon of liquid alum} = 10.84 \text{ lbs}$$

Using specific gravity AND concentration in dose calculations:

If we are trying to calculate the weight of the active chemical in a volume of feedstock we use the following equation:

Sp.Gr. and Concentration Calculations:

$$\text{Weight of active chemical} = \text{Volume (gal)} \times \text{Conc.} \times \text{Sp.Gr.} \times 8.34 \text{ lb/gal}$$

For example, if we have liquid alum at a concentration of 50% and a Sp.Gr. of 1.3, then the weight of alum (most often described as the dry weight) in one gallon of liquid alum is calculated as follows:

Substituting in our values into the Sp.Gr. and Concentration Calculations equation:

$$Weight\ of\ alum\ in\ one\ gallon\ of\ liquid\ alum = 1 \text{ gal} \times \frac{50}{100} \times 1.3 \times 8.34 \text{ lb/gal}$$

Then:

$$\text{Weight of alum in one gallon of liquid alum} = 5.42 \text{ lbs}$$

Question: *Most chemical feed rate and dose calculations only figure out how much of a chemical is added to a certain amount of water or over a certain amount of time. What common dose calculations involve balancing calculations?*

Answers:

1. When calculating the expected chlorine residual based on the amount of chlorine added, the volume of water treated, and the chlorine demand of the water requires some balancing.

2. Dose calculations involving the formation of chloramines require balancing the chlorine and ammonia dose and/or feed rates to get the right ratios for forming monochloramine, and not di-chloramine or tri-chloramine.

Feed Rate: In this module, the feed rate is the measure of how much of a chemical is added to the treatment process per unit of time, regardless of how much water the chemical is added to. *Please note that the term "feed rate" is not the same thing as "dose."*

Typical expressions of feed rate are:

- Gallons per minute (gpm)
    - For example if a feed pump produces 5 gallons in 5 minutes, we are feeding at rate of 1 gpm.

$$Feed\ Rate\ (gpm) = 5\ \text{gal}\ \div\ 5\ \text{min} = 1\ \frac{gal}{min}\ =\ 1\ \text{gpm}$$

    - (Other feed rate calculations are performed in a similar manner. The key is, we are dividing either a volume or a weight of a chemical by the amount of time it takes to apply that volume or weight of chemical to the treatment process.)
- Gallons per hour (gph)
- Milliliters per minute (ml/min)
- Pounds per day (ppd)
- Kilograms per day (abbreviated Kpd)

Dose (or dosage): There are a several ways that the term "dose" is used in drinking water treatment. It is important to be very specific when describing a dose.

A batch dose is the amount of chemical added to a particular volume of water. The batch dose might be:

- The total volume of treatment chemical added to a specific volume of water. The dose can also be reduced to a volume to volume decimal if desired.

- The total weight of a mixture of treatment chemical added to a specific volume of water. The dose can be reduced to a weight to volume decimal if desired.
- The weight of the active ingredient in a solid or a liquid solution that is added to a specific volume of water. The dose can be reduced to a weight to volume decimal if desired.

For example, if you were to add 6.1 cups of a 5.25% solution of bleach to a 10,000 gallon tank, the "dose" could be described as:

  - 6.1 cups of bleach per 10,000 gallons,
  - ____pounds of bleach per 10,000 gallons,
  - 0.17 pounds of chlorine per 10,000 gallons, or
  - 2 milligrams of chlorine per liter of water.

Most of the chemical doses we apply in the drinking water treatment are not to containers of water with no water going in or out. We apply chemicals to untreated water as it flows through pipes, basins, and tanks. For this reason, we combine the untreated water flow rate and the chemical feed rate to get a dose. Sometimes, we also take the desired dose and the untreated water flow rate to calculate feed rates.

An example for calculating a continuous dose based on the water flow and the chemical feed rate is as follows:

- *The operator is feeding chlorine at the rate of 100 ppd.*
- *The raw water flow rate is 1 MGD.*

The continuing treatment dose may be calculated in steps:

$$1\ MGD = 1{,}000{,}000\ gal\ \times 8.34 \frac{\text{lbs}}{\text{gal}} = 8{,}340{,}000 \text{ lbs of water}$$

Dividing the amount of chlorine by the amount of water to which it is added:

$$100\ lbs\ of\ chlorine\ \div\ 8{,}340{,}000\ lbs\ of\ water = 0.00001199\ \frac{lbs}{lbs}$$

And, converting to parts-per-million:

$$0.00001199\ \frac{lbs\ of\ chlorine}{lb\ of\ water}\ \times 1{,}000{,}000 =\ 12 \text{ ppm}$$

100 lbs of chlorine in 1 MGD of water = 12.0 ppm = 12.0 mg/L.

Table 2 contains a list of common drinking water treatment units and conversion factors to calculate between these sets of units.

Table 2: Conversion Factors				
Conversions		**Procedure**		
From	**To**	**Multiply**	**By**	**To Obtain**
Doses				
grains per gallon (gpg)	milligrams per liter (mg/L)	gpg	17.1	mg/L
milligrams per liter (mg/L)	parts per million (ppm)	mg/L	1	ppm
parts per million (ppm)	milligrams per liter (mg/L)	ppm	1	mg/L
Volumes				
barrels (bbl), water	gallons (gal)	bbl	55	gal
cubic feet (ft^3)	cubic meters (m^3)	ft3	0.028317	m^3
cubic inches ($in.^3$)	cubic millimeters (mm^3)	$in.^3$	16,390	mm^3
cubic inches ($in.^3$)	liters (L)	$in.^3$	0.01639	L
cubic meters (m^3)	cubic feet (ft^3)	m^3	35.31	ft^3
cubic yards (yd^3)	cubic meters (m^3)	yd^3	0.7646	m^3
gallons (gal)	cubic meters (m^3)	gal	0.003785	m^3
gallons (gal)	liters (L)	gal	3.785	L
gallons (gal)	milliliters (ml)	gal	3,785	ml
gallons (gal)	cubic feet (ft^3)	gal	0.1337	ft^3
liters (L)	cubic meters (m^3)	L	0.001	m^3
milliliters (ml)	gallons (gal)	ml	0.0002642	gal
ounce, US fluid (oz)	cubic meters (m^3)	oz	0.00002957	m^3
Weights				
grains (gr)	grams (g)	gr	0.0648	g
grains (gr)	kilograms (kg)	gr	6.480×10^{-5}	kg
metric tons (t)	kilograms (kg)	t	1,000	kg
pounds (lbs)	kilograms (kg)	lbs	0.45359	kg
pounds (lbs)	milligrams (mg)	lbs	453,592	mg
tons	kilograms (kg)	tons	907	kg
tons	pounds (lb)	tons	2,000	lb

Table 2: Conversion Factors (Continued)				
Conversions		Procedure		
From	To	Multiply	By	To Obtain
Flow Rates and Feed Rates				
cubic feet/minute (ft3/min)	cubic meters per minute (m^3/min)	ft^3/min	0.02832	m^3/min
cubic feet/minute (ft^3/min)	cubic meters per second (m^3/s)	ft^3/min	0.0004719	m^3/s
cubic feet/second (ft^3/s, cfs)	cubic meters per second (m^3/s)	ft^3/s	0.02832	m^3/s
gallons per day (gpd)	cubic meters per day (m^3/d)	gpd	0.003785	m3/d
gallons per day (gpd)	liters per day (L/d)	gpd	3.785	L/d
gallons per hour (gph)	liters per second (L/s)	gph	0.001052	L/s
gallons per minute (gpm)	liters per second (L/s)	gph	1.75333×10^{-05}	L/s
gallons per minute (gpm)	cubic meters per second (m^3/s)	gpm	0.0000631	m^3/s
gallons of water per minute (gpm)	pounds of water per minute (lbs/min)	gpm	8.34	lbs/min
gallons per minute (gpm)	millions of gallons per day (MGD)	gpm	0.000694	MGD
milliliters per minute (ml/min)	gallons per minute (gpm)	ml/min	0.0002642	gpm
milliliters per minute (ml/min)	gallons per hour (gph)	ml/min	0.01585	gph
milliliters per minute (ml/min)	gallons per day (gpd)	ml/min	0.38041	gpd
millions of gallons per day (MGD)	gallons per minute (gpm)	MGD	1440	gpm
pounds per day (ppd, or lbs/day)	kilograms per day (kpd)	ppd	2.2046	kpd
pounds per day (ppd, or lbs/day)	milligrams per minute (mg/min)	ppd	1531	mg/min
millions of gallons per day (MGD)	gallons per minute (gpm)	MGD	1440	gpm

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Attachment 1 to the Student Guide:
Chemical Feed Rate and Dosage Calculations Form

Directed Assistance Module 2-A
Establishing Appropriate Chemical Feed Rates

Chemical Feed Rate Measurement and Dosage Calculations

I. Chemical Feed Rate Measurements and Dosage Calculations

Raw water flow rate at the time the following information was collected: _______________ *gpm / MGD* *(circle applicable units)*

Appl. Point No.[1]	Chemical [1]	Feed Rate Verification Frequency [1, 2]	Dosage Calculation Method [1, 3]	Reported		Actual	
				Feed Rate [4]	Dosage [5]	Feed Rate [4]	Dosage [5]
1							
2							
3							
4							
5							
6							
7							
8							
9							

NOTES:

(1) For each of the chemical application points shown on the Simplified Plant Schematic.

(2) Is the chemical feed rate verified after each feed rate change, once each shift, once each day, weekly, seldom, never, etc.

(3) What method does the plant staff use to calculate each of the chemical doses; the volumetric method (i.e., gal per MG), the liquid weight method (i.e., lbs of liquid per MG), or the dry weight equivalent method (i.e., lbs of an equivalent amount of dry chemical per MG)?

(4) Enter the reported and actual (measured) feed rates of the chemical. Use whatever method the staff actually uses to measure the chemical feed rates, (i.e. ml per minute, lbs per minute, etc.). Enter the data for each coagulant and coagulant aid used and for at least one of each form of chemical (solid, liquid, gas) used.

(5) Enter the reported and actual (measured) chemical dose for each of the chemicals that should be applied during a jar test. Report the dosage in the same units that the plant staff uses (i.e., gal/MG, lbs of liquid/MG, etc.)

Chemical Feed Rate Measurement and Dosage Calculations (continued)

II. Chemical Feeder Calibration Data [1, 2, 3]

Chemical Feeder ___________________

% Stroke Setting	% Speed Setting	Chemical Feed Rate

Chemical Feeder ___________________

% Stroke Setting	% Speed Setting	Chemical Feed Rate

Notes:

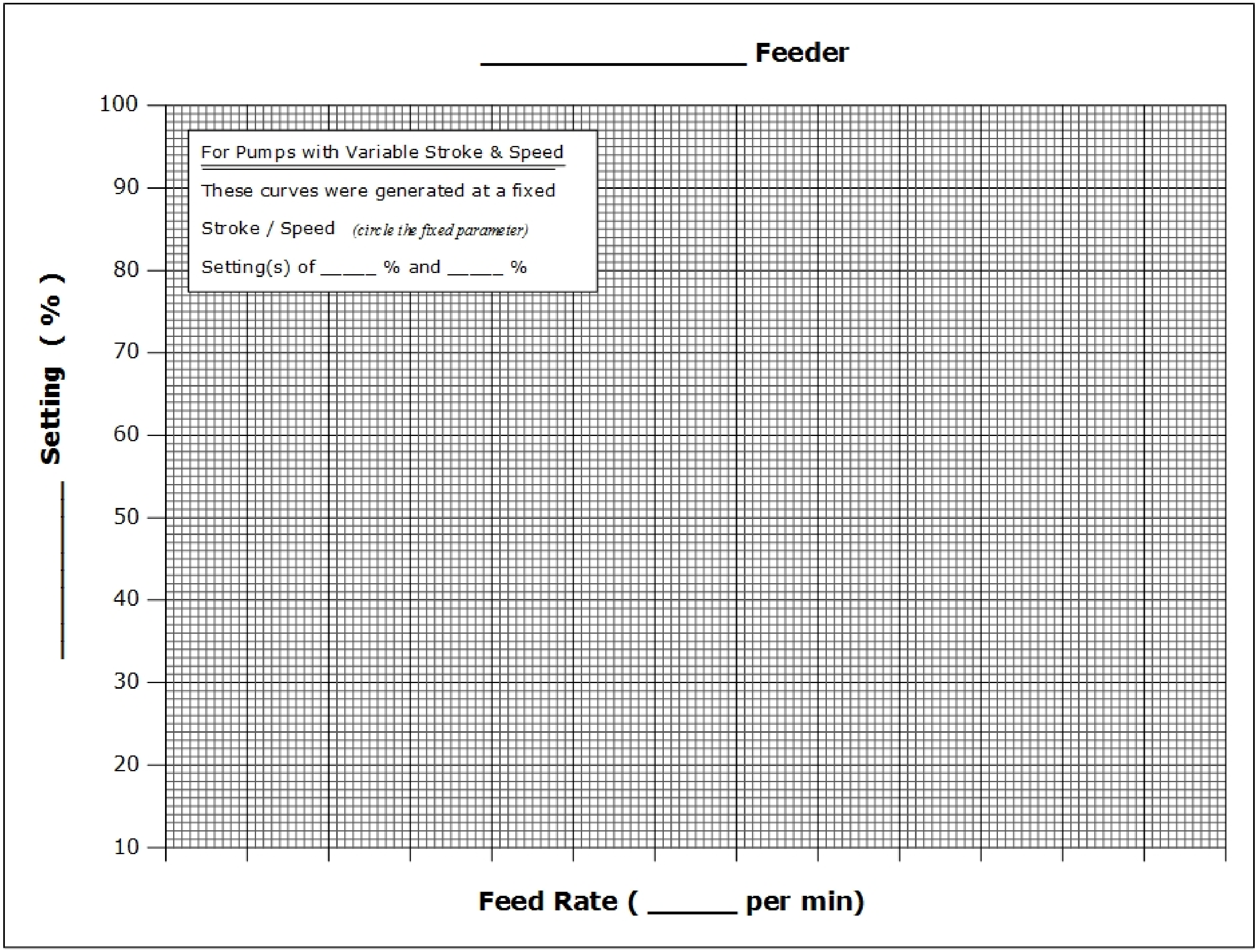
(1) When collecting data on feeders that have both an adjustable stroke and speed, adjust only one of the two settings at a time. For example, if the operators tend to make feed rate adjustments by changing the speed setting, leave the stroke at a fixed setting and adjust the speed. Make feed rate measurements at least three (preferably four or more) settings for whichever parameter the plant staff tends to change when adjusting feed rates.

(2) The two tables may be used to prepare multiple calibration curves on a single feeder that has both stroke and speed adjustments or for preparing calibration curves for multiple feeders. The second table is provided just in case there is time to prepare a second calibration curve.

(3) Use the test data and the following graph to prepare an actual calibration curve for one of the feeders.

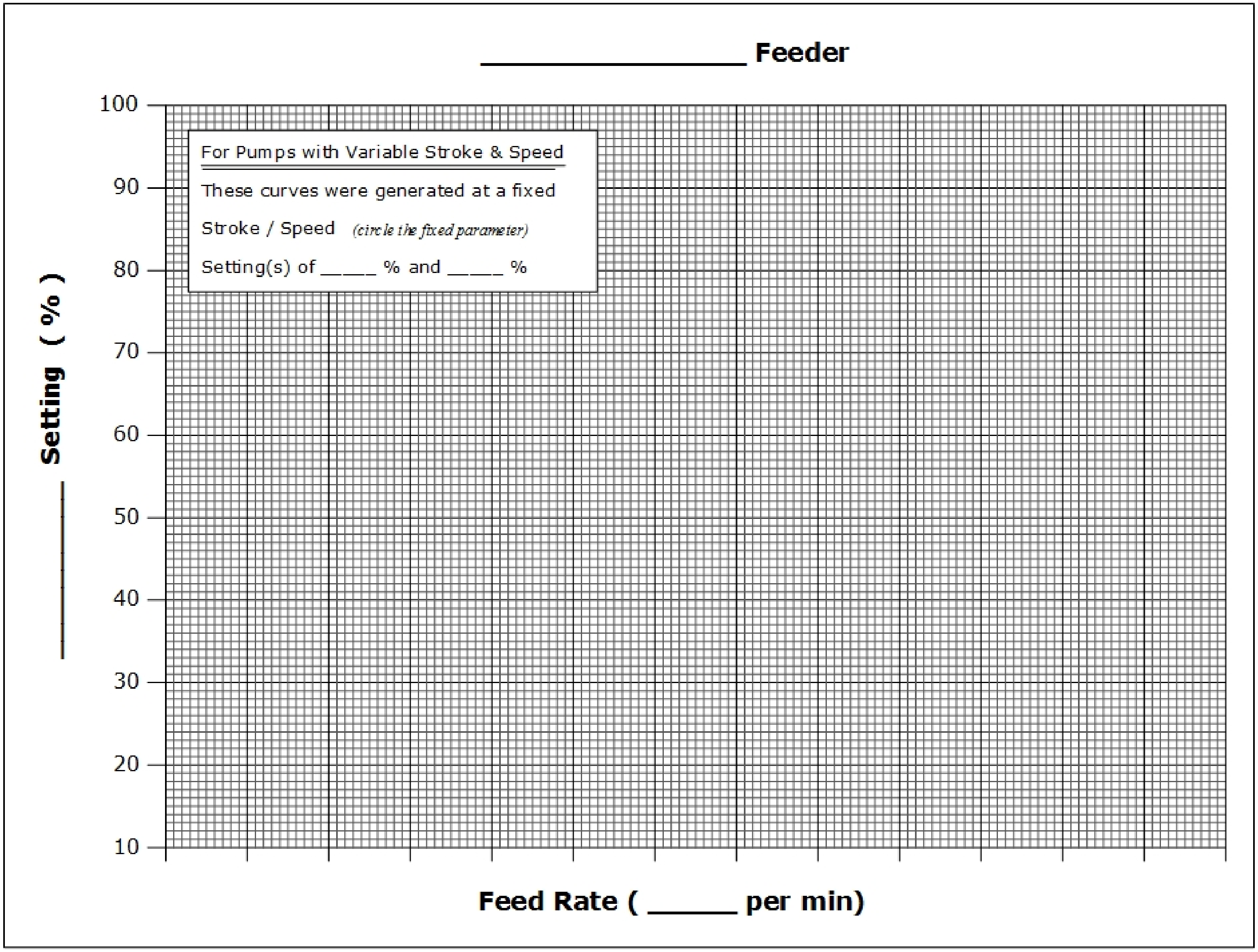
Chemical Feed Rate Measurement and Dosage Calculations (continued)

III. Pump Curve Chart



Chemical Feed Rate Measurement and Dosage Calculations (continued)

III. Pump Curve Chart



Attachment 2 to the Student Guide: Chemical Dosage Calculations

Directed Assistance Module 2-A

Establishing Appropriate Chemical Feed Rates

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Chemical Dosage Calculations

When you feed dry chemicals (and pure gases like chlorine), you calculate the dose by simply dividing the chemical feed rate by the water flow rate and then multiply by 1,000,000 to convert to parts per million. While this seems easy, you must remember to convert the feed rate of the chemical and the flow rate of the water into the same units of measurements. For example, if you are feeding 10 pounds per day of chemical, you must also convert the flow rate to pounds of water per day when you calculate the chemical dose.

While all operators use the same calculation when determining the dosage of dry chemicals and pure gases, they can calculate the chemical dosages for liquid chemicals in three ways; volumetric, liquid weight, or dry weight. Although any of these methods can be used to accurately control liquid chemical feed rates, there are pros and cons to each of these alternatives and you must understand the benefits and limitations of each before deciding which is best suited for each of the liquid chemical(s) used at your plant.

To determine what method your plant is using to calculate the dosage of its liquid chemicals, we need you to answer the following question. We are aware that this might be an unrealistic dose for your plant and that your alum might not come to you this way; we used these numbers to make it easy to calculate and not because anyone was ever observed operating this way.

Question 1:

Assume your plant was feeding 0.1 gpm of liquid coagulant into 1000 gpm of raw water. Also assume that the liquid coagulant has a specific gravity of 1.34 (that means it weighs 1.34 times as much as water, or 11.2 lbs/gal) and contains 50% dry alum.

How would you calculate the coagulant dose that was being applied?

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Chemical Dosage Calculations (continued)

As noted previously, there are three methods to calculate the chemical dose for liquid chemicals. These three methods, and the pros and cons of using each, are summarized in the following table. If you will look at the equations shown on the "Basic Approach" row, you will probably realize that (as you move from left to right) each equation adds one piece of information to the one that was before it. The last line on the table shows the answer to Question 1 when each method is used.

Summary of Methods for Calculating the Dose of Liquid Chemicals

	Method		
	Calculating on a Volumetric Basis	**Calculating on a Liquid Weight Basis**	**Calculating on a Dry Weight Basis**
Basic Approach	$\frac{Feed\ rate}{flow\ rate}\ X\ 10^6$	$\frac{Feed\ rate\ X\ Specific\ Gravity}{flow\ rate}\ X\ 10^6$	$\frac{Feed\ rate\ X\ Specific\ Gravity\ X\ Concentration\ X\ Purity}{flow\ rate}\ X\ 10^6$
Pros	• Easiest calculation because it uses volumes only • Doesn't require any knowledge of chemical composition of the feed solution • Simplifies the preparation of stock solutions for jar tests • Can be used for alum blends	• Almost as simple as the volumetric calculation • Only requires the operator to know the specific gravity of the feed solution • Can be used for alum/polymer blends	• Can be used for both dry and liquid chemicals • Results can be compared with those of other plants since the dry weight method is the industry standard • Allows plants to establish historical dosage benchmarks despite changing vendors or product concentrations • Is the most accurate way to assess the true cost of liquid alum • Can be used for alum/polymer blends based on the alum concentration of the solution • Must be used for liquid ammonium sulfate
Cons	• Can't be used for dry chemicals so it can be confusing to operators that have to use both liquid and solid chemicals • Results can't be compared with those at other plants unless they are using the exact same chemical.	• Can't be used for dry chemicals so it can be confusing to operators that have to use both liquid and solid chemicals • Results can't be compared with those at other plants unless they are using the exact same chemical.	• Most complex of the "liquid chemical" calculations. • Requires the operators to know both the specific gravity and chemical composition of the liquid chemical
Answer to Question 1	$\frac{0.1\ gpm}{1{,}000\ gpm}\ X\ 1{,}000{,}000 = 100\ ppm$	$\frac{0.1\ gpm\ X\ 1.34}{1{,}000\ gpm}\ X\ 1{,}000{,}000 = 134\ ppm$	$\frac{0.1\ gpm\ X\ 1.34\ X\ 0.50\ X\ 1.0}{1{,}000\ gpm}\ X\ 1{,}000{,}000 = 67\ ppm$

Although you can calculate the chemical dose for liquid chemicals using any of the three methods, the TCEQ and most industry organizations recommend that you use the "Dry Weight Basis" method since it is the method used by most water treatment plants and liquid chemical suppliers.

Notice that we must express the concentration of the alum as a fraction, not as a percent. So when calculating on a dry weight basis, we must divide the % concentration by 100 to get the fraction we need to use in the calculation.
Therefore, 50% = 50/100 = 0.50, 48% = 48/100 = 0.48, and so on.

Chemical Dosage Calculations *(continued)*

Now that you have selected the method(s) that you will be using to calculate the dosage of your liquid chemical(s), we need you to answer the following questions to determine if you completely understand the method. Just a reminder . . . these sample calculations might not be "real world" examples.

Question No. 1:

Assume your plant was feeding 0.1 gpm of liquid coagulant into 2000 gpm of raw water. Also assume that the liquid coagulant has a specific gravity of 1.34 (that means it weighs 1.34 times as much as water, or 11.2 lbs/gal) and contains 50% dry alum.

How would you calculate the coagulant dose that was being applied?

Question No. 2:

Assume your plant was feeding 0.3 gpm of liquid coagulant into 5000 gpm of raw water. Also assume that the liquid coagulant has a specific gravity of 1.33 (that means it weighs 1.33 times as much as water, or 11.1 lbs/gal) and contains 48% dry alum.

How would you calculate the coagulant dose that was being applied?

Question No. 3:

Assume your plant was feeding 0.5 gpm of liquid coagulant into 10,000 gpm of raw water. Also assume that the liquid coagulant has a specific gravity of 1.32 (that means it weighs 1.32 times as much as water, or 11.0 lbs/gal) and contains 47% dry alum.

How would you calculate the coagulant dose that was being applied?

Chemical Dosage Calculations *(continued)*

The answers to the three questions (on immediately previous page):

	Method		
	Calculating on a Volumetric Basis	**Calculating on a Liquid Weight Basis**	**Calculating on a Dry Weight Basis**
Basic Approach	$\frac{Feed\ rate}{flow\ rate}\ X\ 10^6$	$\frac{Feed\ rate\ X\ Specific\ Gravity}{flow\ rate}\ X\ 10^6$	$\frac{Feed\ rate\ X\ Specific\ Gravity\ X\ Concentration}{flow\ rate}\ X\ 10^6$
Answer to Question 1	$\frac{0.1\ gpm}{2{,}000\ gpm}\ X\ 1{,}000{,}000 = 50\ ppm$	$\frac{0.1\ gpm\ X\ 1.34}{2{,}000\ gpm}\ X\ 1{,}000{,}000 = 67\ ppm$	$\frac{0.1\ gpm\ X\ 1.34\ X\ 0.50}{2{,}000\ gpm}\ X\ 1{,}000{,}000 = 33.5\ ppm$
Answer to Question 2	$\frac{0.3\ gpm}{5{,}000\ gpm}\ X\ 1{,}000{,}000 = 60\ ppm$	$\frac{0.3\ gpm\ X\ 1.33}{5{,}000\ gpm}\ X\ 1{,}000{,}000 = 79.8\ ppm$	$\frac{0.3\ gpm\ X\ 1.33\ X\ 0.48}{3{,}000\ gpm}\ X\ 1{,}000{,}000 = 38.3\ ppm$
Answer to Question 3	$\frac{0.5\ gpm}{10{,}000\ gpm}\ X\ 1{,}000{,}000 = 150\ ppm$	$\frac{0.5\ gpm\ X\ 1.32}{10{,}000\ gpm}\ X\ 1{,}000{,}000 = 66\ ppm$	$\frac{0.5\ gpm\ X\ 1.34\ X\ 0.47}{10{,}000\ gpm}\ X\ 1{,}000{,}000 = 31\ ppm$

Notice that we must again express the concentration of the alum as a fraction, not as a percent.

So when calculating on a dry weight basis, we must divide the % concentration by 100 to get the fraction we need to use in the calculation.

Therefore, 50% = 50/100 = 0.50, 48% = 48/100 = 0.48, and so on.

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Attachment 3 to the Student Guide: Chemical Feed Rate Calculations

Directed Assistance Module 2-A

Establishing Appropriate Chemical Feed Rates

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Chemical Feed Rate Calculations

Now that you understand how to calculate the chemical dose, make a stock solution, and run a conventional jar test, you need to determine what the actual chemical feed rate should be.

As in the case of calculating the dose of a dry or pure gas chemical, all operators use the same calculation when determining the concentration of a stock solution prepared with dry chemicals. They figure out how many pounds of chemical they want to add and they set the feeder to apply that much. Well surprise . . . . operators can use any of three common methods to determine what the feed rate of liquid chemicals should be: volumetric, liquid weight, or dry weight.

By now you probably know what is coming next . . . To determine what method your plant is using to set its liquid chemical feed rates, we need you to answer the following question. We are aware that liquid alum might not come to you exactly this way; we used these numbers to make it easy to calculate and not because the numbers are exactly right.

Question 1:

Assume that your jar test results show that you should be applying 60 ppm of liquid alum. Also assume that the raw water flow rate is 2,000 gpm and that liquid alum has a specific gravity of 1.34 (that means it weighs 1.34 times as much as water, or 1.34 grams/liter) and contains 50% dry alum.

What should the alum feed rate be (in gpm)?

As we just noted, operators use one of three common methods to calculate the desired feed rate: volumetric, liquid weight, or dry weight. Although you can use any of these methods to accurately calculate the feed rate, you **MUST** use the same method as the one you used to calculate the chemical dose. It is extremely important to use the same method because using different methods can result in poor performance if you use the wrong data for one calculation and not the other.

Just a quick reminder in case you have forgotten that if your plant uses more than one liquid chemical, you can use different methods (volumetric, liquid weight, dry weight) for each chemical. **HOWEVER, FOR ANY GIVEN CHEMICAL, THE DOSE AND STOCK SOLUTION CONCENTRATION MUST BE CALCULATED USING THE SAME METHOD.** The following table summarizes the three different methods and the last line shows the answer to Question 1 when each method is used.

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Chemical Feed Rate Calculations *(continued)*

Method	Basic Approach to Determine mL of Liquid Coagulant Needed	Pros and Cons	Answer to Question 0
If your target dose is determined on a volumetric basis	$\text{Feed Rate (gpm)} = \frac{\text{Volumetric Dose (ppm) X Flow Rate (gpm)}}{10^6}$	It doesn't matter because you **MUST** use the same method that you use to calculate actual chemical dosage. However, if you want to know the pros and cons, refer to the table in Attachment 2.	$\frac{\text{60 ppm X 2,000 gpm}}{1{,}000{,}000} = \text{0.12 gpm}$
If your target dose is determined on a liquid weight basis	$\text{Feed Rate (gpm)} = \frac{\text{Liq. weight Dose (ppm) X Flow Rate (gpm)}}{\text{Specific Gravity X } 10^6}$		$\frac{\text{60 ppm X 2,000 gpm}}{\text{1.34 X 1,000,000}} = \text{0.09 gpm}$
If your target dose is determined on a dry weight basis	$\text{Feed Rate (gpm)} = \frac{\text{Dry weight Dose (ppm) X Flow Rate (gpm)}}{\text{Specific Gravity X Concentration X } 10^6}$		$\frac{\text{60 ppm X 2,000 gpm}}{\text{1.34 x 0.50 X 1,000,000}} = \text{0.18 gpm}$

Chemical Feed Rate Calculations ***(continued)***

Now that you have selected the method(s) that you will be using to calculate the dosage of your liquid chemical(s), we need you to answer the following questions to determine if you completely understand how to convert that dose to the corresponding feed rate. Just a reminder . . . these sample calculations might not be "real world" examples.

Question No. 1:

Assume that your jar test results show that you should be applying 30 ppm of alum. Also assume that the raw water flow rate is 1,000 gpm and that you are using liquid alum that has a specific gravity of 1.34 and contains 50% dry alum.

What should the alum feed rate be (in gpm)? What would it be in mL per minute?

Question No. 2:

Assume that your jar test results show that you should be applying 50 ppm of alum. Also assume that the raw water flow rate is 2,000 gpm and that you are using liquid alum that has a specific gravity of 1.33 and contains 48% dry alum.

What should the alum feed rate be (in gpm)? What would it be in mL per minute?

Question No. 3:

Assume that your jar test results show that you should be applying 60 ppm of alum. Also assume that the raw water flow rate is 694 gpm and that you are using liquid alum that has a specific gravity of 1.34 and contains 48% dry alum.

What should the alum feed rate be (in gpm)? What would it be in mL per minute?

Chemical Feed Rate Calculations *(continued)*

The answers to the three questions above:

	Method		
	If your target dose is determined on a volumetric basis	**If your target dose is determined on a liquid weight basis**	**If your target dose is determined on a dry weight basis**
Basic Approach	**Feed Rate (gpm) =** $\frac{\text{Volumetric Dose (ppm) X Flow Rate (gpm)}}{10^6}$	**Feed Rate (gpm) =** $\frac{\text{Liq. weight Dose (ppm) X Flow Rate (gpm)}}{\text{Specific Gravity X } 10^6}$	**Feed Rate (gpm) =** $\frac{\text{Liq. weight Dose (ppm) X Flow Rate (gpm)}}{\text{Specific Gravity X } 10^6}$
Answer to Question 1	$\frac{30 \text{ ppm X } 1{,}000 \text{ gpm}}{1{,}000{,}000} = 0.030 \text{ gpm}$ $\frac{0.03 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 114 \text{ mL/min}$	$\frac{30 \text{ ppm X } 1{,}000 \text{ gpm}}{1.34 \text{ X } 1{,}000{,}000} = 0.0224 \text{ gpm}$ $\frac{0.0224 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 85 \text{ mL/min}$	$\frac{30 \text{ ppm X } 1{,}000 \text{ gpm}}{1.34 \text{ x } 0.50 \text{ X } 1{,}000{,}000} = 0.045 \text{ gpm}$ $\frac{0.045 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 170 \text{ mL/min}$
Answer to Question 2	$\frac{50 \text{ ppm X } 2{,}000 \text{ gpm}}{1{,}000{,}000} = 0.100 \text{ gpm}$ $\frac{0.10 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 379 \text{ mL/min}$	$\frac{50 \text{ ppm X } 2{,}000 \text{ gpm}}{1.33 \text{ X } 1{,}000{,}000} = 0.0752 \text{ gpm}$ $\frac{0.0752 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 285 \text{ mL/min}$	$\frac{50 \text{ ppm X } 2{,}000 \text{ gpm}}{1.33 \text{ x } 0..48 \text{ X } 1{,}000{,}000} = 0.150 \text{ gpm}$ $\frac{0.150 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 569 \text{ mL/min}$
Answer to Question 3	$\frac{60 \text{ ppm X } 694 \text{ gpm}}{1{,}000{,}000} = 0.04 \text{ gpm}$ $\frac{0.04 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 158 \text{ mL/min}$	$\frac{60 \text{ ppm X } 964 \text{ gpm}}{1.34 \text{ X } 1{,}000{,}000} = 0.031 \text{ gpm}$ $\frac{0.031 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 118 \text{ mL/min}$	$\frac{60 \text{ ppm X } 964 \text{ gpm}}{1.34 \text{ x } 0.48 \text{ X } 1{,}000{,}000} = 0.0647 \text{ gpm}$ $\frac{0.045 \text{ gal}}{\text{min}} \text{ X } \frac{3{,}785 \text{ mL}}{\text{gal}} = 245 \text{ mL/min}$

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Attachment 4 to the Student Guide: Dosage and Feed Rate Formulae and How They Were Derived

Directed Assistance Module 2-A

Establishing Appropriate Chemical Feed Rates

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Volume Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals)

Feed Rate to Dosage Calculation for Volumetric Based Doses

Equation 1 is used to calculate the dose from the feed rate of chemical and water:

$$\textit{Eq. 1:} \quad \frac{\textit{Feed rate of liquid alum}\left(\frac{ml}{minute}\right)}{\textit{Raw water flow rate (gpm)} \times 3{,}785\frac{ml}{gal}} \times 10^6 = \textit{Volume based alum dose (ppm)}$$

For example, if:

- The liquid alum feed rate is 100 ml/minute, and
- The raw water flow rate is 1,000 gpm

Then, substituting our feed rate and flow rate into Eq. 1:

$$\frac{100\left(\frac{ml}{minute}\right)}{1{,}000\ gpm \times 3{,}785\frac{ml}{gal}} \times 1{,}000{,}000 = \frac{100\left(\frac{\cancel{ml}}{\cancel{min}}\right)}{1{,}000\ \cancel{gal/min} \times 3{,}785\frac{\cancel{ml}}{\cancel{gal}}} \times 1{,}000{,}000 = 26\ ppm$$

Note: In Equation 1, above, we chose to measure the feed rate in mL/min; because that is the way we most often measure it. We measured the raw water flow rate in gpm, because we normally measure the raw flow rate in gallons per minute (or MGD). However, to get a dose we can use, the feed rate of liquid alum and the raw water flow rate must be in the same units for the equation to work. We know that there are 3,785 ml in a gallon, so the raw water flow rate was multiplied by this conversion factor to get Equation 1.

Note: no conversions involving concentration or specific gravity were used in this calculation. The only units used were milliliters, gallons, minutes, and parts per million.

Volume Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals) (continued)

Dosage to Feed Rate Calculation for Volumetric Based Doses

Equation 2 (Eq. 2) is used to calculate the feed rate of alum when you know the dose in ppm (mg/L) that you are shooting for, and the water flow rate.

Eq. 2: $$Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{minute}\right) =$$

$$= \frac{Volume\ based\ alum\ dose\ (ppm) \times raw\ water\ flow\ rate\ \left(\frac{gal}{min}\right) \times 3785\ \left(\frac{ml}{gal}\right)}{10^6}$$

For example, if:

- The dose is 30 ppm of liquid alum on a volume basis, and
- The raw water flow rate is 1,000 gpm

Then substituting our dose and raw water flow rates into Eq. 2:

$$Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{minute}\right) = \frac{30\ ppm\ \times\ 1{,}000\ \left(\frac{\cancel{gal}}{min}\right)\ \times\ 3785\ \left(\frac{ml}{\cancel{gal}}\right)}{1{,}000{,}000} = 114\ ml/min$$

<u>Note:</u> we can convert this feed rate to gpm, gph, or gpd by applying the factors from Handout B. Therefore:

$$144\frac{ml}{minute} \times 0.0002642\frac{gpm}{ml/min} = 0.038\ gpm$$

And:

$$144\frac{ml}{minute} \times 0.01585\frac{gph}{ml/min} = 2.28\ gph$$

And:

$$144\frac{ml}{minute} \times 0..38041\frac{gpm}{ml/min} = 54.8\ gpd$$

As with the dose calculation for volume to volume calculations, we had to convert the raw water flow rate to ml/minute using the factor "1 gpm = 3,785 ml/min".

Liquid Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals)

Feed Rate to Dosage Calculation for Liquid Weight Doses

Equation 3 shows how to calculate the dose of alum from the feed rate of liquid alum, its specific gravity, the raw water flow rate, and conversion factors.

Eq.3: $$\frac{Feed\ rate\ of\ liquid\ alum\left(\frac{ml}{minute}\right)\times Sp.Gr.}{Raw\ water\ flow\ rate\ \frac{gal}{min}\ \times 3785\frac{\mathrm{ml}}{\mathrm{gal}}}\ \times\ 10^6\ =\ Liquid\ weight\ based\ alum\ dose\ (ppm)$$

For example, if:

- The unit weight of liquid alum is 11.09 lbs/gal
- The unit weight of raw water is 8.34 lbs/gal
- The Specific Gravity of liquid alum is 1.33 (or, 11.08 lbs/gal ÷ 8.34 lbs/gal)
- The liquid alum feed rate is 100 mL/minute, and
- The raw water flow rate is 1,000 gpm

Then inserting our values into Eq. 3:

$$\frac{100\left(\frac{ml}{minute}\right)\times\ 1.33}{1{,}000\ gpm\ \ \times\ 3{,}785\,\frac{ml}{gal}}\ \times\ 1{,}000{,}000\ \ =\ \ \frac{100\left(\frac{\cancel{ml}}{\cancel{min}}\right)\times\ 1.33}{1{,}000\ \cancel{gal/min}\ \ \times\ 3{,}785\frac{\cancel{ml}}{\cancel{gal}}}\times\ 1{,}000{,}000\ =\ 35\ ppm$$

Liquid Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals) (continued)

Development of the Liquid Weight Based Equation

The simplest liquid weight based equation, using pounds of liquid alum and pounds of raw water would be:

$$\frac{Feed\ rate\ of\ liquid\ alum\ \left(\frac{lbs}{min}\right)}{Raw\ water\ flow\ rate\ \left(\frac{lbs}{min}\right)} \times 10^6 = Liquid\ weight\ based\ alum\ dose\ \left(ppm\ or\ \frac{pounds\ of\ liquid\ alum}{million\ pounds\ of\ raw\ water}\right)$$

However, we normally feeding liquid alum in volume per unit time (for example, ml/min). To convert the liquid alum feed rate to lbs of liquid alum per minute, we must apply several factors:

- The Sp.Gr. for the liquid alum (this may vary from load to load of liquid alum)
- The weight of water (8.34 lbs/gal) to go with the Sp.Gr.
- The conversion factor to convert from ml/min to gpm (3,785 ml/min per gpm)

Applying these factors:

$$Feed\ rate\ \frac{ml}{min}\ X\ \frac{1\ gpm}{3785\frac{ml}{min}}\ X\ Sp.Gr.\ X\ 8.34\frac{lbs}{gal} = Feed\ rate\ in\ lbs/min$$

We also have to convert the raw water flow rate to lbs/min.   We normally get the raw water flow rate in gpm or MGD. Let's use gpm. To convert gpm to lbs/min, we have to apply a single factor:

- The weight of water is 8.34 lbs/gal

$$Raw\ water\ flow\ rate\ \frac{gal}{min}\ X\ 8.34\ \frac{lbs}{gal} = Raw\ water\ flow\ \ rate\ in\ lbs/min$$

Therefore:

$$\frac{Feed\ rate \frac{ml}{min} \times Sp.Gr. \times 8.34\frac{lbs}{gal}}{Raw\ water\ flow\ rate\ \frac{gal}{min} \times \frac{3{,}785\ ml/min}{gal/min} \times 8.34\frac{lbs}{gal}} \times 10^6 = \text{Dose (ppm)}$$

When we cancel out all the like units:

$$\frac{Feed\ rate \frac{ml}{min} \times Sp.Gr. \times \cancel{8.34\frac{lbs}{gal}}}{Raw\ water\ flow\ rate\ \frac{gal}{min} \times \frac{3{,}785\ ml/min}{gal/min} \times \cancel{8.34\frac{lbs}{gal}}} \times 10^6 = \text{Dose (ppm)}$$

And:

$$\frac{Feed\ rate \frac{ml}{min} \times Sp.Gr.}{Raw\ water\ flow\ rate\ (gpm) \times \frac{3{,}785\ ml/min}{gpm}} \times 10^6 = \text{Dose (ppm)}$$

Note: We did not cancel out the gpm units in the denominator because we must insert the raw water flow in gpm. Therefore, leaving the units in helps explain that part of the equation.

Liquid Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals) (continued)

Dosage to Feed Rate Calculation for Liquid Weight Doses

Equation 4 is used to calculate the feed rate for feeding liquid alum.

Eq. 4: $\text{Feed rate of liquid alum}\left(\frac{ml}{minute}\right) =$

$$= \frac{\text{Liquid weight based alum dose }(ppm) \div 10^6 \times \text{raw water flow rate}\left(\frac{gpm}{min}\right) \times 3785\,\frac{\text{ml}}{\text{gal}}}{Sp.Gr.}$$

For example, if:

- The unit weight of liquid alum is 11.09 lbs/gal
- The unit weight of raw water is 8.34 lbs/gal
- The Specific Gravity of liquid alum is 1.33 (or, 11.09 lbs/gal ÷ 8.34 lbs/gal)
- The raw water flow rate will be given in gpm and not ml/mi
- The dose is 30 ppm (or $\frac{30\ lbs\ of\ liquid\ alum}{1{,}000{,}000\ lb\ of\ water}$, or $\frac{30\ mg\ of\ liquid\ alum}{1{,}000{,}000\ mg\ of\ water}$) , and
- The raw water flow rate is 1,000 gpm

Inserting our dose and raw water flow values into Eq. 4:

$$\text{Feed rate of liquid alum}\left(\frac{ml}{min}\right) = \frac{30\ ppm \times 1{,}000\left(\frac{\cancel{gal}}{min}\right) \times 3785\left(\frac{ml}{\cancel{gal}}\right)}{1{,}000{,}000 \times 1.33} = 85\ ml/min$$

Note: we can convert this feed rate to gpm, gph, or gpd by applying the correct conversion factors.

Therefore:

$$85\,\frac{ml}{minute} \times 0.0002642\,\frac{gpm}{ml/min} = 0.0224\ gpm$$

And:

$$85\,\frac{ml}{minute} \times 0.01585\,\frac{gph}{ml/min} = 1.35\ gph$$

And:

$$85\,\frac{ml}{minute} \times 0.38041\,\frac{gpm}{ml/min} = 32.3gpd$$

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Dry Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals)

Feed Rate to Dosage Calculation for Dry Weight Doses of Liquid Alum (or another Chemical Mixed with Water)

Equation 5 shows how to calculate the dosage from the feed rate of alum (or another chemical in solution) based on the dry weight of the chemical.

Eq. 5: $$\frac{Feed\ rate\ of\ liquid\ alum\left(\frac{ml}{minute}\right) \times Sp.Gr. \times \text{Conc.}}{Raw\ water\ flow\ rate\ (gpm) \times 3{,}785\frac{ml}{gal}} \times 10^6 = Dry\ weight\ based\ alum\ dose\ \left(ppm\ or\ \frac{pounds\ of\ dry\ alum}{million\ pounds\ of\ water}\right)$$

For example, if:

- The unit weight of liquid alum is 11.09 lbs/gal
- The unit weight of raw water is 8.34 lbs/gal
- The Specific Gravity of liquid alum is 1.33 (or, 11.08 lbs/gal ÷ 8.34 lbs/gal)
- There are 3,785 mL per gallon, and
- 10^6 = 1,000,000
- The liquid alum feed rate is 200 mL/minute,
- The concentration (Conc.) of liquid alum is 48.1%, or 48.1 lbs of dry alum per 100 pounds of liquid alum (see the assumptions above), and
- The raw water flow rate is 1,000 gpm

Then inserting our values into Eq. 5:

$$\frac{200\left(\frac{ml}{minute}\right) \times 1.33 \times \frac{48.1\text{ lbs of dry alum}}{100\text{ lbs of liquid alum}}}{1{,}000\ gpm \times 3{,}785\frac{ml}{gal}} \times 1{,}000{,}000 = Dose\ (ppm)$$

Crossing out the units that cancel each other out and calculating:

$$\frac{200\left(\frac{\cancel{ml}}{\cancel{min}}\right) \times 1.33 \times .481\frac{\cancel{\text{lbs of dry alum}}}{\cancel{\text{lbs of liquid alum}}}}{1{,}000\ \cancel{gal/min} \times 3{,}785\frac{\cancel{ml}}{\cancel{gal}}} \times 1{,}000{,}000 = 33.8\ ppm$$

Dry Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals) (continued)

Development of the Dry Weight Based Equation

The simplest dry weight calculation of a dose using English units is:

$$\frac{Feed\ rate\ of\ dry\ alum\ (lbs/min)}{Raw\ water\ flow\ rate\ (lbs/min)} \times 10^6 = Dry\ weight\ based\ alum\ dose\ (ppm\ or\ \frac{pounds\ of\ dry\ alum}{million\ pounds\ of\ water})$$

However, we are feeding "liquid alum" and not dry alum. We also measure the raw water flow rate in gpm and not in pounds per minute.

To convert the liquid alum flow rate in ml/min to a flow rate in weight, we multiply by the specific gravity for the liquid by the weight of the same volume of water to get the weight of the liquid chemical.

We also know from the conversion factors in Table 2 in the Student Guide, that there are 3,785 milliliters in each gallon. So we must add conversion factors to our equation to account for the fact that we are feeding a liquid chemical and we are measuring water in gpm.

$$Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{min}\right) \times\ Sp.Gr.\ \times 8.34\frac{\text{lbs}}{\text{gal}}\ \div 3{,}785\frac{ml}{gal} = Feed\ rate\ (\frac{liquid\ lbs}{\text{min}})$$

But now we have a feed rate based on liquid weight. We have to convert the liquid weight to dry weight to account for the fact that the active chemical is only part of the liquid weight. The additional factor we have to take into consideration is that there are only so many pounds of dry alum for each pound of liquid alum, and we call this the concentration (Conc.).

If we add factors to convert, the feed rate becomes:

$$Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{min}\right) \times\ Sp.Gr.\ \times 8.34\frac{\text{lbs}}{\text{gal}} \times \text{Conc.}\ \div 3{,}785\frac{ml}{gal} = Feed\ rate\ (\frac{dry\ lbs}{\text{min}})$$

However, even though we have converted the chemical feed rate in ml/min to dry pounds of alum per minute, we also have to convert the gpm flow rate to pounds of water minute. This is fairly straight forward:

$$\text{Raw water flow rate (gpm)} \times 8.34\frac{\text{lbs}}{\text{gal}} = Raw\ water\ flow\ in\ \frac{\text{lbs}}{min}$$

Dry Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals) (continued)

Development of the Dry Weight Based Equation (continued)

If we go back to our earlier dose calculation equation:

$$\frac{Feed\ rate\ of\ dry\ alum\ (lbs/min)}{Raw\ water\ flow\ rate\ (lbs/min)} \times 10^6 = Dry\ weight\ based\ alum\ dose\ (ppm\ or\ \frac{pounds\ of\ dry\ alum}{million\ pounds\ of\ water})$$

And insert the feed rate and raw water flow rate calculations that we developed above, we get:

$$\frac{Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{min}\right) \times Sp.Gr. \times 8.34\frac{\text{lbs}}{\text{gal}} \times \text{Conc.} \quad \div\ 3{,}785\frac{ml}{gal}}{\text{Raw water flow rate (gpm)} \times 8.34\frac{\text{lbs}}{\text{gal}}} \times 10^6 =$$

$$= Dry\ weight\ based\ alum\ dose\ (ppm\ or\ \frac{pounds\ of\ dry\ alum}{million\ pounds\ of\ water})$$

Notice that we can simplify this equation by crossing out units and factors that cancel:

$$\frac{Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{min}\right) \times Sp.Gr. \times \cancel{8.34}\frac{\cancel{lbs}}{\cancel{gal}} \times Conc.}{Raw\ water\ flow\ rate\ (gpm) \times \cancel{8.34}\frac{\cancel{lbs}}{\cancel{gal}} \times 3{,}785\frac{ml}{gal}} \times 10^6 =$$

$$= Dry\ weight\ based\ alum\ dose\ (ppm\ or\ \frac{pounds\ of\ dry\ alum}{million\ pounds\ of\ water})$$

And this becomes Equation 5.

Eq. 5:

$$\frac{Feed\ rate\ of\ liquid\ alum\ \left(\frac{ml}{minute}\right) \times Sp.Gr. \times \text{Conc.}}{Raw\ water\ flow\ rate\ (gpm) \times 3{,}785\frac{ml}{gal}} \times 10^6 =$$

$$= Dry\ weight\ based\ alum\ dose\ (ppm\ or\ \frac{pounds\ of\ dry\ alum}{million\ pounds\ of\ water})$$

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Dry Weight Based Dosage Calculations for Liquid Aluminum Sulfate (Alum) (and other liquid chemicals) (continued)

Dosage to Feed Rate Calculations for Dry Weight Doses of Liquid Alum (or Another Chemical Mixed with Water)

Equation 6 can be used to calculate the feed rate of liquid alum given the dry weight based alum dose, raw water flow rate, and alum concentration and specific gravity.

Eq. 6: $\textit{Feed rate of liquid alum}\left(\frac{ml}{minute}\right) =$

$$= \frac{\textit{Dry weight based alum dose (ppm)} \times \textit{raw water flow rate}\left(\frac{gal}{min}\right) \times 3{,}785\left(\frac{ml}{gal}\right)}{(10^6 \times Sp.Gr. \times Conc.)}$$

For example, if:

- The liquid alum feed rate is 200 mL/minute,
- The concentration (Conc.) of liquid alum is 48.1%,
  or 48.1 lbs of dry alum per 100 pounds of liquid alum,
- The raw water flow rate is 1,000 gpm, and
- The dose is 30 ppm
  (or $\frac{30\ lbs\ of\ dry\ alum}{1{,}000{,}000\ lb\ of\ water}$, or $\frac{30\ mg\ of\ dry\ alum}{1{,}000{,}000\ mg\ of\ water}$).

Then, inserting our values into Eq. 6:

$$\textit{Feed rate of liquid alum}\left(\frac{ml}{minute}\right) = \frac{30\ ppm \times 1{,}000\left(\frac{\cancel{gal}}{min}\right) \times 3785\left(\frac{ml}{\cancel{gal}}\right)}{1{,}000{,}000 \times 1.33 \times \frac{48.1\ \text{lbs of dry alum}}{100\ lbs\ of\ liquid\ alum}} = 177\ ml/min$$

Note: we can convert this feed rate to gpm, gph, or gpd by applying the factors from Handout 1:

Therefore:

$$177\ \frac{ml}{minute} \times 0.000264\frac{gpm}{ml/min} = 0.047\ gpm$$

And:

$$177\ \frac{ml}{minute} \times 0.01585\frac{gph}{ml/min} = 2.80\ gph$$

And:

$$177\ \frac{ml}{minute} \times 0.38041\frac{gpm}{ml/min} = 67.3gpd$$

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Dosage Calculations for Gaseous Chemicals and Dry Chemicals

Feed Rate to Dosage Calculations for Gas Chemicals

Equation 7a shows how to use the gas feed rate and raw water flow to calculate the dose when feeding gaseous chemical.

Eq. 7(a):

$$Chemical\ Dose\ (ppm)\ = \frac{Gas\ Feed\ Rate\ (ppd)\ \times\ Conc.}{Raw\ Water\ Flow\ rate\ (gpm)\ \times 8.34\frac{lbs}{gal}\ \times\ 1440\frac{min}{day}} \times 10^6$$

Where: Conc. is the fractional concentration of the reactant in the dry chemical mixture.

<u>Note</u>: Typically, gas chemicals are 100% active chemical so a concentration factor becomes 1.0 (*because* 100% ÷ 100 = 1.0).

For example, if:

- The gas feed rate is 20 ppd, and
- The raw water flow rate is 1,000 gpm

Then:

$$Chemical\ Dose\ (ppm) = \frac{20\ ppd}{1{,}000\ gpm \times 8.34\frac{lbs}{gal}\ \times\ 1440\frac{min}{day}} \times 1{,}000{,}000$$

Crossing out the units that cancel each other out, we get:

$$Chemical\ Dose\ (ppm) = \frac{20\ \cancel{lbs}/\cancel{day}}{1{,}000\ \cancel{gal}/\cancel{min} \times 8.34\frac{\cancel{lbs}}{\cancel{gal}}\ \times\ 1440\frac{\cancel{min}}{\cancel{day}}} \times 1{,}000{,}000$$

$$Chemical\ Dose\ (ppm) =\ \ 1.67\ ppm$$

Dosage Calculations for Gaseous Chemicals and Dry Chemicals (continued)

Feed Rate to Dosage Calculations for Solid Dry Chemicals

Equation 7a shows how to calculate chemical dose in parts per million from dry chemical feed rate and raw water flow rate.

Eq. 7(a):

$$Chemical\ Dose\ (ppm)\ = \frac{Dry\ chemical\ feed\ rate\ (ppd)\ \times\ Conc.}{Raw\ Water\ Flow\ rate\ (gpm)\ \times 8.34\frac{lbs}{gal}\ \times\ 1440\frac{min}{day}}\ \times 10^6$$

Where: Conc. is the fractional concentration of the reactant in the dry chemical mixture.

When dosing with dry chemicals that are 100% active ingredient, the concentration factor in Equation 7(a) would be 1.0 (100% ÷ 100 = 1.0).

However, if you were using 65% HTH (for example), the concentration factor would be 0.65 (65% ÷ 100 = 0.65) because the the HTH only contains 65% as much reactive chlorine as chlorine gas does.

For example, if:

- The HTH feed rate is 20 ppd,
- The raw water flow rate is 1000 gpm, and
- The concentration (Conc.) of HTH is 65%
  (or 65 lbs of reactive chlorine per 100 pounds of HTH)

Then:

$$Chemical\ (chlorine)\ Dose\ (ppm) = \frac{\frac{20\ ppd\ HtH}{day}\ X\ \frac{65\ lbs\ of\ chlorine}{100\ lbs\ HtH}}{1{,}000\ gpm\ \times 8.34\frac{lbs}{gal}\ \times\ 1440\frac{min}{day}}\ \times 1{,}000{,}000$$

Crossing out the units that cancel each other out, we get:

$$Chemical\ (chlorine)\ Dose\ (ppm) = \frac{\frac{20\ \cancel{lbs\ HtH}}{\cancel{day}}\ X\ \frac{65\ lbs\ of\ chlorine}{100\ \cancel{lbs\ HtH}}}{1{,}000\ \frac{\cancel{gal}}{\cancel{min}} \times 8.34\frac{\cancel{lbs}}{\cancel{gal}}\ \times\ 1440\frac{\cancel{min}}{\cancel{day}}}\ \times 1{,}000{,}000$$

$$Chemical\ (chlorine)\ \ Dose\ (ppm) =\ \ 1.08\ ppm$$

Dosage Calculations for Gaseous Chemicals and Dry Chemicals (continued)

Dosage to Feed Rate Calculations for Gas Chemicals

Equation 8 is used to determine the gas feed rate using the desired chemical dose and the raw water flow rate.

Eq. 8: $Gas\ feed\ rate\ (ppd, or\ \frac{lbs\ of\ gas}{day}) =$

$$= \frac{Chemical\ Dose\ \left(\frac{lbs}{million\ pounds\ of\ water}, or\ ppm\right)}{Conc.\ X\ \ 10^6} \times Raw\ Water\ Flow\ Rate\ (ppd)$$

Where: Conc. is the fractional concentration of the reactant in the dry chemical mixture.

Note: Typically, gas chemicals are 100% active chemical so a concentration factor is not used. Another way to say this is that the conc. is 1.0.

Because we normally calculate raw water flow rate in MGD or gpm, we need conversion factors to adjust the raw water flow to something we normally use. If we calculate the flow rate in gpm, the equation becomes:

$$Gas\ feed\ rate\ \left(ppd, or\ \frac{lbs\ of\ gas}{day}\right) =$$

$$= \frac{Chemical\ Dose\ (\ ppm)}{10^6} \times Raw\ Water\ Flow\ Rate\ (gpm) \times\ 8.34\frac{lbs}{gal} \times\ 1440\frac{min}{day}$$

For example, if:

- The gas dose is 2 ppm, and
- The raw water flow rate is 1,000 gpm

Then:

$$Gas\ feed\ rate\ (ppd) = \frac{20\ ppm\ \times 1{,}000\ gpm \times\ 8.34\frac{lbs}{gal}\ \times\ 1440\frac{min}{day}}{10^6}$$

$$Gas\ feed\ rate\ (ppd) = \frac{2.0\ ppm}{1{,}000{,}000} \times 1{,}000\ \cancel{gal/min} \times\ 8.34\frac{lbs}{\cancel{gal}} \times\ 1440\frac{\cancel{min}}{day}$$

$$Gas\ feed\ rate\ (ppd)\ =\ \ 24\frac{lbs}{day}$$

Dosage Calculations for Gaseous Chemicals and Dry Chemicals (continued)

Dosage to Feed Rate Calculations for Solid Dry Chemicals

Eq. 8: $Chemical\ feed\ rate\ (ppd, or\ \frac{lbs}{day}) =$

$$= \frac{Dry\ Weight\ Chemical\ Dose\ \left(\frac{lbs}{million\ pounds\ of\ water}, or\ ppm\right)}{Conc.\ X\ 10^6}$$

$$\times\ Raw\ Water\ Flow\ Rate\ (ppd)$$

Where: Conc. is the fractional concentration of the reactant in the dry chemical mixture.

Note: When using dry chemicals, the equation would be exactly the same as the one for a gas chemical if the dry chemical was 100% active ingredient.
If the dry feedstock only has a fraction of active chemical then the dose in ppm would be divided by the fractional concentration.
For example HTH is normally only 65% calcium hypochlorite, so:

conc. of 65% HTH ÷ 100 = 0.65 chlorine,

but the rest of the equation would be the same.

For example, if:

- The chlorine dose needs to be 2 ppm,
- The raw water flow rate is 1,000 gpm, and
- The plant is using 65% HTH

Then:

$$HTH\ feed\ rate\ (ppd) = \frac{2\ ppm\ chlorine}{\frac{65\ lbs\ chlorine}{100\ lbs\ HTH}\ X\ 10^6}\ X\ 1{,}000\ gpm\ \times\ 8.34\frac{lbs}{gal}\ \times\ 1440\frac{min}{day}$$

$$HTH\ feed\ rate\ (ppd)$$

$$= \frac{2.0\ \cancel{ppm\ chlorine}}{0.65\frac{\cancel{lbs\ chlorine}}{lb\ HTH}\ X\ 1{,}000{,}000} \times 1{,}000\ \cancel{gal}/\cancel{min} \times\ 8.34\frac{\cancel{lbs}}{\cancel{gal}}\ \times\ 1440\frac{\cancel{min}}{day}$$

$$Gas\ feed\ rate\ (ppd)\ =\ 40\frac{lbs\ HTH}{day}$$

DAM 2a. Evaluation Form

(to be completed by plant staff who participated in the training activities)

Training location: ______________________________ Date: ______________

Instructor Name: ______________________________

① Strongly Agree ② Agree ③ No Opinion ④ Disagree ⑤ Strongly Disagree

1. The agenda for this workshop accurately described the information being covered.	① ② ③ ④ ⑤
2. The information presented during the workshop was too technical or was too hard.	① ② ③ ④ ⑤
3. The information presented during the workshop was not technical enough.	① ② ③ ④ ⑤
4. The workshop covered too much information or the trainer went too fast.	① ② ③ ④ ⑤
5. The workshop covered too little information or the trainer went too slow.	① ② ③ ④ ⑤
6. The monitoring strategy developed during the workshop is useful.	① ② ③ ④ ⑤
7. The information on the Process Monitoring Form is understandable.	① ② ③ ④ ⑤
8. The training is <u>exactly</u> what we needed.	① ② ③ ④ ⑤
9. The training is valuable and will help us improve plant performance.	① ② ③ ④ ⑤
10. Our water system would be willing pay for this kind of training.	① ② ③ ④ ⑤

Questionnaire continues on the back

Specific Suggestions:

What could we change in the agenda to improve it?

What did we not explain well enough for you to understand?

What areas did we spend too much time on?

What areas did we spend too little time on?

What are some other issues where you feel more training is needed?

What other comments or suggestions do you have?

Revision table

Date	Action	Comment
Ca 2010	Created	
August 2015	Revised	Split DAM 2 into separate DAMs
August 24, 2019	Revised	Revised to meet TCEQ accessibility standards and incorporate feedback from previous training events
December 10, 2019	Revised	Equations revised to meet TCEQ accessibility standards

Thanks for participating in this Directed Assistance Module (DAM)