

PROCESS CONTROL MATH

for

WATER PLANT OPERATORS

Fifth Edition

1999

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INTRODUCTION

Welcome to Process Control Math for Water Plant Operators. This workbook should be used after successful completion of the Water and Wastewater Technologies Core Program. In the Core Program, students were introduced to a process where problems were solved by organizing them into simple steps. Students were encouraged to follow each step, assign units to each value, and draw a diagram of the situation given.

The method of problem solving introduced in the Core Program will be used in solving more complex problems dealing with process control of drinking water facilities. These problems can sometimes involve multiple formulas, so it is extremely important that the steps introduced in the Core Workbook be followed.

As in the Core Workbook, examples will be given for each type of problem. The steps in the examples given in this workbook are not labeled as in the Core Workbook, however, and many of the diagrams have been eliminated for simplicity. In the appendix, there are sample tests that represent each type of problem. The appendix also contains an answer key. Use the formula sheet and the table of equivalents provided in the appendix in completing the sample tests.

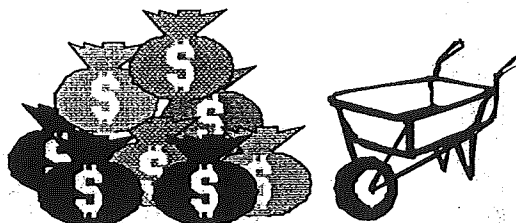
Remember that most students make errors in the actual setup of the problem. Take your time. Keep organized. Write down all information given that concerns the problem, draw a diagram if necessary, keep track of the units, and use the four steps:

1. Write the formula.
2. Substitute knowns for unknowns.
3. Simplify by canceling and calculating.
4. Write the answer in the units called for.

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CHAPTER ONE

Loading Problems



Sedimentation is a process used in water treatment where solid particles are removed by gravitational forces. Sedimentation tanks in water treatment are designed with certain overflow, or loading rates. If the loading rates are exceeded, the efficiency of the sedimentation process diminishes greatly.



WEIR OVERFLOW RATES

Weir overflow rates (sometimes called weir loading rates) are how many gallons of treated water flow over one foot of weir in a certain time period. They involve the total length of the weir and the total flow rate. Sometimes the weir length is given, and other times it must be calculated, such as in circular clarifiers where only the diameter of the clarifier is given. In all cases, the length of weir is in linear units (a single dimension resembling a straight line), usually feet. The flow rate can be given in any combination of gallons and time units and can be written as such in the formula.

The formula for calculating weir overflow rates in gallons per day per foot is:

$$\bullet \text{ Weir overflow rate, gal/day/ft} = \frac{\text{total flow, gal/day}}{\text{length of weir, ft}}$$

Example

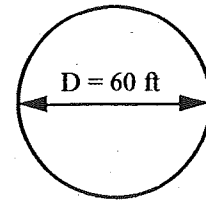
Determine the weir overflow rate of a circular clarifier whose diameter is 60 feet and the flow is 1.5 MGD.

In this case, the length of the weir is not given. Knowing that the clarifier is circular, it is easy to calculate the weir length because it is the same as the circumference.

First, determine the length of the weir in feet by calculating the circumference using the formula $C = \pi \times D$.

$$C = 3.14 \times 60 \text{ ft}$$

$$C = 188.4 \text{ feet, the length of the weir}$$



$$\text{Weir overflow rate, gal/day/ft} = \frac{\text{total flow rate, gal/day}}{\text{length of weir, ft}}$$

$$\text{Weir overflow rate, gal/day/ft} = \frac{1,500,000 \text{ gal/day}}{188.4 \text{ ft}}$$

$$\text{Weir overflow rate, gal/day/ft} = 7,962 \text{ gal/day/ft}$$

(Since no units cancel, the new units for weir overflow rate are in gallons per day per foot.)



SURFACE LOADING RATES

Surface loading is an important guideline used in the design of sedimentation tanks. In order to perform the calculations, the tank influent flow and the total surface area of the sedimentation tank or clarifier are needed. Sometimes the areas are given, and other times a calculation is required. Determine surface areas by the area formulas in the Core Workbook. Notice that the time units in the following formula are in days. The formula can be written with minutes or hours as the time unit. The calculations are performed in the same way.

The formula for surface loading rates is written:

$$\bullet \text{ SLR, gal/day/sq ft} = \frac{\text{influent flow (gal/day)}}{\text{surface area (sq ft)}}$$

Example

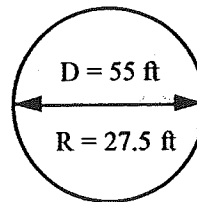
What is the surface loading rate of a sedimentation tank with a diameter of 55 ft and an influent flow rate of 1.152 MGD?

First, calculate the area.

$$A = \pi \times R^2$$

$$A = 3.14 \times 27.5 \text{ ft} \times 27.5 \text{ ft}$$

$$A = 2,374.6 \text{ sq ft}$$



Now that the area is known, substitute the remaining known values into the surface loading rate formula.

$$\text{Surface loading rate, gal/day/sq ft} = \frac{\text{influent flow (gal/day)}}{\text{surface area (sq ft)}}$$

$$\text{Surface loading rate, gal/day/sq ft} = \frac{1,152,000 \text{ gal/day}}{2,374.6 \text{ sq ft}}$$

$$\text{Surface loading rate, gal/day/sq ft} = 485 \text{ gal/day/sq ft}$$

The units are particular to surface loading rates. Notice that none of the units cancel out in the formula, so all of the units must be kept. This gives *gallons per day per square foot*.

Sometimes the answer in gallons per minute per square foot (gal/min/sq ft) as well as gallons per day per square foot (gal/day/sq ft) may be necessary. Use the appropriate conversion factors.

$$\frac{485 \text{ gal/day/sq ft}}{1440 \text{ min/day}} = 0.34 \text{ gal/min/sq ft}$$



RISE RATES

The rise rate of a sedimentation basin or clarifier is calculated from the surface loading rate. Rise rate is actually a velocity, as will be seen by the units that rise rates are expressed in. For a particle to settle in a clarifier or sedimentation tank, it must have a settling rate greater than the rise rate. The units in the following formula will express the answer in the units of *feet per minute*.

The formula used to calculate rise rates is written:

- $\text{Rise rate, ft/min} = \frac{\text{surface loading, gal/min/sq ft}}{7.48 \text{ gal/cu ft}}$



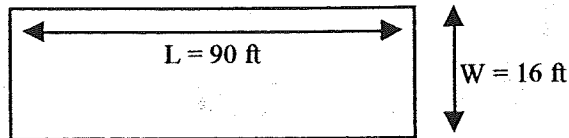
Example

A rectangular settling basin for a surface water treatment facility is 90 feet in length, 16 feet in width, and has an effective depth of 12 feet. What is the rise rate of this basin if the flow is 0.25 million gallons per 8 hour period ?

First, calculate the surface loading rate. In order to do this, the surface area of the rectangular tank is needed. Note in the information above that the depth is given, but it is not essential for this calculation.

$$A = 90 \text{ ft} \times 16 \text{ ft}$$

$$A = 1,440 \text{ sq ft}$$



Next, change the flow through the basin to the units of gallons per minute:

$$0.25 \text{ MG for } 8 \text{ hours} \times 60 \text{ min/hr} = 480 \text{ min.}$$

$$0.25 \text{ MG in } 480 \text{ minutes, or } 250,000 \text{ gallons in } 480 \text{ minutes}$$

$$\frac{250,000 \text{ gal}}{480 \text{ min}} = 521 \text{ gal/min}$$

Now that the surface area and the flow in gallons per minute are known, use the surface loading rate formula.

$$\text{Surface loading rate, gal/min/sq ft} = \frac{\text{influent flow (gal/min)}}{\text{surface area (sq ft)}}$$

$$\text{Surface loading rate, gal/min/sq ft} = \frac{521 \text{ gal/min}}{1440 \text{ sq ft}}$$

$$\text{Surface loading rate, gal/min/sq ft} = 0.362 \text{ gal/min/sq ft}$$

The surface loading rate has been calculated, so substitute the known information into the formula for rise rate, and proceed using the steps:

$$\text{Rise rate, ft/min} = \frac{\text{surface loading, gal/min/sq ft}}{7.48 \text{ gal/cu ft}}$$

$$\text{Rise rate, ft/min} = \frac{0.362 \text{ gal/min/sq ft}}{7.48 \text{ gal/cu ft}}$$

$$\text{Rise rate, ft/min} = 0.05 \text{ ft/min}$$

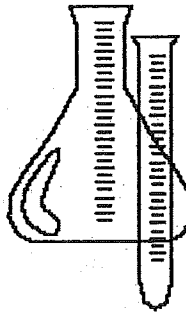
In analyzing what happened with the units, notice that the *gallons* cancel out, the *minutes* remain, and cubic and square feet cancel with *feet* remaining— thus the new units are feet per minute.

This concludes the LOADINGS portion of this program. In the appendix, there is a multiple-choice test that covers all of the information in this section. If you feel comfortable with the subject matter, it is suggested that you take this test now and compare your answers with those provided in the answer key. Write the problem out completely, use the steps, use care in unit conversions, and refer to the formula sheet in the appendix of this workbook.

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CHAPTER TWO

Chemical Mixing and Strength of Solutions



Often, water treatment plant operators will be called upon to calculate chemical feeder settings, dilute chemicals that are received from the manufacturer to a strength that is usable in the treatment plant, and to weigh powdered chemicals and dilute them with water so they can be fed to a treatment unit.



DRY CHEMICAL MIXING

When using dry chemicals, the chemicals are mixed with water in a tank so they can be fed to the treatment process as a solution. Sometimes these mixed chemical solutions are measured as a *percent solution*.

The formula used for preparing a specific percent chemical (or polymer) solution is written below.

$$\bullet \text{ Chemical, \%} = \frac{(\text{dry chemical, lb}) \times (100\%)}{(\text{dry chemical, lb} + \text{water, lb})}$$

Example

An operator weighs 0.132 lb of polymer and adds it to 5 gallons of water. What is the percent of polymer by weight?

$$\text{Polymer, \%} = \frac{(\text{dry polymer, lb}) \times (100\%)}{(\text{dry polymer, lb} + \text{water, lb})}$$

$$\text{Polymer, \%} = \frac{(0.132 \text{ lb}) \times (100\%)}{(0.132 \text{ lb}) + (8.34 \text{ lb/gal} \times 5 \text{ gal})}$$

$$\text{Polymer, \%} = \frac{13.2 \text{ lb}}{41.83 \text{ lb}}$$

$$\text{Polymer, \%} = 0.32 \%$$

Also, with powdered or dry chemicals, it is sometimes necessary to know how many pounds of that specific chemical must be mixed with a certain amount of water to achieve a desired percent solution. To calculate this, it is a requirement to know how many gallons of water will be mixed with the powder, and also the percent strength of the chemical being used.

The formula for calculating the pounds of dry polymer or chemical is written:

- $$\text{Dry polymer, lb} = \frac{\text{water, lb}}{\left(\frac{100\%}{\text{polymer \%}}\right) - 1}$$

Example

How many pounds of dry polymer must be added to a tank containing 100 gallons of water to produce a 0.25 percent polymer solution ?

$$\text{Dry Polymer, lb} = \frac{\text{water, lb}}{\left(\frac{100\%}{\text{polymer \%}}\right) - 1}$$

$$\text{Dry polymer, lb} = \frac{(100 \text{ gal} \times 8.34 \text{ lb/gal})}{\left(\frac{100\%}{0.25\%}\right) - 1}$$

$$\text{Dry polymer, lb} = \frac{834 \text{ lb}}{400 - 1}$$

$$\text{Dry polymer, lb} = 2.1 \text{ lb}$$

By using a variation of the polymer % formula, another unknown can be solved. If the percent polymer solution that must be fed is known, and the pounds of dry polymer to be used is also known, the pounds or gallons of water necessary for mixing can be calculated.

The formula for pounds of water is written:

- $$\text{Water, lb} = \frac{(\text{dry polymer, lb} \times 100\%)}{\text{polymer \%}} - \text{dry polymer, lb}$$

Example

How many gallons of water should be mixed with 1.5 pounds of dry polymer to produce a 0.5 percent polymer solution?

$$\text{Water, lb} = \frac{(\text{dry polymer, lb} \times 100\%)}{\text{polymer \%}} - \text{dry polymer, lb}$$

$$\text{Water, lb} = \frac{(1.5 \text{ lb} \times 100\%)}{0.5 \%} - 1.5 \text{ lb}$$

$$\text{Water, lb} = 300 \text{ lb} - 1.5 \text{ lb}$$

$$\text{Water, lb} = 298.5 \text{ lb}$$

If the answer is required in gallons, use this conversion.

$$\text{water, gal} = \frac{\text{water, lb}}{8.34 \text{ lb/gal}}$$

$$\frac{298.5 \text{ lb}}{8.34 \text{ lb/gal}} = 35.8 \text{ gallons}$$



LIQUID CHEMICALS

When working with liquid polymers or chemicals, the percent strength of chemical in the *concentrated chemical* received from the manufacturer is given. The problem is to determine how much of a concentrated chemical should be mixed with water to give a new batch of diluted chemical at a lower percent strength which then can be fed to the treatment process.

The formula for working with liquid polymers or chemicals is:

$$\bullet \text{ Conc chem, gal} = \frac{(\text{desired chem sol'n, \%}) (\text{gal needed})}{(\text{conc chemical \%})}$$

Example

A liquid polymer is supplied to a water treatment plant as a 30% solution. How many gallons of this polymer should be mixed in a tank to produce 100 gallons of a 0.5 percent solution ?

$$\text{Conc chem, gal} = \frac{(\text{desired chem sol'n, \%}) (\text{gal needed})}{\text{conc chemical, \%}}$$

$$\text{Conc chem, gal} = \frac{(0.5\%) \times (100 \text{ gal})}{30\%}$$

$$\text{Conc chem, gal} = \frac{50 \text{ gal}}{30} \quad (\text{the percent units cancel})$$

$$\text{Conc chem, gal} = 1.7 \text{ gallons}$$

This means that 1.7 gallons of the concentrated solution should be added to 98.3 gallons of water to produce 100 gallons of the 0.5 % solution.

Sometimes when working with liquids, the weight of a volume of a solution with a certain specific gravity must be determined. As defined in the Core Workbook, specific gravity is the weight of a substance in relation to the weight of an equal volume of water. Water has a specific gravity of 1.00.

If one gallon of water (specific gravity of 1.00) weighs 8.34 pounds, then multiply the specific gravity of the liquid to be determined (which will be given in a test situation) times the number of gallons involved times 8.34 lb/gal. Follow this example.

Example

How much will 20 gallons of polymer with a specific gravity of 1.08 weigh?

$$1.08 \times 8.34 \text{ lb/gal} \times 20 \text{ gal} = 180.1 \text{ pounds}$$



CHEMICAL FEEDER SETTINGS

This section will illustrate how to set, adjust, and calibrate chemical feeders. There are two types of chemical feeders that will be discussed— solution feeders and dry chemical feeders.

Usually, adjusting feeders is done by turning a knob or a hand-crank on the feeder itself. The feeder has a rate scale with a pointer that is usually calibrated over a range of zero to 100 percent.

For solution chemical feeders, the formula is written:

- $\text{Scale setting, \%} = \frac{(\text{desired feed rate, gal/hr}) (100 \%)}{(\text{maximum feed rate, gal/hr})}$

Example

A solution chemical feeder has a scale that reads in percent. The maximum output of this feeder is 25 gallons per hour. Where should the feeder be set to feed 8 gallons per hour ?

$$\text{Scale setting, \%} = \frac{(\text{desired feed rate, gal/hr}) (100 \%)}{(\text{maximum feed rate, gal/hr})}$$

$$\text{Scale setting, \%} = \frac{(8 \text{ gal/hr}) \times 100 \%}{(25 \text{ gal/hr})}$$

$$\text{Scale setting, \%} = 32 \%$$

Sometimes, when calculating the setting of a solution chemical feeder, the amount of solution that must be fed will NOT be given. The target dosage in mg/L, the flow that must be treated, and the percentage concentration of the chemical that must be fed by the feeder pump are given.

It may be necessary to convert the solution strength, if given in percent, into pounds of chemical per gallon of solution.

The formula for converting percent strengths into pounds per gallon is written:

- $\text{Chemical sol'n, lb/gal} = \frac{(\text{sol'n \%}) \times (8.34 \text{ lb/gal})}{100 \%}$

In order to determine the desired flow that a feed pump should deliver in gallons per day or any time unit, use this formula:

- $\text{Pump output, gal/day} = \frac{\text{chemical feed, lb/day}}{\text{chemical solution, lb/gal}}$

The time unit *gal/day* could just as well be *gal/hr* or *gal/min*. Be sure to keep track of the time units and do the unit conversions properly.

The above formula shows how to establish the amount of solution, in gallons per time unit that needs to be fed by a chemical pump.

If the required dosage, in mg/L, and the amount of water that must be treated are known, use the pounds formula from the Core Workbook to calculate the amount of chemical required.

The formula is written:

- $\text{Chemical req'd, lb/day} = (\text{Flow, MGD}) \times (\text{dose, mg/L}) \times (8.34 \text{ lb/gal})$

The following example will show how to convert a percent solution of any chemical into the units of *pounds of chemical per gallon (lb/gal)*. Next, the amount of chemical, in gallons per time unit that must be pumped per day will be calculated. After this information has been established, use the *scale setting, %* formula shown previously to complete the problem.

Example

A solution feeder has a scale that reads in percent. The maximum output of this feeder is 40 gallons per day. A polymer solution must be fed which will result in a chemical dose of 2.5 mg/L to a flow of 0.450 MGD. At what percent should the chemical feeder be set if the polymer being fed is in a 6 percent solution ?

In solving this problem, notice that the pump output is in gallons per day and the flow is given in gallons per day. Therefore, it is best to set up the formulas using *days* as the time unit.

First, calculate how many pounds per gallon are contained in a 6% chemical solution.

$$\text{Chemical sol'n, lb/gal} = \frac{(\text{sol'n \%}) \times (8.34 \text{ lb/gal})}{100 \%}$$

$$\text{Chemical sol'n, lb/gal} = \frac{(6 \%) \times (8.34 \text{ lb/gal})}{100 \%}$$

$$\text{Chemical sol'n, lb/gal} = 0.5 \text{ lb/gal}$$

This means that contained in every gallon of solution, there are 0.5 pounds of chemical.

Now, figure the chemical requirement in pounds per day.

$$\text{Chem. req'd, lb/day} = \text{Flow, MGD} \times \text{dose, mg/L} \times 8.34 \text{ lb/gal}$$

$$\text{Chem. req'd, lb/day} = 0.450 \text{ MGD} \times 2.5 \text{ mg/L} \times 8.34 \text{ lb/gal}$$

$$\text{Chem. req'd, lb/day} = 9.4 \text{ lb/day}$$

This means that 9.4 pounds of chemical must be fed to the flow of 0.450 MG.

Now that this information has been established, calculate the flow required of the feed pump.

$$\text{Pump output, gal/day} = \frac{\text{chemical feed, lb/day}}{\text{chemical solution, lb/gal}}$$

$$\text{Pump output, gal/day} = \frac{9.4 \text{ lb/day}}{0.5 \text{ lb/gal}}$$

$$\text{Pump output, gal/day} = 18.8 \text{ gal/day}$$

To treat 0.450 MG, the pump must feed 18.8 gallons per day

Next, use the scale setting formula.

$$\text{Scale setting, \%} = \frac{(\text{desired flow, gal/day}) (100\%)}{\text{maximum feed rate, gal/day}}$$

$$\text{Scale setting, \%} = \frac{(18.8 \text{ gal/day}) (100\%)}{40 \text{ gal/day}}$$

$$\text{Scale setting, \%} = 47 \%$$

For dry chemical feed pumps, the only difference is in the units. Liquid chemical feeders use gallons per hour, minute, or day and dry chemical feeders use *pounds* per time unit. The problems are done in the same manner.

For dry chemical feeders, the formula is written:

- $$\text{Feeder setting, \%} = \frac{(\text{desired feed rate, lb/day}) \times (100 \%)}{(\text{maximum feed rate, lb/day})}$$

Example

It is necessary to feed 45 pounds of dry coagulant per day to a small water treatment system. If the chemical feeder being used has a maximum feed rate of 75 pounds per day, at what percent should the feeder be set?

$$\text{Feeder setting, \%} = \frac{(\text{desired feed rate, lb/day}) \times (100 \%)}{(\text{maximum feed rate, lb/day})}$$

$$\text{Feeder setting, \%} = \frac{(45 \text{ lb/day}) \times (100 \%)}{75 \text{ lb/day}}$$

$$\text{Feeder setting, \%} = 60 \%$$



CHEMICAL DILUTIONS

Another example of a calculation operators may have to perform is dilutions of hypochlorite solutions for use as disinfectants in small water treatment systems. Hypochlorite solutions are ordinarily diluted before being used, and if the operator knows the strength, in percent, of the original solution and also knows the desired strength, the amount of water necessary to dilute the hypochlorite to the new, or desired strength can be calculated. This formula can be used for any type of liquid chemical that must be diluted before being fed.

The formula for chemical dilutions is written as follows:

• Water added, gal =
$$\frac{(\text{Hypo, gal}) (\text{Hypo, \%}) - (\text{Hypo, gal}) (\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

Example

How many gallons of water must an operator add to 5 gallons of a 10 % hypochlorite solution to produce a 1 % hypochlorite solution ?

Water added, gal =
$$\frac{(\text{hypo, gal}) (\text{hypo, \%}) - (\text{hypo, gal}) (\text{desired hypo, \%})}{\text{desired hypo, \%}}$$

Water added, gal =
$$\frac{(5 \text{ gal}) \times (10\%) - (5 \text{ gal}) \times (1\%)}{1\%}$$

Water added, gal =
$$\frac{50 \text{ gal} - 5 \text{ gal}}{1}$$
 (the percents cancel out and the only units left are gallons)

Water added, gal = 45 gallons

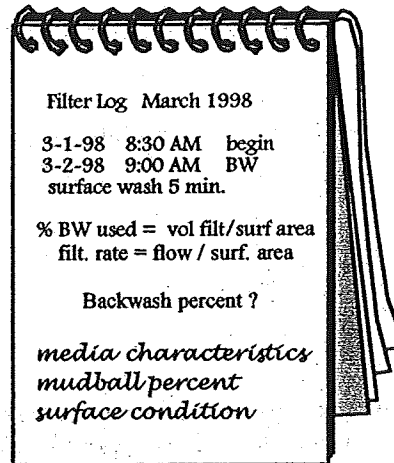
This concludes the CHEMICAL MIXING portion of this program. In the appendix, there is a multiple-choice test that covers all of the information in this section. If you feel comfortable with the subject matter, it is suggested that you take this test now and compare your answers with those provided in the answer key. Write the problem out completely, use the steps, use care in unit conversions, and refer to the formula sheet in the appendix of this workbook.

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Filtration

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CHAPTER THREE



Filtration is the most common method of removing impurities in water treatment. Filtration usually follows flocculation with chemical coagulants and sedimentation. Under the force of gravity, with positive head, water passes downward through the filter media which collects floc and particles. When the filter media becomes filled, or solids break through, or after a certain time limit, the filter bed must be cleaned by backwashing. During a backwash, an upward, or reverse flow fluidizes the media and washes away the impurities that have accumulated there.

Filtration calculations usually involve flows and areas. Most of the errors water treatment operator candidates make occur in conversion of units. Make sure that any conversions are done correctly. Do not take shortcuts in the steps.



GRAVITY FILTRATION

The filtration rate is the flow in gallons per minute which is filtered by one square foot of filter surface area.

The formula for filtration rate is written:

$$\bullet \text{ Filtration rate, gpm/sq ft} = \frac{\text{flow, GPM}}{\text{surface area, sq ft}}$$

Example

What is the filtration rate of a gravity filter with a length of 30 feet, a width of 20 feet, and a depth of 8 feet if the plant treats 2.0 MGD ?

In order to plug in values to the formula, some conversions and calculations must be made.

Convert the 2.0 MGD to GPM by converting to gallons and dividing by 1440 min/day.

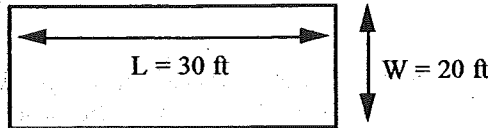
$$\frac{2,000,000 \text{ gal/day}}{1,440 \text{ min/day}} = 1,389 \text{ gal/min}$$

Calculate the surface area of the filter by the area formula introduced in the Core Workbook.

$$A = L \times W$$

$$A = 30 \text{ ft} \times 20 \text{ ft}$$

$$A = 600 \text{ sq ft}$$



Notice that a depth of 8 feet is given in the text of the problem. This information is not needed. Be sure to recognize numbers that are not needed and learn to ignore them. Now that all of the information necessary has been calculated and converted into the proper units, use the filtration rate formula.

$$\text{Filtration rate, gpm/sq ft} = \frac{\text{flow, gpm}}{\text{surface area, sq ft}}$$

$$\text{Filtration rate, gpm/sq ft} = \frac{1,389 \text{ gpm}}{600 \text{ sq ft}}$$

$$\text{Filtration rate, gpm/sq ft} = 2.3 \text{ gal/min/sq ft}$$

Notice the units. Nothing cancels, so everything is kept.

Sometimes operators are confronted with filtration rate problems where a flow is not given. Instead, the operator is said to observe the water level drop in the filter so many inches or feet during a certain amount of time. The filter influent valve will be closed and the filter effluent valve will remain open so the operator can record the drop in the level over a time period.

The operator will know the filter dimensions, and also will know the distance the water will drop in a certain amount of time. The filter dimensions will usually be in feet, and the drop of water may be in inches, which can be converted into feet, so a volume can be obtained (surface area of the filter times the distance the water dropped). By multiplying this volume by 7.48 gallons per cubic foot, a capacity in gallons can be obtained. Then, using the time factor given for the water to drop, a flow in gallons per minute can be calculated. Follow along with this example.

Example

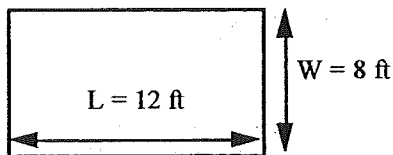
With the influent valve shut, a filter is observed to drop 6 inches in 2 minutes. The filter is 12 feet in length and is 8 feet in width. What is the filtration rate, in gallons per minute?

First, calculate the surface area of the filter.

$$A = L \times W$$

$$A = 12 \text{ ft} \times 8 \text{ ft}$$

$$A = 96 \text{ sq ft}$$



Now, calculate the gallons of water contained in the 6-inch drop. This is actually the amount of water that flowed through the filter in the time period indicated.

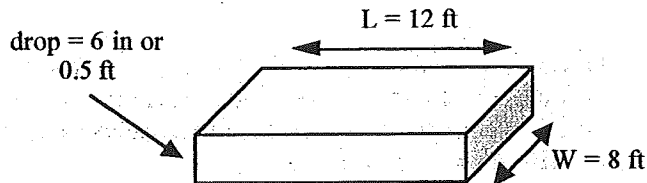
$$V = L \times W \times H$$

$$V = 12 \text{ ft} \times 8 \text{ ft} \times 0.5 \text{ ft}$$

$$V = 48 \text{ ft}^3$$

$$\text{Capacity} = 48 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3$$

$$\text{Capacity} = 359 \text{ gal}$$



Now, calculate the gallons per minute, or the flow through the filter.

$$\text{GPM} = \frac{359 \text{ gal}}{2 \text{ min}}$$

$$\text{GPM} = 179.5 \text{ gal/min}$$

Now, use these values to calculate the filtration rate.

$$\text{Filtration Rate, gpm/sq ft} = \frac{\text{flow, gpm}}{\text{area in sq ft}}$$

$$\text{Filtration Rate, gpm/sq ft} = \frac{179.5 \text{ gpm}}{96 \text{ sq ft}}$$

$$\text{Filtration Rate, gpm/sq ft} = 1.9 \text{ gpm/sq ft}$$



BACKWASHING

Under average operating conditions, granular-media filters are backwashed at a rate of about 15 gpm/sq ft. During backwashing, the filter bed is expanded about 50% or more and the released solids and impurities are flushed out to waste. Problems can occur in backwashing if the pumping rate is too high. Media can be lost with the wash water. If the pumping rate is too low, the bed will not be expanded completely and the cleaning action will be limited.

If a desired backwash (BW) flow rate and the dimensions of the filter are known, the backwash pumping rate in gallons per minute can be determined.

The formula for backwash pumping rate is written:

- $BPR, \text{ gpm} = (\text{filter surface area, sq ft}) (\text{BW rate, gpm/sq ft})$

 **Example**

What is the backwash pumping rate, in gpm, if a filter has a surface area of 550 sq ft and the desired backwash flow is 20 gpm/sq ft ?

$$BPR, \text{ gpm} = \text{filter surface area, sq ft} \times \text{BW rate, gpm/sq ft}$$


$$BPR, \text{ gpm} = 550 \text{ sq ft} \times 20 \text{ gpm/sq ft}$$

$$\text{Backwash pumping rate} = 11,000 \text{ gpm}$$

Sometimes the percentage of water used for backwashing may have to be determined.

The formula for determining the percent of backwash water is written:

- $\text{Backwash, \%} = \frac{(\text{backwash water, gal}) (100\%)}{\text{water filtered, gal}}$

 **Example**

During a 56 hour filter run, 21 MG of water have been filtered. 1.75 million gallons of water were used for backwashing. What is the percent of product water that was used for backwashing ?

$$\text{Backwash, \%} = \frac{(\text{backwash water, gal}) (100 \%)}{\text{water filtered, gal}}$$

$$\text{Backwash, \%} = \frac{(1,750,000 \text{ gal}) (100\%)}{21,000,000 \text{ gal}}$$

$$\text{Backwash, \%} = 8.3 \%$$



UFRV, or UNIT FILTER RUN VOLUME

Another calculation that may be encountered concerning filtration is the UFRV, or unit filter run volume. This is a method of comparing filter runs. It is the volume of water produced by the filter during the filter run time divided by the surface area of the filter. The units will be expressed as gallons per square foot.

The formula for UFRV is as follows:

$$\bullet \text{ UFRV, gal/sq ft} = \frac{\text{volume filtered, gal}}{\text{surface area, sq ft}}$$

Example

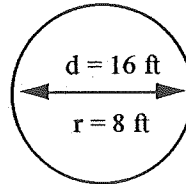
What is the unit filter run volume for a filter with a diameter of 16 feet when the amount of water filtered during the run is 440,000 gallons ?

Calculate the area of this circular filter.

$$A = \pi \times r^2$$

$$A = 3.14 \times 8 \text{ ft} \times 8 \text{ ft}$$

$$A = 200.96 \text{ or } 201 \text{ sq ft}$$



Now, using the UFRV formula:

$$\text{UFRV, gal/sq ft} = \frac{\text{volume filtered, gal}}{\text{surface area, sq ft}}$$

$$\text{UFRV, gal/sq ft} = \frac{440,000 \text{ gal}}{201 \text{ sq ft}}$$

$$\text{UFRV, gal/sq ft} = 2,189 \text{ gal/sq ft}$$

If a filtration rate is given (gal/min/sq ft) and a filter run is given (usually in hours), the UFRV can be calculated by using this formula:

$$\bullet \text{ UFRV, gal/sq ft} = (\text{filtration rate, gpm/sq ft}) (\text{filter run, hrs}) (60 \text{ min/hr})$$

Example

What is the UFRV for a sand filter that had a 1.8 gpm/sq ft filtration rate during a 106 hour filter run?

$$\text{UFRV, gal/sq ft} = (\text{filtration rate, gpm/sq ft}) (\text{filter run, hrs}) (60 \text{ min/hr})$$

$$\text{UFRV, gal/sq ft} = (1.8 \text{ gpm/sq ft}) (106 \text{ hrs}) (60 \text{ min/hr})$$

$$\text{UFRV, gal/sq ft} = 11,488 \text{ gal/sq ft}$$

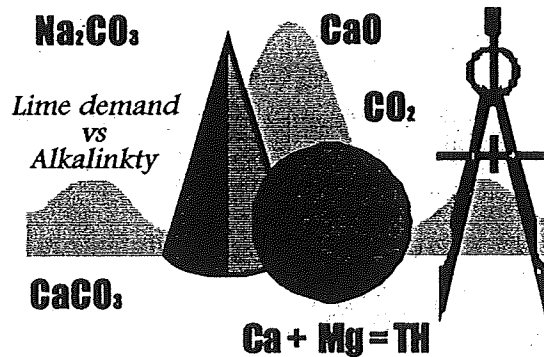
This concludes the filtration rates portion of the program. A ten question multiple choice test covering the material presented in this section can be found in the appendix of this workbook. When you feel comfortable with this material, take the test and score yourself with the answer key provided.

Remember to follow the steps as outlined in the examples. To avoid errors, check your units carefully to be sure that you made all the conversions properly.

4

CHAPTER FOUR

Coagulation, Softening, and Demineralization



COAGULATION CHEMISTRY

Coagulation is the process by which minute particles, or *colloids* dispersed in the water are destabilized and brought together to form larger particles. The larger particles, known as *floc*, are easier to separate from the water by settling or filtering.

For coagulation to take place, chemicals must be added to the water. After the addition of the chemicals, there should be a rapid mixing followed by a gentle agitation called *flocculation*. The gentle mixing causes the particles to clump together, thus forming the floc.

The presence of alkalinity in water is necessary for coagulation to take place. If the water is low in alkalinity, a sufficient amount of chemical must be added to increase the alkalinity so the reaction can take place.

Aluminum sulfate, or alum, is commonly used as a coagulant. For every one mg/L of alum added to water, it is necessary to have 0.45 mg/L alkalinity present for a complete reaction to occur. This means if there is no additional alkalinity added, 1 mg/L of alum would reduce the natural alkalinity of a water by 0.45 mg/L.

If there is not enough alkalinity present to react with the alum, lime or soda ash can be added to provide the necessary alkalinity for complete coagulation. When calcium hydroxide, or hydrated lime, is used to add alkalinity, 0.35 mg/L of lime will react with 1 mg/L of alum. When using soda ash, 0.54 mg/L of soda ash will react with 1 mg/L of alum.

In order to calculate how much alkalinity must be added to allow coagulation to take place, it is necessary to know the raw water's total alkalinity content. Also, excess alkalinity must be present to drive the chemical reaction to completion. The amount of excess alkalinity is usually between 20 and 30 mg/L and will be given in a test situation.

The following formulas are necessary for this calculation.

- $\text{Alk available, mg/L} = (\text{raw water alk, mg/L}) - (\text{alk necessary for precipitation, mg/L})$

- Alum reacting, mg/L = $\frac{(1.0 \text{ mg/L alum})(\text{alkalinity available, mg/L})}{0.45 \text{ mg/L alkalinity}}$
- Alum needing alkalinity, mg/L = (total alum, mg/L) - (alum reacting, mg/L)
- Lime dosage, mg/L = $\frac{(0.35 \text{ mg/L lime})(\text{alum needing alkalinity, mg/L})}{1 \text{ mg/L alum}}$

Example

Water to be treated for turbidity reduction has a total alkalinity of 42 mg/L. Jar testing has shown that a chemical dose of 46 mg/L alum is the ideal dose for reducing the turbidity to acceptable limits. At least 30 mg/L of excess alkalinity are necessary to insure a complete reaction. What is the dose of calcium hydroxide, $\text{Ca}(\text{OH})_2$, that is necessary for a proper reaction?

First, determine the alkalinity that is available to react with the alum.

$$\text{Alk available, mg/L} = (\text{raw water alk, mg/L}) - (\text{alk necessary for precipitation, mg/L})$$

$$\text{Alk available, mg/L} = 42 \text{ mg/L} - 30 \text{ mg/L}$$

$$\text{Alk available, mg/L} = 12 \text{ mg/L}$$

Determine the mg/L of alum that will react with the alkalinity available:

$$\text{Alum reacting, mg/L} = \frac{(1.0 \text{ mg/L alum})(\text{alkalinity available, mg/L})}{0.45 \text{ mg/L alkalinity}}$$

$$\text{Alum reacting, mg/L} = \frac{(1.0 \text{ mg/L alum})(12 \text{ mg/L})}{0.45 \text{ mg/L alkalinity}}$$

$$\text{Alum reacting, mg/L} = 26.7 \text{ or } 27 \text{ mg/L}$$

Now, determine how many mg/L alum need additional alkalinity.

$$\text{Alum needing alkalinity, mg/L} = (\text{total alum, mg/L}) - (\text{alum reacting, mg/L})$$

$$\text{Alum needing alkalinity, mg/L} = (46 \text{ mg/L}) - (27 \text{ mg/L})$$

$$\text{Alum needing alkalinity, mg/L} = 19 \text{ mg/L}$$

Finally, calculate the lime dose.

$$\text{Lime dosage, mg/L} = \frac{(0.35 \text{ mg/L lime})(\text{alum needing alkalinity, mg/L})}{1 \text{ mg/L alum}}$$

$$\text{Lime dosage, mg/L} = \frac{(0.35 \text{ mg/L lime}) (19 \text{ mg/L})}{1 \text{ mg/L alum}}$$

$$\text{Lime dosage, mg/L} = 6.7 \text{ or } 7 \text{ mg/L}$$

As stated previously, 0.54 mg/L soda ash will react with 1 mg/L of alum. If soda ash was to be used in place of lime, the formula could be modified by replacing the 0.35 mg/L lime with 0.54 mg/L soda ash. The problem will then be completed the same way.



LIME SOFTENING

Hardness in water is caused by calcium and magnesium ions. Ions of manganese, iron, strontium, and aluminum also contribute to hardness, but they are not present in sufficient quantities to be involved in calculations or to cause concern.

Hard water is objectionable to consumers in that a sticky precipitate forms when using soap and this collects in the fibers of clothing being laundered. Hard water does not lather freely when bathing. In boilers, hard water forms a scaly crust that insulates the heating surfaces preventing efficient transfer of heat.

The basic mechanism of the lime softening process is the conversion of soluble calcium and magnesium bicarbonates to insoluble calcium carbonate, CaCO_3 , and magnesium hydroxide, Mg(OH)_2 , that can be removed by settling.

The lime used in softening may be either *hydrated lime*, Ca(OH)_2 which is calcium hydroxide, or *quicklime*, CaO , which is calcium oxide. The hydrated lime may be used directly, whereas the quicklime must first undergo a process that involves adding water and heating, which is called *slaking*, to convert the quicklime to the usable form, which is hydrated lime. Lime comes in different percentages of purity. This is important in calculating the lime dosage, as will be shown later.

As stated above, calcium and magnesium are the primary contributors to hardness in water. Since calcium and magnesium are different substances, they cannot be added together to obtain the total hardness. If they are converted to common units then they can be added to obtain the total hardness. The common units that are used are *calcium carbonate equivalents*.



CONVERTING TO CALCIUM CARBONATE EQUIVALENTS

In order to convert from mg/L calcium, magnesium, or any other substance to mg/L calcium carbonate equivalents, the *molecular weights* or the *equivalent weights* of the substances involved must be known. The *equivalent weight* is the molecular weight of a substance divided by the number of positive or negative charges, or *valence* of that substance. In a test situation, these numbers are always given.

A table of molecular weights and equivalent weights for chemical compounds involved in the lime softening process follows. Refer to this table when using this workbook.

MOLECULAR WEIGHTS and EQUIVALENT WEIGHTS		
NAME	MOLECULAR WEIGHT	EQUIVALENT WEIGHT
Alkalinity, as CaCO ₃	100	100
Aluminum sulfate, Al ₂ (SO ₄) ₃	600	100
Carbon dioxide, CO ₂	44	22
Calcium carbonate, CaCO ₃	100	50
Calcium, Ca ²⁺	40.1	20
Ferric chloride, FeCl ₃	162	24.1
Hardness, as CaCO ₃	100	100
Hydrated lime, Ca(OH) ₂	74	37
Magnesium, Mg ²⁺	24.3	12.15
Soda ash, Na ₂ CO ₃	106	53
Sodium hydroxide, NaOH	40	40
Quicklime, CaO	56	28

To convert to calcium carbonate equivalents, use the following formulas.

- **Calcium Hardness, mg/L as CaCO₃ = Ca, mg/L x $\frac{\text{equivalent weight of CaCO}_3}{\text{equivalent weight of Ca}}$**
- **Magnesium Hardness, mg/L as CaCO₃ = Mg, mg/L x $\frac{\text{equivalent weight of CaCO}_3}{\text{equivalent weight of Mg}}$**

Simplify the formulas by substituting the actual equivalent weights for calcium and magnesium.

$$\text{Calcium Hardness, mg/L as CaCO}_3 = \text{Ca, mg/L} \times \frac{50}{20}$$

- **Calcium Hardness, mg/L as CaCO₃ = Ca, mg/L x 2.50**

$$\text{Magnesium Hardness, mg/L as CaCO}_3 = \text{Mg, mg/L} \times \frac{50}{12.15}$$

- **Magnesium Hardness, mg/L as CaCO₃ = Mg, mg/L x 4.12**

Therefore:

$$\bullet \text{ Total Hardness, as CaCO}_3 = 2.50 (\text{Ca, mg/L}) + 4.12 (\text{Mg, mg/L})$$

Now the formulas have become *multiplication factors*. These are used to convert mg/L calcium or mg/L magnesium to calcium carbonate equivalents. Follow this example.

Example

What is the total hardness of a water that contains 45 mg/L of calcium and 9 mg/L of magnesium?

Since calcium and magnesium are different substances, they cannot be totaled. Therefore, convert them to common units of calcium carbonate so they can be added together.

$$\text{Total Hardness, as Ca CO}_3 = (\text{Ca hardness, as Ca CO}_3) + (\text{Mg hardness, as Ca CO}_3)$$

$$\text{Total Hardness, as Ca CO}_3 = 2.50(\text{Ca}) + 4.12 (\text{Mg})$$

$$\text{Total Hardness, as Ca CO}_3 = 2.50 (45 \text{ mg/L}) + 4.12 (9 \text{ mg/L})$$

$$\text{Total Hardness, as Ca CO}_3 = 112.5 \text{ mg/L} + 37.08 \text{ mg/L}$$

$$\text{Total Hardness, as Ca CO}_3 = 149.5 \text{ or } 150 \text{ mg/L as CaCO}_3$$



CALCULATION OF LIME DOSAGES, SODA ASH, and RECARBONATION DOSAGES

Hardness is in two types: *temporary, or carbonate hardness* and *permanent, or non-carbonate hardness*. Temporary hardness or carbonate hardness is caused when calcium and magnesium carbonates combine with carbon dioxide to form calcium or magnesium bicarbonates (HCO_3). When water containing carbonate hardness is heated, the carbon dioxide is driven off and the carbonates, which are insoluble, form a precipitate. When the alkalinity is *greater* than the total hardness, all the hardness is in the carbonate form. If the total hardness and the total alkalinity are *equal*, all hardness is of the carbonate form.

Non-carbonate or permanent hardness is not precipitated by boiling. The ions are more stable than those in temporary hardness and their removal requires the addition of chemicals. These ions are primarily due to the sulfates (SO_4) of calcium and magnesium. If the total hardness is *greater* than the total alkalinity, the alkalinity is equivalent to the carbonate hardness. The noncarbonate hardness is the difference between the total hardness and the alkalinity.

The relationship between hardness and alkalinity is shown in the following chart.

• TOTAL HARDNESS = CARBONATE + NONCARBONATE HARDNESS
• CARBONATE HARDNESS = TOTAL ALKALINITY
• NONCARBONATE HARDNESS = TOTAL HARDNESS – TOTAL ALKALINITY

In order to calculate the pounds or dosage of lime necessary for softening, the type of lime being used must be known. Also, the chemical analysis of the water, which will include carbon dioxide content, total alkalinity, total hardness, magnesium content, and pH should be available as well as the molecular weights for the constituents involved.

When performing lime demand calculations, the chemicals that are in the water which demand lime must be converted to *lime equivalents*. This is done similar to converting substances to calcium carbonate equivalents. The molecular weight of the type of lime used will be the numerator of the fraction, whereas the molecular weight of the individual constituent in the water to be converted will be the denominator. This will become clear in the example given. Notice that *molecular weights* are used in this calculation, not *equivalent weights*.

The formula for calculating lime dosages is written:

• Lime feed, mg/L =
$$\frac{(A + B + C + D) \times 1.15}{\text{purity of lime, as a decimal}}$$

- Where A = CO₂ in source water
- Where B = Bicarbonate alkalinity in source water
- Where C = Hydroxide alkalinity in source water
- Where D = Magnesium in source water

The 1.15 is a constant used to *add* 15% excess lime to the lime that is required. The lime purity will given, usually as a percent, and is easily converted to a decimal.

NOTE: If “A” is present, there will be no “C”, and if “C” is present, “A” cannot exist.

Example

What is the dosage, in mg/L, of calcium oxide, 90% pure, necessary for the water as analyzed below if the molecular weight of calcium oxide is 56, carbon dioxide 44, alkalinity 100, and magnesium is 24.3?

CONSTITUENTS	SOURCE WATER	FINISHED WATER
CO ₂ , mg/L =	7	0 mg/L
Total Alkalinity as CaCO ₃ , mg/L =	125	22 mg/L
Total Hardness as CaCO ₃ , mg/L =	240	35 mg/L
Magnesium, mg/L	38	8 mg/L

$$\text{Lime feed, mg/L} = \frac{(A + B + C + D) \times 1.15}{\text{purity of lime, as a decimal}}$$

Convert the A, B, C, and D to *lime equivalents*.

$$A = \text{CO}_2 \text{ in source water (mg/L CO}_2) \times (56/44)$$

The 56 is the molecular weight of calcium oxide.

The 44 is the molecular weight of carbon dioxide.

If the problem called for hydrated lime, the 56 would be replaced by the molecular weight of hydrated lime, which is 74.

$$B = \text{Bicarbonate alkalinity in source water (mg/L as Ca CO}_3) \times (56/100)$$

In this case, all of the alkalinity is bicarbonate.

The 56 is the molecular weight of calcium oxide.

The 100 is the molecular weight for alkalinity.

$$C = \text{Hydroxide alkalinity in source water (mg/L as Ca CO}_3) \times (56/100)$$

In this problem, there is no (0) hydroxide alkalinity

$$D = \text{Magnesium in source water (mg/L as Mg)} \times (56/24.3)$$

The 56 is the molecular weight of calcium oxide.

The 24.3 is the molecular weight of magnesium.

The 1.15 is a factor that automatically adds the 15% excess lime required in softening operations.

NOTE: If calcium hydroxide rather than calcium oxide was used as the type of lime, the 56 (molecular weight of calcium oxide) would be replaced everywhere in the formula with 74, which is the molecular weight of the calcium hydroxide. The molecular weights will be given in a test situation.

Calculate the A, B, C, and D values explained above.

$$A = (\text{CO}_2, \text{ mg/L}) \times 56/44$$

$$A = (7 \text{ mg/L}) \times 56/44$$

$$A = 9 \text{ mg/L}$$

$$B = (\text{alkalinity, mg/L}) \times 56/100$$

$$B = (125 \text{ mg/L}) \times 56/100$$

$$B = 70 \text{ mg/L}$$

$$C = (\text{hydroxide, mg/L}) \times 56/100$$

$$C = 0 \quad (\text{there is no hydroxide})$$

$$D = (\text{Mg, mg/L}) \times 56/24.3$$

$$D = (38 \text{ mg/L}) \times 56/24.3$$

$$D = 87.6 \text{ mg/L}$$

Now, using the steps, substitute the known values into the formula, replacing the unknowns:

$$\text{Lime feed, mg/L} = \frac{(A + B + C + D) \times 1.15}{\text{lime purity, as a decimal}}$$

$$\text{Lime feed, mg/L} = \frac{(9 \text{ mg/L} + 70 \text{ mg/L} + 0 \text{ mg/L} + 87.6) \times 1.15}{0.90}$$

$$\text{Lime feed, mg/L} = \frac{166.6 \text{ mg/L} \times 1.15}{0.90}$$

$$\text{Lime feed, mg/L} = 213 \text{ mg/L}$$

Now that the lime demand in mg/L is known, it is easy to calculate the pounds of lime required for treating any amount of water. In the problem above, if the flow is given as 1,000,000 gallons per day and the pounds of lime necessary to soften the water are needed, just use the *pounds* formula.

$$\text{lb/day} = \text{flow (MG)} \times 8.34 \text{ lb/gal} \times \text{mg/L}$$

$$\text{lb/day} = 1 \text{ MG} \times 8.34 \times 213 \text{ mg/L}$$

$$\text{lb/day} = 1,776 \text{ lb/day}$$

For stabilization of waters after being treated by the lime softening process, carbon dioxide gas is often used. The recarbonation process lowers the pH, thus converting some of the existing carbonates into bicarbonates. This prevents severe scaling in filters, distribution mains, and scaling at residences served by the water system.

The dose of carbon dioxide required for recarbonation is calculated by using the following formula.

$$\bullet \text{ CO}_2 \text{ feed, mg/L} = (\text{lime excess, mg/L}) (44/56) + (\text{Mg remaining, mg/L}) (44/24.3)$$

If $\text{Ca}(\text{OH})_2$ is the lime used rather than CaO , use 44/74 in this formula instead of 44/56.

Now, using the information in the preceding example, calculate the estimated CO_2 feed.

Example

First, calculate the mg/L of excess lime that has been fed. Most of these calculations have been made when determining the lime feed in the preceding example. Use the formula below:

$$\text{Excess lime, mg/L} = (A + B + C + D) \times 0.15$$

(the 0.15 is the 15% excess lime used in the lime feed formula)

$$\text{Excess lime, mg/L} = (9 + 70 + 0 + 87.6) \times 0.15$$

(the substituted numbers for A, B, C, and D are from the lime feed calculations in the previous example)

$$\text{Excess lime, mg/L} = (166.6) \times (0.15)$$

$$\text{Excess lime, mg/L} = 24.9 \text{ or } 25 \text{ mg/L}$$

To get the Mg remaining, refer to the information given in the original problem used in this example. *There are 8 mg/L of Mg remaining in the treated water.* Using the formula for CO₂ feed:

$$\text{CO}_2 \text{ feed, mg/L} = (\text{CaO}) \text{ excess, mg/L} (44/56) + (\text{Mg remaining, mg/L}) (44/24.3)$$

$$\text{CO}_2 \text{ feed, mg/L} = (25 \text{ mg/L}) (44/56) + (8 \text{ mg/L}) (44/24.3)$$

$$\text{CO}_2 \text{ feed, mg/L} = (19.6 \text{ mg/L}) + (14.5 \text{ mg/L})$$

$$\text{CO}_2 \text{ feed, mg/L} = 34.1 \text{ mg/L}$$

Soda ash can be used to remove non-carbonate hardness. Estimate the soda ash dosage by using the following formula. The molecular weight of soda ash is 106.

- **Soda ash feed, mg/L = (noncarbonate hardness removed, mg/L as CaCO₃) x (106/100)**

Example

Using the information below, calculate the soda ash dosage.

CONSTITUENTS	SOURCE WATER	FINISHED WATER
Total Alkalinity as CaCO ₃ , mg/L =	109	26 mg/L
Total Hardness as CaCO ₃ , mg/L =	225	60 mg/L

First, determine the amount of noncarbonate hardness that has been removed. To do this, the source water hardness and alkalinity as well as the finished water hardness and alkalinity are necessary. Remember that noncarbonate hardness is the total hardness minus the alkalinity.

Source noncarbonate hardness = (source TH, mg/L) - (source alkalinity, mg/L)

Source noncarbonate hardness = (225 mg/L) - (109 mg/L)

Source noncarbonate hardness = 116 mg/L

Finish noncarbonate hardness = (finish TH, mg/L) - (finish alkalinity, mg/L)

Finish noncarbonate hardness = (60 mg/L) - (26 mg/L)

Finish noncarbonate hardness = 34 mg/L

Noncarbonate hardness removed = (source NCH) - (finish NCH)

Noncarbonate hardness removed = (116 mg/L) - (34 mg/L)

Noncarbonate hardness removed = 82 mg/L

Now, using the formula given above:

Soda ash feed, mg/L = (NCH removed, mg/L as CaCO₃) x (106/100)

Soda ash feed, mg/L = 82 mg/L x (106/100)

Soda ash feed, mg/L = 87 mg/L

If a percentage purity of soda ash is given, be sure to divide the answer by the decimal equivalent of the percentage purity. Using the example above, if the percentage purity of the soda ash being used was 90 percent, proceed as follows:

soda ash feed = $\frac{87 \text{ mg/L}}{0.90}$

Soda ash feed = 96.6 or 97 mg/L

If the calculations shown above seem confusing and lengthy, which they most likely will, practice them using the same procedure and substituting different numbers for the water analysis shown in the example. Write out every step and follow each step systematically.



ION EXCHANGE SOFTENING

One of the most satisfactory methods of softening water is through ion exchange. Water can be softened to *zero* hardness using this method. Ion exchange resins may be a natural sodium aluminosilicate called zeolite (Z) or synthetic resinous materials. These materials have the ability of removing the hardness-producing ions and replacing them with non hardness producing ions— thus the name ion exchange.

The resin serves as the medium in which the ion exchange takes place. As hard water is passed through the resin, the calcium and magnesium ions that contribute to the hardness in the water are replaced with sodium ions from the resin. The calcium and magnesium ions are retained by the resin and the sodium ions remain in the water.

The ability of the resin to produce a soft water has been exhausted when all of the sodium ions have been replaced with calcium and magnesium ions. The unit is then removed from service and back-washed with a solution of sodium chloride. This removes the calcium and magnesium in the form of their soluble chlorides and at the same time restores the resin to its original sodium condition. The calcium and magnesium chlorides flow to waste. The bed is then rinsed free of excess salts and returned to service.

In lime softening, hardness is expressed as mg/L of calcium carbonate (CaCO_3). In ion exchange softening, the units of hardness are expressed in *grains per gallon* or gpg. The exchange capacity of ion exchange softeners is expressed in kilograins of hardness removed per cubic foot of media, or resin. A kilograin is 1,000 grains.



HARDNESS CONVERSION FACTOR and FORMULAS

If 1 grain per gallon is equal to 17.1 mg/L, then:

- $\text{Hardness, gpg} = \frac{\text{hardness, mg/L}}{17.1}$
- $\text{Hardness, mg/L} = \text{hardness, gpg} \times 17.1$

Example

A water has a hardness of 240 mg/L. What is this in grains per gallon ?

$$\text{Hardness, gpg} = \frac{\text{hardness, mg/L}}{17.1}$$

$$\text{Hardness, gpg} = \frac{240 \text{ mg/L}}{17.1}$$

$$\text{Hardness, gpg} = 14 \text{ grains/gal}$$

To calculate the exchange capacity of an ion exchange softener, the formula is written:

- $\text{Exchange capacity, grains} = (\text{removal cap, grains/cu ft}) (\text{media vol, cu ft})$

To obtain the amount of water that can be treated before the softener must be regenerated, use this formula.

$$\bullet \text{ Water treated, gal} = \frac{\text{exchange cap, grains}}{\text{hardness removed, grains/gal}}$$

Example

An ion exchange softening unit contains 75 cubic feet of resin. The resin has an exchange capacity of 15 kilograins per cubic foot. The raw water analysis shows a hardness of 220 mg/L. How many gallons of water can be softened by this unit before it needs to be regenerated?

The volume of the resin is given in this problem. Sometimes, the dimensions of the softening unit are given and the volume must be calculated.

The hardness, however, is given in mg/L and a conversion to gpg is necessary.

$$\text{Hardness, gpg} = \frac{\text{hardness, mg/L}}{17.1}$$

$$\text{Hardness, gpg} = \frac{220 \text{ mg/L}}{17.1}$$

$$\text{Hardness, gpg} = 12.9 \text{ gpg}$$

Now, calculate the exchange capacity of the softener in grains.

$$\text{Exch cap, grains} = (\text{removal cap, gr/cu ft}) \times (\text{media vol, cu ft})$$

$$\text{Exch cap, grains} = (15,000 \text{ gr/cu ft}) \times (75 \text{ cu ft})$$

$$\text{Exch cap, grains} = 1,125,000 \text{ grains}$$

NOTE: the 15,000 gr/cu ft is 15 kilograins converted to grains (15 kg x 1,000 gr/kg = 15,000 grains)

Now, to find the amount of water that can be treated, use the *water treated* formula.

$$\text{water treated, gal} = \frac{\text{exchange cap, grains}}{\text{hardness removed, grains/gal}}$$

$$\text{water treated, gal} = \frac{1,125,000 \text{ grains}}{12.9 \text{ grains/gal}}$$

$$\text{water treated, gal} = 87,209 \text{ gallons}$$

Remember that ion exchange units may produce a water with zero hardness. This water is very corrosive, and must be blended with water that has a known hardness concentration, such as the source or raw water. Blending is done by bypassing the softener with untreated water to produce a finished product with a desired, usable hardness. A meter is used to obtain the correct bypass flow.

The formula for blending or bypassing is written:

- **Bypass flow, gal/day = $\frac{(\text{total flow, gal/day}) (\text{softener effluent hardness, gpg})}{\text{raw water hardness, gpg}}$**

Example

An ion exchange plant treats a flow of 75,000 gallons per day. The raw water hardness is 26.5 grains per gallon and the desired hardness in the finished water is 5 grains per gallon. What is the bypass flow in gallons per day?

$$\text{Bypass, gal/day} = \frac{(\text{total flow, gal/day}) (\text{softener effluent hardness, gpg})}{\text{raw water hardness, gpg}}$$

$$\text{Bypass, gal/day} = \frac{(75,000 \text{ gal/day}) \times (5 \text{ grains/gal})}{26.5 \text{ grains/gal}}$$

$$\text{Bypass, gal/day} = \frac{375,000 \text{ gal/day}}{26.5}$$

$$\text{Bypass, gal/day} = 14,151 \text{ gallons/day}$$

Ion exchange plants use salt or brine to regenerate the media. For regeneration, the amount, in pounds, of salt are required per 1,000 grains of capacity must be known.

The formula for pounds of salt required is written:

- **Salt, lbs = (salt req'd, lbs/1000 grains) (hardness removed, grains)**

Also, for regeneration, the salt is mixed with water to form a concentrated brine solution and then it is pumped through the resin. The optimum concentration is around 10 to 14 % brine. To find the gallons of brine solution necessary to regenerate a softener, use the brine formula.

- **Brine, gal = $\frac{\text{salt needed, lbs}}{\text{salt sol'n, lbs/gal}}$**

Example

How many pounds of salt are needed and how many gallons of brine solution will be required to regenerate an ion exchange facility which can remove 1,250,000 grains of hardness if 0.33 pounds of salt are required for every 1,000 grains of hardness removed and a salt solution of 1.5 pounds of salt per gallon of water is to be used ?

$$\text{Salt, lbs} = (\text{salt req'd, lbs/1000 grains}) (\text{hardness removed, grains})$$

$$\text{Salt, lbs} = (0.33 \text{ lbs/1000 grains}) (1,250,000 \text{ grains})$$

$$\text{Salt, lbs} = 412.5 \text{ pounds}$$

Notice that the units of *grains* cancel out and *lbs* are the only units remaining.

Now, using the next formula:

$$\text{Brine, gal} = \frac{\text{salt needed, lbs}}{\text{salt sol'n, lbs/gal}}$$

$$\text{Brine, gal} = \frac{412.5 \text{ lbs}}{1.5 \text{ lbs/gal}}$$

$$\text{Brine, gal} = 275 \text{ gallons}$$



DEMINERALIZATION

The purpose of demineralization is to separate minerals from a source water. Sometimes this process is called reverse osmosis or membrane filtration. The ability of a membrane to reject the minerals is called mineral rejection. Mineral rejection can be calculated for each parameter that is known, but usually is calculated for total dissolved solids (TDS).

The formula for mineral rejection is written:

$$\bullet \text{ Mineral Rejection, \%} = \left(1 - \frac{\text{product TDS, mg/L}}{\text{feedwater TDS, mg/L}} \right) \times 100\%$$

Example

What is the ability of reverse osmosis plant to reject minerals as a percent if the feedwater contains 1,500 mg/L total dissolved solids and the product water contains 150 mg/L total dissolved solids ?

$$\text{Mineral Rejection, \%} = \left(1 - \frac{\text{product TDS, mg/L}}{\text{feedwater TDS, mg/L}} \right) \times 100\%$$

$$\text{Mineral Rejection, \%} = \left(1 - \frac{150 \text{ mg/L}}{1,500 \text{ mg/L}} \right) \times 100\%$$

$$\text{Mineral Rejection, \%} = (1 - 0.1) \times 100\%$$

$$\text{Mineral rejection, \%} = 90 \%$$

Recovery is the percentage of feedwater which is recovered as product water, or finished water. The formula for recovery percent is written as follows:

$$\bullet \text{ Recovery, \%} = \frac{\text{product flow}}{\text{feed flow}} \times 100\%$$

Example

What is the percent recovery of a reverse osmosis unit if the feed flow is 5.88 MGD and the product flow is 5.0 MGD ?

$$\text{Recovery, \%} = \frac{\text{product flow}}{\text{feed flow}} \times 100\%$$

$$\text{Recovery, \%} = \frac{5.00 \text{ MGD}}{5.88 \text{ MGD}} \times 100\%$$

$$\text{Recovery, \%} = 0.85 \times 100\%$$

$$\text{Recovery, \%} = 85 \%$$

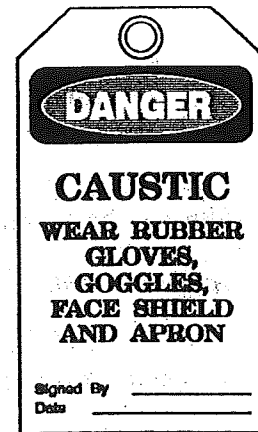
This concludes the softening and demineralization portion of this program. A multiple-choice test concerning the subject matter covered in this section is located in the appendix. Read the instructions carefully, adhere to the time limit, and try to do your work in the same manner as described in the examples. Remember to write down all of the information and follow the steps as closely as possible.

When you finish, check your answers with those provided in the answer key at the end of this workbook. Most candidates find this to be a difficult section. If you are having problems, review the examples given and try them using different numbers. Practice them several times if necessary.

5

CHAPTER FIVE

Fluoridation



Fluoride can be added to water in dry or powder form or as a liquid. There are many different types. The most commonly used compounds for fluoridation of water supplies are sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid. Sodium silicofluoride is commercially available in various gradations for application by dry feeders. Hydrofluosilicic acid is strong, and is often applied by liquid feeders without prior dilution.

Sometimes, source water that must be fluoridated contains an amount of natural fluoride. This is determined by laboratory analysis. In a test situation, this concentration will be given. If this is the case, be sure to subtract the natural fluoride level concentration in the source water from the desirable concentration in the treated water before calculating the dose of fluoride chemical required.

In fluoridation calculations, the chemical symbols, atomic weights, and molecular weights of the elements and compounds involved will be given.

CHEMICAL NAME	CHEMICAL SYMBOL	MOLECULAR WEIGHT
Sodium fluoride	NaF	42
Sodium silicofluoride	Na ₂ SiF ₆	188.1
Hydrofluosilicic acid	H ₂ SiF ₆	144.1



FLUORIDE ION PERCENTAGE and PURITY

In the fluoride compounds listed above, there are other elements present besides fluoride. A calculation that may be necessary when using fluoridation chemicals is the percent of fluoride ion purity in fluoride chemicals.

The formula for percent of fluoride ion purity is written:

$$\bullet \text{ Fluoride ion purity, \%} = \frac{\text{(molecular wt. of F in compound)} (100\%)}{\text{molecular weight of compound}}$$

Example

What is the fluoride ion purity, as a percent, of hydrofluosilicic acid $H_2 Si F_6$?

Atomic weights: $H = 1$ $Si = 28.09$ $F = 19$

In solving this problem, calculate the molecular weight of the compound $H_2 Si F_6$.

Follow the format set up below.

Symbol	No. of atoms	x	Atomic wt	=	Molecular wt
H	2	x	1	=	2.00
Si	1	x	28.09	=	28.09
F	6	x	19	=	<u>114.00</u>
				Total	= 144.09

Now, use the formula given above:

$$\text{Fluoride ion purity, \%} = \frac{(\text{molecular wt. of F in compound}) (100\%)}{\text{molecular weight of compound}}$$

$$\text{Fluoride ion purity, \%} = \frac{(114.00) (100\%)}{144.09}$$

$$\text{Fluoride ion purity, \%} = 79.2 \%$$

This means that in $H_2 Si F_6$, there is 79.2 percent fluoride. Or, for every pound of $H_2 Si F_6$ there is 0.792 pounds of fluoride available.

There are some other important facts required concerning fluoridation calculations. The percentage of fluoride ion in various chemical compounds has been discussed previously. Commercial fluoride chemicals are not 100 percent pure. Usually, on the label of the chemical container, there will be the *commercial purity* %. In exam situations, the commercial purity percent is always given.

To calculate the portion of *working* fluoride ion in a commercial chemical, use this formula.

$$\bullet \text{ Portion F} = \frac{(\text{commercial purity, \%}) (\text{fluoride ion \%})}{(100 \%) (100\%)}$$

Example

What is the portion of fluoride contained in a commercial batch of sodium silicofluoride when the commercial purity of the chemical is 98% and the percent fluoride ion of this chemical (Na_2SiF_6) is 60.7 % ?

$$\text{Portion F} = \frac{(\text{commercial purity, \%}) (\text{fluoride ion \%})}{(100 \%) (100 \%)}$$

$$\text{Portion F} = \frac{(98.0 \%) \times (60.7 \%)}{(100 \%) (100 \%)}$$

$$\text{Portion F} = \frac{5,948.6}{10,000} \quad (\text{notice that the units \% cancel})$$

$$\text{Portion F} = 0.595$$

This means that there are 0.595 pounds of *working* fluoride ion in each pound of the sodium silicofluoride.



FEEDING FLUORIDE CHEMICALS

When calculating feed rates for fluoridation, there are several different formulas that can be used. The one used will depend upon the information given in the stem of the problem. The first one is the fluoride feed rate in pounds per day. This formula is used when an acid such as hydrofluosilicic acid is being fed.

The formula is written:

$$\bullet \text{ Feed rate, lb/day} = \frac{(\text{flow, MGD}) (\text{desired F, mg/L}) (8.34 \text{ lb/gal}) (100\%)}{\text{acid solution, \%}}$$

The feed rate in pounds per day is first determined and if the weight of one gallon of the fluoride chemical is known, the feed rate of the chemical in gallons per day can be calculated by using the following formula.

$$\bullet \text{ Feed rate, gal/day} = \frac{\text{feed rate, lb/day}}{\text{chem sol'n, lb/gal}}$$

Example

A treatment plant uses a 20% hydrofluosilicic acid solution for fluoridation. This solution weighs 9.5 lb/gal. The raw water contains 0.2 mg/L fluoride naturally and the desired concentration is 1.6 mg/L. The daily flow for this plant is 1.5 MGD. What is the feed rate of acid in lb/day and also in gallons per day if the commercial grade acid has an ion purity of 79.2% ?

In solving this problem, the raw water has 0.2 mg/L fluoride in it already, and a 1.6 mg/L concentration is desired. So 1.4 mg/L must be added to this water to achieve the required dosage of 1.6 mg/L.

$$\text{Feed rate, lb/day} = \frac{(\text{flow, MGD})(\text{desired F, mg/L})(8.34 \text{ lb/gal})(100\%)}{\text{acid solution, \%}}$$

$$\text{Feed rate, lb/day} = \frac{(1.5 \text{ MGD})(1.4 \text{ mg/L})(8.34 \text{ lb/gal})(100\%)}{20 \%$$

$$\text{Feed rate, lb/day} = \frac{1751.4 \text{ lb/day}}{20}$$

$$\text{Feed rate, lb/day} = 87.6 \text{ lb/day}$$

Since the commercial grade acid is only 79.2 percent pure, it will take more of it to achieve the desired results. In the example above, the feed rate was calculated to be 87.6 lb/day. This answer is correct only when the chemical purity is 100 percent.

In order to get the feed rate for an acid that is not 100 percent pure, divide the answer by the decimal equivalent of the percent purity given. Follow the example:

$$\text{Feed rate} = \frac{87.6 \text{ lb/day}}{0.792}$$

NOTE: the 0.792 is the decimal equivalent of 79.2%

$$\text{Feed rate} = 110.6 \text{ lb/day}$$

In converting to gal/day:

$$\text{Feed rate, gal/day} = \frac{\text{feed rate, lb/day}}{\text{chem sol'n lb/gal}}$$

$$\text{Feed rate, gal/day} = \frac{110.6 \text{ lb/day}}{9.5 \text{ lb/gal}}$$

$$\text{Feed rate, gal/day} = 11.6 \text{ gal/day}$$

Notice how the units cancel in the substitution step of this problem leaving gal/day. Now the time can be changed to gallons per hour by using conversion factors:

$$\text{Feed rate} = \frac{11.6 \text{ gal/day}}{24 \text{ hr/day}}$$

$$\text{Feed rate} = 0.48 \text{ gal/hr}$$

Use the *pounds* formula to calculate the amount of fluoride necessary per day. Then combine the answer from that formula with the feed rate formula shown below to calculate the pounds per day of commercial fluoride chemical that should be fed to a certain amount of water.

The pounds formula is written:

- Fluoride req'd. , lb/day = (flow, MGD) (dose, mg/L) (8.34 lb/gal)

The feed rate formula is written:

- Feed rate, lb/day = $\frac{\text{fluoride, lb/day}}{\text{fluoride, lb/lb of commercial chemical}}$

The following example combines several formulas.

Example

A treatment plant that uses Na F for fluoridation treats a flow of 0.750 MGD. The fluoride ion percent of this chemical is 45.3 %. The supplier delivers a 96% pure chemical. If the desired fluoride dose is 1.2 mg/L and there is no natural fluoride occurring in the source water, how many pounds of this chemical must be fed?

Calculate the portion of fluoride ion in the commercial sodium fluoride first.

$$\text{Portion F} = \frac{(\text{NaF purity, \%}) (\text{fluoride ion, \%})}{(100 \%)(100\%)}$$

$$\text{Portion F} = \frac{(96.0 \%)(45.3 \%)}{(100\%)(100\%)}$$

$$\text{Portion F} = \frac{4,348.8}{10,000}$$

$$\text{Portion F} = 0.435$$

There are 0.435 pounds of fluoride per pound of commercial chemical.

Now, use the *pounds* formula.

$$\text{F req'd, lb/day} = (\text{flow, MGD}) (\text{dose, mg/L}) (8.34 \text{ lb/gal})$$

$$\text{F req'd, lb/day} = (0.750 \text{ MGD}) (1.2 \text{ mg/L}) (8.34 \text{ lb/gal})$$

$$\text{F req'd, lb/day} = 7.5 \text{ lb/day}$$

To get the feed rate, in pounds per day, for the actual chemical being used:

$$\text{Feed rate, lb/day} = \frac{\text{fluoride req'd, lb/day}}{\text{fluoride, lb/lb of Na F}}$$

$$\text{Feed rate, lb/day} = \frac{7.5 \text{ lb/day}}{0.435 \text{ lb/lb}}$$

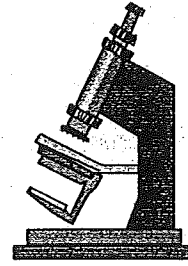
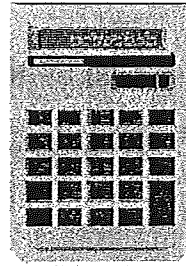
$$\text{Feed rate, lb/day} = 17.2 \text{ lb/day}$$

This concludes the portion of the program on fluoridation mathematics. Try the multiple-choice test on fluoridation in the appendix of this workbook, and check your answers with the answer key provided. Use the same format as the examples given in this chapter. Remember to write each step of the problem out completely.

6

CHAPTER SIX

Laboratory Mathematics



FLUSHING AND SAMPLING

Good sampling techniques are an important part of any water treatment operation. It is recommended that when sampling from a tap that the water in the line be replaced twice. To do this, a calculation is often necessary.

The formula is written as follows.

$$\bullet \text{ Flush time, min.} = \frac{\text{(capacity of pipe, gal)} (2)}{\text{flow, gal/min}}$$

In a practical situation, an estimate of the flow can be obtained by timing how long it takes to fill a gallon jug from a faucet. If it takes one minute to fill the gallon jug, the flow is one gallon per minute.

$$\bullet \text{ Flow, gal/min} = \frac{\text{gallons}}{\text{time, min}}$$

The capacity of the pipe is obtained by using the volume formula and then converting to gallons. Remember to use the same units throughout the problem.

Example

A 1 inch service line must be sampled. How long should the line be flushed if the flow is 1.5 gal/min and the line is 120 feet long?

First, calculate how many gallons are contained in the pipe.

$$V = \pi \times r^2 \times L$$

$$V = 3.14 \times 0.042 \text{ ft} \times 0.042 \text{ ft} \times 120 \text{ ft}$$

NOTE: The 0.042 feet is the pipe radius, which is 0.5 inches, converted to feet.

$$V = 0.66 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 4.97 \text{ or } 5 \text{ gallons}$$

$$\text{Flush time, min.} = \frac{(\text{capacity of pipe, gal}) (2)}{\text{flow, gal/min}}$$

$$\text{Flush time, min.} = \frac{(5 \text{ gal}) (2)}{1.5 \text{ gal/min}}$$

$$\text{Flush time, min.} = 6.7 \text{ or } 7 \text{ minutes}$$



MOLAR AND NORMAL SOLUTIONS

A *solution* is a homogeneous mixture of 2 or more substances, the composition of which may be varied within definite limits. The dissolved substance in a solution is called the *solute*. The substance in which the solute is dissolved in is called the *solvent*. A solution in which water is the solvent is called an *aqueous* solution. A solution containing a relatively large amount of solute is said to be *concentrated*. If the amount of solute is small, the solution is *dilute*. There are many ways to describe solution concentration, but all of them must express the amount of solute present in a given amount of solvent. The concentrations are generally expressed in the following physical ways.

- By weight of the solute per unit volume of solution— 20 grams of KCl per liter of solution.
- By percentage composition or the number of grams of solute per 100 grams of solution— A 10 percent NaCl solution contains 10 grams of NaCl per 100 grams of solution, which is 10 grams of NaCl and 90 grams of water.
- By weight of solute per weight of solvent— 0.05 grams of NaCl in 1 gram of water.

Concentrations of solutions can also be expressed in chemical units. A *molar (M)* solution consists of 1-gram molecular weight, or *mole*, of solute in one liter of solution. A mole is the atomic weight or formula weight of the substance expressed in grams. In a molar solution, the quantity of the solute is given in moles and the volume of the solution is expressed in liters. For example, a one molar (M) solution of H_2SO_4 contains 98.08 grams, which is one mole, of H_2SO_4 per liter of solution since the molecular, or formula weight of H_2SO_4 is 98.08.

Example

How many grams per liter of hydrochloric acid (HCl) are in a 0.25 M solution when the atomic weights are as follows?

Atomic weights: H = 1 Cl = 35.5

Molecular weight of HCl = 1 + 35.5, or 36.5

A 0.25 M solution is equal to $0.25 \times 36.5 =$

9.125 grams per liter

A *normal (N)* solution contains *1-gram equivalent weight* of solute made up to 1000 mL with lab-pure water. This concentration is expressed as a 1-normal (1N) solution. A 2N solution would contain 2-gram equivalent weights of solute made up to 1 liter. The normality of a solution is expressed by the number of gram-equivalents of solute per liter of solution.

An equivalent weight, or gram-equivalent weight, is obtained by dividing the substance's atomic (or molecular) weight by the valence number of that substance. Valences can be obtained from tables, but will be given in a test situation.

Use this formula:

- **Weight of solute, gm = normality desired x gram-equivalent wt.**

Example

How many grams of NaOH would be required to prepare 1 liter of a 0.1 N solution?

Atomic weights: Na = 23, O = 16, H = 1, valence number = 1

Molecular weight of NaOH = $23 + 16 + 1$, or 40

Equivalent weight of NaOH = $\frac{40}{1}$

Equivalent weight of NaOH = 40

Weight of solute, grams = normality desired x gram-equivalent wt.

Weight of solute, grams = 0.1×40

Weight of solute, grams = 4.0 grams

Example

How many grams of CaCl_2 would be required to prepare one liter of a 0.025 N solution if the molecular weight of CaCl_2 equals 111 and the valence number is 2?

$$\text{Equivalent weight} = \frac{111}{2} = 55.5$$

Weight of solute, grams = normality desired x gram-equivalent wt.

$$\text{Weight of solute, grams} = 0.025 \times 55.5$$

$$\text{Weight of solute, grams} = 1.3875 \text{ grams}$$

In the problem above, if only 100 mL of the solution needs to be made, just take the number of grams needed and divide by 10, since 100 mL is 0.1 liters.

$$\frac{1.3875 \text{ gm}}{10} = 0.13875 \text{ grams needed}$$



STOCK SOLUTIONS

Stock solutions are stronger in normality than those used in daily laboratory determinations. Strong solutions are more stable than weaker solutions and can be stored longer. A strong stock solution of a known normality can easily be diluted to give any weaker desired normality. A formula for diluting strong stock solutions of a known normality is:

$$\bullet \text{ mL of stock solution needed} = \frac{(\text{mL desired}) \times (\text{N desired})}{\text{N of stock solution}}$$

Example

How many mL of a 0.8 N stock solution of NaOH are necessary to prepare 150 mL of a 0.025 N NaOH solution ?

$$\text{mL of stock solution needed} = \frac{(\text{mL desired}) \times (\text{N desired})}{\text{N of stock solution}}$$

$$\text{mL of stock solution needed} = \frac{(150 \text{ mL}) \times (0.025 \text{ N})}{0.8 \text{ N}}$$

$$\text{mL of stock solution needed} = 4.6875 \text{ mL}$$

This states that 4.6875 mL of 0.8 N NaOH should be made up to 150 mL with lab-pure water to get the desired 150 mL of a 0.025 N solution.

When preparing standard solutions, a chemical may have to be weighed to an exact amount and diluted to one liter with lab-pure water, as seen in some of the examples above. In reality, sometimes it is difficult to get the exact weight. When this happens, more or less than 1 liter of lab-pure will have to be added to get the exact solution strength. Use the following formula when preparing solutions where the exact amount cannot be weighed.

- $$\text{mL lab-pure water to add} = \frac{(\text{actual wt. grams}) \times (1,000 \text{ mL})}{\text{desired wt., grams}}$$

 **Example**

Calculations show that 5.2585 grams of a chemical must be diluted to 1,000 mL to make up a desired solution. However, only 5.1060 grams can be weighed. How much water must be used to produce the desired normality ?

$$\text{mL lab-pure water to add} = \frac{(\text{actual wt. grams}) \times (1,000 \text{ mL})}{\text{desired wt., grams}}$$

$$\text{mL lab-pure water to add} = \frac{(5.1060 \text{ grams}) \times (1,000 \text{ mL})}{5.2585 \text{ grams}}$$

$$\text{mL lab-pure water to add} = 971 \text{ mL}$$



DATA ANALYSIS

Sometimes operators may be required to analyze and calculate data from laboratory results, flows, or other groups of measurements. The *average, or arithmetic mean*, is adding all of the measurements and dividing by the total number of measurements. The formula for finding an average or mean is written:

- $$\text{Average} = \frac{\text{sum of all measurements}}{\text{number of measurements}}$$

In a drinking water facility that operates 7 days per week, *moving averages* may be used. They are calculated the same way that averages are, except that each day the oldest measurement is replaced with the newest measurement. Moving averages are used to better reveal trends in treatment plant operation.

A useful method of indicating a spread in a series of measurements is the *range*. The range is calculated by subtracting the smallest measurement from the largest measurement.

- Range = largest value - smallest value

Example

The laboratory submits the following influent hardness values for one week. What is the *mean (or average) and range* of these values ?

DAY	HARDNESS, mg/L
1	190
2	220
3	225
4	195
5	208
6	210
7	204

$$\text{Average} = \frac{\text{sum of all measurements}}{\text{number of measurements}}$$

$$\text{Average} = \frac{1,452}{7}$$

$$\text{Average} = 207 \text{ mg/L}$$

$$\text{Range} = \text{largest value} - \text{smallest value}$$

$$\text{Range} = 225 - 190$$

$$\text{Range} = 35 \text{ mg/L for the 7-day period}$$

In analyzing data, high values in a list of numbers may sometimes be encountered. In this case, the *median* value may be better to use than the mean, or average value.

To calculate the median, first rank all of the measurements in ascending or descending order, and then pick the middle measurement.

Example

What is the median value of the weekly data for flows shown below?

<i>DAY</i>	<i>FLOW, MGD</i>
1	2.7
2	1.9
3	3.4
4	5.6
5	1.9
6	1.8
7	2.0

First, rank the flows in ascending order.

FLOWS: 1.8 1.9 1.9 2.0 2.7 3.4 5.6

Now, pick the middle measurement:

Median = 2.0 MGD

The next measurement that operators should be familiar with is the *mode*. The mode is the measurement that occurs most frequently in a series of measurements. In the example given above, the mode would be 1.9 MGD, since it is the only measurement that occurs twice in the 7-day period.

This concludes the laboratory mathematics section of this program. A 10 question multiple choice test can be found in the appendix. Try to adhere to the time limit, keep organized, and set up the problems according to the steps.

Do your work on a separate sheet of paper and feel free to consult the formula sheet and table of equivalents. Be sure to read the problem carefully, and check your answers with the answer key provided at the end of the workbook.

TEST NO. 1

LOADING PROBLEMS

The following test is of the multiple choice variety. There is only one correct answer per question, so circle the letter representing the answer that is most nearly correct. You have 1 hour for the completion of this test.

1. A sedimentation tank has a depth of 8 feet and a diameter of 60 feet. This tank receives a flow of 375,000 gal/day. The weir begins one foot in from the edge of the tank and goes completely around. What is the weir overflow rate for this tank?

- A. 4,118 gal/day/ft
- B. 3,981 gal/day/ft
- C. 2,059 gal/day/ft
- D. 1,990 gal/day/ft

2. A sedimentation tank for a surface water facility has a depth of 10 feet, a length of 60 feet, and a width of 26 feet. What is the surface loading of this tank when the flow is 0.755 MGD?

- A. 48.3 gal/day/sq ft
- B. 216 gal/day/sq ft
- C. 480 gal/day/sq ft
- D. 484 gal/day/sq ft

3. A small water plant has a settling tank with a diameter of 16 feet. If the weir runs around the edge of the tank, what is the weir overflow rate *and* surface loading rate if this plant treats 38 gallons per minute?

weir overflow rate *surface loading rate*

- | | |
|---------------------|--------------------|
| A. 1,089 gal/day/ft | 272 gal/day/sq ft |
| B. 2,190 gal/day/ft | 272 gal/day/sq ft |
| C. 1,089 gal/day/ft | 68.5 gal/day/sq ft |
| D. 1,565 gal/day/ft | 0.19 gal/min/sq ft |

4. In the previous problem (3), what is the rise rate in the tank?

- A. 0.019 ft/min
- B. 0.025 ft/min
- C. 0.50 ft/min
- D. 0.57 ft/min

5. A weir measures 36 yards in length. The flow over this weir is 0.850 MGD. What is the weir overflow rate?

- A. 790 gal/day/ft
- B. 2,361 gal/day/ft
- C. 7,870 gal/day/ft
- D. 23,611 gal/day/ft

6. A rectangular sedimentation basin has a length of 100 feet and a width of 12 yards and is 96 inches deep. If the flow through this basin is 250,000 in a 6 hour period, what is the rise rate?

- A. 2.80 ft/min
- B. 0.193 ft/min
- C. 0.078 ft/min
- D. 0.026 ft/min

7. A treatment plant uses 2 settling tanks running in parallel. Each one has a diameter of 30 feet and a depth of 8 feet. If the flow through this plant is 350 gallons per minute, what is the surface loading rate?

- A. 713 gal/day/sq ft
- B. 357 gal/day/sq ft
- C. 178 gal/day/sq ft
- D. 89 gal/day/sq ft

8. A rectangular clarifier has a surface area of 1,200 sq ft. The flow averages 220 gallons per minute. What is the surface loading in gal/day/sq ft?

- A. 164 gal/day/sq ft
- B. 264 gal/day/sq ft
- C. 440 gal/day/sq ft
- D. 545 gal/day/sq ft

9. A clarifier has a length of 30 yards and a width of 20 feet. The average daily flow is 0.350 MGD. What is the rise rate in this tank in ft/min?

- A. 0.0135 ft/min
- B. 0.0180 ft/min
- C. 0.130 ft/min
- D. 0.142 ft/min

10. A rectangular sedimentation tank has a weir that runs across the tank as shown in the diagram below. What is the surface loading rate *and* weir overflow rate of this tank if the flow is 0.0375 MGD?

- | <i>surface loading rate</i> | <i>weir overflow rate</i> |
|-----------------------------|---------------------------|
| A. 22 gal/day/sq ft | 0.5 gal/min/ft |
| B. 28 gal/day/sq ft | 0.5 gal/min/ft |
| C. 27 gal/day/sq ft | 1.1 gal/min/ft |
| D. 26 gal/day/sq ft | 1.5 gal/min/ft |

TEST NO. 2

CHEMICAL MIXING PROBLEMS

The following test is of the multiple choice variety. There is only one correct answer per question, so circle the letter representing the answer that is most nearly correct. You have 1 hour for the completion of this test.

1. Liquid polymer is supplied as a strength of 10,500 mg/L. In order to make 55 gallons of a 0.05 percent solution, how many gallons of the supplied polymer must be used?
 - A. 0.53 gal
 - B. 1.60 gal
 - C. 1.83 gal
 - D. 2.62 gal

 2. A dry chemical feeder is used at a water treatment plant. It is determined that 17 pounds of chemical must be fed every day. The feeder has a capacity to feed 80 lb per day. At what percent should this feeder be set?
 - A. 21 percent
 - B. 28 percent
 - C. 42 percent
 - D. 47 percent

 3. A solution feeder used to feed corrosion control chemicals has a maximum feed rate of 5 gal/hr. Calculations show that the chemical should be fed at 0.25 gal/hr. At what percent of the scale should the feeder be set ?
 - A. 20 percent
 - B. 15 percent
 - C. 5.0 percent
 - D. 2.5 percent

 4. A dry cationic polymer must be mixed with water to be fed as a solution. How many gallons of water must be mixed with 20 pounds of dry polymer to produce a 1 percent polymer solution?
 - A. 16,513 gal
 - B. 1,980 gal
 - C. 265 gal
 - D. 237 gal
-
-

5. A supplier delivers a corrosion control chemical to a water treatment facility as a 15 percent solution. The mix tank is 6 feet deep and has a diameter of 60 inches. How many gallons of the corrosion control chemical must be mixed with water to fill the tank with a 0.5 percent solution?

- A. 7.8 gal
- B. 26.4 gal
- C. 29.4 gal
- D. 37.4 gal

6. A tank is 4 feet wide, 4 feet long, and has a depth of 4 feet. A dry polymer must be mixed to produce a 1.15 percent solution. How many pounds of dry polymer are needed to make a full tank of this solution?

- A. 55.6 lb
- B. 46.5 lb
- C. 19.5 lb
- D. 5.6 lb

7. What is the weight of 5 gallons of polymer with a specific gravity of 1.04 ?

- A. 8.67 lb
- B. 41.7 lb
- C. 43.4 lb
- D. 58.4 lb

8. A water treatment plant uses a liquid polymer which comes from the manufacturer as a 26 percent solution. The mix tank has a 250 gallon capacity. How many gallons of this polymer must be mixed to fill the tank with a 1.5 percent solution?

- A. 26 gal
- B. 14.4 gal
- C. 9.6 gal
- D. 4.3 gal

9. How many gallons of water must be added to 1 gallon of a 5.5 percent hypochlorite solution to produce a 0.05 percent solution?

- A. 109 gallons
- B. 100 gallons
- C. 55 gallons
- D. 25 gallons

10. An operator adds 1.25 lb of sodium hexametaphosphate to 50 gallons of water for use as a sequestering agent. What is the percent hexametaphosphate by weight?

- A. 0.02 percent
- B. 0.30 percent
- C. 3.30 percent
- D. 30 percent

TEST NO. 3

FILTRATION PROBLEMS

The following test is of the multiple choice variety. There is only one correct answer per question, so circle the letter representing the answer that is most nearly correct. You have 1 hour for the completion of this test.

1. What is the unit filter run volume for a filter system that has 2 filters, each with a length of 12 feet, a width of 8 feet and a depth of 6 feet, when the filter run is 400,000 gallons between washings?

- A. 980 gal/sq ft
- B. 1040 gal/sq ft
- C. 2083 gal/sq ft
- D. 2112 gal/sq ft

2. A filter should be backwashed for 7 minutes. If the backwash rate is 18 gpm/sq ft and the filter has a diameter of 12 feet and depth of 8 feet, how many gallons of water are required for this?

- A. 44,725 gal
- B. 23,373 gal
- C. 14,243 gal
- D. 6391 gal

3. A filter treated a flow of 0.982 MG in a 24 hour period. If the diameter of this filter is 12 feet, what is the filtration rate in gpm/sq ft?

- A. 0.8 gpm/sq ft
- B. 2.4 gpm/sq ft
- C. 6.0 gpm/sq ft
- D. 8.0 gpm/sq ft

4. What is the backwash pumping rate for a filter 25 ft long and 15 ft wide and 6 feet deep if the desired backwash rate is 22 gpm/sq ft ?

- A. 102 gpm
- B. 4950 gpm
- C. 5575 gpm
- D. 8250 gpm

5. A filter, while in the backwash mode, is observed to rise 1 ft 3 inches in a period of 50 seconds. What is the backwash rate if the filter is 20 feet long, 6 feet wide and 6 feet deep?
- A. 1122 gpm
 - B. 1250 gpm
 - C. 1280 gpm
 - D. 1346 gpm
6. With the influent valve shut, an operator observes the filter water level drop 3 inches in 1 minute and 30 seconds. If the filter measures 10 feet long and 8.5 feet wide, what is the filtration rate in gpm per sq ft?
- A. 0.53 gpm/sq ft
 - B. 1.08 gpm/sq ft
 - C. 1.25 gpm/sq ft
 - D. 1.57 gpm/sq ft
7. A filter has a diameter of 16 feet and a height of 10 feet. What is the filtration rate when the flow is 0.440 MGD?
- A. 1.52 gal/min/sq ft
 - B. 0.66 gal/min/sq ft
 - C. 2.63 gal/min/sq ft
 - D. 4.57 gal/min/sq ft
8. A filtration plant is designed with a filtration rate of 2.5 gal/min/sq ft. The plant treats 2.85 MGD and the 4 filters measure 20 ft long, 12 ft wide and 10 feet deep each. What percent over or under the designed filtration rate is the plant operating, using all four filters?
- A. 8.2 percent over
 - B. 18 percent over
 - C. 8.2 percent under
 - D. 17.6 percent under
9. The filter media must be replaced at a water treatment plant. There are three filters, each 12 ft long, 6 ft wide and 8 feet deep. The media runs from the underdrain to a height of 4.5 ft. How many cubic yards of media should be ordered?
- A. 12 cubic yards
 - B. 21.3 cubic yards
 - C. 36 cubic yards
 - D. 269 cubic yards

10. A filter measures 12 feet wide, has a length of 16 feet and is divided into two separate bays. The desired backwash rate is 22 gpm/sq ft. What is the minimum capacity of the pump that must be used for backwashing if each bay is backwashed separately?

- A. 87 gpm
- B. 872 gpm
- C. 2,112 gpm
- D. 4,225 gpm

TEST NO. 4

SOFTENING & DEMINERALIZATION PROBLEMS

The following test is of the multiple choice variety. There is only one correct answer per question, so circle the letter representing the answer that is most nearly correct. You have 1 hour for the completion of this test.

1. A source water has a magnesium content of 14 mg/L. What is this expressed as calcium carbonate equivalents?

$$\begin{array}{rcl} \text{equivalent wt of Mg} & = & 12.15 \\ \text{equivalent wt of CaCO}_3 & = & 50 \end{array}$$

- A. 57.7 mg/L
B. 32.1 mg/L
C. 12.2 mg/L
D. 4.10 mg/L
2. Water to be treated for turbidity has an alkalinity of 40 mg/L. Jar testing determined that an ideal alum dose is 48 mg/L with an excess alkalinity of 30 mg/L required for a complete reaction. What dose of hydrated lime should be added to this water in mg/L?

- A. 2 mg/L
B. 7 mg/L
C. 9 mg/L
D. 16 mg/L

3. An ion exchange softening plant has a resin with a capacity of 12.5 Kgr/cu ft. The softening unit has a diameter of 6 feet and a height of 10 feet. What is the exchange capacity of this unit in grains?

- A. 442.3 gr
B. 22,734 gr
C. 516,212 gr
D. 3,532,500 gr

4. An ion exchange unit has an exchange capacity of 750,000 grains. The source water hardness is 192 mg/L. How many gallons of water can be treated by this softener before regeneration?

- A. 66,797 gal
B. 100,225 gal
C. 390,625 gal
D. 397,400 gal
-
-

5. An ion exchange plant treats a flow of 0.090 MGD. The raw water hardness is 312 mg/L. The desired hardness in the product water is 80 mg/L. What is the bypass flow in gallons per day?

- A. 66,921 gal/day
- B. 44,106 gal/day
- C. 23,077 gal/day
- D. 20,700 gal/day

6. An ion exchange plant can remove 1,500,750 grains of hardness before regeneration is necessary. If 0.25 lb of salt are required for every 1,000 grains of hardness removed, how many pounds of salt should be on hand for regeneration?

- A. 3,758 lb
- B. 625 lb
- C. 375 lb
- D. 195 lb

7. In the above problem, how many gallons of brine solution (1.5 lb/gal) must be made up to regenerate this unit?

- A. 130 gal
- B. 250 gal
- C. 417 gal
- D. 425 gal

8. The following information is given for a lime softening plant.

Flow:	1.25	MGD
Lime used:	90 %	CaO
CO ₂ :	12.0	mg/L
Mg:	32.0	mg/L
Alkalinity:	186	as CaCO ₃ mg/L
Hardness:	226	as CaCO ₃ mg/L

Molecular wt: CO₂ = 44, Mg = 24.3, Ca (OH)₂ = 74, Ca O = 56

Molecular wt of alkalinity (as CaCO₃) = 100

What is the lime dose and how many pounds of lime per day are necessary to soften this water?

- A. 247 mg/L / 1,875 lb/day
- B. 250 mg/L / 2,235 lb/day
- C. 247 mg/L / 2,573 lb/day
- D. 266 mg/L / 2,773 lb/day

9. A membrane filtration plant treats a flow of 650 gpm under normal operating conditions. If the product flow is 875,000 gal/day, what is the percent recovery of this plant?

- A. 87 percent
- B. 89 percent
- C. 94 percent
- D. 99 percent

10. A reverse osmosis facility treats 1.5 MGD and has a product flow of 675 gallons per minute. The TDS of the source water is 1,575 mg/L. The product TDS is 180 mg/L. What is the percent mineral rejection?

- A. 85 percent
- B. 89 percent
- C. 90 percent
- D. 93 percent

TEST NO. 5

FLUORIDATION PROBLEMS

The following test is of the multiple choice variety. There is only one correct answer per question, so circle the letter representing the answer that is most nearly correct. You have 1 hour for the completion of this test.

1. What is the fluoride ion purity of magnesium silicofluoride, $Mg Si F_6$ if the atomic weights are as follows?

$$Mg = 24.3, Si = 28.09, F = 19$$

- A. 41.5 percent
 - B. 60.5 percent
 - C. 68.5 percent
 - D. 108 percent
2. A plant uses hydrofluosilicic acid, 24 percent, in treatment. It weighs 10.5 lb/gal. The source water contains 0.15 mg/L fluoride and a concentration of 1.5 mg/L is desired. If the plant treats 0.95 MGD, what is the feed rate in gallons per day?

- A. 44 gal/day
- B. 19 gal/day
- C. 5.0 gal/day
- D. 4.2 gal/day

3. In the problem above, what would be the feed rate in liters per hour if one gallon contains 3.785 liters?

- A. 0.66 L/hr
- B. 0.79 L/hr
- C. 3.0 L/hr
- D. 6.9 L/hr

4. Calcium fluoride is being considered as the fluoride chemical for a treatment plant that treats 1.25 MGD. The desired fluoride dose is 1.2 mg/L. The commercial purity for this powder is 85 percent. What is the percent fluoride ion purity in the chemical formula, CaF_2 ?

$$\begin{aligned} \text{atomic wt of F} &= 19 \\ \text{atomic wt of Ca} &= 40.1 \end{aligned}$$

- A. 50.9 percent
- B. 48.7 percent
- C. 41.5 percent
- D. 20.2 percent

5. In the problem above, how many pounds of fluoride ion are there per pound of commercial chemical?

- A. 0.17 lb/lb
- B. 0.35 lb/lb
- C. 0.43 lb/lb
- D. 0.41 lb/lb

6. Concerning the previous problem, how many pounds of this commercial chemical must be fed daily for fluoridation?

- A. 27.2 lb/day
- B. 30.5 lb/day
- C. 35.5 lb/day
- D. 73.0 lb/day

7. A flow of 5.6 MGD is to be treated with a 15percent solution of H_2SiF_6 that contains a fluoride ion purity of 79.2 percent. The water to be treated contains 0.2 mg/L of fluoride and the desired fluoride concentration is 1.6 mg/L. The H_2SiF_6 weighs 9.8 pounds per gallon. What is the feed rate?

- A. 550 lb/day
- B. 3,114 lb/day
- C. 8,256 lb/day
- D. 43,590 lb/day

8. In the problem above, what would be the feed rate in gallons per minute?

- A. 3.09 gal/min
- B. 0.22 gal/min
- C. 0.59 gal/min
- D. 0.04 gal/min

9. A flow of 1.4 MGD is treated with sodium silicofluoride. The raw water contains 0.4 mg/L fluoride ion and the desired fluoride ion concentration is 1.6 mg/L. What is the chemical feed rate in pounds per day if each pound of commercial sodium silicofluoride contains 0.6 lb of fluoride ion?

- A. 14.0 lb/day
- B. 18.7 lb/day
- C. 23.4 lb/day
- D. 31.1 lb/day

10. An operator calculated that 60.5 pounds of commercial grade fluoride compound must be fed daily. The manufacturer has stated that this compound is 74.5 percent pure. How many pounds of this compound will be used in a 30-day period?

- A. 2,436 pounds
- B. 2,072 pounds
- C. 1,966 pounds
- D. 1,815 pounds

TEST NO. 6

LABORATORY MATHEMATICS

The following test is of the multiple choice variety. There is only one correct answer per question, so circle the letter representing the answer that is most nearly correct. You have 1 hour for the completion of this test.

1. If a 2 gallon per minute flow is recommended for water sampling, how long must a service tap run to flush the pipe 2 volumes if the service line has a 1 inch diameter and runs a length of 65 feet?

- A. 1.6 min
- B. 2.0 min
- C. 2.7 min
- D. 5.4 min

2. The pH of a source water was recorded daily for one week. What is the median measurement *and* the mode measurement?

DAY:	1	2	3	4	5	6	7
pH:	6.9	7.2	7.4	7.0	6.9	7.3	6.8

median *mode*

- A. 6.9 6.9
- B. 7.0 7.4
- C. 7.0 6.9
- D. 7.4 6.8

3. In the pH analysis in the problem above, what is the *range* of the measurements?

- A. 49.4
- B. 7.07
- C. 7.0
- D. 0.6

4. In making a standard solution, 12.0075 grams of chemical must be mixed in 1,000 mL of lab-pure water. Only 11.9295 grams of the chemical can be weighed. How much lab-pure water should be used to make the standard to the desired concentration?

- A. 989.0 mL
- B. 990.6 mL
- C. 993.5 mL
- D. 998.6 mL

5. A volume of 200 mL of a 0.015 N solution must be prepared from a 5 N stock solution. How many mL of the stock solution must be brought up to volume with lab-pure water?

- A. 15 mL
- B. 3 mL
- C. 0.6 mL
- D. 0.4 mL

6. How many grams of H_2O_2 would be necessary to make 1 liter of a 5N solution?

atomic wt $H = 1$ $O = 16$
valence number = 2

- A. 34 grams
- B. 85 grams
- C. 170 grams
- D. 188 grams

7. 100 mL of a 0.020 N solution of sulfuric acid must be made. How many grams of H_2SO_4 will be needed?

atomic wt $H = 1$ $O = 16$ $S = 32$
valence number = 2

- A. 1.05 grams
- B. 0.98 grams
- C. 0.49 grams
- D. 0.098 grams

8. To make a desired solution, it has been calculated that 9.6106 grams of chemical must be diluted to 1,000 mL. Only 6.2116 grams of chemical are available, however. How many mL of lab-pure water must be added to produce the desired concentration?

- A. 295 mL
- B. 646 mL
- C. 702 mL
- D. 1,475 mL

9. 500 mL of a 0.02 N solution is needed. The stock solution on hand is a 2 N strength. How many mL of this stock solution must be diluted to 500 mL to make the desired 0.02 N solution?

- A. 0.05 mL
- B. 0.50 mL
- C. 2.50 mL
- D. 5.00 mL

10. Flow data for the month is listed below. What is the *mean* and *mode* measurements?

<i>DAY</i>	<i>FLOW, MGD</i>	<i>DAY</i>	<i>FLOW, MGD</i>
1	1.1 MGD	16	1.6 MGD
2	1.5 MGD	17	1.5 MGD
3	1.2 MGD	18	1.4 MGD
4	1.2 MGD	19	1.6 MGD
5	1.0 MGD	20	1.2 MGD
6	0.9 MGD	21	1.3 MGD
7	1.2 MGD	22	1.0 MGD
8	1.1 MGD	23	1.4 MGD
9	1.0 MGD	24	1.3 MGD
10	1.2 MGD	25	1.5 MGD
11	1.3 MGD	26	1.2 MGD
12	1.4 MGD	27	1.0 MGD
13	1.1 MGD	28	1.1 MGD
14	1.0 MGD	29	1.1 MGD
15	1.1 MGD	30	1.2 MGD

- | | <i>mean</i> | <i>mode</i> |
|----|-------------|-------------|
| A. | 1.1 | 1.5 |
| B. | 1.2 | 1.2 |
| C. | 1.3 | 1.2 |
| D. | 1.4 | 1.3 |

ANSWER KEYS

Allow 10 points for each correct answer. The minimum passing score for each test is 70 percent. If you missed a question, go back to your work and retrace your steps and your unit conversions.

TEST NO. 1

1. C
2. D
3. A
4. B
5. C
6. D
7. B
8. B
9. B
10. C

TEST NO. 2

1. D
2. A
3. C
4. D
5. C
6. B
7. C
8. B
9. A
10. B

TEST NO. 3

1. C
2. C
3. C
4. D
5. D
6. C
7. A
8. D
9. C
10. C

TEST NO. 4

1. A
2. C
3. D
4. A
5. C
6. C
7. B
8. C
9. C
10. B

TEST NO. 5

1. C
2. D
3. A
4. B
5. D
6. B
7. A
8. D
9. C
10. A

TEST NO. 6

1. C
2. C
3. D
4. C
5. C
6. B
7. D
8. B
9. D
10. B

APPLIED DRINKING WATER MATH FORMULA SHEET AND CONVERSION FACTORS

Below is a list of basic conversion factors and formulas that will be used with throughout this workbook. Refer to this page when doing the section tests.

12 in	= 1 ft	12 in/ft	1000 mg	= 1 gm	1000 mg/gm
3 ft	= 1 yd	3 ft/yd	1000 gm	= 1 kg	1000 gm/kg
144 sq in	= 1 sq ft	144 sq in/sq ft	1000 mL	= 1 liter	1000 mL/L
9 sq ft	= 1 sq yd	9 sq ft/sq yd	1 meter	= 39.37 in	39.37 in/meter
27 cu ft	= 1 cu yd	27 cu ft/cu yd	1 gram	= 0.035 oz	0.035 oz/gram
5,280 ft	= 1 mile	5,280 ft/mi	60 sec	= 1 min	60 sec/min
7.48 gal	= 1 cu ft	7.48 gal/cu ft	60 min	= 1 hour	60 min/hr
8.34 lb	= 1 gal	8.34 lb/gal	24 hr	= 1 day	24 hr/day
62.4 lb	= 1 cu ft	62.4 lb/cu ft	43,560 sq ft	= 1 acre	43,560 sq ft/ac

VELOCITIES and FLOW RATES

- $V = \frac{\text{distance, feet}}{\text{time, min}}$
- $Q = V \times A$ (Flow rate = velocity, ft/sec x area, sq. Ft.)

RETENTION TIME

- Ret. time = $\frac{\text{tank cap (gal)}}{\text{flow (gal/time)}}$

PARTS PER MILLION / POUNDS

- $\text{mg/L} = \frac{\text{pounds of chemical}}{(8.34 \text{ lb/gal} \times \text{MG})}$
- $\text{lb} = 8.34 \text{ lb/gal} \times \text{mg/L} \times \text{MG}$

LOADINGS

- Weir overflow, gal/day/ft = $\frac{\text{total flow, gal/day}}{\text{length of weir, ft}}$
- Surface loading, gal/day/sq ft = $\frac{\text{flow, gal/day}}{\text{surface area, sq ft}}$

$$3. \text{ Rise rate, ft/min} = \frac{\text{surface loading, gal/min/sq ft}}{7.48 \text{ gal/cu ft}}$$

CHEMICAL MIXING & SOLUTION STRENGTHS

$$1. \text{ Polymer, \%} = \frac{(\text{dry polymer, lb}) \times (100\%)}{(\text{dry polymer, lb} + \text{water, lb})}$$

$$2. \text{ Dry polymer, lb} = \frac{\text{water, lb}}{\left(\frac{100\%}{\text{polymer, \%}}\right) - 1}$$

$$3. \text{ Water, lb} = \frac{\text{dry polymer, lb} \times 100\%}{\text{polymer \%}} - (\text{dry polymer, lb})$$

$$4. \text{ Conc chemical, gal} = \frac{(\text{desired chem. solution, \%}) (\text{gal needed})}{\text{conc chemical, \%}}$$

$$5. \text{ Scale setting, \%} = \frac{(\text{desired feed rate, gal/hr}) (100\%)}{\text{maximum feed rate, gal/hr}}$$

$$6. \text{ Feeder setting, \%} = \frac{(\text{desired feed rate, lb/day}) (100\%)}{(\text{maximum feed rate, lb/day})}$$

$$7. \text{ Water added, gal} = \frac{(\text{hypo, gal}) (\text{hypo, \%}) - (\text{hypo, gal}) (\text{desired hypo, \%})}{\text{desired hypo, \%}}$$

FILTRATION

$$1. \text{ Filtration rate, gal/min/sq ft} = \frac{\text{flow, gal/min}}{\text{surface area, sq ft}}$$

$$2. \text{ Backwash pumping rate, gal/min} = (\text{filter surface area, sq ft}) (\text{BW rate, gal/min/sq ft})$$

$$3. \text{ Backwash \%} = \frac{(\text{backwash water, gal}) (100\%)}{\text{water filtered, gal}}$$

$$4. \text{ UFRV, gal/sq ft} = \frac{\text{volume filtered, gal}}{\text{filter surface area, sq ft}}$$

SOFTENING & DEMINERALIZATION

$$1. \text{ Lime feed, mg/L} = \frac{A + B + C + D}{\text{lime purity as a decimal}} \times 1.15$$

A = carbon dioxide, source water
 B = bicarbonate alkalinity, source water
 C = hydroxide alkalinity, source water
 D = magnesium, source water

2. Exchange capacity, grains = (removal capacity, gr/cu ft) (media vol, cu ft)
3. water treated, gal =
$$\frac{\text{exchange capacity, grains}}{\text{hardness removed, grains/gal}}$$
4. Bypass flow, gal/day =
$$\frac{(\text{total flow, gal/day}) (\text{softener effluent hardness, gr/gal})}{\text{raw water hardness, gr/gal}}$$
5. Salt, lb = (salt req'd, lb/1000 grains) (hardness removed, grains)
6. Brine, gal =
$$\frac{\text{salt needed, lb}}{\text{salt sol'n, lb/gal}}$$
7. Mineral rejection, % =
$$1 - \left(\frac{\text{product TDS, mg/L}}{\text{feedwater TDS, mg/L}} \right) \times 100 \%$$
8. Recovery, % =
$$\frac{\text{product flow}}{\text{feed flow}} \times 100 \%$$

FLUORIDATION

1. Fluoride ion purity, % =
$$\frac{(\text{molecular wt. of F in compound}) (100 \%)}{\text{molecular wt of compound}}$$
2. Feed rate, lb/day =
$$\frac{(\text{flow, MGD}) (\text{desired F, mg/L}) (8.34 \text{ lb/gal}) (100\%) (100\%)}{(\text{acid sol'n, \%}) (\text{fluoride ion purity, \%})}$$
3. Feed rate, gal/day =
$$\frac{\text{feed rate, lb/day}}{\text{chem sol'n, lb/gal}}$$
4. Portion of F =
$$\frac{(\text{commercial chemical purity, \%}) (\text{Fluoride ion, \%})}{(100 \%)(100 \%)}$$
5. Feed rate, lb/day =
$$\frac{\text{fluoride, lb/day}}{\text{fluoride, lb / lb of commercial chemical}}$$

