There are three basic shapes used in water treatment plant calculations: rectangles, triangles, and circles.

Formulas:

Rectangle Area = (length)(width)

$= lw$

Triangle Area $= \frac{(\text{base})(\text{height})}{2}$

$= \frac{bh}{2}$

Circle Area = (0.785)(Diameter^2)

$= (0.785)(D^2)$

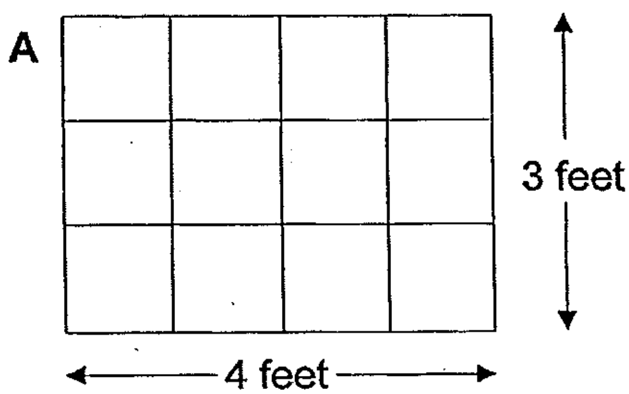
or

= (3.14)(radius^2)

$= (3.14)(r^2)$

$= \pi r^2$

Rectangles



Area of rectangle A = (length)(width)

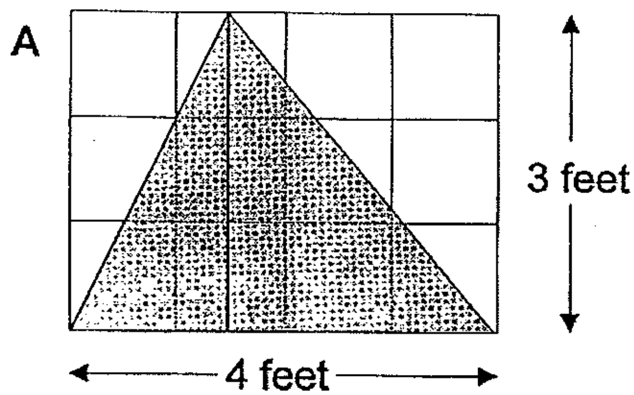
= (4 feet)(3 feet)

= 12 square feet

Note: Each square is equal to 1 square foot. Check this calculation by counting the squares.

Triangles

The area of a triangle is equal to the base length of the triangle times the height of the triangle divided by two. The height of the triangle must be measured vertically from the horizontal base.



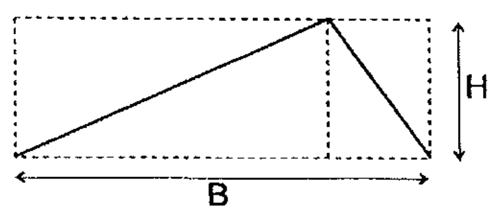
Area of triangle A $= \frac{\text{(base)(height)}}{2}$

$= \frac{\text{(4 feet)(3 feet)}}{2}$

$= \frac{\text{12 square feet}}{2}$

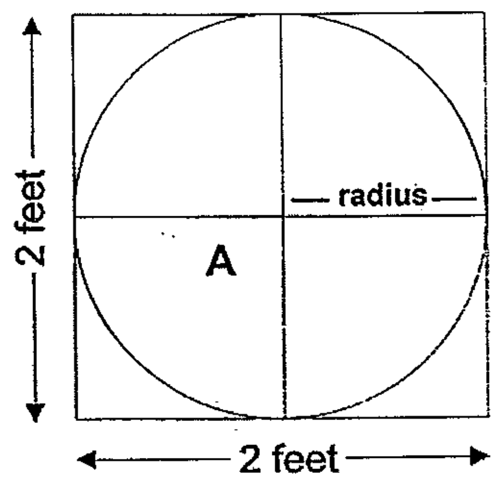
= 6 square feet

Note: The area of any triangle is equal to 1/2 the area of the rectangle that can be drawn around it. The area of the rectangle is B x H. The area of the triangle is 1/2 B x H.



Circles

The most familiar formula for the area of a circle is πr^2. The r stands for radius, the distance from the center point of the circle to the edge of the circle. The radius of any circle is equal to half the diameter. The area of a circle can also be derived by using the formula $(0.785)(D^2)$.



Area of circle A $= \pi r^2$

$= (3.14)(D/2)^2$

$= (3.14)(1^2)$

$= 3.14$ square feet

or

$= (0.785)(D^2)$

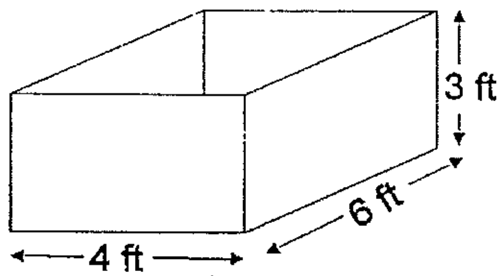
$= (0.785)(4)$

$= 3.14$ square feet

Formulas:

Rectangular Tanks or Basins

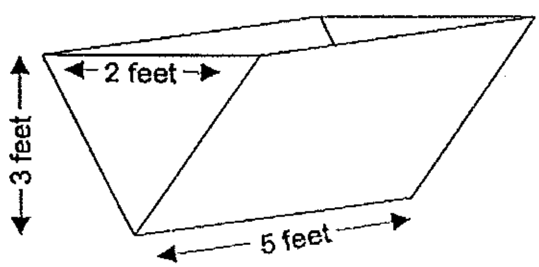
Volume = (area of rectangle)(depth)
= (lw)(depth)



Rectangle example: = (area of rectangle)(depth)
= (4 ft X 6 ft)(3 ft)
= 72 cu. ft.

Troughs

Volume = (area of triangle)(length)



$$= \frac{(bh)}{2}(\text{length})$$

Trough example: = (area of triangle)(length)

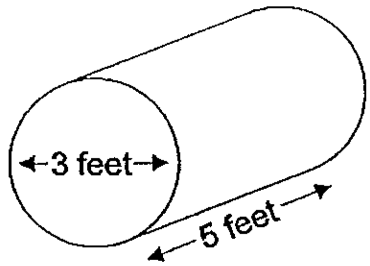
$$= \frac{(2\text{ ft} \times 3\text{ ft})}{2}(5\text{ ft})$$

= (3 sq ft)(5 ft)
= 15 cu. ft.

Basic Geometry

Cylinders

Volume = (area of circle)(depth)
= (0.785 D^2)(depth)



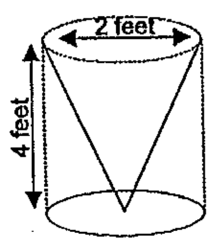
Cylinder example:

Volume = (circle area)(depth)
= (0.785 D^2)(depth)
= (0.785)(9 sq ft)(5 ft)
= 35.325 cubic feet

Cones

Volume = 1/3(volume of cylinder)

$$= \frac{(0.785\ D^2)(\text{depth})}{3}$$



Cone example:

Volume = 1/3(volume of cylinder)

$$= \frac{(0.785\ D^2)(\text{depth})}{3}$$

$$= \frac{(0.785)(4\ \text{sq ft})(4\ \text{ft})}{3}$$

= 4.18666 cubic feet

Chapter Three

Velocity and Flow Rates

Velocity

Velocity is the measurement of the speed at which something is moving. It is expressed by the distance traveled in a specific amount of time. Velocity can be expressed in any unit of distance per any unit of time, as in three miles per year, a mile per second, etc., however, for the purpose of measuring water's rate of flow in a channel, pipe, or other conduit, it is usually expressed in feet per second, or feet per minute.

Formula: $\text{Velocity} = \frac{\text{Distance (unit)}}{\text{Time (unit)}}$

Example:

The water in a pipe travels 210 feet every three minutes. The velocity of the water would be figured:

$$V = \frac{210\ (\text{ft})}{3\ (\text{minutes})}$$

V = 70 feet per minute

To convert this answer to feet per second, multiply by 1 min./60 seconds (one minute is equal to 60 seconds, so this fraction is equal to one and does not change the relative value of the answer).

$$V = \frac{70\ \text{feet}}{1\ \text{minute}} \times \frac{1\ \text{minute}}{60\ \text{seconds}}$$

$$V = \frac{70\ \text{feet}}{60\ \text{seconds}}$$

V = 1 1/6 feet per second

Flow rate units of measurement are normally dependent on the unit of measurement used for the velocity variable. If the velocity is determined in feet per second, then the flow rate must be expressed as cubic feet per second. If the velocity is represented as meters per day, then the flow rate must be expressed as cubic meters per day.

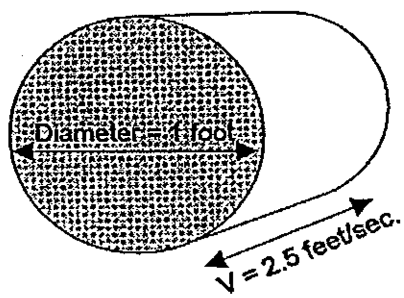
Calculations:

Circular Pipes (assuming it is flowing full)

Flow Rate = (Circle Area)(Velocity)

= (πr^2)(Distance/Time)

Circular Pipe Example



Flow Rate = (Circle Area)(Velocity)

= (πr^2)(Distance/Time)

= $(3.14)(r^2)(2.5\text{ ft./sec.})$

= $(3.14)(.5\text{ ft})^2(2.5\text{ ft./sec.})$

= $(3.14)(.25\text{ ft}^2)(2.5\text{ ft/sec.})$

= $(.785\text{ ft}^2)(2.5\text{ ft/sec.})$

= 1.9625 cubic feet per second (cfs)

Chapter Four

Pressure, Force and Head

Force: The push exerted by water on a surface being used to confine it. Force is usually expressed in pounds, tons, grams, or kilograms.

Pressure: Pressure is the force per unit area. It is commonly expressed as pounds per square inch (psi).

Head: Head is the vertical distance from the water surface to a reference point below the surface. It is usually expressed in feet or meters.

Formulas:

Force (lbs.) = psi x area (in square feet)

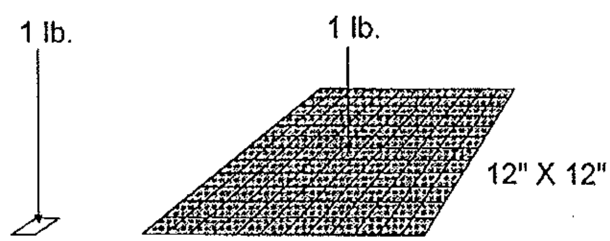
Head (feet) = psi x 2.31

psi = H x 0.433

OR

$$psi = \frac{H}{2.31}$$

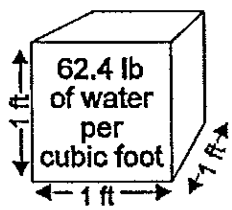
where: H = Head (in feet)
psi = pounds per square inch



1 lb/sq. in. (psi) 1 lb/sq. ft

Knowing that a cubic foot of water weighs 62.4 pounds, the force of the water pushing down on the square foot surface area is 62.4 pounds. Using this information, we can determine the pressure in pounds per square inch (psi).

$$\frac{62.4 \text{ lb}}{1 \text{ sq ft}} = \frac{62.4 \text{ lb}}{(1 \text{ ft})(1 \text{ ft})}$$

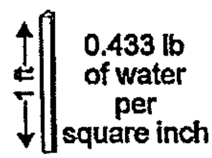


$$= \frac{62.4 \text{ lb}}{(12 \text{ in})(12 \text{ in})}$$

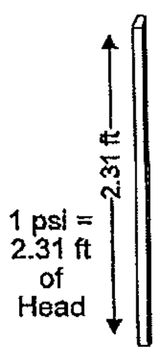
$$= \frac{62.4 \text{ lb}}{144 \text{ sq in}}$$

$$= 0.433 \text{ lb/sq in}$$

$$= 0.433 \text{ psi}$$



Based on the calculation above, a foot high column of water above one square inch of surface area weighs almost half a pound (0.433 lb), and is expressed as 0.433 psi of pressure. Now that we have determined this factor, it allows us to convert from pressure measured in feet of water to pounds per square inch. The height of water is the most important factor in determining pressures. To convert from psi to feet of head:



$$\frac{1 \text{ ft}}{0.433 \text{ psi}} = \frac{x \text{ ft}}{1 \text{ psi}}$$

$$x = \frac{(1 \text{ft})(1 \cancel{\text{psi}})}{0.433 \cancel{\text{psi}}}$$

$$x = 2.31 \text{ ft}$$

At 1 psi, head = 2.31 feet as shown above.

Head

Head is the ratio between foot pounds of water and pounds, and is measured in feet. For every pound per square inch there is 2.31 feet of head.

Formula: Head (in feet) = psi x 2.31

Head is an important measurement tool in hydraulics. It can be used to determine the hydraulic forces in a pipeline and pump requirements.

There are three types of head:

1. Pressure head
2. Elevation head
3. Velocity head

Pressure head is the measurement of the energy in water from pressure. It is the height above the pipe that water will rise to in an open ended tube. Pressure head can be used to plot hydraulic gradient lines (HGL).

Elevation head is the measurement of energy in water from elevation. It is measured from a specific point, like sea level, to a desired point of interest in the system.

Velocity head is the measurement of the energy in water from its flow. The faster the flow, the greater the energy. Velocity head is also determined in feet and is determined by the formula shown below:

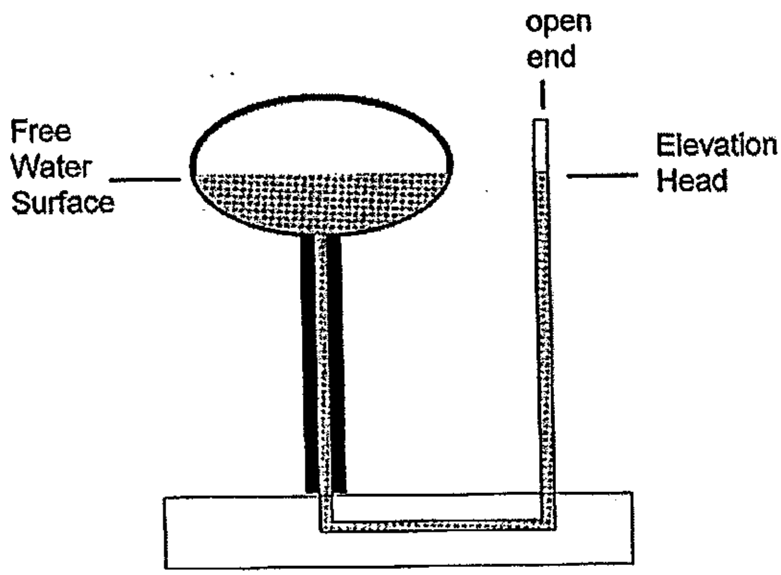
$$\text{Velocity Head} = \frac{V^2}{64.4\ \text{ft/sec}^2}$$

where V = water velocity

Elevation Head & Pressure Head

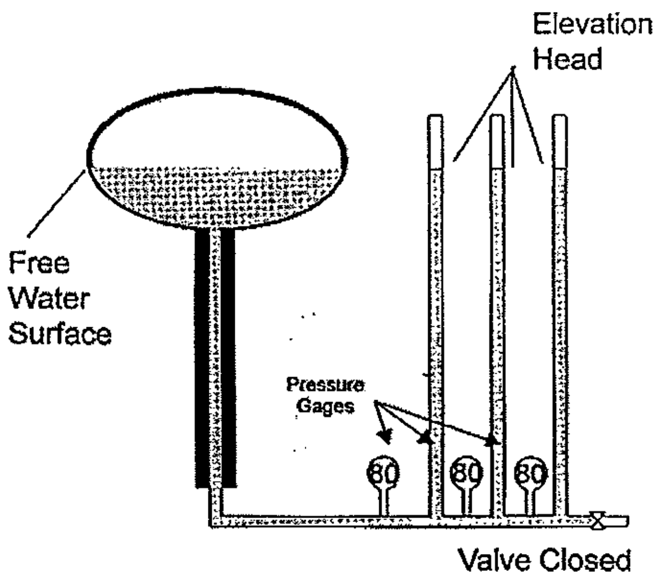
An important concept in water systems is the relationship between pressure head and elevation head. The figure below illustrates an open ended tube attached to a tank to measure head. Under static conditions the water level in the tube would rise to the water level in the tank. This water level would represent the elevation head.

This method of measuring head in a system is impractical. Instead of measuring elevation head, water systems install pressure gages in the system to measure pressure head.

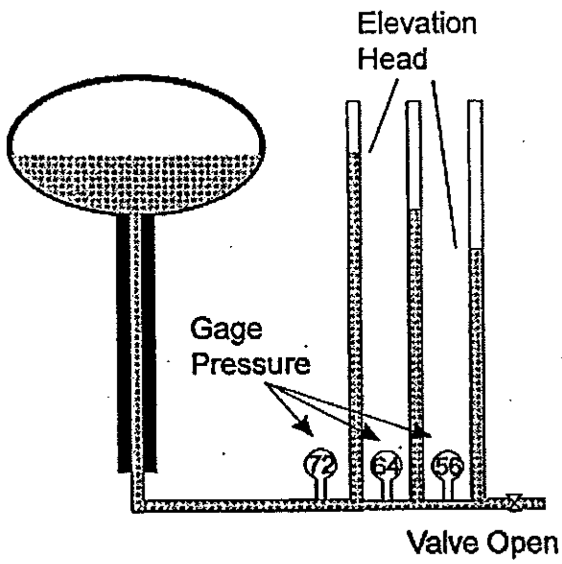


The illustration above shows head elevation for a body of static water. The head elevation would change if the water was flowing.

The following illustration demonstrates the relationship between elevation head and pressure head during static water conditions (when the water is not moving). The water level in the water tank and tubes is at the same elevation. Therefore the elevation head is equal to the pressure head throughout the system.



Under dynamic conditions (when water is moving in the system) the elevation head and pressure head decrease proportionally as you move away from the tank.



Sample Problem:

Determine the chlorinator setting in pounds per day if you have a flow of 200 GPM and your target chlorine dose is 2.0 mg/L.

1. Convert flow from gallons per minute to million gallons per day (MGD).

Multiply flow in gallons/minute by 1440 (the number of minutes in a day) to convert to gallons per day (GPD).

200 gpm X 1440 min/day = 288,000.0 gal/day

Move the decimal point six places to the left to convert to million gallons per day.

.288 MGD

2. Use the formula for chemical feeds to determine the chlorinator setting in pounds per day.

Chemical Feed = (Flow, MGD)(Dose, mg/L)(8.34 lbs/gal)

Chemical Feed = (.288 MGD)(2.0 mg/L)(8.34 lbs/gal)

Chemical Feed = (.288)(2.0)(8.34)

Chemical Feed = 4.8 lbs/day

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.288 MGD

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Chemical Feed = (Flow, MGD)(Dose, mg/L)(8.34 lbs/gal)

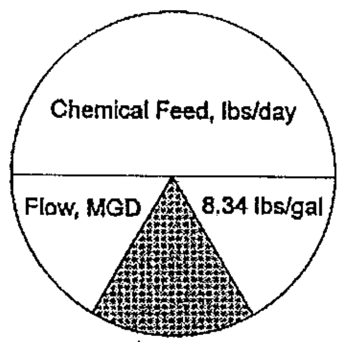
Chemical Feed = (.288 MGD)(2.0 mg/L)(8.34 lbs/gal)

Chemical Feed = (.288)(2.0)(8.34)

Chemical Feed = 4.8 lbs/day

Calculating Dose

If you know what the chemical feed and flow are and want to calculate the dose, cover the dose section of the pie to set up the correct formula as seen below.



$$\text{Dose, mg/}L = \frac{\text{Chemical Feed, lbs/day}}{\text{(Flow, MGD)(8.34 lbs/gal)}}$$

Sample Problem:

A .52 MGD system is feeding chlorine at a rate of 12 lbs/day. What will be the resulting chlorine dose?

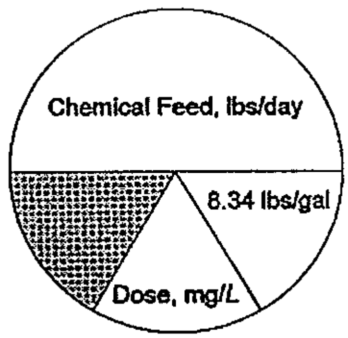
$$\text{Dose, mg/l} = \frac{\text{Chemical Feed, (lbs/day)}}{\text{(Flow, MGD)(8.34 lbs/gal)}}$$

$$= \frac{\text{12 lbs/day}}{\text{(.52 MGD)(8.34 lbs/gal)}}$$

$$\text{Dose, mg/l} = 2.76 \text{ mg/}L$$

Calculating Flow

If you know what the chemical feed and dose are and want to calculate the flow, cover the flow section of the pie to set up the correct formula as seen below.



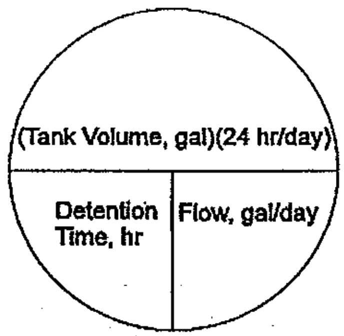
$$\text{Flow, MGD} = \frac{\text{Chemical Feed, lbs/day}}{(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})}$$

Detention Time

Formula:

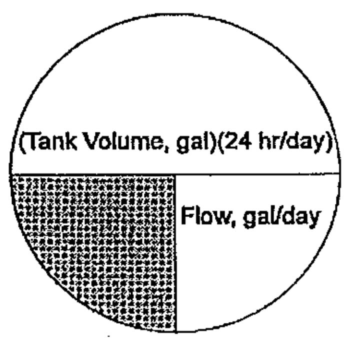
$$\text{Detention Time, Hr} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

An easy way to visualize and use this formula is in a Davidson Pie chart seen below.



Calculating Detention Time

To determine detention time in hours when the flow and tank volume are known, cover the Detention Time, hr portion of the pie as seen below. What is left uncovered is the correct formula.



Detention Time in Hours is equal to:

$$\frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

Typical Water Problems

Sample Problem:

A rectangular basin 12 feet long and 9 feet wide is 6 feet deep. It treats a flow of 90,000 gallons per day. Determine the detention time in hours.

Formula:

$$\text{Detention Time, Hr} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

1. Determine tank volume in gallons.

   Volume = (length)(width)(depth)
   Volume = (12 ft)(9 ft)(6 ft)
   Volume = 648 ft^3 or 648 cubic feet

2. To convert from cubic feet to gallons multiply by 7.48. There are 7.48 gallons in each cubic foot.

   648 cu ft X 7.48 gal/cu ft = 4,847 gallons (volume)

3. Calculate the resulting detention time in hours using the formula state above.

$$\text{Detention Time, hr} = \frac{(4{,}847\ \text{gal})(24\ \text{hr/day})}{90{,}000\ \text{gal/day}}$$

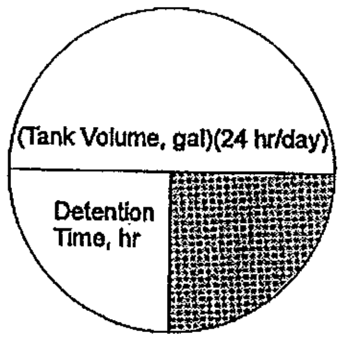
$$\text{Detention Time, hr} = \frac{(4{,}847\ \cancel{\text{gal}})(24\ \text{hr/}\cancel{\text{day}})}{90{,}000\ \cancel{\text{gal/day}}}$$

$$\text{Detention Time, hr} = \frac{(4{,}847)(24\ \text{hr})}{90{,}000}$$

$$\text{Detention Time, hr} = 1.29\ \text{hours}$$

Calculating Flow

If you know what the tank volume and detention times are and want to calculate the flow, cover the flow section of the pie to set up the correct formula as seen below.



$$\text{Flow, gal/day} = \frac{\text{(Tank Volume, gal)(24 hr/day)}}{\text{Detention Time, hr}}$$

Sample Problem:

Determine the required flow in gal/day for a settling basin that is 20 feet long, 10 feet wide, and six feet deep with a detention time of 3 hours.

1. Determine tank volume in gallons.

Volume	=	(l)(w)(d)
	=	(10)(20)(6)
	=	1,200 cu ft

2. To convert from cu ft to gallons multiply by 7.48.

   1,200 cu ft X 7.48 gal/ft^3 = 8,976 gal

3. Calculate required flow in gal/day using the formula stated above.

$$\text{Flow, gal/day} = \frac{\text{(8,976 gal)(24 hr/day)}}{\text{3 hr}}$$

Flow, gal/day = 71,808 gal/day

Typical Water Problems

Well Disinfection

If the targeted sodium hypochlorite dose to disinfect a well is 100 mg/L, the casing diameter is 15 inches, the length of water filled casing is 40 feet, and sodium hypochlorite is 5.25 percent or 52,500 mg/*L* chlorine, how much chlorine (in gallons) is required to disinfect the well?

Formula:

$$\text{Chlorine, gal} = \frac{(\text{Casing Volume, gal})(\text{Dose, mg}/L)}{\text{Chlorine Solution, mg}/L}$$

1. Determine the casing volume in gallons using the formula for cylinder volume.

   Cylinder Volume = (0.785)(D^2)(L, ft)

   Casing volume = (0.785)(1.25 ft)^2(40 ft)

   Casing volume = 49.06 ft^3 or 49.06 cubic feet

2. To convert from cubic feet to gallons multiply by 7.48. There are 7.48 gallons in each cubic foot.

   49.06 cu ft X 7.48 gal/cu ft = 366.99 gallons

3. Calculate the required chlorine in gallons using the formula stated above.

$$\text{Chlorine, gal} = \frac{(366.99\text{, gal})(100\text{ mg}/L)}{52{,}500\text{ mg}/L}$$

$$\text{Chlorine, gal} = \frac{(366.99\text{, gal})(100\ \cancel{\text{mg}/L})}{52{,}500\ \cancel{\text{mg}/L}}$$

$$\text{Chlorine, gal} = \frac{36{,}699}{52{,}500}\text{ gal}$$

Chlorine requirement = 0.699 gallons

Note: Sometimes concentrations are listed as parts per million (ppm). One ppm is the equivalent of one milligram per liter (mg/l).

Typical Water Problems

Disinfecting Storage Tanks

A storage tank 25 feet in diameter and 10 feet deep is taken off line for maintenance. To disinfect it before use, an initial does of 100 mg/L is expected to create a chlorine residual of more than 50 mg/L for a 24-hour period. How many gallons of 12 percent sodium hypochlorite solution are needed for disinfection?

1. Determine the volume of water in the tank in gallons using the volume formula for a cylinder.

   Cylinder Volume = $(0.785)(D^2)(\text{depth})$

   Tank Volume = $(0.785)(25\ \text{ft})^2(10\ \text{ft})$

   Tank Volume = 4,906.25 cubic feet

2. To convert from cubic feet to gallons multiply by 7.48. There are 7.48 gallons in each cubic foot.

   4,906.25 cubic feet X 7.48 = 36,698.75 gallons

3. Determine pounds of chlorine needed.

Formula:

Chlorine, lbs = (Volume, M Gal)(Dose, mg/L)(8.34 lbs/gal)

Chlorine, lbs = (.03669875 M Gal)(100 mg/L)(8.34 lbs/gal)

Chlorine, lbs = 30.6 lbs

4. Calculate gallons of 12% hypochlorite solution needed.

Formula:

$$\text{Hypochlorite, gal} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$\text{Hypochlorite, gal} = \frac{(30.6\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(12\%)}$$

Hypochlorite required = 30.58 gallons

Filtration Rates

If a sand filter is 18 feet wide by 24 feet long and treats a flow of 750 gallons per minute, what is the filtration rate in gallons per minute per square foot of filter area?

Formula:

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

1. Determine the surface area of the filter using the formula for the area of a rectangle.

   Rectangle Area = (length)(width)

   Filter area = (18 ft)(24 ft) = 432 ft^2 or 432 sq ft

2. Calculate the filtration rate in gallons per minute per square foot.

   $$\text{Filtration Rate, GPM/sq ft} = \frac{\text{750 GPM}}{\text{432 sq ft}}$$

   Filtration Rate = 1.74 GPM/sq ft

BACKWASH FLOW

Calculate the backwash flow required in gallons per minute to backwash the filter above at 15 gallons per minute per square foot.

Formula:

$$\text{Backwash Rate, GPM/sq ft} = \frac{\text{Backwash Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$\text{15 GPM/sq ft} = \frac{\text{Backwash Flow, GPM}}{\text{432 sq ft}}$$

Backwash Flow, GPM = (15 GPM/sq ft)(432 sq ft)

Backwash Flow required = 6,480 GPM

Chapter Six

Conversions and Formulas

Basic Water Units

One cubic foot of water weighs 62.4 pounds
One cubic foot of water contains 7.48 gallons
One gallon of water weighs 8.34 pounds

Cubic Foot	=	62.4 pounds
Cubic Foot	=	7.48 gallons
One Gallon	=	8.34 pounds

Frequently used rates and units

1 liter of water	=	1,000 grams
1 ounce	=	28.35 grams
1 milliliter of water	=	1 gram
1 part per million	=	1 lb per million lbs
1 part per million	=	8.34 lb/million gallons
1 part per million	=	1 milligram per liter
1 percent	=	10,000 parts per million
1 ounce per cubic foot	=	1 gram per liter
1 million gallons per day ..	=	1.55 ft^3 per second
1 million gallons per day ..	=	694 gallons per minute
1 cubic foot per second ...	=	450 gallons per minute
1 psi	=	2.31 feet of head
1 foot of head	=	0.433 psi