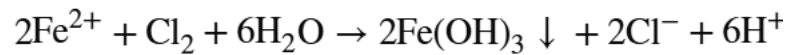


Chlorine Disinfection: Dose, Demand, and Residual. Handout 1

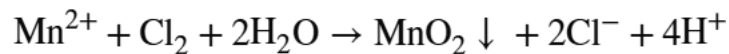
You can use the following stoichiometric relationships as a reference to complete selected problems in this worksheet.

Stoichiometric Relationships

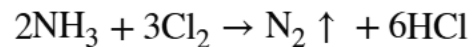
- **Iron (Fe):** 0.64 mg of chlorine is required to oxidize 1.0 mg of ferrous iron



- **Manganese (Mn):** 1.29 mg of chlorine is required to oxidize 1.0 mg of manganese



- **Ammonia (NH₃):** 7.6 mg of chlorine is required to completely oxidize 1.0 mg of ammonia-nitrogen to nitrogen gas



Part 1: Estimating reducing compound demand.

1. Estimate the chlorine demand for a groundwater source that has 0.3 mg/L of iron (Fe)

$$\text{Demand} = 0.3 \text{ mg/L (Fe)} \times 0.64(\text{Cl/Fe}) = \mathbf{0.19 \text{ mg/L Chlorine demand}}$$

2. A groundwater has an iron (Fe) concentration of 0.2 mg/L and a manganese (Mn) concentration of 0.01 mg/L. Estimate the resulting free residual if a dose of 1.2 mg/L chlorine is applied.

$$\text{Demand (Fe)} = 0.2 \text{ mg/L (Fe)} \times 0.64(\text{Cl/Fe}) = 0.128 \text{ mg/L}$$

$$\text{Demand (Mn)} = 0.01 \text{ mg/L (Mn)} \times 1.29 (\text{Cl/Mn}) = 0.0129$$

$$\text{Total demand} = 0.128 + 0.0129 = 0.1409 \approx \mathbf{0.14 \text{ mg/L}}$$

$$\text{Residual} = \text{Dose} - \text{demand} = \mathbf{1.2 \text{ mg/L} - 0.14 \text{ mg/L} = 1.06 \text{ mg/L}}$$

3. A surface water source has an ammonia concentration of 0.15 mg/L. Estimate the residual free chlorine remaining if a dose of 1.7 mg/L chlorine is applied.

$$\text{Demand} = 0.15 \text{ mg/L} \times 7.6 (\text{Cl/Amn}) = \mathbf{1.14 \text{ mg/L}}$$

$$\text{Residual} = \mathbf{1.7 \text{ mg/L} - 1.14 \text{ mg/L} = 0.56 \text{ mg/L}}$$

Part 2: Calculate the gas chlorine feed rate or dose for the following disinfection scenarios.

1. A plant has a flow of 2.4 MGD and needs to apply a dose of 2.7 mg/L gas chlorine. Determine the chlorinator setting in lbs/day.

$$2.4 \text{ MGD} \times 2.7 \text{ mg/L} \times 8.34 \text{ lbs/gal} = \mathbf{54 \text{ lbs/day}}$$

2. A plant has a gas chlorine feed rate of 17 lbs per day and a plant flow of 1.0 MGD. What is the dose for this plant?

$$\frac{17 \text{ pounds per day}}{1 \text{ MGD} \times 8.34 \text{ lb/gal}} = \mathbf{2.04 \text{ mg/L}}$$

3. A surface water plant has a flow of 3 MGD and needs to achieve a free chlorine residual of 1.0 mg/L. What should be the chlorine gas feed rate in pounds per day if the ammonia concentration is 0.02 mg/L?

$$\text{Demand} = 0.02 \text{ mg/L (Amm)} \times 7.6 \text{ (Cl/Amm)} = 0.152 \text{ mg/L}$$

$$\text{Dose} = 1 \text{ mg/L residual} + 0.152 \text{ demand} = 1.152 \text{ mg/L} \approx \mathbf{1.15 \text{ mg/L}}$$

$$3 \text{ MGD} \times 1.15 \text{ mg/L} \times 8.34 \text{ lbs/gal} = 28.77 \text{ lbs/day} \approx \mathbf{28.8 \text{ lbs/day}}$$

4. A groundwater system has a plant flow of 0.9 MGD and needs to achieve a free chlorine residual of 1.0 mg/L. What should be the chlorine gas feed rate in pounds per day if the iron concentration is 0.2 mg/L and the manganese concentration is 0.04 mg/L?

$$\text{Iron demand: } 0.2 \text{ mg/L} \times 0.64 = \mathbf{0.128 \text{ mg/L}}$$

$$\text{Mn demand} = 0.04 \text{ mg/L} \times 1.29 = \mathbf{0.0516 \text{ mg/L}}$$

$$\text{Total demand} = 0.128 + 0.0516 = 0.1796 \text{ mg/L} \approx \mathbf{0.18 \text{ mg/L}}$$

$$\text{Dose} = 1.0 \text{ mg/L residual} + 0.18 \text{ mg/L demand} = \mathbf{1.18 \text{ mg/L}}$$

$$\text{Feed rate} = 0.9 \text{ MGD} \times 1.18 \text{ mg/L} \times 8.34 \text{ lbs/gal} = \mathbf{8.86 \text{ lbs/day}}$$

Chlorine Disinfection. Feed rates for sodium hypochlorite. Handout 2.

$$\text{Feed rate (gpd)} = \frac{\text{Flow (MGD)} \times \text{Conc (mg/L)} \times 8.34 \text{ lbs/gal}}{\% \text{strength} \times \text{s.g.} \times 8.34 \text{ lbs/gal}}$$

1. A groundwater system has a flow of 1.4 MGD and needs a dose of 1.3 mg/L chlorine. What should be the feed rate of 12.5% sodium hypochlorite in GPD? (assume s.g. = 1.2)

$$\frac{1.4 \text{ MGD} \times 1.3 \text{ mg/L} \times 8.34 \text{ lb/gal}}{0.125 \times 1.2 \times 8.34 \text{ lb/gal}} = \mathbf{12.13 \text{ GPD}}$$

2. A groundwater system produces a flow of 800 gallons per minute. The desired free residual is 1.2 mg/L. What should be the feed rate of 12.5% sodium hypochlorite in GPD if the iron concentration is 0.25 mg/L and the manganese concentration is 0.015 mg/L? (assume s.g. = 1.2).

$$\text{Convert to MGD: } \frac{800 \text{ GPM} \times 1440 \text{ min/day}}{1,000,000 \text{ gal/MG}} = \mathbf{1.152 \text{ MGD}}$$

$$\text{Iron demand } 0.25 \text{ mg/L} \times 0.64 = 0.16 \text{ mg/L}$$

$$\text{Mn demand } 0.015 \text{ mg/L} \times 1.29 = 0.01935 \text{ mg/L}$$

$$\text{Total demand} = 0.16 + 0.01935 = 0.17935 \text{ mg/L} \approx 0.18 \text{ mg/L}$$

$$\text{Dose} = 1.2 \text{ mg/L} + 0.18 \text{ mg/L} = \mathbf{1.38 \text{ mg/L}}$$

$$\text{Feed} = \frac{1.152 \text{ MGD} \times 1.38 \text{ mg/L} \times 8.34 \text{ lbs/gal}}{0.125 \times 1.2 \times 8.34 \text{ lbs/gal}} = \mathbf{10.60 \text{ gpd Cl}}$$

3. A sodium hypochlorite feed pump is rated for 0.5 GPH. Estimate the output of this pump in GPD if the stroke and speed are both set at 70%.

$$0.5 \text{ GPH} \times 0.7 \times 0.7 \times 24 \text{ hr/day} = \mathbf{5.88 \text{ GPD}}$$

4. A water system with a flow of 750 gpm purchased a sodium hypochlorite feed pump rated at 1 GPH. This system aims to feed the correct amount of chlorine to achieve a dosage of 2 mg/L. The sodium hypochlorite strength is 12.5% and has a s.g. of 1.2. The operators have connected the chemical feed pump and have set the speed at 89%. Estimate the stroke setting as a percent needed to achieve the correct feed rate in GPD.

$$750 \text{ GPM} \times 1440 \text{ min/day} = 1.08 \text{ MGD}$$

$$1,000,000 \text{ gal/MG}$$

$$\text{Feed (GPD)} = 1.08 \text{ MGD} \times 2 \text{ mg/L} \times 8.34 \text{ lb/gal} = 14.4 \text{ GPD}$$

$$.125 \times 1.2 \times 8.34 \text{ lb/gal}$$

$$\text{Convert to GPH: } 14.4 \text{ GPD} \div 24 \text{ hr/day} = 0.6 \text{ GPH}$$

$$\text{Solve for stroke\%: } 1 \text{ GPH} \times 0.89 \times S = 0.6 \text{ GPH}$$

$$0.89 \times S = 0.6 \text{ (divide both sides by 0.89)}$$

$$S = 0.6 \div 0.89 = \mathbf{0.67 \text{ (67\% stroke)}}$$

$$\text{Check: } 1 \text{ GPH} \times 0.89 \times 0.67 = 0.596 \approx \mathbf{0.6 \text{ GPH}}$$

5. A water utility has a flow of 1.6 MGD and wants to deliver a dose that results in a 1.2 mg/L free residual. The water source includes 0.05 mg/L of manganese and 0.01 mg/L of ammonia. 5.25% sodium hypochlorite will be fed with a chemical feed pump and has a s.g. of 1.08. If the following feed pump ratings were your only options, which one would you select for this application, and why? (show your work).

Demand:

$$\text{Mn: } 0.05 \text{ mg/L} \times 1.29 = 0.0645 \text{ mg/L}$$

$$\text{Amm: } 0.01 \text{ mg/L} \times 7.6 = 0.076$$

$$\text{Total demand} = 0.1405$$

$$\text{Dose} = 1.2 \text{ mg/L (free)} + 0.14 \text{ mg/L (demand)} = \mathbf{1.34 \text{ mg/L}}$$

$$\text{Feed (GPD)} = \frac{1.6 \text{ MGD} \times 1.34 \text{ mg/L} \times 8.34 \text{ lbs/gal}}{0.0525 \times 1.08 \times 8.34 \text{ lbs/gal}} = \mathbf{37.8 \text{ GPD}}$$

$$\text{Feed rate per hour: } 37.8 \text{ GPD} \div 24 \text{ hr/day} = \mathbf{1.58 \text{ GPH (Option A)}}$$

- Chemical feed pump rated at 2.5 GPH (provides sufficient adjustment capacity and runs around 60 % capacity – a good setting for efficiency and accuracy – not too low.)
- Chemical feed pump rated at 1.6 GPH (no room to increase if needed)
- Chemical feed pump rated at 0.75 GPH (too small)

Chlorine Disinfection CT Compliance – Worksheet 3

1. A plant has a flow of 2.2 MGD and a disinfection clear well with a volume of 100,000 gallons. The clear well has superior baffling with a BF = 0.7. If the free residual in the water exiting the clear well is 1.5 mg/L, what CT has been achieved?

$$\text{Flow in GPM} = \frac{2,200,000 \text{ gal}}{1440 \text{ min/day}} = 1,527.8 \text{ GPM}$$

$$\text{Contact Time} = \frac{100,000 \text{ gallons} \times 0.7}{1,527.8 \text{ GPM}} = 45.8 \text{ minutes}$$

$$\text{CT} = 45.8 \text{ minutes} \times 1.5 \text{ mg/L} = \mathbf{68.7}$$

2. Water has a temperature of 5 degrees Celsius, a pH of 6.5, and a final free chlorine residual of 1.6 mg/L. If the plant flow is 1 MGD and the clear well has a volume of 100,000 gallons with a BF of 0.7, what is the Log treatment that was achieved by disinfection alone? (show your work).

$$\text{Flow in GPM} = \frac{1,000,000 \text{ GPD}}{1440 \text{ min/day}} = 694.4 \text{ GPM}$$

$$\text{Contact time} = \frac{100,000 \text{ gal} \times 0.7}{694.4 \text{ GPM}} = 100.8 \text{ minutes}$$

$$\text{CT achieved} = 100.8 \text{ min} \times 1.6 \text{ mg/L} = \mathbf{161.28 \text{ min-mg/L}}$$

$$\text{Required CT}_{99.9} = \mathbf{132 \text{ min-mg/L}} \text{ (from table)}$$

$$\text{Log} = \frac{161.28 \text{ min-mg/L}}{132 \text{ min-mg/L}} \times 3\text{-log} = \mathbf{3.66 \text{ Log}}$$

3. Water in a surface water treatment plant has a temperature of 10 degrees Celsius, a pH of 7.5, and a free chlorine residual of 1.2 mg/L (at the end of the chlorine contact basin). This plant has a flow of 2 MGD and is credited with a 2.5-log removal credit toward 3-log Giardia compliance. What is the minimum chlorine contact time required to achieve 1-log inactivation toward 3-log Giardia compliance? (Bonus question: What would be the minimum required volume (in gallons) of the clear well if the baffling factor was 0.5?)

*From Table: CT_{99.9} is **137 min-mg/L to achieve 3 log***

$$1 \text{ log: } \frac{137 \text{ min-mg/L}}{3} = \mathbf{45.67 \text{ min-mg/L}}$$

$$\mathbf{Minimum \text{ contact time for 1 LOG} = 45.67 \text{ min-mg/L} \div 1.2 \text{ mg/L} = \mathbf{38.1 \text{ minutes}}}$$

Bonus question:

$$\text{Flow (GPM)} = \frac{2,000,000 \text{ gpd}}{1,440 \text{ min/day}} = \mathbf{1,389 \text{ GPM}}$$

$$\frac{\text{Volume (gal)} \times 0.5}{1,389 \text{ GPM}} = \mathbf{38.1 \text{ minutes}}$$

$$\mathbf{Minimum Volume} = \frac{38.1 \text{ minutes} \times 1,389 \text{ GPM}}{0.5} = \mathbf{105,841.8 \text{ gallons}}$$

4. Flow from a groundwater well is chlorinated with sodium hypochlorite to achieve a free residual of 0.9 mg/L. The water temperature is 10 degrees Celsius, and the pH is 7.0. Water flows from the well at a rate of 700 GPM through an 8-inch water main. From the disinfection point, water flows through 1,000 feet of water main to reach the first connection. Has this system achieved 4 Log treatment for viruses?

$CT_{99.99} = 6 \text{ min-mg/L}$ from table

Volume of main: $0.785 \times 0.67\text{ft} \times 0.67\text{ft} \times 1,000\text{ft} \times 7.48\text{gal/cf} = \mathbf{2,635.85 \text{ gallons}}$

Time = $\frac{2,635.85 \text{ gallons}}{700 \text{ gpm}} = \mathbf{3.77 \text{ min}}$ (using volume by flow)

(Using $Q = A \times v$)

$700 \text{ GPM} \div 7.48 \text{ gal/cf} \div 60\text{sec/min} = 1.56 \text{ cfs}$

Area of pipe = $0.67\text{ft} \times 0.67\text{ft} \times 0.785 = 0.352 \text{ ft}^2$

Velocity = $\frac{1.56 \text{ cfs}}{0.352\text{ft}^2} = 4.43 \text{ feet per second.}$

Time to travel 1000 feet = $1,000 \text{ ft} \div 4.43 \text{ ft/sec} = 225.7 \text{ seconds}$ or **3.76 minutes**

CT Achieved = $0.9 \text{ mg/L} \times 3.76 \text{ minutes} = \mathbf{3.38 \text{ min-mg/L}}$

No, we did NOT achieve 4-log inactivation of viruses by the first connection. We need to increase the dosage or add contact time.

Residual needed: $\text{Residual} \times 3.76 \text{ min} = 6 \text{ min-mg/L}$

Residual = $\frac{6.00 \text{ min-mg/L}}{3.76 \text{ min}} = 1.596 \text{ mg/L} \approx \mathbf{1.6 \text{ mg/L}}$

So, if we increase the dosage to achieve a free residual of 1.6 mg/L at the first service connection, we can still achieve 4-log virus inactivation.

Chlorine Disinfection: Emergency or repair-based disinfection. Handout 4.

1. A well has a 10-inch casing and a water column height of 300 feet. How many gallons of 12.5% bleach should be added to the casing to achieve a dose of 100 mg/L?

Volume of water column:

$$\frac{0.833\text{ft} \times 0.833\text{ft} \times 0.785 \times 300\text{ft} \times 7.48\text{gal}/\text{cf}}{1,000,000 \text{ gal}/\text{MG}} = 0.001222 \text{ MG}$$

$$\text{Gallons Liq. Cl} = \frac{0.001222 \text{ MG} \times 100 \text{ mg}/\text{L} \times 8.34 \text{ lbs}/\text{gal}}{0.125 \times 1.2 \times 8.34 \text{ lbs}/\text{gal}} = \mathbf{0.81 \text{ gallons of bleach}}$$

2. A distribution system crew needs to disinfect a newly installed 1,000-foot-long section of 12-inch water main with a dose of 25 mg/L. 1-inch tablets of calcium hypochlorite (HTH) will be used. Each tablet has a strength of 68% and weighs 5 grams, which is equivalent to 0.011 lbs. Estimate the minimum number of tablets needed.

Volume of Main

$$\frac{1\text{ft} \times 1\text{ft} \times 0.785 \times 1,000\text{ft} \times 7.48 \text{ gal}/\text{cf}}{1,000,000 \text{ gal}/\text{MG}} = \mathbf{0.00587 \text{ MG}}$$

$$\text{Lbs HTH needed: } \frac{0.00587 \text{ MG} \times 25 \text{ mg}/\text{L} \times 8.34 \text{ lb}/\text{gal}}{0.68} = \mathbf{1.8 \text{ lbs HTH}}$$

$$\text{Number of tablets: } \frac{1.80 \text{ lbs total HTH}}{0.011 \text{ lbs}/\text{tablet}} = \mathbf{163.6 \text{ tablets}}$$

In practice, operators would not use a partial tablet, so we could round this up to 164 tablets as the minimum number needed. In addition, operators will place a set number of tablets in each section of the main as they assemble it.

If each section is 20 feet long, there are 50 pipe sections in this 1,000-foot main. Let's see how many tablets are needed per section. $164 \text{ tablets} \div 50 \text{ pipe sections} = 3.28 \text{ tablets per pipe section}$. Once again, we round this up to 4 tablets (we need more than 3 tablets, and will not be using a partial tablet).

This coincides with the AWWA C651 standard, which recommends 4 tablets per 20-foot section of 12-inch pipe to achieve a baseline dose of 25 mg/L. If we do this, we will actually be using 200 tablets (50 sections \times 4 tablets/section = 200 tablets). A little extra chlorine dose will also help us maintain the residual over the 24-hour period.

3. A storage tank has been drained for repairs and needs to be disinfected before refilling. The interior of the tank will be sprayed with a 200 mg/L solution of sodium hypochlorite. How many gallons of 12.5% sodium hypochlorite will be needed to make 5 gallons of 200 mg/L solution? (There are 3.785 liters in a gallon.)

We will use the following dilution formula:

$$C1 \times V1 = C2 \times V2$$

- C1 = conc in mg/L of 12.5% bleach. $12.5\% \times 10,000 \text{ mg/L} = 125,000 \text{ mg/L}$
- V1 = the amount of bleach we need to add (in L or mL)
- C2 = 200 mg/L (the intended concentration)
- V2 = 5 gallons (solution size). Convert to liters ($5 \text{ gal} \times 3.785 \text{ L/gal} = 18.925 \text{ L}$)

$C1 \times V1 = C2 \times V2$ (We'll plug our values into the dilution formula; V1 is our unknown)

$$125,000 \text{ mg/L} \times V1 = 200 \text{ mg/L} \times 18.925 \text{ Liters (next divide both sides by 125,000)}$$

$$V1 = \frac{200 \text{ mg/L} \times 18.925 \text{ Liters}}{125,000 \text{ mg/L}} = \mathbf{0.03028 \text{ Liters}}$$

Multiply by 1,000 to convert L to mL (easier to measure with a graduated cylinder)

$$0.03028 \text{ L} \times 1,000 \text{ mL/L} = \mathbf{30.28 \text{ mL}}$$

Converted back to gallons: $0.03028 \text{ L} \times 1 \text{ gal}/3.785 \text{ L} = 0.008 \text{ gallons}$ (Difficult to measure)