# DW Module 27:
# Ozonation
# Answer Key

**Unit One Exercise.**

1. The chemical formula for ozone is

   __________________$O_3$______________________________.

2. Ozone has a _______pungent_______ smell.

3. Ozone is clear to _______bluish_______ in color.

4. Ozone is chemically unstable, and must be used as quickly as it is

   ________generated_____________.

5. Ozone is a strong ________oxidant_______ and can be ________hazardous___________

   to handle.

6. Ozone is generated in nature when high voltage electric arcs convert part of the

   ________oxygen_________ in the atmosphere into ________ozone__________.

7. Ozone is a strong disinfectant, and does not produce harmful byproducts that

   _______chlorine_______ does.

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**Unit Two Exercise.**

1. What are the advantages of a LOX feed system?

   Answers could include: LOX systems can generate ozone at concentration up to 12% (four times that of an air prep system). A much smaller volume of gas is required to obtain the desired ozone dosage. Ozone piping and valves can be smaller. Fewer and smaller diffusers are required.

   There are fewer mechanical components to power and maintain. There are no large electrical loads associated with the LOX evaporators and feed equipment.

2. What are the disadvantages of a LOX feed system?

Answers could include: You have to buy the LOX.

LOX can be hazardous to handle. Too high a concentration of oxygen in the air can be as harmful to humans as too low a concentration.

3. What is the primary purpose of the power supply unit of an ozone generator?

Answers could include: The power supply takes in normal 480 volt, 3 phase, 60 hertz power and outputs high voltage (3,500 volts to 11,500 volts, depending upon the system) medium or high frequency current to the ozone generator.

4. What is the primary purpose of an ozone generator?

Answers could include: convert oxygen from air into ozone.

5. Describe two ways that an operator can control the amount of ozone that is generated.

a. by varying the amount of electrical power applied to the ozone generator.

b. by regulating the flow rate of air or oxygen to the generator.

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☑ <u>Exercise for Diffuser Systems</u>.

1. List two types of chambers in an ozone contact basin. Describe what occurs in each chamber.

Ans: Two types: Application Chamber and Contact Chamber.
Describe what occurs in each. Answers could include:

- Application Chamber: Diffusers are submerged in water, ozone gas is piped in, and fine bubble diffusers release ozone gas into the water.
- Contact Chamber: Ozone is allowed to dissolve into water for chemical reaction and disinfection to take place; at several points, water is sampled to measure dissolved ozone.

2. List at least 3 ozone application safety controls and / or measures that must exist in a diffuser system.

Ans: Answers could include:

- Isolation valves – submerged isolation valves prevent ozone gas from escaping.
- Sample taps – taps in contact basin measure dissolved ozone.
- Neutralizing agent, usually sodium bisulfite – neutralizes any remaining dissolved oxygen before water leaves the contact basin.
- Access hatches – must be sealed.
- Vacuum – chamber operates under a slight vacuum to prevent ozone gas from escaping.
- Ozone Destruct Unit – maintains vacuum and draws air from above basin, which is processed through a catalytic destructor before being discharged to atmosphere.
- Spray nozzles – knock down ozone foam that forms on water.

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## Exercise for Side Stream Injection.

1. A treatment plant is looking to construct an ozone application method for oxidation use (and not disinfection). You have been asked to recommend whether the plant should construct a diffuser system or a side stream injection system. What would you recommend and why?

Ans: What: Side steam injection. Why: Side stream injection 1) is well suited for plants that use ozone for oxidation only, 2) requires less space (since no significant amount of contact time is needed), and 3) costs less to construct.

2. What cautions would you give the plant about your recommendations?

Ans: For side stream injection systems: 1) transfer efficiencies (i.e., how much ozone dissolves) can vary depending on the ratio of gas volume to liquid volume flowing through the injector, and 2) if more contact time is needed in the future, possibly for disinfection, a contact basin must be constructed downstream.

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## Exercise

What is the required ozone generation rate if a plant is treating 14 MGD with a dosage of 2.5 mg/L of ozone? The plant uses a LOX system that generates ozone at a concentration of 12% and contact basins with a transfer efficiency of 92%.

**ANS** $O_3$(lbs/day) = (14 MGD x 2.5 mg/L x 8.34) ÷ 0.92 = 317 lbs/day

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For example: Given an ozone contact basin with an initial ozone residual of 2.2 mg/l, a total detention time of 4 minutes, and a decay constant of –0.22.

- The ozone residual concentration formula can be used to calculate ozone residual at several points in time. For this example, it will be every 30 seconds (0.5 minutes). At 0.5 minutes, ozone residual is:

$$C_i = 2.2 \times e^{(-0.22 \times 0.5)} = 1.97 \text{ mg/l}$$

The data from several calculations is included in a table at the bottom of page 4-7. Figure 4.1 shows a graph of the data from these calculations. Use the graph to fill in the data missing from the table.

| Detention Time (minutes) | Ozone Residual (mg/L) |
|---|---|
| 1.0 | 1.77 |
| 1.5 | 1.58 |
| 2.0 | 1.42 |
| 2.5 | 1.27 |
| 3.0 | 1.14 |
| 3.5 | 1.02 |
| 4.0 | 0.91 |

☑ Fill in the missing numbers in the above table by using the graph in Figure 4.1 on the next page.

Ans: the missing data points are shown in bold in the above table.

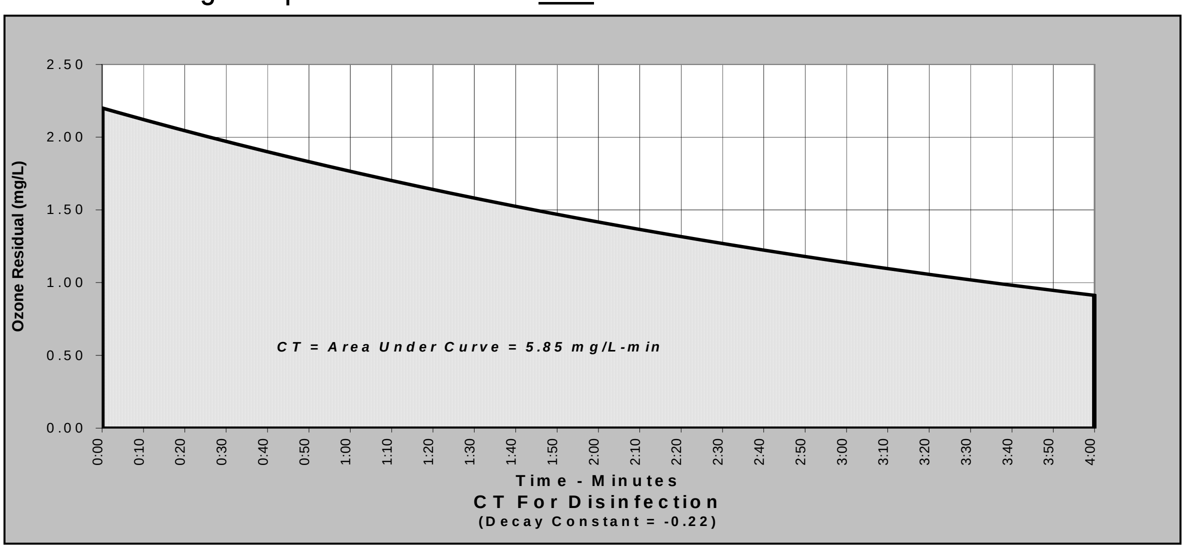


Figure 4.1 CT for Disinfection

The CT, 5.85 mg/L-min in this case, is represented by the area under the curve in Figure 4.1.

Exercise

*[Note: This exercise uses an air prep system. As a result, when calculating total volumetric flow rate (#2), you need to modify certain calculation steps for this type of ozone application. The modifications are noted earlier in the workbook*.]

Given the following parameters:

a. Plant flow = 22 MGD

b. Ozone dosage = 3.0 mg/L

c. Initial ozone residual = 1.9 mg/L

d. Effective detention time = 3.5 minutes

e. Final ozone residual concentration = 0.7 mg/l

f. Air Prep system – generates ozone at a concentration of 3%

g. Diffuser/contact basin system with 95% transfer efficiency

Calculate the following:

1. Required ozone generation rate (lbs/day)
2. Total volumetric gas flow rate (scfm)
3. Ozone demand
4. CT achieved

1. Required ozone generation rate.

ANS

| |
|---|
| $O_3$ (lbs/day) = (Q x D x 8.34) ÷ E = (22 x 3.0 x 8.34) ÷ 0.95 = 579 lbs/day |

2. Actual total volumetric flow rate – requires several calculations to get here.

Here, we must use the required air prep system considerations in the calculations. Let's review how the total volumetric flow rate is calculated, step-by-step, using the workbook information.

ANS

| |
|---|
| ➊ A: Ozone volumetric gas flow rate (scfm)<br>Volume $O_3$ = $O_3$ lbs/day ÷ $O_3$ weight (lbs/ft3) ÷ 1440 min/day<br>Volume O3 = 579 lbs/day ÷ 0.125 lbs/ft3 ÷ 1440 min/day = 3.2 scfm |

ANS

❶ B: Total feed gas weight (lbs/day)
Feed Gas (lbs/day) = $O_3$ lbs/day ÷ 0.12
Feed Gas (lbs/day) = 579 ÷ 0.03 = **19,300 lbs/day**

ANS

❸ A: Air weight (lbs/day)
Air (lbs/day) = total weight of feed gas x (1 – Ozone weight)
Air (lbs/day) = 19,300 x (1 – 0.03) = **18,721 lbs/day**

Note that Step ❷ is skipped since air prep systems do not require nitrogen in feed gas (as LOX systems do). Note that Steps ❸ A and B are also modified from the previous exercise using a LOX system, as noted on workbook page 4-4.

ANS

❸ B: Air volumetric flow rate (scfm)
Volume Air = weight in lbs/day ÷ weight in lbs per standard ft3 ÷1440 min/day
Volume Air = 18,721 ÷ 0.076lbs/ft3 ÷ 1440 min/day = **171.1 scfm**

ANS

❹ : Total volumetric gas flow rate (scfm).
Total volumetric flow rate = $O_3$ scfm + $O_2$ scfm
Volume Feed Gas = 3.2 scfm + 171.1 scfm = **174.3 scfm**

Note that Step ❹ does not include nitrogen, as did our previous exercise using a LOX system.

3. Ozone demand

ANS

$O_3$ Demand = Dosage of ozone applied – initial ozone residual (C1)
$O_3$ Demand = 3.0 mg/L $O_3$ Applied – 1.9 mg/L Initial $O_3$ Residual = **1.1 mg/L**

Why is it important that we know ozone demand?

ANS Answers should include: Knowing ozone demand is critical to determining ozone dosage. The ozone demand will consume part of the ozone that's fed almost immediately. You need to feed enough ozone to meet that demand plus the amount you need for a residual for disinfection CT. If you don't account for ozone demand, you probably won't be feeding enough ozone to get the disinfection CT you need.

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4. CT Achieved

ANS

$K = \ln (C_2 \div C_1) \div DT$

$K = \ln (C_2 \div C_1) \div DT = \ln (0.7 \text{ mg/L} \div 1.9 \text{ mg/L}) \div 3.5 \text{ min} = -0.28$

Where: K = Decay constant

$C_2$ = Ozone residual concentration at the end of the contact time (mg/L)

$C_1$ = Ozone residual concentration at the beginning of the contact time (mg/L)

DT = Effective detention time

"ln" signifies to take the natural logarithm (base e) of $(C_2 \div C_1)$

ANS

$CT = C_1 \times [e^{(KxDT)} – 1] \div K$

$CT = C_1 \times [e^{(KxDT)} – 1] \div K = 1.9 \text{ mg/L} \times [e^{(-0.28x3.5 \text{ min})} – 1] \div (-0.28) =$ 4.2 mg/L-min

Where: CT = Measure of disinfection achieved (Concentration x Time)

C1 = Initial ozone residual concentration (mg/L)

e = Base of natural logarithms

K = Decay constant

DT = Effective detention time (minutes)

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☑ Exercise for Unit 4.

1. A 2 log inactivation results in a _______99_______% inactivation of pathogens.

2. A contact basin should be periodically _______**drained**___ for cleaning and inspection.

3. Ozone piping and supports must be examined periodically for evidence of_________________________MIC__________________________

4. CT is an abbreviation for _______________Contact Time____________________

5. A PLC is often used to control equipment in a ozone system. What does PLC stand for? Programmable Logic Controller

6. The ________Side Stream___ injection process is often used in bottled water plants.

7. MIC stands for ______________Microbiologically___________________ ____________Influenced_______ ______Corrosion___________.

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☑ Unit Five Exercise.

1. The acronym OSHA stands for: Occupational Safety and Health Administration.
2. The acronym MSDS stands for: Material Safety Data Sheet.
3. Manufacturers are required to supply an MSDS for every chemical that they sell.

   a. True _____X_____ b. False __________

4. Confined space requirements should be followed whenever ozone or other hazardous gases are being used.

   a. True _____X_____ b. False __________

5. LOX is the liquid form of oxygen and is considered to be a __cryogenic__ liquid.