Drinking Water Operator Certification Training Instructor Guide

Module #27 Ozone

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

A Note to the Instructor

Dear Instructor:

The primary purpose of this course, *Ozone* is to provide a general overview of ozone generation and application. In addition, ozone system operation and safety and handling will be discussed. This module has been designed to be completed in 3 hours, but the actual course length will depend upon content and/or delivery modifications and results of course dry runs performed by the Pa. DEP-approved sponsor. The number of contact hours of credit assigned to this course is based upon the contact hours approved under the Pa. DEP course approval process. To help you prepare a personal lesson plan, timeframes have been included in the instructor guide at the Unit level and at the Roman numeral level of the topical outline. You may adjust these timeframes as necessary; however, please make sure that all teaching points are covered and that the course is delivered as approved by Pa. DEP.

Web site URLs and other references are subject to change, and it is the training sponsor's responsibility to keep such references up to date.

Delivery methods to be used for this course include:

- Lecture
- Exercises/Activities
- Calculations
- Quizzes

To present this module, you will need the following materials:

- One workbook per participant
- Extra pencils
- Flip Chart
- Markers
- Laptop (loaded with PowerPoint) and an LCD projector **or** overheads of presentation and an overhead projector
- Screen

Icons to become familiar with include:

Participant Workbook	Instructor Guide
Exercise/Activity	Same icons for Participant Workbook apply to the Instructor Guide.
Case Study	**Ans:** Answer to exercise, case study, discussion, question, etc.
Discussion Question	PowerPoint Slide
Calculation(s)	Overhead
Quiz	Flip Chart
Key Definition(s)	Suggested "Script"
Key Point(s)	

Instructor text that is meant to be general instructions for the instructor are designated by being written in script font and enclosed in brackets. For example:

[Ask participants if they have any questions on how to read the table. Answer any questions participants may have about how to read the table.]

If your module includes the use of a PowerPoint presentation, below are some helpful controls that you may use within the Slide Show.

PowerPoint Slide Show Controls

You can use the following shortcuts while running your slide show in full-screen mode.

To	**Press**
Advance to the next slide	N, ENTER, or the SPACEBAR (or click the mouse)
Return to the previous slide	P or BACKSPACE
Go to slide <number>	<number>+ENTER
Display a black screen, or return to the slide show from a black screen	B
Display a white screen, or return to the slide show from a white screen	W
Stop or restart an automatic slide show	S
End a slide show	ESC
Return to the first slide	Both mouse buttons for 2 seconds
Change the pointer to a pen	CTRL+P
Change the pen to a pointer	CTRL+A
Hide the pointer and button temporarily	CTRL+H
Hide the pointer and button always	CTRL+L
Display the shortcut menu	SHIFT+F10 (or right-click)
Erase on-screen annotations	E
Go to next hidden slide	H
Set new timings while rehearsing	T
Use original timings while rehearsing	O
Use mouse-click to advance while rehearsing	M

INTRODUCTION OF MODULE: 5 minutes

Display Slide 1—Module 27: Ozone.

[*Welcome participants to "Module 27: Ozone." Indicate the primary purpose of this course is to acquaint the participants with ozone, its generation and application, ozone system operations, and safety and handling requirements and issues*.]

[*Introduce yourself*.]

[*Provide a brief overview of the module*.]

The module contains 5 units. On page i, you will see the topical outline for Unit 1—General Overview, Unit 2—Generation of Ozone, and the beginning of Unit 3—Application of Ozone.

[*Briefly review outline on this page*.]

[*Continue to briefly review the topical outline for Unit 3—Application of Ozone and Unit 4—Ozone System Operation*.]

[*Continue to briefly review the topical outline for Unit 5—Safety and Handling*.]

[This page was intentionally left blank.]

UNIT 1 GENERAL OVERVIEW: 20 minutes

Display Slide 2—Unit 1: General Overview.

At the end of this unit, you should be able to:

- State the physical description of ozone.
- Describe where ozone comes from.
- Describe what ozone is used for.

Our overview to ozone has three components. We will begin by reviewing the physical description of ozone.

WHAT IS OZONE?: 3 minutes

Physical Description

[*Review the information as presented in the workbook*.]

As noted on this page, ozone is a very strong oxidant. Because of that, it is an excellent disinfectant. Use of ozone for disinfection will be covered later in this module. Since ozone is a very strong oxidant, it can also be hazardous to handle. Appropriate materials for contact with ozone, safety and handling requirements, and first aid procedures will also be covered in detail later in this module.

Now, let's focus on answering the question: How is ozone generated?

HOW IS OZONE GENERATED: 3 minutes

Ozone can be generated two ways: naturally or by a controlled generation process that simulates the natural generation process. First we'll focus on the natural generation process.

Natural Process

[*Review the information*.]

On-Site Generation

[*Review the information. Reinforce the point that ozone is chemically unstable, and, as a result, it must be used as quickly as it is generated*.]

We have reviewed the physical description of ozone and how it is generated. Now, let's take a look at how ozone is used in water treatment. Turn to the next page.

HOW IS OZONE USED IN WATER TREATMENT: 6 minutes

As a Strong Oxidant

[*Review the information. Remind participants that oxidation was covered in Module 7 – Chemistry.*]

As a Strong Disinfectant

In addition to being a strong oxidant, ozone is also a strong disinfectant.

[*Briefly review the information.*]

Both Giardia and Cryptosporidium form "oocysts," which means they form tough outer shells. Ozone inactivates them by attacking and breaking down the outer shells. Ozone is less effective against Cryptosporidium, because it forms an especially tough outer shell. Cryptosporidium's oocyst is four times as resistant to ozone as a Giardia oocyst. This will become apparent when disinfection with ozone is covered later in this Module.

Compared to Chlorine

[*Review the information.*]

As you can see, using ozone rather than chlorine to inactivate pathogens and oxidize compounds, when appropriate, provides an important benefit: no harmful byproducts are created, except possibly when the source water contains bromide.

[Review the Key Points for Unit 1 – General Overview.]

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.

This concludes Unit 1, General Overview of the Ozone module.

[Ask *participants if they have any questions regarding Unit 1. Respond accordingly.*]

UNIT 2 GENERATION OF OZONE: 40 minutes

In Unit 1, you received a general overview of ozone and how it is generated. In Unit 2, we will take a closer look at the generation of ozone.

Display Slide 3—Unit 2: Generation of Ozone.

At the end of this unit, you should be able to:

- Identify the two sources of oxygen used to generate ozone and discuss the advantages/disadvantages of each.
- Describe the main components of the power supply and generator vessel used to generate ozone.

This unit is organized into three sections: sources of oxygen, power supply, and ozone generator. We'll begin by looking at two sources of oxygen. Please turn the page.

SOURCES OF OXYGEN?: 20 minutes

The first source of oxygen we'll review is Atmospheric Oxygen, which is an "Air Prep System."

Atmospheric Oxygen (Air Prep System)

[*Review the bulleted information above Figure 2.1. Mention that "ambient atmospheric oxygen" is simply the oxygen in the air all around us.*]

Display Slide 4—Figure 2.1 Air Prep System Schematic.

[*Use the slide and script below to provide an overview of an Air Prep System.*]

Figure 2.1 provides an illustration of an Air Prep System. At the top of the figure, you'll see that Air is fed into the Compressor Package and moves through its three main components: 1) the Inlet Filter and Silencer to clean the air and reduce noise, 2) the Liquid Ring Compressor to compress the air and 3) the Discharge Separator to remove any liquid from the compressed air. You'll also see that Cooling/Make Up Water is fed into the Liquid Ring Compressor to help cool down the liquid in the Compressor, which is heated from the compression.

From here, the Air moves to the Refrigerant Drier, which dries the Air by condensing the moisture, similar to an air conditioner.

Since the Air must be extremely dry, it is then processed through a Coalescing Filter, which traps droplets of oil or moisture. Next, the Air is dried once more—this time with a Desiccant Drier that uses absorbent media in a closed vessel. Most Air Prep Systems use both types of driers in a series. Then, once more, the Air goes through a filter—this time a Particulate After-Filter, which strains dust and dirt from the Air. Last, the Clean, Dry, Compressed Air is sent to the Ozone Generator.

[*Point out the bulleted information in the workbook that details Figure 2.1.*]

[*Briefly review the advantage and disadvantages of an Air Prep System.*]

The advantage of free raw material when using an Air Prep System is counterbalanced by the costs associated with purchasing, running and maintaining compressors and multiple filters and driers. In addition, an Air Prep System requires a larger quantity of the air/ozone mixture in order to get the desired ozone dosage.

[*Ask if there are questions about Air Prep Systems. Respond accordingly.*]

Now we will turn to the second source of oxygen—a Liquid Oxygen (or LOX – pronounced “locks”) System.

Liquid Oxygen (LOX) System

[*Review bulleted information appearing above Figure 2.2.*]

Display Slide 5—Figure 2.2 Liquid Oxygen (LOX) System.

[*Use the slide and script below to provide an overview of a LOX System.*]

Figure 2.2 provides an illustration of a LOX System. At the top left of the schematic, you'll see the LOX Storage Tank where the purchased liquid oxygen is stored. The Tank is equipped with both Isolation and Pressure Relief Valves. The LOX is sent to Ice Racks and Evaporators, which are constructed as two parallel sets, and absorb heat from the surrounding air in order to evaporate the liquid oxygen into gaseous oxygen. This process creates a very cold environment since oxygen evaporates at very low temperatures, and ice is created. Ice Rack coils are widely spaced to allow for ice build up to fall away, and Evaporators are used after the LOX has already absorbed some heat. When too much ice build up occurs, the second set of Ice Racks and Evaporator is used, and the ice build-up on the first set is allowed to melt off.

From here, the oxygen's temperature and pressure are checked by the Temperature Sensor and Pressure Reducing Valve before it is fed into the Ozone Generator. It is important to monitor and control the pressure since the pressure in LOX storage tanks can be significantly higher than pressure allowed in the generator.

Next, the Nitrogen Feed System, which is comprised of an Air Compressor and Air Drier, adds a small amount of nitrogen to the oxygen. The 3-5% nitrogen added helps prevent build up of deposits in the generator. The oxygen and nitrogen then pass by a Pressure Sensor and Particulate Filter, and are sent to the Ozone Generator.

Storage tanks, ice racks, and evaporators can be owned by the owner of the water treatment plant, or they can be leased from the LOX supplier.

[*Point out the bulleted information that details Figure 2.2*.]

[*Review the advantages and disadvantages of a LOX Feed System.*]

[*Review the information regarding the increasing use of LOX systems.*]

[*Ask if there are questions about LOX Feed Systems. Respond accordingly.*]

As we discussed earlier, ozone is generated by arcing high voltage electricity through air or oxygen. We have just completed our review of two possible sources of air or oxygen for ozone generation. Now, we will focus on the power supply of an ozone generation system, which supplies the "electric arc."

POWER SUPPLY: 10 minutes

Display Slide 6—Figure 2.3 Ozone Generator Power Supply Unit.

[*Use the slide, script below and workbook information to provide an overview of the Power Supply Unit.*]

Figure 2.3 shows a typical Ozone Generator Supply Unit. This Unit shows a cabinet-like structure to the left-hand side, and a series of connected pipes, coils, and controls to the right. The cabinet is divided into several compartments, each of which houses one of the main components of the power supply. The pipes, coils, and controls are part of the cooling system for the power supply.

Inputs

[Review *the information, pointing out the increased voltage current that is dispersed to the ozone generator.*]

Main Components

The Ozone Generator Supply Unit has four main components.

[*Review the information on first three main components.*]

[*Review the information on the fourth and final main component. Note that varying electrical power input will change the percentage of oxygen that's converted to ozone. That's how varying power can be used to control the amount of ozone generated.*]

Always keep in mind that the power supply uses very high voltage. All safety rules associated with working near high voltage electricity must be followed at all times. Safety practices are covered in more detail later in this Module.

[*Ask if there are questions about Power Supply. Respond accordingly.*]

The previous two sections discussed the two main ingredients needed to make ozone: oxygen and electricity. These two ingredients come together in the ozone generator. This is where the "controlled lightning" is applied to the oxygen to make ozone.

OZONE GENERATOR: 6 minutes

Display Slide 7—Figure 2.4 Ozone Generator and Power Supply.

Figure 2.4 shows a typical Ozone Generator and Power Supply. This illustration displays the "generator side." Now, let's take a closer look at what's inside the generator.

Main Components

Display Slide 8—Figure 2.5 Cross Section of Ozone Generator.

The main components of an Ozone Generator are illustrated in Figure 2.5, which presents a cross section of the generator.

As you can see, the Generator Shell holds everything together. Inside, the body of the generator contains parallel horizontal areas of Cooling Water and Low Voltage Electrode Tubes. Inside the electrode tubes are High Voltage Dielectrics. There are points where air/oxygen and cooling water go in, and where ozone comes out.

[*Ask participants to turn page.*]

Operation of Ozone Generator

[*Continue displaying slide. Use the slide, script below and workbook information to provide an overview of the operation of an ozone generator.*]

Here's how it works.

Air/Oxygen In shows where the air or oxygen is fed into the generator. It then flows through precise gaps between Dielectrics and Electrode Tubes. Here, high voltage is applied to dielectrics and is discharged to electrode tubes—and this, converts a portion of oxygen to ozone.

The air/oxygen/ozone mixture is discharged at Ozone Out, and is sent to the point of application.

Cooling water is fed into the generator, where it circulates between Electrode Tubes to remove heat that is created from the electric arcs. Tube Plates hold the water inside and keep it away from Fused High Voltage Connections and gas inlet (Air/Oxygen In) and gas outlet (Ozone Out). In addition, End Covers enclose the gas inlet and outlet, and electrical connections while the generator is operating—but can be removed for maintenance and inspection. You'll see there are Viewing Windows, which operators can use to monitor operations inside the vessel.

[*Review information following bulleted list regarding controlling the amount of generated ozone.*]

[Review the Key Points for Unit 2 – Generation of Ozone.]

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.

This concludes Unit 2, Ozone Generator.

[*Ask participants if they have any questions regarding Unit 2. Respond accordingly*.]

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UNIT 3 APPLICATION OF OZONE: <u>35 minutes</u>

Display Slide 9—Unit 3: Application of Ozone.

At the end of this unit, you should be able to:

- Identify the two main methods of applying ozone.
- Discuss the main components of each ozone application method.

This unit is organized into three sections, beginning with a general section, and followed by sections on two types of application systems. Please turn the page.

GENERAL: <u>3 minutes</u>

Overview

[*Review the bulleted information*.]

The two important things to remember: 1) ozone must first be dissolved into water before it can react with other compounds, and 2) the primary kinds of systems to do this are diffuser systems and side stream injection. We will review each in this Unit.

Special Consideration

[*Review the first bullet*.]

Oxidation may only take 1 to 3 minutes for the reaction to take place. Disinfection of Giardia generally takes 3 to 5 minutes of contact time, depending on temperature, ozone concentration, and the required "log removal." Disinfection of Cryptosporidium can take 20 minutes or more of contact time. Disinfection "CTs" for ozone are discussed in Unit 4 of this Module.

[*If necessary, remind participants that "log removal" and "CT" are concepts that were covered in Module 5 – Disinfection*.]

Contact time and how it is provided varies. We will see later in this Unit that contact time could be provided in separate chambers during different application stages, or provided in one chamber in one stage.

[*Review the second bullet and supporting information*.]

This list gives us an overview of special considerations for handling and working with ozone. We will learn more about these, as they relate to application systems, later in this unit.

Now, let's turn the page and focus on the first ozone application system: the diffuser system.

DIFFUSER SYSTEM: 15 minutes

Description

[*Review the bulleted information*.]

Operating Principles

[*Mention that the operating principles will be reviewed with Figure 3.1 in a moment. Briefly review the bulleted information*.]

Now, let's turn the page and see how an Ozone Contact Basin works.

Display Slide 10—Figure 3.1 Ozone Contact Basin.

[*Use the slide and script below to provide an overview of the ozone contact basin. Mention that information about the application of ozone is on page 3-5.*]

Figure 3.1 provides an illustration of an Ozone Contact Basin for a diffuser system. You can see the multiple, alternating Application Chambers and Contact Chambers. The dividing baffle walls will direct the water flow. Fine bubbles of ozone are applied in stages, in each of the Application Chambers by using Diffusers. After each application, contact time is provided in each of the Contact Chambers.

Here's how it works. Water flows in at the Flow In point, passes through the submerged Isolation Gate (when open), and flow into and through the basin, guided by baffles. In the Application Chamber, ozone gas is supplied through the Supply Pipe, and is distributed and applied by the Diffusers. As the ozone bubbles discharged by the diffusers float upward through the Application Chamber, they are dissolved into the water. The water is directed to the Contact chamber where the dissolved ozone reacts with the various chemical compounds in the water and inactivates any pathogens. Sample Taps measure dissolved ozone at several points. Spray Nozzles are positioned to control any foam that forms on the water surface.

Next, the process is repeated in a second pair of Application and Contact chambers. Finally, the last samples are taken, and then the processed water flows out.

There are several additional controls used with the basin, most are located at the top of the figure. The Off-Gas Discharge routes the air that's drawn from above the contact basin to the Ozone Destruct Unit, where the air is processed to destroy ozone before being discharged into the atmosphere. The Demister removes any mist from the Off-Gas stream as it leaves the Contact Basin. Mist in the Off-Gas can be harmful to the ozone destruct unit. The Effluent Weir is used to maintain an appropriate water level in the basin. Remember, the water level must be 18 to 20 feet above the diffusers for effective transfer of ozone gas into the water. Last, the Pressure/Vacuum Relief Valve ensures the vacuum is at an appropriate level, and prevents the pressure or vacuum in the Contact Chamber from becoming high enough to damage the basin structure.

[*Ask participants if they have any questions regarding the ozone contact basin. Respond accordingly.*]

We just reviewed how ozone is applied in the application chambers of a contact basin; however, there is information on this page that we can use as a brief review.

How Ozone is Applied

[*Briefly review information*.]

Advantages and Disadvantages of Diffuser System

[*Review advantages and disadvantages. Note that these will become more meaningful after learning about side stream injection*.]

[*Ask if there are questions about Diffuser Systems. Respond accordingly*.]

Now we will turn to the second method of ozone application—Side Stream Injection.

Exercise for Diffuser Systems.

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.

SIDE STREAM INJECTION: <u>15 minutes</u>

Description

We'll begin with high-level information on how this system operates.

[*Review information*.]

[*Refer learners to Figure 3.2 in their book -- Skid Mounted Side Stream Injection System for an example of what this system looks like. (There is no slide for this figure.)*]

Now, let's turn the page and take a closer look at a side stream injection system.

Display Slide 11—Figure 3.3 Side Stream Injection System Schematic.

[*Use the slide and script below to provide an overview of the side stream injection system. Mention that operation information begins on page 3-7*.]

Figure 3.3 illustrates a Side Stream Injection System. At the top of the figure, you'll see the main process flow of water, moving left to right. A portion of the main process flow is drawn off as a Side Stream Flow by the Recirculation Pump, and is pumped through the Gas Injector. The flow through the Gas Injector nozzle creates a vacuum, which pulls in air/oxygen/ozone mixture from the ozone generator.

Next, the side stream flow goes into the Reactor Vessel, where the injected air/oxygen/ozone mixture is given time to dissolve into the water. Then, it moves to the Degassing Separator where undissolved gas bubbles are removed and vented to an Ozone Destruct Unit. The side stream, now the ozonated water, is then recombined with the main process stream and sent to a Contact Chamber.

[*Point out the operating principles. Note the 65-95% transfer efficiencies in the third bullet*.]

[*Point out the remaining operating principles. Note the required pressure (usually 30-40 psi) in the first bullet for the reactor vessel and degassing separator*.]

Advantages and Disadvantages of Side Steam Injection

[*Review advantages and disadvantages*.]

[Review the Key Points for Unit 3 – Application of Ozone.]

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.

[*Ask participants if they have any questions regarding diffuser and/or side stream injection systems. Respond accordingly*.]

This concludes Unit 3, Application of Ozone. In this Unit, we focused on identifying the two main methods of applying ozone, and their main components.

[*Ask participants if they have any questions regarding Unit 3. Respond accordingly*.]

[*No need to review references on this page*.]

[At this point, a 5 minute break may be appropriate.]

UNIT 4 OZONE SYSTEM OPERATION: 125 minutes

Display Slide 12—Unit 4: Ozone System Operation

At the end of this unit, you should be able to:

- Calculated ozone generation rate using the ozone dosage and plant flow.
- Calculate CT (Concentration x Time) when using ozone for disinfection.
- Describe the parameters that need to be monitored by the operator for each main piece of equipment.

As you can see from the Learning Objectives, this unit will have us working through calculations for ozone generation rates and for disinfection. Let's turn the page and get started.

GENERAL: 70 minutes

Required Ozone Generation Rate

In this section we will need to perform two primary calculations to identify 1) the required ozone generation rate, and 2) the actual ozone generation rate. The required rate is pretty straightforward—that is, there is one calculation to perform. The actual rate, however, requires multiple calculation steps and a few considerations that we'll cover later.

[*Review calculation and information below it. Remind participants if needed that:*
- *8.34 is a factor to convert mg/L to lbs per day.*
- *mg/L is an abbreviation for "milligrams per Liter", which is a measure of chemical concentration.*
- *MGD is an abbreviation for "million gallons per day"*.]

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%.

[*Allow participants 3 minutes to complete the exercise. Then, ask participants for solution. Record solution on easel and answer questions as needed.*]

Record solution for the required ozone generation rate in lbs/day on easel.

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

Now that we understand how to calculate the required ozone generation rate, we will focus on the actual ozone generation rate. If you'll remember, this is the rate that requires multiple calculations.

[*Review key information. Point out that the calculated required ozone generation rate, plus the five calculation steps needed to determine the actual ozone generation rate, are used to verify that the required amount is being generated.*]

Now that we know the required ozone generation rate for the plant in our exercise, let's verify the actual ozone generation rate. This will tell us whether we are actually generating the required rate. We'll work through a sample exercise together over the next few pages of your workbook. Here's where it's important to pay attention to the ozone application method, a LOX system for this exercise, and data we have to work with. Please turn the page.

Sample Exercise to calculate verify ozone generation rate

Allow 10 minutes to review the sample exercise (Steps 1-5). Be sure to point out information as noted below about specific steps. Answer questions as needed.

Operators generally have two parameters available to them: 1) the feed gas flow rate in standard cubic feet per minute (scfm), and 2) the ozone concentration in the feed gas (percent by weight).

In order to determine if the required amount of ozone is actually being generated, operators must first convert the required ozone generation rate in lbs/day to a gas flow rate in scfm at the measured ozone concentration. Then, operators can compare the calculated feed gas flow rate to the actual feed gas flow rate. If the rates are the same, the required amount of ozone is being generated.

[*Review Steps ❶ and ❷. Mention the following.*

- ***❶ A*** *-- Uses the 317 lbs/day from our required generation rate calculation. The 1.8 scfm figure will be used in a later step, ❹.*
- ***❶ B*** *-- Uses 317 lbs/day from our required generation rate calculation and a* <u>*measured*</u> *ozone concentration. The ozone system should have an ozone analyzer on the outlet of the ozone generator. The 2,642 lbs/day figure will be used in a two later steps,* ***❷ A*** *and* ***❸ A.***
- *❷ -- Since this exercise uses a LOX system, we must calculate the amount of nitrogen to account for nitrogen that's added to the LOX supply. Remind participants, if necessary, about the need to divide by minutes/day.*
- ***❷ A*** *-- Uses our 2642 lbs/day figure from 1 B. The 79 lbs/day will be used in the next step,* ***❷ B****.*
- ***❷ B*** *-- Uses the 79 lbs/day we just calculated. The 0.8 scfm figure will be used in a later step, ❹.*]

[*Ask if there are questions. Respond accordingly.*]

Let's continue with Step ❸, where we will focus on calculating the amount of oxygen in the feed gas for our LOX system.

[*Review Step ❸. Mention the following:*

- ***❸ A** -- Uses the 2,642 lbs/day from Step **❶ B**. The calculation from this step is fed into the next Step, **❸ B**.*
- ***❸ B** -- Uses 2,246 bs/day from our last step. The 19.0 scfm we just calculated will be used in the next Step, ❹.*]

[*Ask if there are questions. Respond accordingly.*]

Review key information. Point out that this information concerns the ozone application method—and highlights considerations for calculating actual ozone generation for an air prep system. Have participants turn back to Step ❷ in the workbook and review why this step is not needed for an air prep system. Review ❸ **A** and ❸ **B** calculations on this page, and discuss the air prep system modifications. Encourage participants to highlight this important information.

Let's continue with calculating the actual ozone generation rate for our LOX plant exercise. Step ❹ is where we'll see our previous calculations come together.

[*Review Step ❹. Mention the following.*

- *The Ozone figure (scfm) is from Step **❶ A**. The Nitrogen figure (scfm) is from Step **❷ B**. The Oxygen figure (scfm) is from Step **❸ B**.*
- *These three figures are added and result in the total volumetric gas flow rate.*]

This total volumetric flow rate is the flow rate of the gas mixture of ozone, oxygen, and nitrogen leaving the ozone generator. It is sometimes referred to as the "feed gas" going to the ozone.

Let's continue with Step ❺, which is a "simple" comparison of the *calculated* flow rate from the last step to the *measured* flow rate from the ozone generator's flow meter. The ozone system should have a gas flow meter on the outlet of the ozone generator. The "actual measured" flow rate is the flow reading from that meter If these volumetric flow rate amounts match, then the required amount of ozone is being generated.

These numbers <u>should match within 3 to 5%.</u> If they are *significantly different*, the operator needs to increase (or decrease) the flow rate of oxygen (or air for an air prep system) until it matches the calculated gas flow rate for the measured ozone concentration. If your system controls the ozone generation rate automatically from a set point, meaning the operator enters a rate in lbs/day into the control system and the system is supposed to automatically adjust to generate the preset rate, then a variation greater than a 3 to 5% variation between calculated and measured gas flow rates may mean a problem in the control system. All instruments should be checked and calibrated and all automatic valves should be checked to make sure they are working properly.

[*Ask if there are questions about the sample exercise. Respond accordingly*.]

[*Briefly review the first two calculation considerations. Mention that the air prep system information is a review of the important key information discussed with Steps ❷ and ❸*.]

So far, we've calculated the required and actual ozone generation rates for a LOX system. We've also discussed considerations for air prep system calculations. Appendix 3 contains information about side stream injection systems. *[Option to discuss if time permits]*

We've now completed the first portion of the General section of this unit. This first portion focused on calculations to identify the required and actual ozone generation rates for LOX, air prep, and side stream injector systems. Now, we'll continue on to the second portion, which covers using ozone for disinfection.

Use of Ozone for Disinfection

Earlier in the unit, we discussed ozone application methods related to two types of treatment: oxidation and disinfection. We learned that for disinfection to take place there must be an appropriate amount of contact time permitted in a contact basin. Now we will take a closer look at disinfection

[*Review information*.]

[*Inform participants that they will now learn three calculations that must be completed to identify CT: 1) calculating the decay constant, 2) calculating the CT, and 3) estimating the ozone residual concentration. Following this, they will have the opportunity to complete an exercise and apply what they've learned*.]

[*Review information on calculating the decay constant*.]

[*Review information on ozone demand*.]

Since ozone decays rapidly, it's important to calculate the decay constant. This tells us how quickly the ozone residual dissipates. Once we have the decay constant figure, we are able to calculate CT, which indicates the level of disinfection achieved with the ozone. CT is usually expressed in units of concentration x time and is written as mg/L x min.

[*Review information on calculating the CT*.]

After the CT is calculated, that information can be used to determine log inactivations for viruses, Giardia, and Cryptosporidium. You can compare the calculated CT to the values in CT tables to determine the log inactivation you are achieving. There are CT tables for viruses, Giardia, and Cryptosporidium on page 4-9 of the workbook.

You can also use the decay constant to estimate ozone residual at any point in time. If you do this for several points in time at a particular interval and plot the results, you will see a graphical "picture" of how CT is determined when the disinfectant residual varies, as it does with ozone. We'll take a closer look at this shortly.

In addition to the CT, the ozone residual concentration can also be estimated after you identify the decay constant.

[*Review information on estimating ozone residual concentration*.]

Now we will review an example that will result in the plotting of ozone residuals and the CT area. Our example gives us the decay constant, so we will not need to calculate that. First, we will review the ozone residual calculation.

[*Review information. Mention that the second bullet illustrates the ozone residual for each calculated detention time of 1 – 4 minutes at 0.5 minute intervals. Ask if there are questions; respond accordingly*.]

Let's do a short exercise. 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.

[*Continue reviewing example. Mention the following about Figure 4.1:*

Indicate that the figure plots ozone residual amounts (on vertical axis) to corresponding Time-Minutes (on horizontal axis). For this figure, 0.00 – 4.00 minutes are included on the horizontal axis. Indicate that these plotted amounts create a curve that shows how ozone residual varies over time.

Indicate that participants most likely will not plot graphs like these on the job, but this exercise should help them understand how CT works when disinfectant residual varies. Being able to calculate ozone residuals at any point in time and comparing them to actual measured values from an ozone residual analyzer can be a good check on how the system is operating.

Ask participants if there are questions. Respond accordingly.]

[*Briefly orient participants to the three tables on the page. Remind participants that log inactivation was covered in Module 5, Disinfection*.]

[Provide *an overview of how a table is read, using the below script*.]

For example, if you need to achieve 2.0 log inactivation of Giardia, and the water temperature is 5 degrees C, go to Table 4.2, find the row for 2.0 log inactivation, and read across to the column for 5 degrees C. The table indicates you would need to achieve a CT of 1.3 mg/L-min.

State and federal regulations related to disinfection will tell you what log inactivation you need to achieve. You will need to refer to these tables to find the corresponding CT as water temperature changes from one season of the year to the next.

[*Briefly review bullet information following tables*.]

Now you will have a chance to “put everything together” that we covered so far in this unit. Please turn the page, and we’ll work through an exercise focused on ozone generation rates, in addition to ozone demand and CT achieved.

Exercise

[*Prior to beginning the exercise, point out to participants that this exercises uses an air prep system. As a result, when calculating total volumetric flow rate (#2), they will need to modify certain calculation steps for this type of ozone application. The modifications are noted earlier in their workbook following the appropriate steps*.]

[*Review exercise parameters and items to calculate*.]

[*Option 1: (15 minutes total) Allow participants to complete the exercise in their workbook. Allow 7 minutes; then begin debriefing the exercise (using PowerPoint slides for solutions) and completing any uncompleted steps together as a large group. Encourage participants to refer to their workbooks when needed. Monitor the exercise, and, if needed, assist in calculations and/or provide calculation solutions.*

Option 2: (10 minutes total). Work through the entire exercise as a large group, having participants complete the calculations in their workbooks. Display PowerPoint slides for each step's solution.]

1. Required ozone generation rate.

Display Slide 13—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**

Now we know that the plant in our exercise requires an ozone generation rate of 579 lbs/day.

Let's continue with the second item we needed to calculate—total volumetric flow rate (scfm).

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.

Display Slide 14—Calculate Ozone Volumetric Gas Flow Rate (scfm)

ANS

> ❶ **A**: Ozone volumetric gas flow rate (scfm)
> Volume O_3 = O_3 lbs/day ÷ O_3 weight (lbs/ft3) ÷ 1440 min/day
> Volume O3 = 579 lbs/day ÷ 0.125 lbs/ft3 ÷ 1440 min/day = **3.2 scfm**

Display Slide 15—Calculate Total Feed Gas Weight (lbs/day)

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**

Display Slide 16—Calculate Air Weight (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.

Display Slide 17—Calculate Air Volumetric Flow Rate (scfm)

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**

Display Slide 18—Calculate Total Volumetric Gas Flow Rate (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

Display Slide 19—Calculate 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.

Let's review the fourth and final calculation—CT achieved. Remember, this is a two-step process. We must first calculate the Decay Constant, and then we can calculate CT.

4. CT Achieved

Display Slide 20—Calculate Decay Constant

ANS

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

Display Slide 21—Calculate CT Achieved

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)

[*Ask if there are any questions regarding the exercise. Respond accordingly.*

[If needed, allow the class to take a 5 minute break.]

EQUIPMENT OPERATION: 35 minutes

In this section we will focus on equipment and the corresponding parameter information operators should know in order to operate ozone systems. First, we'll start with General information, and then we'll move into details about particular systems and their operating parameters. In addition, we'll review important parameters, instruments and/or signals on system diagrams.

General

[*Review information*.]

The PLC is the "brains" of the system. It takes in information from all the various instruments in the system, analyzes that information, and uses it to control the major components of the system, or to shut the system down if the information from one or more of the instruments indicates something is wrong. The instruments normally provided and the signals that are normally available to the PLC are shown in Figure 4.2.

Please turn the page and locate the PLC on Figure 4.2.

Display Slide 22—Ozone Generator and Power Supply Control Diagram.

The PLC is located within the Power Supply box near the top of the diagram. Note the many dashed lines, representing instrument data, entering the PLC. See figure 4.2.

Additionally, let's locate several instruments that provide important signals (or parameters) to Operators. These are listed on page 4-15. Note that each of these feeds data into the PLC.

- Power Monitor – This is also located within the Power Supply box
- Water Temp -- There are two shown on this diagram; they are cooling water temperature transmitters and appear above and below the Power Monitor.
- Cooling water flow meter – There are two meters; each is located beneath a Water Flow box on the left-side of the figure.

You'll see that the Ozone Generator is the second large component of the figure. Let's review several key instruments. These are also listed on 4-15.

- Gas Temp – There are two; they provide gas temperature parameters in generator inlet and discharge. If there is too much of a temperature rise in the gas going through the generator, that's an indication the cooling system is not working properly.
- Pressure – There are two located near Gas Temp boxes.
- Gas Flow Meter – Located next to Gas Temp (meter is beneath Gas Flow box) on left-side of diagram; provides data about ozone generation rate.
- Water Flow Meter – Located just beneath Water Flow box.
- Water Temp – Located above Ozone Generator.
- Ozone Residual – Located to left of Ozone Generator; provides data for ozone concentration in generator discharge.
- Valves – Note the number of valves that appear. Operators will be able to tell if the valves are open or closed.

[*Ask if there are questions. Respond accordingly*.]

Power Supply Operating Parameters

[*Simply point out that this is the information discussed with Figure 4.2*.]

Ozone Generator Operating Parameters

[*Simply point out that this is the information discussed with Figure 4.2*.]

Now let's move on to the second type of equipment in this section—ozone contact basin. Please turn the page.

Figure 4.3 illustrates an ozone contact basin control diagram. We've seen a similar figure earlier in this module—however, now we're concerned with the contact basin's various meters and instruments. Let's use page 4-17 as a guide to reviewing the figure.

Contact Basin (Diffuser System) Operating Parameters

Display Slide 23—Figure 4.3 Ozone Contact Basin Control Diagram.

[*Review first two bullets. Point out Motor Operated Valve and Rotameters to left-side of figure using script below*.]

In this example, total gas flow to the basin is automatically controlled by a motor operated flow control valve. The gas flow split between the two stages of the basin is manually controlled using the manual valves and rotameters.

[*Review third bullet. Point out the first two Ozone Residual Analyzer using below script*.

Note the two ozone residual analyzers that can take samples from several points immediately following ozone application.

[*Review last two bullets. For last bullet--point out the last Ozone Residual Analyzer using below script*.]

This is measured by ozone residual analyzer furthest to the right, just before the water leaves the basin.

[*Emphasize that ozone residual leaving basin <u>must be zero</u>*.]

[*Ask if there are questions about ozone contact basis operating parameters. Respond accordingly*.]

Now we'll move on the fourth and final control diagram in this section—ozone destruct system.

Earlier in the module, we reviewed figures for ozone application methods (such as ozone contact basin and side stream injection) that noted off-gas discharge would be sent to an ozone destruct unit. Now, we can see how the ozone destruct system works.

Ozone Destruct System Operating Parameters

Display Slide 24—Ozone Destruct System Control Diagram.

[*Review first bullet. Mention that the motor operated valve is used to isolate equipment to take it off line for maintenance, rather than flow control.*

Review second bullet. Emphasize that this pressure shows that the blower is working. Blower must be working for the system to function at all.

Review third, fourth, fifth and sixth bullets. Mention that these parameters should be within certain ranges (specified by the manufacturer). If they are, it indicates that the catalyst is working properly.

Review seventh bullet. Emphasize that concentration of less than 0.1 ppm ozone in discharge must be maintained at all times due to environmental and health concerns.

Ask if there are questions about the ozone destruct system operating parameters. Respond accordingly.]

We've finished reviewing system diagrams and important operational information from each. Operators must be aware of this important information that is available to them through instrumentation and controls, as well as normal operation parameters. We will now take a look at additional monitoring that must be performed—but this time, the monitoring must be completed in several different locations in the ozone facility, not within a particular system.

Ozone/Oxygen Leak Monitoring

[*Review information. Note that additional information concerning health hazards related to ozone and LOX will be covered in Unit 5, Safety and Handling*.]

We're ready to move on to the final section of this unit, Equipment Maintenance.

EQUIPMENT MAINTENANCE: 20 minutes

An ozone system involves many different pieces and types of equipment that must all be in good working order and working together for the system to function properly and safely. Some of the maintenance tasks normally associated with an ozone system are listed below. The operator must be familiar with and must follow the specific maintenance instructions provided by the manufacturer for his equipment.

Air Prep Systems

[*Review information.*]

Power Supplies

[*Review information.*]

Generators

[*Review information. Mention that participants will have an opportunity to work through an exercise to calculate generator efficiency.*]

Equipment maintenance tasks continue on the next page.

Contact Basin

[*Review information*.]

Destruct Units

[*Review information*.]

Instrumentation and Analyzers

[*Review information*.]

[Go over the Key Points for Unit 4 – Ozone System Operation.]

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**____________.

We have completed Unit 4—Ozone System Operation. In this Unit, we calculated ozone generation rates for a variety of ozone systems. In addition, we calculated CT (Concentration x Time) when using ozone for disinfection and reviewed related information concerning log inactivations. Last, we focused on equipment operation and maintenance, including how to calculate generator efficiency. Our final Unit is on Safety and Handling.

UNIT 5 SAFETY AND HANDLING: 20 minutes

Display Slide 25—Unit 5: Safety and Handling.

At the end of this unit, you should be able to:

- State the materials suitable for contact with ozone.
- Describe the health hazards related to ozone and the first aid steps in dealing with them.
- Describe required safety equipment and procedures when dealing with ozone.

This unit is organized into three sections: material safety data for ozone, equipment safety, and material safety data for LOX systems. Please turn the page.

MATERIAL SAFETY DATA FOR OZONE?: 5 minutes

A Strong Oxidant

As a strong oxidant, ozone should only come in contact with suitable materials. Contact with certain other materials can cause explosions.

[*Review information*.]

[*Have participants turn to Appendix 1, page A-2, to see a sample of an Material Safety Data Sheet for ozone*.]

In particular, note the Fire and Explosion Hazard data and Health Hazard data on page A-3, and the First Aid Measures and Exposure Control/Personal Protection information on page A-4. These 4 sections of the ozone MSDS contain information that you should be familiar with.

Health Hazards

Exposure to high concentrations of ozone is linked to health hazards. The stronger the concentration, the more severe the hazard is.

[*Review information*.]

First Aid

If exposure does occur, it's important that appropriate first aid procedures are implemented immediately.

[*Review information*.]

[*Ask if there are questions about Material Safety Data for Ozone. Respond accordingly*.]

Now let's turn the page, and focus on the second section of the Unit: Equipment Safety – Safety Rules and Procedures.

EQUIPMENT SAFETY: 3 minutes

Safety Rules and Procedures

The previous section discussed the effects of ozone gas on the human body. There are also other safety considerations related to the operation of the equipment itself.

[*Review information. Note that electrical safety procedures are especially important due to the high voltage used by the ozone generators. Note that proper confined space entry procedures require special equipment, training and certification*.]

[*Ask if there are questions about Safety Rules and Procedures. Respond accordingly*.]

Now let's turn the page to the third and final section of the unit. This section focuses on LOX or liquid oxygen and associated hazards.

MATERIAL SAFETY DATA FOR LOX?: 5 minutes

LOX Hazards

We learned that LOX can be purchased as a source of oxygen used to generate ozone. It is stored on-site in a bulk tank or tanks as a compressed liquid. LOX does have hazards associated with it—for contact with equipment and health hazards.

[*Review information*.]

[*Have participants turn to Appendix 2, page A-5, to see a sample of an Material Safety Data Sheet for LOX*.]

In particular, note the Hazards Identification and Health Effects on pages A-5 and A-6, First Aid Measures on page A-6, Firefighting Measures on page A-7, and Exposure Controls, Personal Protection on page A-8. These 5 sections of the LOX MSDS contain information that you should be familiar with. Also, as with any location where oxygen is being used, there must be NO SMOKING.

[*Ask participants if they have any questions regarding LOX hazards. Respond accordingly*.]

This concludes Unit 5 and Module 27 – Ozone. Remember, this was intended to provide an overview of ozone; information on the generation and application of ozone; information on operating ozone systems; and information on safety and handling related to ozone.

The next section contains Appendices for Module 27.

[Go over the Key Points for Unit 5 – Safety and Handling.]

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.

[No need to discuss references.]

[*Thank participants and dismiss*.]

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Appendix 1
Sample Ozone Material Safety Data Sheet (MSDS)

OSMONICS

5951 Clearwater Drive • Minnetonka, Minnesota 55343-8995 USA • Phone (952) 933-2277 • Fax (952) 933-0141

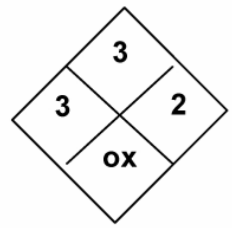
MATERIAL SAFETY DATA SHEET

Product Name: Ozone (Ambient Air or Oxygen Feed Gas) **Date Prepared:** 16 Jan 01

PRODUCT AND COMPANY IDENTIFICATION

Manufacturer/Supplier:
Osmonics
5951 Clearwater Drive
Minnetonka, MN 55343-8995
Emergency Telephone:
(952) 933-2277
(800) 424-9300 CHEMTREC
Common Name: Ozone
Chemical Name: Triatomic Oxygen

NFPA Codes:



Health: 3
Fire: 3
Reactivity: 2
Special: Oxidizer

MATERIAL COMPOSITION

Hazardous Components (1% or greater for hazardous components, 0.1% or greater for carcinogens)	**CAS#**	**%**	**OSHA PEL**	**ACGIH TLV**	**Other Limits Recommended**
Ozone (O_3)	10028-15-6	100*	0.1 ppm (0.2 mg/m^3)	0.1 ppm (c) (0.2 mg/m^3)	0.3 ppm STEL, 5 ppm IDLH

*Equipment emits ozone at 1-4% concentration by weight for ambient air feed gas and 5-15% for oxygen feed gas.

PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling point: -170°F (-112°C)

Vapor pressure: >1 atm
[1 mm Hg & -292.7°F (-180.4°C)]

Vapor density: 1.65
(Air = 1)

Solubility in water: Almost insoluble
[0.0003 g/100 mL at 68°F (20°C)]

Appearance and odor: Colorless/blueish gas with pungent odor detectable at 0.01 to 0.04 ppm, sharp disagreeable odor at 1 ppm

Specific gravity: 1.614

Melting point: -313°F (-192°C)

Evaporation rate: Not applicable
(H_2O= 1)

Water reactive: Not applicable

pH: Not applicable

FIRE AND EXPLOSION HAZARD DATA

Flash point: Not applicable

Auto-ignition temp: Not applicable

Flammability limits in air % by volume:
Lower explosive limit (LEL): Not applicable
Upper explosive limit (UEL): Not applicable

Special fire fighting procedures: Ozone is an oxidizer and will accelerate combustion; use media appropriate for extinguishing surrounding materials.

Unusual fire and explosion hazards: Can react explosively with readily oxidizable substances and reducing agents. It may present dangerous fire hazards when exposed to aniline, diethyl ether, hydrogen iodide, nitrogen oxides, organic liquids, lithium aluminum hydride, metal hydrides, nitroglycerin, hydrazine, stilbene, ammonia, arsine, nitrogen, and phosphine. Ozone is also incompatible with acetylene, alkyl metals, citronellic acid, fluoroethylene, hydrogen, and tetramethyl ammonium chloride. Ozone reacts with alkenes to form peroxides that are often explosive. Gelatinous explosive ozonides are formed with benzene and other aromatic compounds. Ozone may also react with bromine and hydrogen bromide. Combustion is also possible if high concentrations of ozone off-gas are exposed to carbon-containing ozone destruct devices.

STABILITY AND REACTIVITY DATA

Stability: Unstable. Ozone gas rapidly decomposes to oxygen (O_2).

Reactivity: Reacts with any oxidizable organic or inorganic material. Ozone reacts with alkenes and other unsaturated organic compounds to form ozonides, many of which are highly unstable and explosive.

Conditions to avoid: Avoid contact with oxidizable materials, powerful reducing agents, and heat or flame.

Hazardous decomposition: None.

HEALTH HAZARD DATA

Emergency overview: Ensure adequate ventilation has been engineered in the area where the ozone generation equipment is located. Exposure to ozone may cause headaches, irritation of the eyes, throat and mucous membranes, coughing, dizziness and tightness in the chest.

Potential health effects:

Eyes: Irritating to eyes.

Skin: Not an expected route of entry.

Ingestion: Not an expected route of entry.

Inhalation: Irritating to respiratory system. May cause respiratory complications, coughing, difficulty breathing, chest pain, headache, pulmonary edema, and bronchial pneumonia.

Chronic/carcinogenicity:
NTP: Not listed
OSHA: Not listed
IARC: Not listed

Medical restrictions: Persons with asthma, allergies, respiratory disorders, or emphysema may be further aggravated by exposure to ozone.

FIRST AID MEASURES

Eyes: In the event of irritating eye contact, promptly wash eyes with copious amounts of water for 15 minutes (lifting upper and lower lids occasionally) and obtain medical attention.

Skin: Not applicable

Ingestion: Not applicable

Inhalation: Respiratory protection may be necessary in the event of an accidental release of ozone. An ozone leak can easily be detected by its characteristic pungent odor. If a large amount of ozone is inhaled, move the person to fresh air and seek medical attention immediately.

EXPOSURE CONTROL/PERSONAL PROTECTION

Engineering controls: Ozone generation equipment should never be operated without the parallel use of an efficient destruct unit to destroy any off-gassing ozone. Provide general or local exhaust ventilation systems to maintain airborne concentrations as low as possible.

Personal protection:

Eyes/face: None required

Skin: None required

Respiratory: For concentrations greater than 0.1 ppm, use a NIOSH-approved supplied air respirator or self-contained breathing apparatus (SCBA).

Handling: Not applicable

Storage: Ozone cannot be stored. Use ambient room ozone monitor for detection.

DISPOSAL INFORMATION

RCRA hazardous waste: Not applicable (gas)

Waste disposal: Ozone rapidly decomposes to form oxygen (O_2). Small to moderate amounts of excess ozone can be vented to a fume hood or other exhaust system. A 1% off gas at 10 cfm or more is considered to be a large amount of ozone. When large amounts of excess ozone are anticipated, the excess gas should be passed through a series of traps containing a 1 to 2% solution of potassium iodide (or other reducing agent), or a catalytic destruct module before venting to atmosphere.

OTHER

Prepared by: Osmonics Regulatory Affairs Department (952) 933-2277

The above information and recommendations are believed accurate and reliable. Because it is not possible to anticipate all conditions of use, additional safety precautions may be required.

User responsibility: Each user should read and understand this information and incorporate it into individual site safety programs in accordance with applicable hazard communication standards and regulations.

Appendix 2
Sample Liquid Oxygen Material Safety Data Sheet (MSDS)

BOC GASES

MATERIAL SAFETY DATA SHEET

Distributed by:	MSDS:000022
Machine & Welding Supply Co.	
P.O. Box 1708	Phone: (910) 892-4016
Hwy 301 South	Fax: (910) 892-3575
Dunn, NC 28335	Internet: www.mwsc.com

PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID

1. Chemical Product and Company Identification

BOC Gases,
Division of
The BOC Group, Inc.
575 Mountain Avenue
Murray Hill, NJ 07974

TELEPHONE NUMBER: (908) 464-8100
24-HOUR EMERGENCY TELEPHONE NUMBER:
CHEMTREC (800) 424-9300

BOC Gases
Division of
BOC Canada Limited
5975 Falbourne Street, Unit 2
Mississauga, Ontario L5R 3W6

TELEPHONE NUMBER: (905) 501-1700
24-HOUR EMERGENCY TELEPHONE NUMBER:
(905) 501-0802
EMERGENCY RESPONSE PLAN NO: 20101

PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID
CHEMICAL NAME: Oxygen
COMMON NAMES/SYNONYMS: Liquid Oxygen, LOX
TDG (Canada) CLASSIFICATION: 2.2 (5.1)
WHMIS CLASSIFICATION: A, C

PREPARED BY: Loss Control (908)464-8100/(905)501-1700
PREPARATION DATE: 6/1/95
REVIEW DATES: 6/7/96

2. Composition, Information on Ingredients

INGREDIENT	% VOLUME	PEL-OSHA[1]	TLV-ACGIH[2]	LD_{50} or LC_{50} Route/Species
Oxygen FORMULA: O_2 CAS: 7782-44-7 RTECS #: RS2060000	99.6 to 99.997	Not Available	Not Available	Not Available

[1] As stated in 29 CFR 1910, Subpart Z (revised July 1, 1993)
[2] As stated in the ACGIH 1994-95 Threshold Limit Values for Chemical Substances and Physical Agents

3. Hazards Identification

EMERGENCY OVERVIEW

Elevated oxygen levels may result in cough and other pulmonary changes. High concentrations of oxygen (greater than 75%) causes symptoms of hyperoxia which included cramps, nausea, dizziness, hypothermia, ambylopia, respiration difficulties, bradycardia, fainting spells and convulsions capable of leading to death. Nonflammable. Oxidizer, will accelerate combustion. Contact with liquid form may cause frostbite or freeze burns in exposed tissues.

ROUTE OF ENTRY:

Skin Contact	Skin Absorption	Eye Contact	Inhalation	Ingestion
Yes	No	Yes	Yes	Yes

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PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID

HEALTH EFFECTS:

Exposure Limits No	Irritant No	Sensitization No
Teratogen No	Reproductive Hazard No	Mutagen No
Synergistic Effects None known		

Carcinogenicity: -- NTP: No IARC: No OSHA: No

EYE EFFECTS:
Contact with liquid product may cause tissue freezing.

SKIN EFFECTS:
Contact with liquid product may cause tissue freezing.

INGESTION EFFECTS:
Contact with liquid product may cause tissue freezing.

INHALATION EFFECTS:
High concentrations of oxygen (greater than 75%) causes symptoms of hyperoxia which included cramps, nausea, dizziness, hypothermia, ambylopia, respiration difficulties, bradycardia, fainting spells and convulsions capable of leading to death. The property is that of hyperoxia which leads to pneumonia. Concentrations between 25 and 75 % present a risk of inflammation of organic matter in the body.

NFPA HAZARD CODES	HMIS HAZARD CODES	RATINGS SYSTEM
Health: 3	Health: 3	0 = No Hazard
Flammability: 0	Flammability: 0	1 = Slight Hazard
Reactivity: 0	Reactivity: 0	2 = Moderate Hazard
		3 = Serious Hazard
		4 = Severe Hazard

4. First Aid Measures

EYE:
Never introduce ointment or oil into the eyes without medical advice! In case of freezing or cryogenic "burns" caused by rapidly evaporating liquid, DO NOT WASH THE EYES WITH HOT OR EVEN TEPID WATER! Remove victim from the source of contamination. Open eyelids wide to allow liquid to evaporate. If pain is present, refer the victim to an ophthalmologist for treatment and follow up. If the victim cannot tolerate light, protect the eyes with a light bandage.

SKIN:
For dermal contact or frostbite: Remove contaminated clothing and flush affected areas with lukewarm water. DO NOT USE HOT WATER. A physician should see the patient promptly if the cryogenic "burn" has resulted in blistering of the dermal surface or deep tissue freezing.

INGESTION:
A physician should see the patient promptly if the cryogenic "burn" has resulted in blistering of the dermal surface or deep tissue freezing.

INHALATION:

PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID

PROMPT MEDICAL ATTENTION IS MANDATORY IN ALL CASES OF OVEREXPOSURE TO OXYGEN. RESCUE PERSONNEL SHOULD BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS. Conscious persons should be assisted to an uncontaminated area and inhale fresh air. Quick removal from the contaminated area is most important. Further treatment should be symptomatic and supportive. Inform the treating physician that the patient could be experiencing hyperoxia.

5. Fire Fighting Measures

Conditions of Flammability: Not flammable, Oxidizer		
Flash point: None	Method: Not Applicable	Autoignition Temperature: None
LEL(%): None	UEL(%): None	
Hazardous combustion products: None		
Sensitivity to mechanical shock: None		
Sensitivity to static discharge: None		

FIRE AND EXPLOSION HAZARDS:
High oxygen concentrations vigorously accelerate combustion.

EXTINGUISHING MEDIA:
Water spray to keep cylinders cool. Extinguishing agent appropriate for the combustible material.

FIRE FIGHTING INSTRUCTIONS:
If possible, stop the flow of oxygen which is supporting the fire.

6. Accidental Release Measures

Evacuate all personnel from affected area. Use appropriate protective equipment. If leak is in user's equipment, be certain to purge piping with inert gas prior to attempting repairs. If leak is in container or container valve, contact the appropriate emergency telephone number listed in Section 1 or call your closest BOC location.

7. Handling and Storage

Electrical classification:
Nonhazardous.

Liquid oxygen cannot be handled in carbon or low alloy steel. 18-8 and 18-10 stainless steel are acceptable as are copper and its alloys, nickel and its alloys, brass bronze, silicon alloys, Monel®, Inconel® and beryllium. Teflon®, Teflon® composites, or Kel-F® are preferred non-metalic gasket materials.

Check with supplier to verify oxygen compatability for the service conditions.

Stationary customer site vessels should operate in accordance with the manufacturer's and BOC's instruction. Do not attempt to repair, adjust or in any other way modify the operation of these vessels. If there is a malfunction or other type of operations problem with the vessel, contact the closest BOC location immediately.

Oxygen, refrigerated liquid is delivered to a customer into stationary, vacuum-jacketed vessels at the customer's location or in portable vacuum-jacketed "liquid" cylinders.

No smoking or open flames should be allowed near these vessels.

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PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID

Liquid oxygen vessels should be used only in well ventilated areas in accordance with manufacture and BOC's instructions. Cylinders must always be kept upright. Specialized trucks are needed for their movement. Full and empty cylinders should be stored away from flammable products.

For additional recommendations, consult Compressed Gas Association Pamphlets G-4, P-12, P-4.

Never carry a compressed gas cylinder or a container of a gas in cryogenic liquid form in an enclosed space such as a car trunk, van or station wagon. A leak can result in a fire, explosion, asphyxiation or a toxic exposure.

8. Exposure Controls, Personal Protection

EXPOSURE LIMITS[1]:

INGREDIENT	% VOLUME	PEL-OSHA[2]	TLV-ACGIH[3]	LD_{50} or LC_{50} Route/Species
Oxygen FORMULA: O_2 CAS: 7782-44-7 RTECS #: RS2060000	99.6 to 99.997	Not Available	Not Available	Not Available

[1] Refer to individual state of provincial regulations, as applicable, for limits which may be more stringent than those listed here.
[2] As stated in 29 CFR 1910, Subpart Z (revised July 1, 1993)
[3] As stated in the ACGIH 1994-1995 Threshold Limit Values for Chemical Substances and Physical Agents.

ENGINEERING CONTROLS:
Use local exhaust to prevent accumulation of high concentrations that increase the oxygen level in air to more than 25%.

EYE/FACE PROTECTION:
Safety goggles or glasses as appropriate forr the job. Faceshield is recommended for cryogenic liquids.

SKIN PROTECTION:
Protective gloves made of any suitable material appropriate for the job. Insulated gloves recommended for cryogenic liquids.

OTHER/GENERAL PROTECTION:
Safety shoes, safety shower.

PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID

9. Physical and Chemical Properties

PARAMETER	VALUE	UNITS
Physical state (gas, liquid, solid)	: Cryogenic liquid	
Vapor pressure	: Above critical temp.	
Vapor density (Air = 1)	: 1.11	
Evaporation point	: Not Available	
Boiling point	: -297.3	°F
	: -182.9	°C
Freezing point	: -361.8	°F
	: -218.8	°C
pH	: Not Applicable	
Specific gravity	: 1.105	
Oil/water partition coefficient	: Not Available	
Solubility (H20)	: Slightly soluble	
Odor threshold	: Not Applicable	
Odor and appearance	: Clear, odorless, pale blue liquid.	

10. Stability and Reactivity

STABILITY:
Stable

INCOMPATIBLE MATERIALS:
All flammable materials.

HAZARDOUS DECOMPOSITION PRODUCTS:
None

HAZARDOUS POLYMERIZATION:
Will not occur.

11. Toxicological Information

MUTAGENIC:

Oxygen concentrations between 20 to 95% have produced genetic changes in mammalian cell assay test systems.

12. Ecological Information

No data given.

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PRODUCT NAME: OXYGEN, REFRIGERATED LIQUID

13. Disposal Considerations

Do not attempt to dispose of residual waste or unused quantities. Return in the shipping container PROPERLY LABELED, WITH ANY VALVE OUTLET PLUGS OR CAPS SECURED AND VALVE PROTECTION CAP IN PLACE to BOC Gases or authorized distributor for proper disposal.

14. Transport Information

PARAMETER	United States DOT	Canada TDG
PROPER SHIPPING NAME:	Oxygen, refrigerated liquid	Oxygen, refrigerated liquid
HAZARD CLASS:	2.2	2.2, 5.1
IDENTIFICATION NUMBER:	UN 1073	UN 1073
SHIPPING LABEL:	NONFLAMMABLE GAS, OXIDIZER	NONFLAMMABLE GAS, OXIDIZER

15. Regulatory Information

SARA TITLE III NOTIFICATIONS AND INFORMATION

SARA TITLE III - HAZARD CLASSES:
Fire Hazard
Sudden Release of Pressure Hazard

16. Other Information

Compressed gas cylinders shall not be refilled without the express written permission of the owner. Shipment of a compressed gas cylinder which has not been filled by the owner or with his/her (written) consent is a violation of transportation regulations.

DISCLAIMER OF EXPRESSED AND IMPLIED WARRANTIES:
Although reasonable care has been taken in the preparation of this document, we extend no warranties and make no representations as to the accuracy or completeness of the information contained herein, and assume no responsibility regarding the suitability of this information for the user's intended purposes or for the consequences of its use. Each individual should make a determination as to the suitability of the information for their particular purpose(s).

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Appendix 3
Unit 4 – Additional Material – Optional if time permits.

Now we will focus on side stream injection systems. In Unit 3, we learned that a disadvantage of side stream infection is that transfer efficiencies can vary significantly from 65% to 95%, depending on the V_g/V_l ratio. This page gives us details.

[*Review special calculation information about side stream injectors. Review first three bullets*.]

[*Review fourth bullet (beginning "Figure A.1") and relate it to Figure A.1. (The first two bullets provide textual details.)*]

[*Review remaining bullet*.]

The relationship between V_g/V_l ratio and transfer efficiency is clear: the smaller the amount of air/oxygen/ozone (V_g) going into the injector, the higher transfer efficiency. (Remember, the amount of water (V_l) is fairly constant.)

[*Review key information about the additional SSI steps 1-5*.]

It's important to remember that these five additional steps are intermixed with the five steps from the previous exercise on page 4-3. Now, you'll have an opportunity to practice the calculation skills you used in the *Sample Exercise* and incorporate the additional steps required for side stream injectors, noted by SSI throughout the exercise.

[Continue reviewing Figure A.1]

Chapter 4. Side Stream Injection exercise.

Exercise
Work through the steps and calculations to identify the required ozone generation rate. Use the previous example problem; however, this time, use a **side stream injector (SSI)** for the exercise. In our example, the injector uses 1,090 gpm of water.

[*Briefly review step SSI-1; ask if there are questions about this and respond accordingly. Mention that they will not be able to complete Step 5, however, since it requires having a “real life” flow meter. Select one of the following two options and give class the appropriate instructions.*

Option 1: (15 minutes total) Allow participants to complete the exercise. Allow 7 minutes; then begin debriefing the exercise (recording solutions on easel) and completing any uncompleted steps together as a large group. Encourage participants to refer to the Sample Exercise when needed. Monitor the exercise, and, if needed, assist in calculations and/or provide calculation solutions. Option 2: (10 minutes total). Work through the entire exercise as a large group, recording each step’s solution on easel.]

[*Record* ***all*** *solutions on easel.]*

Calculate *required* ozone generation rate using the assumed transfer efficiency.

O_3 = (Q x D x 8.34) ÷ E

ANS O_3(lbs/day) = (14 MGD x 2.5 mg/L x 8.34) ÷ 0.85 = **343 lbs/day**

Calculate total volumetric gas flow rate

❶ **A** Ozone gas flow rate (scfm)

Volume O_3 = O_3 lbs/day ÷ O_3 weight (lbs/ft3) ÷ 1440 min/day

ANS Volume O_3 = 343 lbs/day ÷ 0.125 lbs/ft^3 ÷ 1440 min/day = **1.9 cfm**

❶ **B** Total feed gas weight (lbs/day)

Feed Gas (lbs/day) = O_3 lbs/day ÷ 0.12

ANS Feed Gas(lbs/day) = 343 lbs/day ÷ 0.12 = **2,858 lbs/day**

❷ **A** Nitrogen weight (lbs/day)

N_2 (lbs/day) = total weight of feed gas (lbs/day) x 0.03

ANS | N_2(lbs/day) = 2,858 lbs/day x 0.03 = **85.8 lbs/day**

❷ **B** Nitrogen volume (scfm)

Volume N_2 = N_2 lbs/day ÷ 0.072 lbs/ft^3 ÷ 1440 min/day

ANS | Volume N_2 = 85.8 lbs/day ÷ 0.072 lbs/ft^3 ÷ 1440 min/day = **0.8 scfm**

❸ **A** Oxygen weight (lbs/day)

O_2 (lbs/day) = total weight of feed gas x [1 – (Ozone weight + Nitrogen weight)]

ANS | O_2(lbs/day) = 2,858 lbs/day x [1 – (0.12 + 0.03)] = **2,429 lbs/day**

❸ **B** Oxygen volumetric flow rate (scfm)

Volume O_2 = weight in lbs/day ÷ weight in lbs per standard ft3 ÷1440 min/day

ANS | Volume O_2= 2,429 lbs/day ÷ 0.082 lbs/ft^3 ÷ 1440 min/day = **20.6 scfm**

❹ Total volumetric gas flow rate (scfm)

Total volumetric flow rate = O_3 scfm + N_2 scfm + O_2 scfm

ANS | 1.9 scfm + 0.8 scfm + 20.6 scfm **= 23.3 scfm**

SSI-2 Convert the water flow rate to ft^3/min (cfm)

ft^3/min (cfm) = total gal/min side stream injector uses ÷ 7.48 gal/ft^3

ft^3/min (cfm) = 1,090 gal/min ÷ 7.48 gal/ft^3 = **146 ft^3/min**

Remember: 7.48 is a conversion factor. A volume of one cubic foot contains 7.48 gallons.

SSI-3 Calculate V_g/V_l ratio

V_g/V_l = total volumetric flow rate of feed gas (scfm) ÷ water flow rate (cfm)

ANS V_g/V_l = 23.3 scfm ÷ 146 cfm = **0.16**

SSI-4 Identify the **actual transfer efficiency** using the calculated V_g/V_l ratio

Let's look at a slide that illustrates the actual transfer efficiency using the V_g/V_l ratio we calculated in the last step.

Display Slide 26—SSI Exercise: Actual Transfer Efficiency

[*Using the slide, demonstrate how 0.16 V_g/V_l is used to identify the actual transfer efficiency.*
- *Find 0.16 on V_g/V_l horizontal axis*
- *Move vertically until curve is intersected*
- *From intersection point, move to the left to the vertical axis, Transfer Efficiency (Percent)*.]

ANS Actual transfer efficiency using Figure 4.1: **85%**

SSI-5 Compare assumed transfer efficiency to actual transfer efficiency.

ANS

Calculated transfer efficiency: **85%**
Assumed transfer efficiency: **85%**

The good news is that the assumed (or estimated) transfer efficiency and the calculated transfer efficiency are the same! This means the assumption was correct and the calculated transfer efficiency is the correct value to use to calculate required ozone generation rate. This also means that we can continue on with the calculations—rather than repeating all the steps we completed, to this point using a different assumed transfer efficiency.

We have one more step to review.

❺ Compare calculated flow rate to actual measured flow rate.

ANS

Calculated total volumetric gas flow rate (scfm): **23.3 scfm**
Actual measured volumetric gas flow rate (scfm): **Measured by generator's flow meter**.

Remember, the calculated flow rate was found in Step ❹. If these two flow rates in Step ❺ match, then the required amount of ozone is being generated.

[*Ask participants if there are questions. Respond accordingly*.]

Side Stream Injection System Diagram.

Figure A.2 illustrates a side stream injection system control diagram. You'll see there is a Contact Chamber added downstream. Let's use page A-18 as a guide to reviewing the figure.

Side Stream Injector System Operating Parameters

Display Slide 27—Side Stream Injection System Control Diagram.

[*Review first two bullets. Point out flow meters and motor operated valves are used to control both water flow and gas flow into the injector.*

Review third bullet. Mention that the ozone residual and water flow rate at this point, compared to the amount of ozone applied, can give you an indication of transfer efficiency.

Review fourth bullet. Indicate that ozone residual at that point is the initial ozone residual used for CT calculations.

Review fifth bullet. Mention that this part of the system works basically the same as the contact chamber in one stage of a diffuser system.

Review sixth and seventh bullet. Indicate that these pressures must be within certain ranges (specified by the system manufacturer) in order for the system to work properly.

Review eighth bullet. Mention that this is the same as a diffuser/contact basin system.]

Appendix 4 – Optional Exercise

Exercise

[*Review exercise parameters. Tell participants there are four (4) calculation steps to complete as listed in their workbook, and that you will work through the first portion together.*]

Note that in Part 1 of this unit, we knew the ozone generation rate in lbs/day and used that to calculate the gas flow rate in scfm as a check. In this example, we know the gas flow rate and need to work backwards to determine the ozone generation rate. We'll work through this first step in your workbook together. These calculations are broken down as follows.

❶ Calculate the actual ozone generation rate in lbs/day.

❶ **A** Determine total weight of feed gas in lbs/day. Use a weighted average based on the unit weight of each component in the feed gas.

[*Review calculations and information presented in workbook. Ask for questions and respond accordingly.*]

[*Then, allow participants to complete Steps* ❶ ***B*** *through* ❹ *using one of the two Options listed below. Debrief exercise using PowerPoint slides.*

Option 1: (10 minutes total) Allow participants to complete the remainder of the exercise in their workbook. Allow 5 minutes; then begin debriefing the exercise (using PowerPoint slides for solutions) and completing any uncompleted steps together as a large group. Encourage participants to refer to their workbooks when needed. Monitor the exercise, and, if needed, assist in calculations and/or provide calculation solutions.
Option 2: (10 minutes total). Work through the entire remainder of the exercise as a large group, having participants complete the calculations in their workbooks. Display PowerPoint slides for each step's solution.]

❶ **B** Calculate ozone generation rate in lbs/day. Feed gas stream is 11% ozone by weight.

Display Slide 28—Ozone Generation Rate.

ANS

❶ **B**: Ozone generation rate (lbs/day)
O_3 Generation Rate = 0.11 x 3568 lbs/day = **392 lbs/day**

This procedure is the reverse of the calculations demonstrated under "Required Ozone Generation Rate" at the beginning of this unit. There, the calculation started with ozone generation in lbs/day and used that to determine gas flow rate in scfm. Here, the calculation started with feed gas flow rate in scfm and used that to determine ozone generation rate in lbs/day.

Display Slide 29—Ozone Pounds Generated.

ANS

❷ O_3 Generated (lbs)
O_3 Generated (lbs) = (392 lbs/day ÷ 1440 min/day) x 40 min = **10.9 lbs 0_3**

Display Slide 30—Kilowatt-Hours Consumed.

ANS

❸ Power consumed during the test (KWH)
KWH = 1177 – 1124 = **53 KWH**

Display Slide 31—Generator Efficiency.

ANS

❹ Generator efficiency (KWH/lb))
Efficiency = 53 KWH ÷ 10.9 lbs 0_3 = **4.86 KWH/lb**

[*Ask participants if there are questions regarding exercise. Respond accordingly*.]

[*Review bullet information. Note that if the amount of power required to generate a pound of ozone is considerably higher than what would be expected for a particular system, the cause should be identified and corrected*.]