Wastewater Treatment Plant Operator Certification Training Instructor Guide

Module 17: The Activated Sludge Process Part III

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, *Module 17: The Conventional Activated Sludge Process Part III*, is to discuss the reasons for modifying the conventional process and to discuss the components of several common modification processes. This module has been designed to be completed in approximately 3 hours, but the actual course length will depend upon content and/or delivery modifications and results of course dry runs performed by the DEP-approved sponsor. The number of contact hours of credit assigned to this course is based upon the contact hours approved under the 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 need to adjust these timeframes as necessary to match course content and delivery modifications made by the sponsor. Please make sure that all teaching points are covered and that the course is delivered as approved by 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.

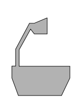
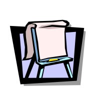
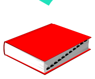
Delivery methods to be used for this course include:

- Lecture
- Discussion Questions
- PowerPoint Slides

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

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

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 is 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: <u>5 minutes</u>

[Display Slide 1—Module 17: The Activated Sludge Process, Part III.

Welcome participants to "Module 17 – The Activated Sludge Process, Part III." Indicate the primary purpose of this course is to discuss the reasons for modifying the conventional process and to discuss the components of several common modification processes.

Introduce yourself.

Provide a brief overview of the module.]

This module contains 3 units. On page i, you will see the topical outline for Unit 1 – Modifications of the Conventional Activated Sludge Process and the beginning of the outline for Unit 2 – The Sequencing Batch Reactor.

[Briefly review outline.]

If you turn the page, you will see the remainder of the outline for Unit 2 and the outline for Unit 3 – Pure Oxygen Activated Sludge.

[Continue to briefly review outline.]

UNIT 1: 65 minutes

[Display Slide 2—Unit 1: Modifications of the Conventional Activated Sludge Process.]

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

- Explain why it may be necessary to modify the conventional activated sludge process.
- List and explain other common modifications of operating the activated sludge process.

REVIEW OF THE CONVENTIONAL ACTIVATED SLUDGE PROCESS: 5 minutes

Process Description

Since this training module is the third part in a series for activated sludge, you should have already encountered the basics of the conventional activated sludge process. We will take just a few minutes to review those basics.

[Briefly review the information in this section; make sure to review the definitions and highlight the importance of the key information.]

Key Process Design Parameters

As we complete this module, we will encounter several modifications to the conventional activated sludge process. For each modification, key process design parameters will be shown to you. In order to accurately compare all of these processes, we will start our discussion of parameters with the conventional activated sludge process itself. Keep this information in mind as we compare and contrast other processes throughout this training session.

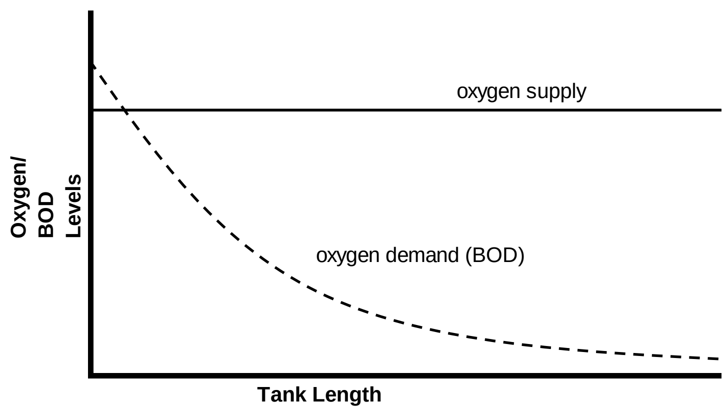
[Briefly review the parameters. Remind participants that, at the end of each parameter section, there will be an area to help them understand the chart. Abbreviations, conditions, and guidelines are found there.

Review the definitions of BOD *and* MLVSS*. These terms will be used throughout the course, but participants should be familiar with the terms from prior modules.]*

[Display Slide 3 – Schematic Drawing of a Conventional Activated Sludge System.]

On page 1-4 of your workbook, you will find Figure 1.1, Schematic Drawing of a Conventional Activated Sludge System. This figure depicts the configuration of the aeration tank for a conventional activated sludge process. This process represents the traditional method for secondary wastewater treatment using a suspended growth biological process. In the conventional process, all the effluent from the primary clarifier and all the return sludge from the secondary clarifier are introduced into the head of the aeration tank. This combined mixture, referred to as the mixed liquor, travels along the length of the aeration tank until it reaches the effluent end of the tank where the mixed liquor is then discharged through the secondary clarifier. As the mixed liquor travels through the aeration tank, little back-mixing occurs (this refers to mixing along the axis of flow); therefore, the flow pattern approximates a plug flow reactor. In this process configuration, the organic load at the head of the tank is high, which creates a high oxygen demand in that portion of the tank.

[Display Slide 4 – Oxygen Supply vs. Oxygen Demand for Conventional Aeration.]



Oxygen Supply vs. Oxygen Demand for Conventional Aeration

Now we will look at a slide that will clarify the changes in oxygen supply and demand along the length of the tank. You may want to sketch the information into your workbook.

As the mixed liquor flows along the tank, the organic material is gradually decomposed, resulting in a decreasing oxygen demand as the mixed liquor moves farther away from the head of the aeration tank. Because the distribution of the aerators is uniform along the length of the tank in a conventional system, the supply of oxygen to the mixed liquor, as it travels through the tank, is constant and not synchronized with the oxygen demand. Consequently, the head of the aeration tank may be prone to oxygen deficiencies while the end of the aeration tank is subject to over-aeration. This design does not provide efficient use of the oxygen applied to the system and can result in aeration problems, especially for systems that are subject to even relatively normal peak loads. This process is best suited to low-strength domestic wastewaters with minimal peak load concerns.

REASONS FOR MODIFYING THE CONVENTIONAL ACTIVATED SLUDGE PROCESS: <u>10 minutes</u>

Now you have a little insight into one reason that the conventional process may require modification. Let's look now at our second section, "Reasons for Modifying the Activated Sludge Process," and the three reasons for modification.

Operational Benefits

Perhaps the most common reason for modifying a conventional activated sludge system is to achieve some perceived operational benefit not available with the conventional system.

[Briefly review the information under this topic; it supports the introduction from the last slide.]

Site Characteristics

[Briefly review the information under this topic. Remind learners that site characteristics will be discussed throughout the session.]

Economic and Labor Benefits

[Briefly review the information under this topic.]

If you work at a wastewater treatment plant, what are some of the factors that affected the way the treatment plant was designed and how it is run?

Ans: *[(Allow participants to discuss the operational needs, site characteristics, and economic and labor requirements of their particular plant.)]*

It is important to take into consideration all of these aspects during the design phase of a treatment plant as well. A plant should not be built based on one site or operational criteria, without considering all aspects of the plant operation.

COMMON MODIFICATIONS OF THE ACTIVATED SLUDGE SYSTEM: 50 minutes

We will begin to look at some of the common modifications of the activated sludge system. We will compare and contrast these models. At the end of the unit, you will find a helpful table that summarizes the information.

Contact Stabilization

[Briefly review the information on this topic. Emphasize the two-tank model.]

[Continue to review Contact Stabilization by noting the key process design parameters and the system configuration information.]

[Instruct participants to look at Figure 1.2, Schematic Drawing of a Contact Stabilization System, on page 1-8 of their workbooks.

Display Slide 5 – Schematic Drawing of a Contact Stabilization System.]

Remember that the Contact Stabilization process is designed on the premise that microbial destruction of organic matter (BOD) is a two-step process in which BOD is first adsorbed by the microorganisms, and then subsequently metabolized by the microorganisms for energy and growth. Consequently, two separate tanks are used in this process modification.

In the mixed liquor aeration tank, which is known as the **contact tank**, primary clarifier effluent and return sludge from the return sludge reaeration tank are introduced. In the contact tank, colloidal and particulate BOD is brought into contact with the microorganisms in the mixed liquor to allow the BOD to be adsorbed by the microorganisms. However, the retention time in the contact tank is low, on the order of 30 to 90 minutes, so there is limited opportunity for the microorganisms to metabolize the BOD in this tank. Following the contact period, the mixed liquor is settled in the secondary clarifier and the sludge containing the microorganisms and the adsorbed BOD is transferred into the **stabilization tank** where reaeration of the return sludge occurs. Retention time in the stabilization tank ranges from 4 to 6 hours. It is in the stabilization tank that the microorganisms metabolize the BOD that they adsorbed in the contact tank. In the process of metabolism, the microorganisms obtain energy needed for reproduction. Because oxygen is required for the reactions that break down the BOD during metabolism, the oxygen demand in the stabilization tank is greater than the demand in the contact tank.

Ten States Standards and Commonwealth of Pennsylvania guidance indicate that 30% to 35 % of the oxygen demand for the entire Contact Stabilization process should be allocated to the contact tank. Even though the oxygen demand is greater in the stabilization tank, the volume of the stabilization tank is generally less than the contact tank because the contact tank receives the full wastewater volume that passes through the primary clarifier plus the reaerated sludge, while the stabilization tank only receives the concentrated sludge from the secondary clarifier.

Conversion of a conventional activated sludge plant to a contact stabilization plant will generally allow the new facility to increase its design capacity. Furthermore, the contact stabilization plant would be more stable when subjected to variable flow and loading.

Kraus Process

The next modification is the Kraus Process. You will note some similarities with the Contact Stabilization information we have just discussed. I will point out the differences in the systems, as well.

[Briefly review the information on Kraus Process; indicate the key process design parameters.]

See the modifications to the conventional system that are listed under the System Configuration heading here. Let's look at the drawing to really understand these changes.

[Refer participants to page 1-10 of their workbook, Figure 1.3, Schematic Drawing of a Kraus System.

Display Slide 6 – Schematic Drawing of a Kraus System.]

The Kraus process was developed to overcome difficulties associated with aerobically treating wastewaters low in nitrogen. Consequently, the process finds application at wastewater treatment plants with a significant industrial contribution from high carbohydrate wastewaters. However, it has also proven beneficial in dealing with activated sludge with poor settling characteristics.

The aeration tank configuration for the Kraus process is similar to the Contact Stabilization process but there are some important process flow and operational differences. Notice that only a portion of the return sludge from the secondary clarifier is returned to the sludge reaeration tank (tank B); the remainder is returned to the mixed liquor aeration tank (tank A). Also, a significant difference is the introduction of sludge and supernatant from the anaerobic digester, which provides a source of ammonia nitrogen.

When oxidized in the sludge reaeration tank, ammonia nitrogen is converted to nitrate nitrogen. When the discharge from the sludge reaeration tank is added to the mixed liquor aeration tank, the additional nitrate nitrogen corrects the nitrogen deficiency of the primary effluent.

Finally, the sludge reaeration tank for the Kraus process has a retention time of approximately 24 hours to allow sufficient time for the ammonia nitrogen to be converted to nitrate nitrogen by the slower-growing nitrobacter and nitrosomonas organisms. It is this change in the population dynamics in the sludge reaeration tank that makes the splitting of the secondary clarifier sludge flow necessary. The appropriate microbial population to sustain the desired performance from tank A must be provided by returning some secondary clarifier sludge directly to the mixed liquor aeration tank.

Step-Feed Aeration

Step-Feed Aeration is the third modification of the conventional activated sludge process. There are several modes of feeding the primary effluent to the aeration tanks. Let's take a closer look at these modifications.

[Briefly review the information presented under this topic. Point out the design parameters and the system configuration information.]

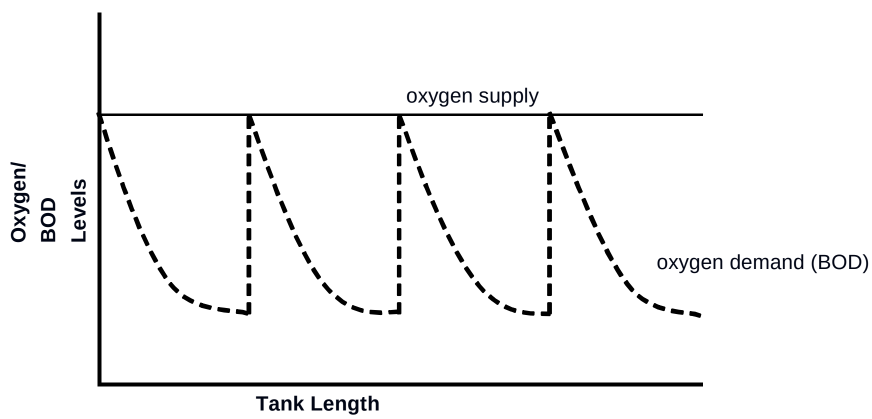
[Refer participants to page 1-12, Figure 1.4, Schematic Drawing of Various Step-Feed Aeration Modes.

Display Slide 7 – Schematic Drawing of Various Step-Feed Aeration Modes.]

The Step Aeration process modification is used to provide a more uniform distribution of oxygen demand throughout the aeration tank. The modification is relatively simple in concept; it is implemented by feeding primary effluent to two or more locations along the flow path of the mixed liquor as it travels from the head to the end of the aeration tank. As in the conventional process, return sludge is returned entirely to the head of the aeration tank. This simple modification distributes the organic load (BOD) along the length of the tank thus reducing the oxygen demand at the head of the aeration tank and distributing it to two or more locations where it can more readily be satisfied. Consequently, Step Aeration is particularly beneficial in reducing the impacts associated with variable shock loads.

Now let's take a look at a sketch for the Step Aeration process that shows the relationship between oxygen supply versus oxygen demand along the length of the aeration tank.

[Display Slide 8 – Oxygen Supply versus Oxygen Demand for Step Aeration.]



Oxygen Supply versus Oxygen Demand for Step Aeration

Notice that the oxygen supply is constant along the length of the tank. However, the oxygen demand varies in a spiked pattern along the tank length. At each location where primary effluent is introduced into the aeration tank, the oxygen demand spikes up then gradually declines until it spikes up again at the next point where primary effluent is added to the aeration tank.

Complete Mix

The next modification is the Complete Mix; here the conditions in the tank are the same throughout. Let's find out why.

[Briefly review the information presented under this topic. Point out the key design parameters and their comparison to other modifications.]

Turn to page 1-14 now and you will see Figure 1.5, Schematic Drawing of a Completely-Mixed Aeration System.

[Display Slide 9 – Schematic Drawing of a Completely-Mixed Aeration System.]

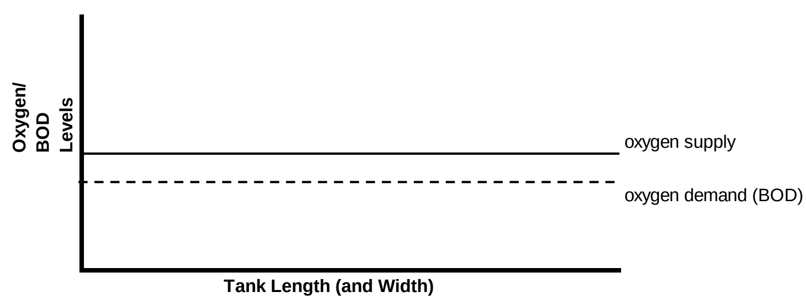
The Complete Mix modification for the activated sludge process is intended to produce uniform treatment and loading conditions throughout the entire aeration tank. To accomplish this, both the primary clarifier effluent and the return sludge are distributed uniformly along the length of the aeration tank. Figure 1.5 shows points of addition for the primary effluent and return sludge. In practice, this may be accomplished using point discharges or by a distribution trough running the length of the aeration tank.

What other differences can you see between Complete Mix and Step Aeration?

Ans: One of the features that make Complete Mix Aeration different from Step Aeration is that mixed liquor is also removed from the tank at several locations. This, together with the orientation of the aerators, creates a series of backmixing zones within the aeration tank that produce a uniform environment throughout the aeration tank.

We have been looking at some supplemental PowerPoint slides that show oxygen demand and various modifications. Let's look at a graph that will show the relationship between oxygen supply versus oxygen demand along the length of the aeration tank.

[Display Slide 10 – Oxygen Supply vs. Oxygen Demand for Complete Mix Aeration.]



Oxygen Supply vs. Oxygen Demand for Complete Mix Aeration

Notice that both the oxygen supply and the oxygen demand are constant along the length and width of the tank. The complete mix process provides for the most efficient use of the oxygen supplied because the supply closely matches the demand throughout the entire tank.

Extended Aeration (Oxidation Ditch)

Extended Aeration, or Oxidation Ditch, process is discussed in Module 4, Fundamentals of Wastewater Treatment, of the Plant Operator Training. We will, therefore, have just a brief overview here today.

[Briefly review the information in this section; emphasize the key process design parameters.]

[Briefly review the system configuration of the Extended Aeration modification.

Display Slide 11 – Schematic Drawing of an Oxidation Ditch.]

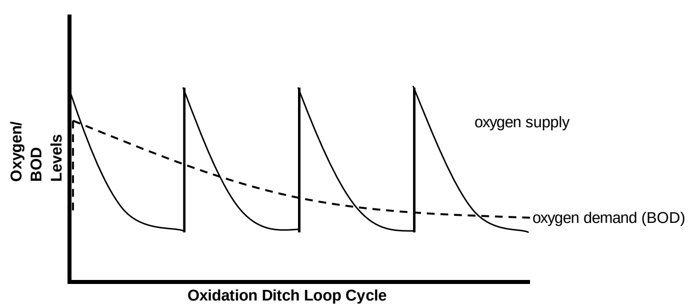
Look at Figure 1.6 in your workbook. The long aeration time (minimum of 24 hours) and extended solids retention time allow Extended Aeration systems to thoroughly oxidize the influent BOD including nitrification of ammonia nitrogen. Therefore, net sludge production for an extended aeration plant is less than that for other activated sludge modifications. Extended Aeration systems can be built in a variety of configurations, which are specifically suited to the site requirements. Package plants commonly use the extended aeration process. Figure 1.6 depicts a particular extended aeration configuration, called an oxidation ditch that has become very commonly used. In this arrangement the influent flow is pretreated to remove gross solids via a bar screen; note that primary clarification is not used.

The aeration tank is configured as a continuous loop that is aerated and mixed by a series of intermittently spaced aeration devices. The motive force provided by the aeration devices imparts the momentum necessary to maintain the fluid velocity required to keep the solids in suspension, generally greater than 1 foot per second. Oxygen provided by each aeration device travels around the loop with the wastewater. Typically, the dissolved oxygen concentration will be high at the aerators and will decline steadily around the loop before being replenished at the next aerator.

As you can see in Figure 1.6, oxidation ditches may be built around a central secondary clarifier in order to save space.

Modifications to the extended aeration oxidation ditch also include systems designed to denitrify by removing nitrates. This can be accomplished by creating anoxic zones where mixing energy is imparted without the addition of oxygen. As the wastewater travels through the anoxic zone, a carbon source is added to facilitate denitrification.

[Display Slide 12 – Oxygen Supply versus Oxygen Demand for Oxidation Ditch.]



Oxygen Supply versus Oxygen Demand for Oxidation Ditch

This slide depicts the variable oxygen supply available to the wastewater as it travels around the oxidation ditch. This slide assumes that the effluent from the ditch is removed just prior to the introduction of the influent. As you can see, the oxygen demand (BOD) decreases continually as the wastewater travels around the oxidation ditch.

Biological Nutrient Removal Processes:
Bardenpho, Anaerobic/Anoxic/Oxidation (A^2/O), Modified Ludzack-Ettinger (MLE)

The final modification for this unit involves processes that enhance the removal of nutrients from wastewater. There are several models of Biological Nutrient Removal Processes (BNR). In the interest of time, the Bardenpho process is used in this section to represent BNR. This topic is covered in more detail in Module 8, Overview of Advanced Wastewater Treatment, of the Plant Operator Training.

You may notice that, on page 1-17, the key design parameters are presented in a different format from the other sections because we are giving an overview of several processes here. On page 1-18, you will see the design parameters in our typical format for one specific model, the Bardenpho activated sludge process.

[Review the information presented on this topic.]

[Briefly review the parameters and system configuration of a Bardenpho process.]

Please look at page 1-19 of your workbook to find Figure 1.7, Schematic Drawing of the Representative Bardenpho System.

[Display Slide 13 – Schematic Drawing of the Representative Bardenpho System.]

The Bardenpho process depicted in Figure 1.7 is one of many modifications to the conventional activated sludge process that addresses nutrient removal. There are even different versions of the Bardenpho process. The Bardenpho process shown in Figure 1.7 is a four tank process designed to enhance nitrogen removal.

In this version of the Bardenpho process, primary effluent, return sludge from the secondary clarifier, and mixed liquor from the first aeration tank are all introduced into the first anoxic tank. The purpose of the first anoxic zone (tank) is to denitrify the wastewater by converting some of the nitrate nitrogen produced in the first aeration tank into nitrogen gas. The primary clarifier effluent provides the necessary carbon source for denitrification.

The effluent from the first anoxic tank discharges to the first aeration tank where nitrification occurs (ammonia nitrogen is converted to nitrate nitrogen).

The effluent from the first aeration tank discharges to the second anoxic tank where denitrification occurs.

The final aeration tank is used to raise the dissolved oxygen concentration and to condition the activated sludge so it will settle well in the secondary clarifier.

A five-tank version of the Bardenpho process adds an anaerobic tank to the front end to create conditions suitable for removing phosphorus.

Sequencing Batch Reactor (SBR)

The topic of SBR will be covered in depth in Unit 2. We will examine six key differences between SBRs and continuous activated sludge processes. Keep the conventional process in mind as we look at these concepts.

Pure Oxygen System

The Pure Oxygen System is the subject of Unit 3. High-purity oxygen gas, rather than atmospheric air, is used to dissolve oxygen in wastewater in a series of covered tanks.

On this page, you will find a chart that is helpful in assimilating some of the design parameters we have compared in Unit 1. Take some time in the next few days to review this information.

We have completed Unit 1. Remembering our objectives for this unit, you should now know why we sometimes modify the conventional activated sludge process.

What were the three reasons for modification?

Ans: Operational Benefits; Site Characteristics; Energy and Labor Requirements

You have also accomplished the second objective by knowing what common modifications are available.

[Have the participants review the Key Points for Unit 1 – Modifications of the Conventional Activated Sludge Process.]

Exercise for Unit 1 - Modifications of the Conventional Activated Sludge Process

1. BOD measurements are used as a measure of the _organic_ strength of wastes in water.

2. The conventional activated sludge process uses a _plug_ - _flow_ reactor that is generally long and relatively narrow.

3. Potential benefits of modifying the conventional activated sludge system include:
   a. Increasing organic loading.

   b. Providing additional nutrients required for proper treatment.

   c. Accommodating flow rate or organic loading that varies seasonally.

   d. Achieving nutrient removal.

   e. All of the above

4. The contact stabilization process assumes that BOD is first _absorbed_ by the microorganisms and then BOD is _metabolized_ by the microorganisms for energy and growth.

5. In a contact stabilization activated sludge process the maximum organic loading should be no more than _60 # BOD_ per 1,000 cubic feet/day.

6. The Kraus Process is applicable to treatment facilities receiving waste water that is low in carbohydrates.

   a. True b. False

7. The _step_ - _feed_ Aeration Process can be used to provide a more uniform distribution of oxygen demand throughout the aeration tank.

8. In general, the _extended aeration (or oxidation ditch)_ process requires the longest minimum aeration time.

9. Oxidation ditches are configured in a ring with _continuous_ flow around the ring that is induced by aerators.

[Indicate that this page contains the references used in Unit 1.]

UNIT 2: 45 minutes

[Display Slide 14—Unit 2: The Sequencing Batch Reactor.]

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

- Explain the basic operating principles of Sequencing Batch Reactors.
- State the differences between a Sequencing Batch Reactor and Continuous Activated Sludge Process.
- Explain the configuration of a Sequencing Batch Reactor System, including preliminary treatment, reactor components, sequencing control, and ancillary treatment.

[Display Slide 15—Unit 2: The Sequencing Batch Reactor.]

You should also have mastered these objectives:

- Describe the stages of operation for a Sequencing Batch Reactor.
- Discuss the reasons for wasting sludge from a Sequencing Batch Reactor.
- Identify key guidelines for operating a Sequencing Batch Reactor.
- Describe important process control considerations for a Sequencing Batch Reactor.

DESCRIPTION OF THE SEQUENCING BATCH REACTOR (SBR) PROCESS: 15 minutes

Basic Operating Principles of the SBR

In Unit 1, we discussed general overviews for several modifications of the conventional activated sludge process. In the next two units, we will discuss in more detail two further modifications. Unit 2 focuses on a process that is similar in many ways to the conventional process. We will refer to the Sequencing Batch Reactor process as SBR.

We start by examining the basic operating principles of SBR. The SBR is basically a batch reactor.

[Review the information under this topic.]

Parameters of the SBR

The most unique feature of SBRs is that multiple treatment processes occur in a single reactor. Process controllers are programmed with the timed sequencing that is required for each treatment process. If necessary, the processing times can be adjusted or altered manually.

[Review the information under this topic.]

Key Differences Between SBRs and Continuous Activated Sludge

We will examine six key differences between SBRs and continuous activated sludge processes. Keep the conventional process in mind as we look at these concepts.

Inflow/Outflow Characteristics

[Review the information under this topic.]

How do influent and effluent flows occur in the conventional activated sludge process?

Ans: Both influent and effluent flows occur continuously in the conventional process.

Aeration Schedule

[Review the information under this topic.]

When does aeration occur in the conventional activated sludge process?

Ans: Aeration occurs continuously in the conventional process.

Organic Loading Schedule

[Review the information under this topic.]

When does organic loading occur in the conventional activated sludge process?

Ans: Organic loading is continuous in the conventional process.

Mixed Liquor Management

[Review information under this topic.]

What happens to the return sludge in the conventional activated sludge process?

Ans: Conventional activated sludge systems receive return sludge from the secondary clarifier to make up for the sludge that was lost during the discharge of mixed liquor.

Clarification Efficiency

[Review information under this topic.]

What makes clarification efficiency less than ideal in the conventional activated sludge process?

Ans: The clarifier is always receiving influent, which creates opportunities for short-circuiting and currents that disrupt the clarification process.

Complexity of Operation

[Review information under this topic.]

Now that you know the six differences in the models, we can talk about the SBR's configuration.

CONFIGURATION OF A SEQUENCING BATCH REACTOR (SBR) SYSTEM: 15 minutes

Preliminary Treatment

Typically required preliminary treatment includes screens, grit removal, and grease removal.

[Review information under this topic.]

Exceptions to the principle of not using primary clarification include retrofitted treatment plants or situations where unusually heavy solids loading are expected in the influent.

Look now at page 2-5, Figure 2.1, in your workbook to see how preliminary treatment fits into the process train for an SBR.

Reactor Components

The four components of the reactor that we will examine are: tanks; decanters; aeration and mixing equipment; and activated sludge wasting.

Tanks

Figure 2.2 shows SBR tanks in operation. Note the foam patterns that indicate that the aeration system is operating.

[Review information under this topic.]

Think about the fact that SBR tanks are often deeper than the conventional process tanks.

Why do you think it is important for SBR tanks to have such depth?

Ans: Sufficient depth is required to accommodate the variable depth requirements associated with a fill and draw operation.

Decanters

[Review information under this topic.]

Figure 2.3 on page 2-8 of your workbook shows a floating decanter in the fill mode (out of the water) and in the decant mode.

We will discuss the function of decanters, along with the other equipment mentioned here, in a few minutes.

Aeration and Mixing Equipment

[Review the first and second bulleted items.]

Why are mechanical mixers favored in SBRs?

Ans: When doing nutrient removal, they can provide mixing energy without aerating.

[Review the third bulleted item.]

Why would an air diffuser prohibit anoxic, or anaerobic, treatment cycles that are required for nutrient removal?

Ans: When operating, the diffuser's bubbles provide oxygen to the environment; anoxic and anaerobic treatment cycles require no free oxygen.

Activated Sludge Wasting Components

[Review information under this topic.]

Sequencing Control

The PLC

SBRs are controlled by microprocessor-based controllers, called Programmable Logic Controllers, or PLCs. These electronic controllers are programmed to meet individual treatment needs. Take a look at Figure 2.4, which shows the front panel of the PLC, as well as the wiring inside the panel.

[Review information under this topic.]

Automatically Actuated Valves

[Review information under this topic.]

Instrumentation

[Review information under this topic.]

Software

[Review information under this topic.]

Ancillary Treatment

Ancillary post treatment is usually limited to disinfection of the effluent and processing of waste activated sludge. However, some SBR facilities may be designed to equalize SBR effluent prior to additional post treatment processes.

Disinfection of Effluent

[Review information under this topic.]

Processing of Waste Activated Sludge

[Review information under this topic.]

Figure 2.5, on page 2-12, shows a sludge drying bed, which is commonly used with SBR systems.

Now that we have visited the components of SBR, let's move into the specifics of its operation.

OPERATION OF SEQUENCING BATCH REACTORS (SBRS): 15 minutes

[Display Slide 16—SBR Stages of Operation.]

Stages of Operation

SBRs typically cycle through a series of four or more treatment stages to complete a treatment cycle. SBRs that provide nutrient removal incorporate additional or extended cycles. The idle stage, which we will discuss in a few minutes, is used only when necessary. Let's look at Figure 2.6, which shows all the stages commonly used in an SBR cycle, and then we will go through them one at a time.

Fill

[Review information under this topic.]

Note that influent is added during the fill cycle and the air may be on or off, depending on the treatment objectives. The fill stage typically occurs for about 25% of the overall SBR cycle time, although actual percentages vary with the treatment objectives.

React

[Review information under this topic.]

The operational flexibility of operating the react stage with mixing but without aeration may be appropriate if the treatment objective is denitrification or nutrient removal. Note that the react stage is operated at full liquid depth and it occurs over about 1/3 of the total SBR cycle time.

Settle

[Review information under this topic.]

Although the control of the settling stage is usually based on the PLC's timed cycles, it can also be controlled by sludge blanket sensors. The settling occurs for about 20% of the total SBR cycle time.

Decant

[Review information under this topic.]

Decanting occurs for only about 15% of the SBR cycle time; therefore, the effluent flow rate is typically much greater than the treatment plant influent flow rate.

Idle

As noted earlier, this stage is only used if necessary.

[Review information under this topic.]

Operating Guidelines

[Review the introductory paragraph with the participants. Remind them that we are offering a glimpse into a typical system's operations. Individual variations are too numerous and specific to mention in the scope of a session such as this.]

F/M Ratio

Who can tell me what F/M ratio means?

Ans: F/M ratio is the ratio of food to microorganisms.

[Review information under this topic.]

MLSS Concentration

What is the MLSS concentration?

Ans: MLSS stands for Mixed Liquor Suspended Solids concentration.

[Review information under this topic.]

Sludge Age

[Review information under this topic.]

Reaction Stage Dissolved Oxygen (DO) Concentration

[Review information under this topic.]

Process Control Considerations

As we have discussed throughout this unit, SBRs have a great deal of flexibility in their operations. Let's look at the modification possibilities now.

Modifying the Stages of a Cycle to Affect Performance

[Review information under this topic.]

Figure 2.7 presents some typical operational strategies for SBR systems with different treatment objectives. Note the time scale at the top of the figure and the various cycle times for each stage, depending upon the treatment objective.

[Note the changes in Figure 2.7 in comparison to the BOD and SS removal time frames.
BOD, SS Removal and Nitrification: Longer retention time.
BOD, SS and Nitrogen Removal: Longer retention time.
BOD, SS, Nitrogen and Phosphorus Removal: Longer Retention and Settling time.]

Why is the settling time longer when removing phosphorus (P)?

Ans: The extra settling time is needed to create the anaerobic conditions for the biological phosphorus removal process.

Monitoring Consistency

[Review information under this topic.]

Knowing Your PLC

[Review information under this topic.]

Now you know something more about SBRs, including the basic operating principles, differences from the continuous process, and the configuration and stages of operation for the SBR. Next we will review Key Points for Unit 2 and work through an exercise before moving on to Unit 3.

[Have the participants review the Key Points for Unit 2 – The Sequencing Batch Reactor (SBR).]

☑ Exercise for Unit 2 – The Sequencing Batch Reactor

1. The maximum operating depth of a typical SBR system ranges from __12__ to __20__ feet.

2. SBR systems can in general use the same aeration and mixing equipment that is used for conventional activated sludge systems.
   a. True b. False

3. PLC means __Programmable__ __Logic__ __Controller__. A PLC controls the mechanical equipment and the timing of the different stages.

4. List the five stages of operation in a SBR and briefly explain what happens in each stage.
   a. __fill-__

   ____
   ____
   ____

   b. __react-__

   ____
   ____
   ____

   c. __settle-__

   ____
   ____
   ____

   d. __decant-__

   ____
   ____
   ____

   e. __idle-__

   ____
   ____
   ____

[Indicate that this page contains references used in this unit.]

[This page was intentionally left blank.]

UNIT 3: 70 minutes

[Display Slide 17—Unit 3: Pure Oxygen Activated Sludge.]

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

- Describe a Pure Oxygen Activated Sludge system and its component parts.
- Name two types of Oxygen Generating Systems, describe their system configurations, and explain their operating principles.
- Discuss control guidelines for a Pure Oxygen Activated Sludge System.
- List and explain the process and operator safety considerations of the Pure Oxygen process.

DESCRIPTION OF THE PURE OXYGEN ACTIVATED SLUDGE SYSTEM: 15 minutes

What is a Pure Oxygen Activated Sludge System?

The third, and final, unit on modifications of the activated sludge system involves a system that uses pure oxygen. The oxygen we are talking about here is different than air; the air we breathe contains much more than just oxygen. For this modification, the oxygen must be high purity.

Let's take a brief overview of this modification and its typical system configuration.

[Briefly introduce the topic by reviewing page 3-2.]

It will help to understand this process if we take a look at the diagram on page 3-3.

[Display Slide 18—A Typical Pure Oxygen System.]

The most commonly used configuration for a pure oxygen activated sludge system uses multiple, covered reactor tanks operating in series. Primary effluent, return sludge and pure oxygen are all introduced into the first stage of the series of reactors and flow concurrently through the reactors. The aeration tanks are covered to capture and reuse as much of the oxygen as possible because of the expense involved in producing the pure oxygen.

Liquid flow through the reactors is maintained by gravity. The flow of oxygen through the reactors is controlled by pressure. In the first reactor, a small pressure, in the range of 2 to 4 inches of water, is maintained. The final reactor is vented to the atmosphere. The pressure differential between the first and the last reactor causes the oxygen to flow through the series of reactors and minimizes the opportunity for backmixing of the oxygen.

Oxygen is dissolved into the wastewater with the aid of aeration devices within each reactor. The aerators most commonly used include surface aerators, sparged turbines, and jet aerators. The physical configuration of the reactors has some bearing on the selection of the aerators.

Advantages of Pure Oxygen Systems

[Refer participants to the list of bulleted items indicating advantages of the system. Address the list by using the script below. There is no need to reiterate the items on the list.]

The concurrent flow of the wastewater and oxygen through the series of reactors has an inherent benefit in that it qualitatively matches oxygen supply with oxygen demand. As the wastewater flows through the reactors, the BOD is reduced in each reactor, so oxygen demand decreases as the wastewater flow passes through the reactors. Similarly, for the reasons noted above, the concentration of oxygen in the gas above each reactor decreases as the gas stream flows through the series of reactors. Therefore, the pure oxygen system uses the applied oxygen efficiently by matching the oxygen supply closely to the oxygen demand.

Pure oxygen systems have other advantages. The use of pure oxygen creates a greater driving force for dissolving oxygen in the wastewater. This greater oxygenation capacity allows pure oxygen systems to operate with greater MLSS concentrations and consequently, the volumetric loading of pure oxygen systems can be greater than for air systems. The overall result is that pure oxygen activated sludge systems require less tank volume for the same level of treatment as air systems. Additional fringe benefits include reduced air emissions and—generally—better sludge settleability.

Disadvantages of Pure Oxygen Systems

[Refer participants to the list of bulleted items indicating disadvantages of the system. Address the list by using the script below. There is no need to reiterate the items on the list.]

However, there is a price to pay for these benefits; certain disadvantages do exist. Pure oxygen, obviously, must be produced and/or purchased, and then stored on site. The cost of the oxygen generation system is expensive, as is the cost of covering the aeration tanks. In addition, because of the complexity of the oxygen generating systems and the controls for regulating and monitoring the oxygen flow, operation of pure oxygen systems is more complex than the operation of air systems. Finally, the use of pure oxygen creates greater fire and explosion hazards, as well as additional operator safety concerns.

System Components

On page 3-5, we begin the section that will describe the system components of a pure oxygen system. We have seen most of this information in the diagram, so let's quickly review.

Reactors

[Briefly review the information under this topic.]

Oxygen Generating Systems

As we have discussed, this type of system requires pure oxygen on site. Some facilities have the capability of producing oxygen; there are two methods.

[Briefly review the information under this topic.]

Mechanical Aeration

Let's take a quick look in your workbook at the mechanical aerator. This is the most commonly used aeration equipment for pure oxygen systems. Either surface aerators or sparged turbines may be used.

[Review the information under this topic. Participants should be familiar with this topic from previous Activated Sludge training modules.]

Jet Aeration

Next we will discuss the jet aerator, which uses a liquid motive stream and a gas stream to mix and distribute gas into the wastewater. Jet aerators are finding wider use in pure oxygen systems based on their ability to mix well with low gas flows.

[Briefly review the information under this topic. Participants should be familiar with this topic from previous Activated Sludge training modules.]

Proprietary Mixers

In addition, proprietary mixing systems have been developed. They are very effective. For example, pure oxygen may be premixed with a portion of the wastewater flow before being introduced into the first stage reactor. Subsequently, this two-phase mixture may be introduced into the reactor through liquid-liquid eductors, or mixers. In the reactor, the initially injected oxygen dissolves by diffusion from the finely dispersed oxygen bubbles.

Pressure Swing Adsorption

[Review the key point.]

A typical layout for a Pressure Swing Adsorption (PSA) Oxygen Generating System is shown in Figure 3.2. The diagram is on page 3-8 of your workbook. I will put it up on the screen so you can see it while we discuss the operating principles and configuration of a PSA.

[Display Slide 19—PSA Oxygen Generating System.]

PSA oxygen generation systems are generally most economical for small- to medium-sized treatment plants, up to approximately 35 tons of oxygen per day. A principal benefit of PSA is that it can be operated over a fairly wide oxygen output range without a significant loss in efficiency. In addition, PSA is a simpler process compared to the common alternative, which is Cryogenic generation.

Operating Principles

A pure oxygen plant that uses PSA technology will need to install multiple compressors and molecular sieves so that a constant supply of oxygen can be provided to the activated sludge system even when equipment is out of service for maintenance, repairs, or cleaning. The molecular sieves require periodic cleaning to maintain their effectiveness. Cleaning involves a desorption process to remove the impurities and gases adsorbed from the atmospheric air.

The desorption process is fairly simple. Once the molecular sieve is depressurized, much of the nitrogen, carbon dioxide, water, and hydrocarbons that were adsorbed under pressure are released to the atmosphere. This is followed by a purge with product oxygen. The molecular sieve can then be repressurized.

[Review information under this topic.]

System Configuration

The relevant processes included in generating oxygen this way are compression of atmospheric air, followed by purification of the compressed air, to create a high purity oxygen effluent (approximately 90% oxygen). More specifically, atmospheric air is compressed to 30 to 60 pounds per square inch (PSI) pressure, then cooled to remove the heat of compression and to condense out any water. Next the compressed gas passes through a molecular sieve which adsorbs impurities and most gases other than oxygen. The oxygen gas stream is normally sent to the pure oxygen activated sludge system for immediate use.

A modification of the PSA system uses a vacuum pump to regenerate the molecular sieves by drawing off the desorbed impurities and discharging them to atmosphere. These Vacuum Swing Adsorption Systems can deliver up to 100 tons of oxygen per day.

Page 3-8 contains the diagram of the PSA model, which has just been discussed and seen on the PowerPoint slide.

Cryogenic Air Separation

Figure 3.3, on page 3-10 of your workbook, depicts a Cryogenic Oxygen Generating System. I will put the diagram on the screen now so that you can visualize the process while we discuss the principles of this system, as shown on page 3-9.

[Display Slide 20—Cryogenic Oxygen Generating System.]

Operating Principles

A small- to medium- sized pure oxygen plant that uses cryogenic technology will generally install multiple compressors and molecular sieves so that a constant supply of oxygen can be provided to the activated sludge system even when this equipment is out of service for maintenance, repairs, or cleaning. Large treatment plants will install more than one oxygen generation plant.

Cryogenic oxygen generation systems are generally most economical for larger treatment plants that require more than 30 tons of oxygen per day. The principal reason for using cryogenic technology is its larger oxygen generating capacity. Because of its high cost and complexity of operation, cryogenic technology is generally not the system of choice when other options are available.

[Review information under this topic.]

System Configuration

- After atmospheric air is filtered, it is compressed and cooled.
- A surge tank dampens pulsations and removes water.
- The compressed air stream is further cooled (through the reversing heat exchangers) by super-cool waste streams from the separation process. Water, carbon dioxide, and other impurities in the inlet air stream that condensed and solidified in the reversing heat exchanger must be removed by purging the heat exchanger periodically with clean, cold nitrogen from the separation columns. The nitrogen warms while passing through the heat exchanger and carries out the impurities previously deposited there. The reversing action of the heat exchangers occurs by automatically switching the flow direction through each exchanger so that inlet air, which was flowing through one exchanger (while effluent nitrogen flowed through a second exchanger), switches to flow through the second exchanger while effluent nitrogen switches to flow through the first exchanger.
- The air is filtered through a gel trap (molecular sieve).
- The clean cold air is liquefied and separated into nitrogen and oxygen by a two-column fractional distillation process. The higher pressure bottom column produces a mixture of liquid oxygen and nitrogen, which is recycled to the upper fractionation column, and a vapor stream rich in nitrogen that is returned to the top of the upper column. Nitrogen, the more volatile component, is exhausted from the top of the upper column.
- The pure oxygen gas (approximately 98%) is taken from near the bottom of the upper column, warmed, and then delivered to the activated sludge system. Liquid oxygen can also be removed from the bottom of the upper column and sent to storage.

[Review information under this topic.]

Page 3-10 contains a diagram of the Cryogenic Air Separation process, which has just been discussed and displayed on the PowerPoint.

Except for the complexity related to the oxygen supply systems, star-up, operation, and control of a pure oxygen system is similar in many ways to that of an air activated sludge system. There are a few control parameters that are specific to the pure oxygen system. In this section, we will examine those parameters.

Reactor Vent Gas

Monitoring

Typically, the target concentration for the vent gas is approximately 50% oxygen. If there were much less, the desired activated sludge treatment rate would not be achieved. If there were much more, too much oxygen would be wasted; oxygen is expensive to generate.

[Briefly review the information under this topic.]

Control

[Briefly review the information under this topic.]

Reactor Gas Space Pressure

Monitoring

Because the reactor tanks are covered in this system, a gas space exists above each reactor stage.

[Briefly review the information under this topic.]

Control

The operator has the flexibility to adjust the pressure set point, which in turn, will affect the performance of the system.

[Briefly review the information under this topic.]

Monitoring

[Briefly review the information under this topic.]

Control

[Briefly review the information under this topic.]

SAFETY CONSIDERATIONS: <u>10 minutes</u>

Process Safety

A normal atmosphere contains about 19.5% oxygen. When that concentration is increased, a potentially dangerous atmosphere is created. Although dealing with oxygen generation involves additional safety issues, the risks can be managed with appropriate safety procedures and precautions.

Potentially Explosive Atmosphere

[Review the information under this topic.]

Liquid Oxygen (LOX) Storage

[Review the information under this topic.]

Alarms and Emergency Disconnects

[Review the information under this topic.]

Operator Safety

Personnel Protection Equipment

[Review the information under this topic.]

Material Handling Considerations

[Review the information under this topic including the definition for intrinsically safe.]

Liquid Oxygen Spill Response

Due to the specially designed storage and transfer equipment, as well as the procedures used for handling liquid oxygen, the chances of a spill are small. However, if a spill should occur, special procedures are required. Let's look at the important key points on page 3-15 so you will be prepared.

[Review the key points under this topic.]

You can describe a pure oxygen activated sludge system and you know about two types of oxygen generating systems. We have discussed the control guidelines for this modification. And, you have become familiar with some of the process and operator safety considerations of the pure oxygen process.

[Have the participants review the Key Points for Unit 3 – Pure Oxygen Activated Sludge.]

CASE STUDY: <u>20 minutes</u>

We are now going to finish the session with a short case study to review the principles presented in today's module. Please read through the case study description in your workbooks on page 3-16. Take up to 10 minutes to read the case study and collect your thoughts. Then we will have a short discussion to share our thoughts about the case study.

[After no more than 10 minutes, ask for ideas about the case. Direct the discussion to focus on the ideas presented in Unit 1 concerning why different modifications of the activated sludge system may be selected. The three classifications of reasons were:

- *Operational benefits*
- *Site characteristics*
- *Economic and labor benefits*

Not all the information needed to make a final decision is presented in the case study; therefore, the participants' discussion should identify the data gaps and present assumptions made for the purposes of the discussion.

There is no correct answer to the case study, but the answers should focus on striking a proper balance between operational benefits, site characteristics, and economic and labor benefits.

You may wish to write some of the thoughts on a flipchart.]

[This page is provided to the participants as additional space to write their thoughts about the case study.]

[Indicate that this page contains the references used in Unit 3.]

This concludes the formal instruction for Module 17: The Activated Sludge Process – Part III.

[Ask for and respond to questions.

Thank attendees for their participation.]