Wastewater Treatment Plant Operator Certification Training

Module 17: The Activated Sludge Process Part III

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Topical Outline

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II. Reasons for Modifying the Conventional Activated Sludge Process
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Unit 1 – Modifications of the Conventional Activated Sludge Process

Learning Objectives

- 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.

Process Description

The following elements describe the conventional activated sludge process:

- Both influent or primary clarifier effluent and return sludge are introduced at the head of the aeration tank, which creates the greatest oxygen demand at that point.
- Oxygen demand decreases uniformly from the inlet to the outlet of the aeration tank.
- The conventional activated sludge process is susceptible to failure from shock loads.

Shock Load is wastewater with elevated concentrations of contaminants that arrives at the treatment plant for a brief period of time.

Mixed Liquor Suspended Solids (MLSS), also known as mixed liquor, consists of a mixture of the influent or primary clarifier effluent and the return sludge, which contains the microorganisms needed to maintain the treatment process.

Because of its relatively low mixed liquor suspended solids (MLSS) concentration and its head-end loading, the conventional activated sludge process is most suitable for low-strength, domestic wastes with minimal peak load considerations.

Key Process Design Parameters

The following range of process design parameters is permissible for a conventional activated sludge process:

F/M Ratio*...0.2 - 0.5 #BOD / #MLVSS / day

Organic Loading (maximum) ....40 #BOD / 1,000 cubic feet / day

MLSS...1000 – 3000 mg / liter

Aeration Retention Time (minimum)** ....6 hours

Solids Recycle Rate**.....................................15% – 100%

*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate

Biochemical Oxygen Demand (BOD) is the rate at which organisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation. BOD measurements are used as a measure of the organic strength of wastes in water.[1]

Mixed Liquor Volatile Suspended Solids (MLVSS) is the organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure of the amount of microorganisms present.[2]

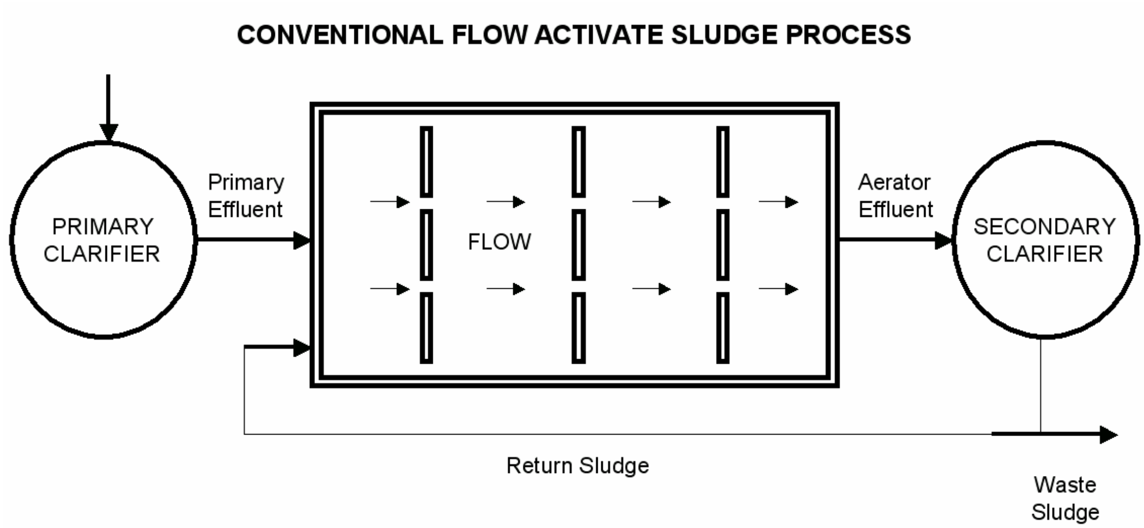


Figure 1.1 Schematic Drawing of a Conventional Activated Sludge System

- The conventional activated sludge process uses a plug-flow reactor that is generally long and relatively narrow.
- Aeration capacity is uniform along the length of the tank and is designed to minimize back-mixing.
    - Commingling of mixed liquor upstream or downstream in any part of the reactor is minimized.
- Mixed liquor is removed at the end of the aeration tank and transferred to the secondary clarifier.

Operational Benefits

Modifications to the process can be made in an existing system or in the design process of a new system. Potential operational benefits of modifying the conventional activated sludge system include:

- Increasing organic loading.
- Providing additional nutrients required for proper treatment.
- Accommodating flow rate or organic loading that varies seasonally.
- Achieving nutrient removal.

Site Characteristics

Another common reason for modification of the process is to provide a treatment system that is suitable to the available site conditions. For example, extended aeration systems, especially oxidation ditch configurations, require more space than conventional systems. Alternately, where space is limited, a pure oxygen system or a complete mix configuration would be more suitable.

These systems, along with others, will be discussed in more detail throughout the chapter.

Economic and Labor Benefits

The energy and labor requirements of each system are determinants in choosing the best modification. A smaller municipality may not be able to sustain some of the more labor and energy intensive systems. For example, oxidation ditches are usually low energy, low labor systems. Pure oxygen systems, however, require greater amounts of energy and labor.

Contact Stabilization

Process Description

Contact Stabilization presumes that organic matter (BOD) destruction is a two-step process in which:

- BOD is first adsorbed by the microorganisms.
- BOD is then metabolized by the microorganisms for energy and growth.

Adsorption refers to the process in which the colloidal and particulate organic content of the wastewater becomes attached to the microorganisms.

Based upon that presumption, the contact stabilization process requires two aeration tanks: a contact tank and a stabilization tank.

A **Contact Tank** is used for aeration of the mixed liquor.

- Influent or primary clarifier effluent is added to the contact tank.
- While in the contact tank, colloidal and particulate organic matter (BOD) is adsorbed onto the microorganisms.
- Residence time in the contact tank is approximately 30 to 90 minutes.
- After leaving the contact tank, the mixed liquor is settled in the secondary clarifier and the MLSS containing the biomass is returned to the stabilization tank.
- The treatment cycle then restarts.

A **Stabilization Tank** is used to reaerate return sludge prior to mixing it with the primary effluent.

- While in the stabilization tank, most of the organic material that was adsorbed by the microorganisms in the contact tank is metabolized.
- Residence time in the stabilization tank is approximately 4 to 6 hours.

Key Process Design Parameters

The following range of process design parameters is permissible for a Contact Stabilization activated sludge process:

F/M Ratio*..0.2 - 0.6 #BOD/#MLVSS/day

Organic Loading (maximum) ....60 #BOD/1,000 cubic feet/day

MLSS...1000 – 3000 mg/liter

Aeration Retention Time (minimum)**ƚ...5 hours

Solids Recycle Rate**..50% – 150%

*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate
ƚ based on total aeration capacity in contact and stabilization tanks. (The stabilization tank is typically 30-35% of the capacity of the contact tank)

System Configuration

To modify the conventional activated sludge system into a contact stabilization system, the following changes are made:

- Primary effluent is introduced into the Contact Zone.
- A stabilization tank is added to stabilize the adsorbed organics.
- Overall oxygen demand is split between contact tank and stabilization tank.

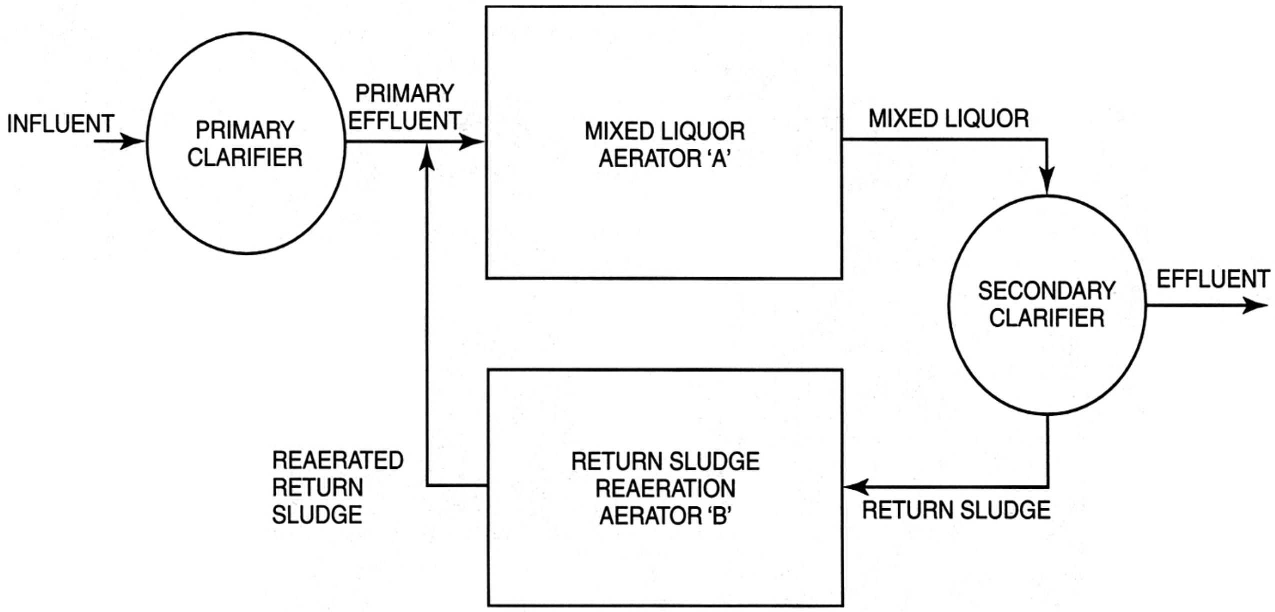


Figure 1.2 Schematic Drawing of a Contact Stabilization System[3]

Kraus Process

Process Description

Kraus Process is used to treat wastewater that is deficient in nitrogen. It is also used when activated sludge has poor settling characteristics. This modification is most applicable for treatment facilities receiving wastewater that is high in carbohydrates.

The process uses a reaeration tank that is similar to the contact stabilization process, with some important modifications:

- Not all of the return sludge is reaerated; some is returned without being retreated.
- Digester supernatant and digester sludge is also added to the reaeration tank.
- Retention time in the reaeration tank is approximately 24 hours.

Ammonia nitrogen in the digester sludge and supernatant is converted to nitrate nitrogen in the reaeration tank. Effluent from the reaeration tank is mixed with the return sludge to correct the nitrogen deficiency in the influent wastewater. Also, the concentration of inert solids from the digester, when mixed with the mixed liquor, improves the settleability of the mixed liquor.

Key Process Design Parameters

The following range of process design parameters is permissible for a Kraus activated sludge process.ŧ

F/M Ratio*..0.3 - 0.8 #BOD/#MLVSS/day

Organic Loading (maximum) ....70 #BOD/1,000 cubic feet/day

MLSS..1000 – 2500 mg/liter

Aeration Retention Time (minimum) ....4 hours

Solids Recycle Rate**..15% – 100%

ŧ Does not consider the reaeration tank
*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate

System Configuration

To modify the conventional activated sludge system into a Kraus process system, the following changes are made:

- The reaeration tank is added.
- Recycling and reaeration of the digester supernatant and solids occurs.
- A portion of the return sludge is reaerated.

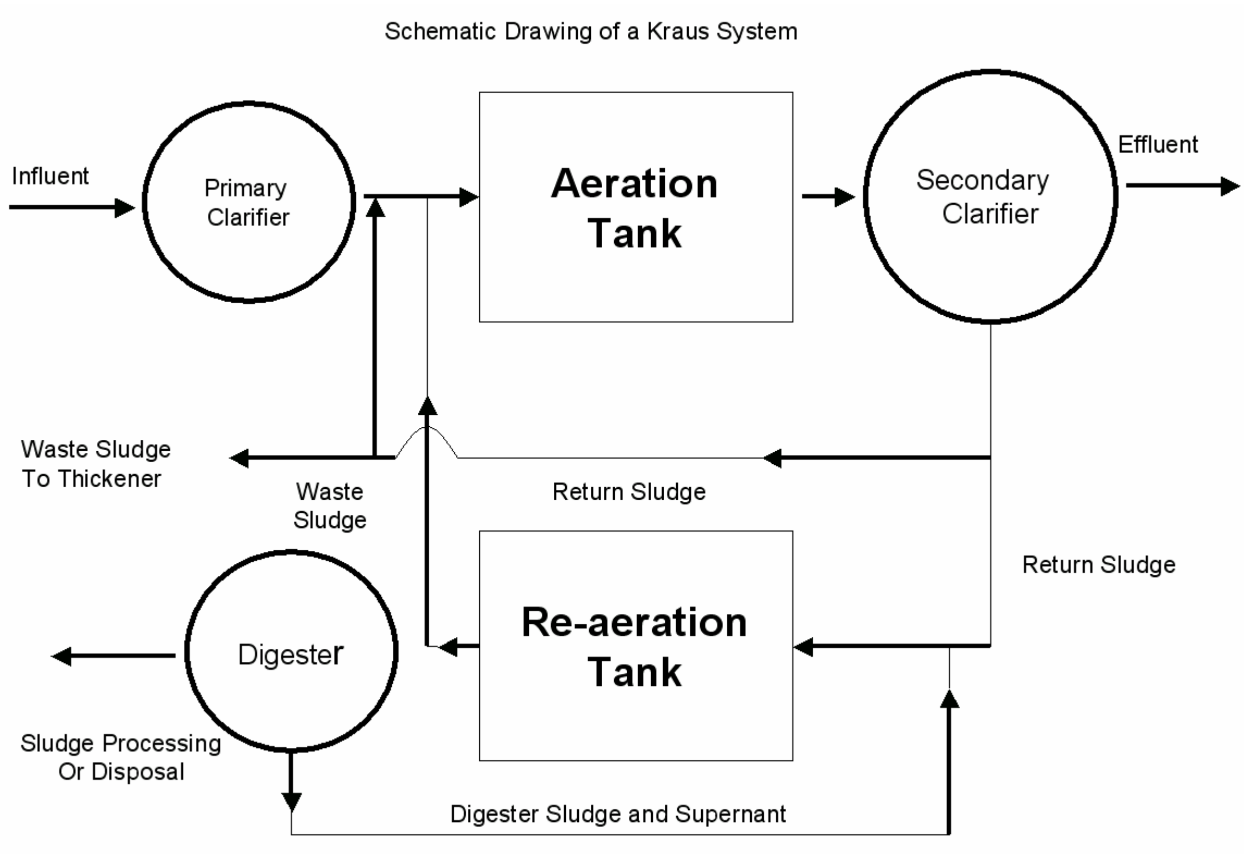


Figure 1.3 Schematic Drawing of a Kraus System

Step-Feed Aeration

Process Description

This process modification is used to provide a more uniform distribution of oxygen demand throughout the aeration tank. It is particularly beneficial when dealing with variable shock loads.

- Primary effluent is piped to two or more locations along the length of the aeration tank.
- Distributed loading minimizes any decreases in dissolved oxygen concentration along the length of the aeration tank.
- The percent of primary effluent distributed to each location can be varied to optimize process performance.

Key Process Design Parameters

The following range of process design parameters is permissible for a step feed activated sludge process:

F/M Ratio*.. 0.2 - 0.5 #BOD/#MLVSS/day

Organic Loading (maximum) .... 40 #BOD/1,000 cubic feet/day

MLSS.. 1000 – 3000 mg/liter

Aeration Retention Time (minimum) .... 6 hours

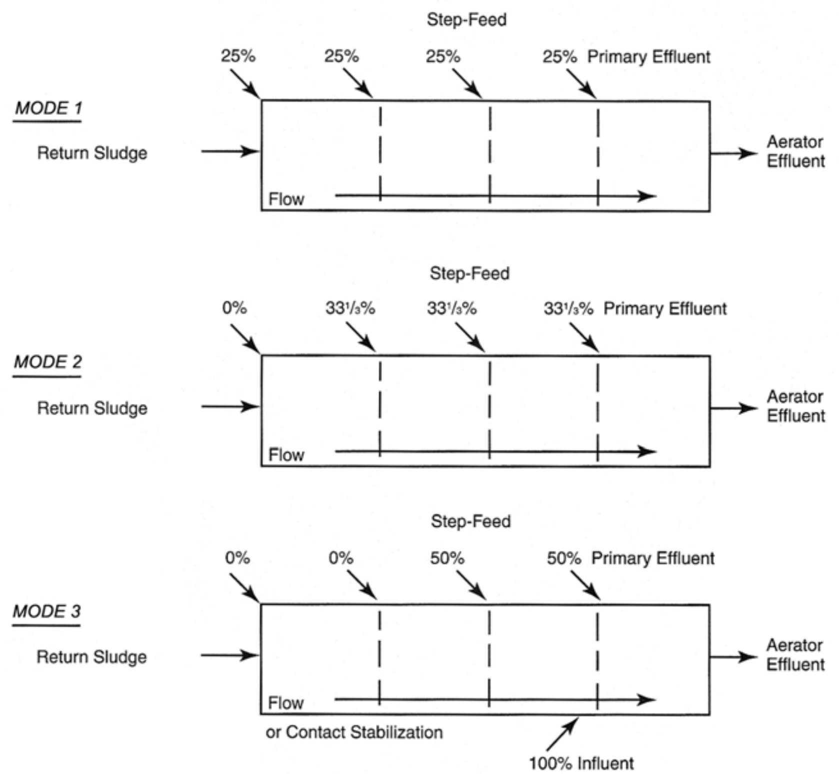
Solids Recycle Rate**... 15% – 100%

*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate

System Configuration

To modify the conventional activated sludge system into a step-feed aeration system, the following changes are made:

- Primary effluent is distributed to multiple locations in the aeration tank.
- Baffling of the aeration tank creates multiple mixing zones coincident with the distribution points.
- Operational flexibility is achieved by varying the amount of primary effluent distributed to each area.



Several possible modes of feeding primary effluent to the aeration tanks. Some tanks may have more or fewer points of discharge into the tank

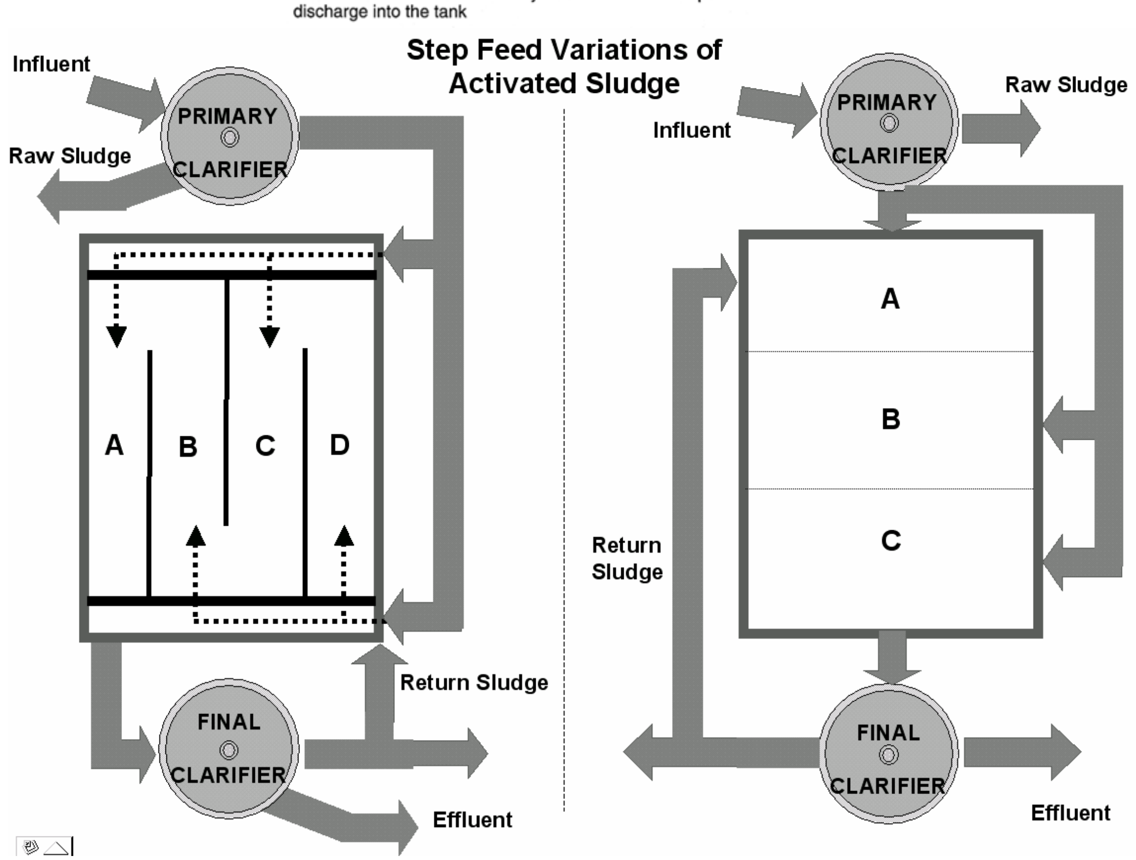


Figure 1.4 Schematic Drawings of Various Step-Feed Aeration Modes[5]

Complete Mix

Process Description

This modification is used to simulate a completely-mixed reactor tank in which conditions within the tank are the same throughout the tank. The benefits of this modification include greater volumetric loading, a more stable microbial population, more efficient aeration, and tolerance of shock loads.

- Both primary effluent and return sludge are distributed uniformly along the length of the aeration tank.
- Mixed liquor is removed uniformly from the length of the aeration tank.
- Aerators are located uniformly along the aeration tank.

Key Process Design Parameters

The following range of process design parameters is permissible for a complete mix activated sludge process:

F/M Ratio*.. 0.2 - 0.5 #BOD/#MLVSS/day

Organic Loading (maximum) .... 40 #BOD/1,000 cubic feet/day

MLSS.. 1000 – 3000 mg/liter

Aeration Retention Time (minimum) .... 6 hours

Solids Recycle Rate**.. 15% – 100%

*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate

System Configuration

To modify the conventional activated sludge system into a complete mix system, the following changes are made:

- Primary effluent is distributed to multiple locations throughout the aeration tank.
- The flexibility of operation is enhanced by varying the amount of primary effluent distributed to each location.
- Baffling of the aeration tank creates multiple mixing zones coincident with the distribution points.

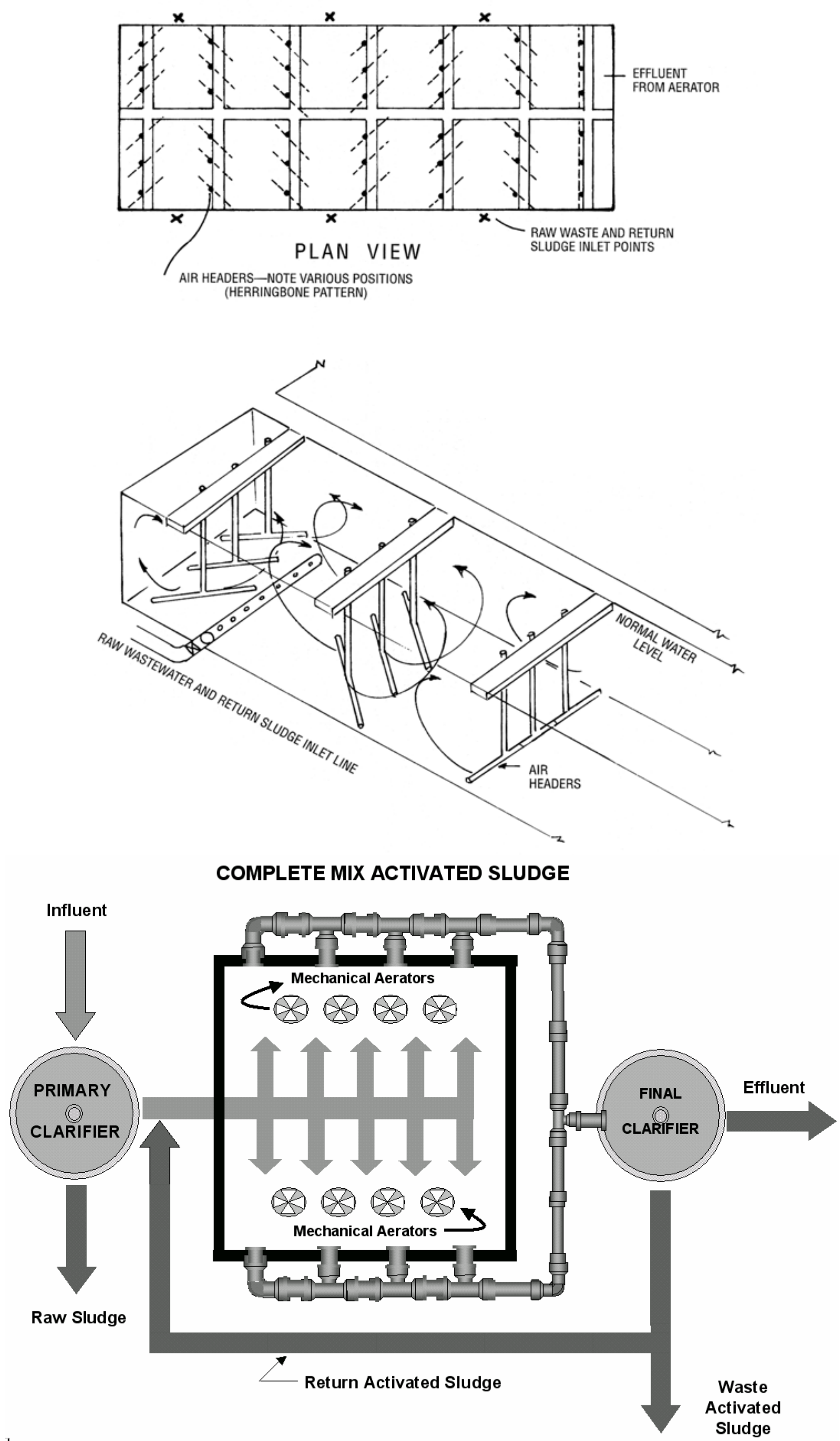


Figure 1.5 Schematic Drawings of a Completely-Mixed Aeration System[5]

Extended Aeration (Oxidation Ditch)

Process Description

Extended aeration is often used for small treatment facilities requiring a simple process, in the form of a package treatment plant. It is also used for larger treatment plants in the form of oxidation ditches. Principal benefits of extended aeration modifications include reduced sludge handling and lower power requirements.

(NOTE: an overview of package plants and oxidation ditches is available in Module 4 of the DEP Wastewater Treatment Plant Operator Training.)

- A long aeration time (hydraulic loading) and low organic loading characterize this process.
- Primary clarification is often eliminated.
- Dissolved oxygen (DO) is introduced at intermittently spaced aerators and the DO concentration may be allowed to decrease significantly between aerators.
- The ditch configuration and the mixing energy applied are designed to maintain a velocity of approximately one foot per second, in order to keep solids in suspension.

Key Process Design Parameters

The following range of process design parameters is permissible for a extended aeration and oxidation ditch activated sludge processes:

F/M Ratio*.. 0.05 - 0.1 #BOD/#MLVSS/day

Organic Loading (maximum) .... 15 #BOD/1,000 cubic feet/day

MLSS.. 3000 – 5000 mg/liter

Aeration Retention Time (minimum) .... 24 hours

Solids Recycle Rate**.. 50% – 150%

*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate

System Configuration

In this example of extended aeration, an oxidation ditch configuration is presented as a representative of the extended aeration modification. Many other configurations are possible. The principal differences between an oxidation ditch and a conventional activated sludge system are:

- An oxidation ditch is configured as a ring with continuous flow around the ring, which is induced by aerators.
- A clarifier may be located within the annular space of the ditch to save on construction costs and the amount of land required.
- Oxidation ditch rings may be interconnected at the ends in order to produce a long, continuous loop.

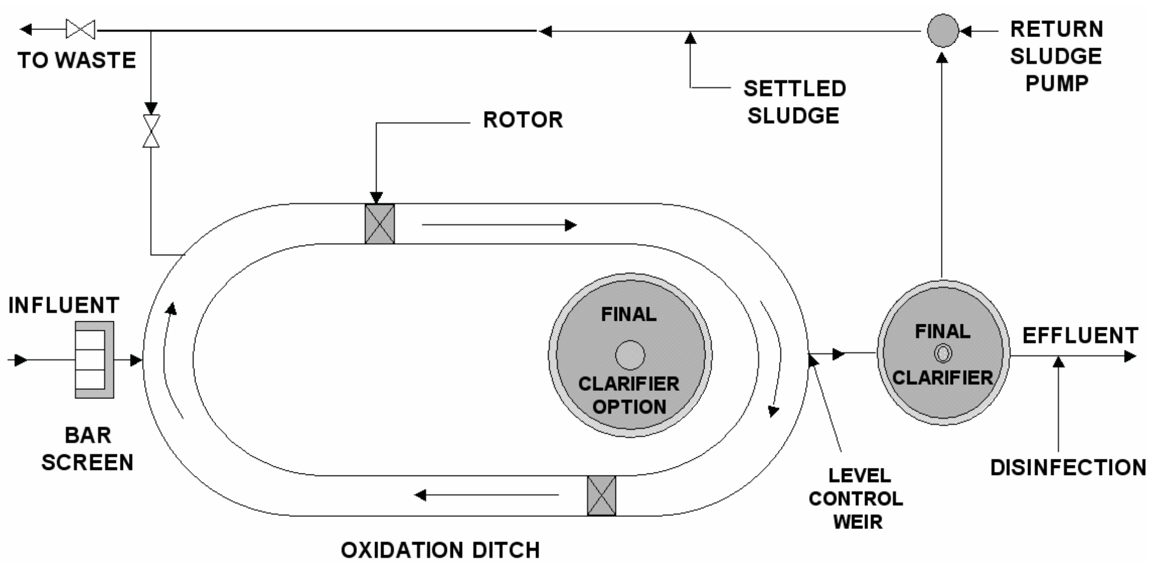


Figure 1.6 Schematic Drawing of an Oxidation Ditch

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

Process Description

These process modifications to the conventional activated sludge system are made to enhance the removal of nutrients from wastewater. A simple Bardenpho process is presented here to represent the range of Biological Nutrient Removal Processes.

(NOTE: An overview of Biological Nutrient Removal processes is available in Module 8, Overview of Advanced Wastewater Treatment, of the DEP Wastewater Treatment Plant Operator Training.)

- Ammonia nitrogen, which is present in raw municipal wastewater, is converted to nitrate nitrogen during normal activated sludge treatment.
- Anoxic (containing no residual dissolved oxygen) tanks or zones are added to the conventional activated sludge process train to convert the nitrates to nitrogen gas.
- In the anoxic zones, facultative bacteria strip oxygen from the nitrates since oxygen is not available in dissolved form in the wastewater.

Key Process Design Parameters (Typical Design)

The successful operation of a biological nutrient removal (BNR) system is dependent upon several process parameters, including:

- Temperature, which affects microbial reaction rates.
- pH and alkalinity, which must be controlled to prevent inhibition of microbial reactions.
- Dissolved oxygen concentration, which affects reaction rates and creates inhibitions.
- Mixing, this ensures uniform reactor conditions.
- Return of activated sludge and internal nitrate recycling, which provides necessary microorganisms and nitrate for the denitrification process in the anoxic zones.

The following range of process design parameters is permissible for the aeration tank in a Bardenpho activated sludge process:

F/M Ratio*.. 0.08 - 0.16 #BOD/#MLVSS/day

Organic Loading (maximum) .... 20 #BOD/1,000 cubic feet/day

MLSS.. 2000 – 5000 mg/liter

Aeration Retention Time (minimum) .... 12 hours

Clarifier Solids Recycle Rate** .... 15% – 100%

Aeration Tank MLSS Recycle Rate**…..…………………………………….. 400%

*F/M = food to microorganism ratio
#BOD = pounds of Biochemical Oxygen Demand (BOD)
#MLVSS = pounds of Mixed Liquor Volatile Suspended Solids
**Based on maximum monthly average influent flow rate

System Configuration

A simple four-tank Bardenpho process may be configured as follows:

- Influent wastewater, return sludge from the clarifier, and nitrified mixed liquor from the effluent end of the first aeration zone are introduced into the first anoxic tank.
- Effluent from the first anoxic tank discharges to an aerobic tank where nitrification occurs.
- Effluent from the nitrifying tank discharges to a second anoxic tank where denitrification occurs.
    - Nitrate-nitrogen is converted to nitrogen gas.
- Effluent from the denitrification tank discharges to a second aerobic tank.
    - Second tank raises DO level of the wastewater before clarification process begins.
- To obtain phosphorus removal, as well as nitrogen removal, an anaerobic tank is typically added to the front of the treatment train.

Several other configurations have been used to achieve biological nutrient removal.

- The MLE (Modified Ludzak Ettinger) process uses only the first two tanks in the four-stage Bardenpho process: the anoxic tank followed by the aeration tank. Both clarifier solids and aeration tank MLSS are returned to the anoxic tank.
- The A^2/O (anaerobic, anoxic and aerobic, or oxic) process adds an anaerobic tank to the head of the MLE process and returns clarifier solids to this tank rather than the anoxic tank. The A^2/O process will provide phosphorus as well as nitrogen removal.

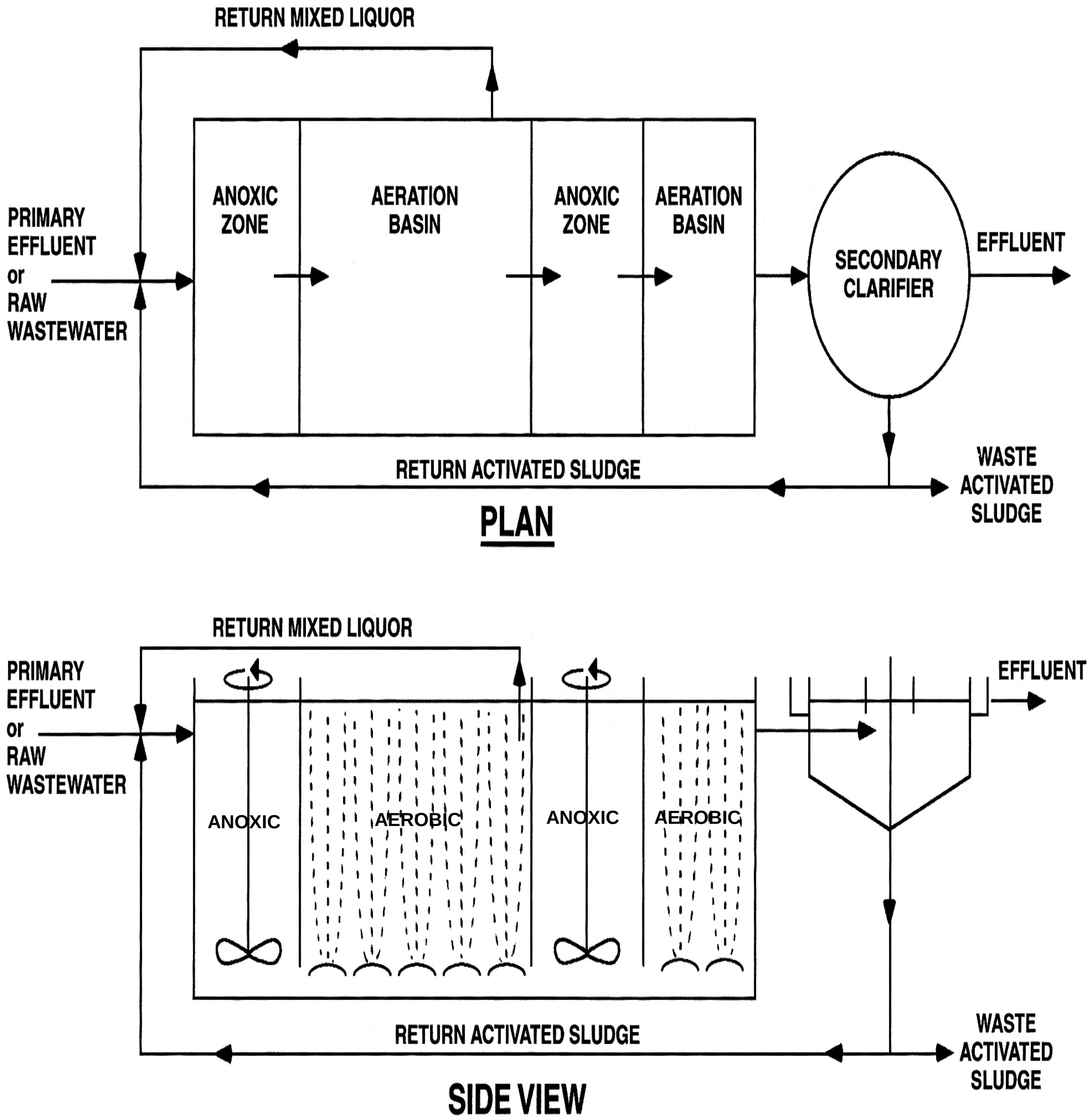


Figure 1.7 Schematic Drawing of the Representative Bardenpho System[9]

Sequencing Batch Reactor (SBR)

The SBR modifications are discussed in detail in Unit 2 of this module. There are six key differences between SBRs and continuous activated sludge processes.

Pure Oxygen System

The pure oxygen system modifications are discussed in detail in Unit 3 of this module. It uses a high-purity oxygen gas rather than atmospheric air to dissolve oxygen in wastewater.

Permissible Aeration Tank Capacities and Loadings[7]

Process	Mode of Aeration	Minimum Aeration Retention Time—Hours (based on maximum monthly average flow)	Maximum Aeration Tank Organic Loading***** Lb. BOD/1000 cu. ft./day	F/M Ratio lb. BOD/lb. MLVSS/day	MLSS mg/liter
Step Aeration, Complete Mix, and Conventional Activated Sludge	Air System	6	40	0.2 – 0.5	1000 – 3000
	Pure Oxygen System	2	160	0.3 – 1.0	3000 – 5000
Contact Stabilization	Air System	5*	60	0.2 – 0.6	1000 – 3000
Combined Carbon Oxidation-Nitrification	Air System	12	20	.08 - .16	2000 -5000
	Pure Oxygen System	4	60	.10 - .20	3000 – 5000
Extended Aeration and Oxidation Ditches	Air System	24	15	.05 – 0.1	3000 – 5000
Carbonaceous Stage of Separate Stage Nitrification	Air System	4	70	0.3 – 0.8	1000 – 2500
	Pure Oxygen System	1.5	250	0.5 – 1.0	3000 – 5000
Nitrification Stage of Separate Stage Nitrification	Air System	6	10***	.05 - .20****	1000 – 3000
	Pure Oxygen System	2	25***	.08 - .20****	3000 - 5000

* Total aeration capacity includes both aeration and reaeration capacities. Normally the contact zone equals 30-35% of the total aeration capacity.
** Not recommended if wastewater temperatures are expected to fall below 10º C.
*** Lb. NH_3-N/1000 cu. ft./day
**** Lb. NH_3-N/lb. MLVSS/day
***** Based on maximum daily BOD load to aeration tank.

Key Points for Unit 1 - Modifications of the Conventional Activated Sludge Process

- Because of its relatively low mixed liquor suspended solids (MLSS) concentration and its head-end loading, the conventional activated sludge process is most suitable for low-strength, domestic wastes with minimal peak load considerations.

- Typical key process design parameters for an activated sludge process include:
  - F/M Ratio, Organic Loading (max)
  - MLSS
  - Aeration Retention Time (minimum)
  - Solids Recycle Rate

- The conventional activated sludge process uses a plug-flow reactor that is generally long and relatively narrow.

- Oxidation ditch systems require more space than conventional systems but are usually low energy and low labor systems.

- The contact stabilization process requires two aeration tanks, a contact tank and a stabilization tank.

- The Kraus Process is often used to treat wastewater that is nitrogen deficient or has poor settling characteristics.

- A step-feed aeration system is beneficial when dealing with variable shock loads.

- A complete mix process can result in greater volumetric loading capacity.

- Influent with low organic loading may be a good candidate for extended aeration in package treatment plant or oxidation ditch treatment processes.

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

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

2. The conventional activated sludge process uses a _________ - __________ 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 organic matter is first ________________ by the microorganisms and then organic matter is __________________ by the microorganisms for energy and growth.

5. In a contact stabilization activated sludge process the maximum organic loading should be no more than _________________ 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 _______-__________ Aeration Process can be used to provide a more uniform distribution of oxygen demand throughout the aeration tank.

8. In general, the ___________________________ process requires the longest minimum aeration time.

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

[1] California State University, Sacramento, Department of Civil Engineering, *Operation of Wastewater Treatment Plants Volume I , 4th ed*., (Sacramento, CA: The California State University, Sacramento Foundation, 1994).

[2] Operation *of Wastewater Treatment Plants Volume 1, 4th ed.*

[3] *Operation of Wastewater Treatment Plants Volume II, 5th ed.*, page 86, figure 11.23.

[4] *Operation of Wastewater Treatment Plants Volume II, 5th ed.*, p. 89, figure 11.25.

[5] *Operation of Wastewater Treatment Plants Volume II, 5th ed.*, p. 91, figure 11.26.

[6] *Operation of Wastewater Treatment Plants Volume II, 5th ed.*, p. 92, fig. 11.28.

[7] www.dep.state.pa.us, and search for document 362-0300-001.pdf, p. 78.

Unit 2 – The Sequencing Batch Reactor

Learning Objectives

- 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.
- 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.

Basic Operating Principles of the Sequencing Batch Reactor (SBR)

Following are the basic overview principles of the SBR:

- The SBR is a fill-and-draw activated sludge system.
- Wastewater enters a partially filled reactor containing biomass.
- When the required operating liquid level is reached, influent flow to the reactor stops and a specified, timed treatment sequence begins.
- Because the influent flow to each reactor is not continuous, at least two reactors are necessary to accommodate a system with continuous influent flow.

Parameters of the SBR

- Multiple processing stages occur in one tank.
  - SBRs use specified time durations for each treatment process.
  - A typical operating schedule includes fill, react, settle, decant, and idle stages.
  - Stage timing is usually controlled automatically.
- Multiple processing cycles occur each day.
  - Typically, from two to six complete treatment cycles will be completed in each reactor each day.
- Batch processing of wastewater occurs.
  - A normal SBR system operates in the batch mode, wherein the influent flow is cyclic and each batch is processed through the entire treatment process.
- SBR modifications provide continuous processing of wastewater.
  - A modification of the normal SBR process allows for continuous influent flow without sacrificing the benefits of the SBR process.
    - The Intermittent Cycle Extended Aeration System (ICEAS) operates with a continuous influent flow and a periodic discharge.
    - ICEAS uses an inlet baffle to separate the inlet zone from the reactor zone, allowing semi-batch treatment with minimal disruption of clarification.

Key Differences Between SBRs and Continuous Activated Sludge

The unit processes of SBRs and conventional activated sludge systems are the same. However, these processes occur over time in the SBR; in the conventional system, the unit processes occur simultaneously.

Inflow/Outflow Characteristics

- Both influent and effluent flows occur periodically in an SBR, which is a batch activated sludge process; therefore, the continuous treatment plant influent periodically transitions from one reactor to another.

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

Aeration Schedule

- Aeration is just one of several treatment stages in the SBR.

When does aeration occur in the conventional activated sludge process?

Organic Loading Schedule

- Organic loading occurs intermittently, within the influent flow, in the SBR.

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

Mixed Liquor Management

- Mixed liquor always remains in the reactor in SBR systems; no sludge return is required.

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

Clarification Efficiency

- Clarification occurs in an ideal environment in the SBR because there is no flow through the reactor during the clarification stage.

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

Complexity of Operation

- There is not a significant difference in the overall complexity of operation between SBRs and conventional activated sludge processes.

- Each SBR reactor is required to perform several functions, making operation of the reactor more complex than any one component of a conventional activated sludge system.

- Because the conventional activated sludge system uses several individual components, operation of the conventional system may be considered to be more complex than operation of any one SBR reactor.

- SBR systems require a minimum of two reactors to handle continuous flow; however, each reactor has less mechanical equipment than a conventional activated sludge system (including the clarifier and return activated sludge components).

Preliminary Treatment

- Most treatment plants have some preliminary treatment to protect treatment equipment and preserve the effectiveness of the treatment process.

- As is typical of most extended aeration systems, primary clarification is not commonly used for SBRs

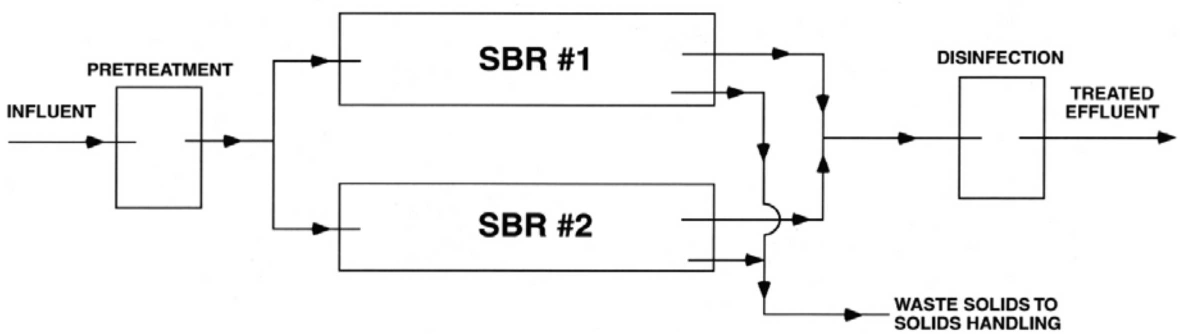


Figure 2.1 SBR Treatment Train with Preliminary Treatment[1]

Reactor Components

Tanks

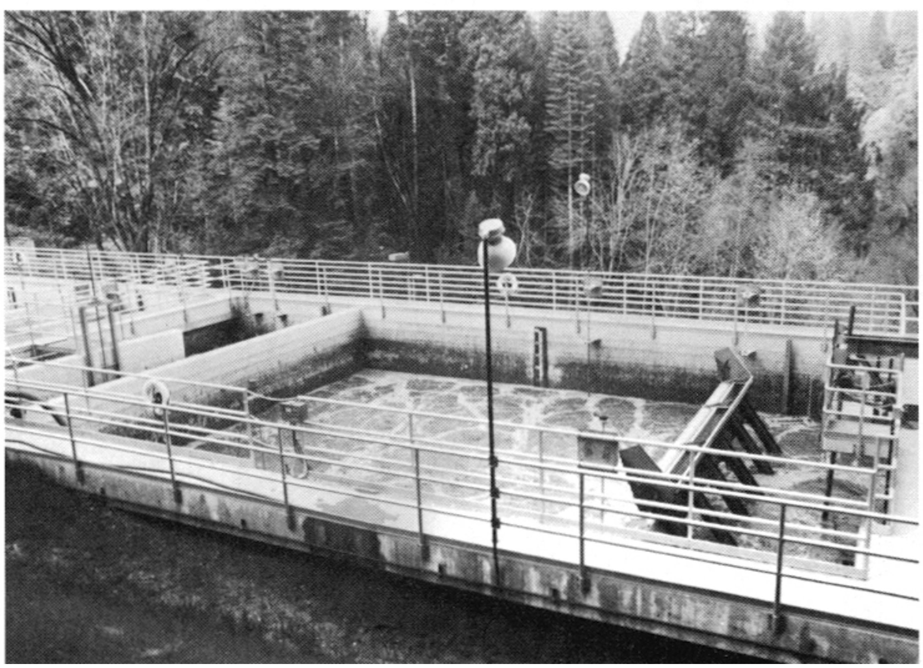
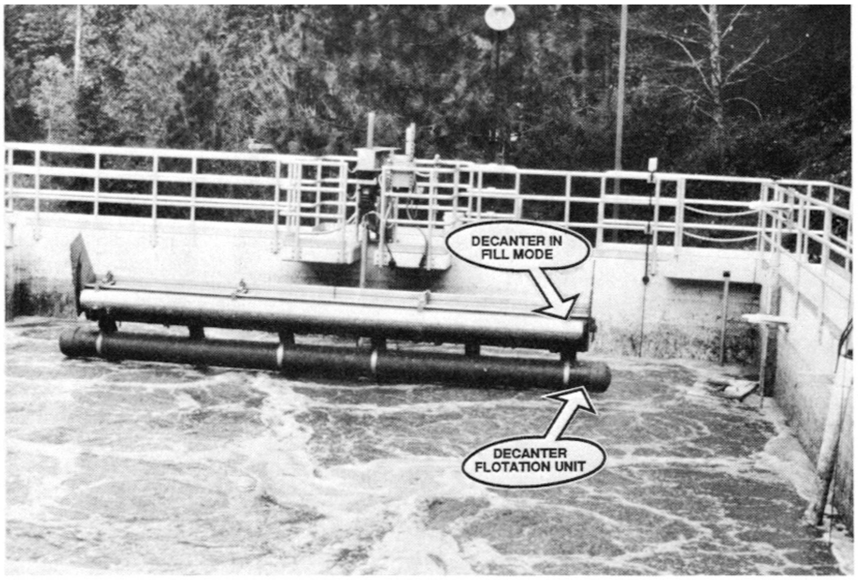


Figure 2.2 Reactor Tanks[2]

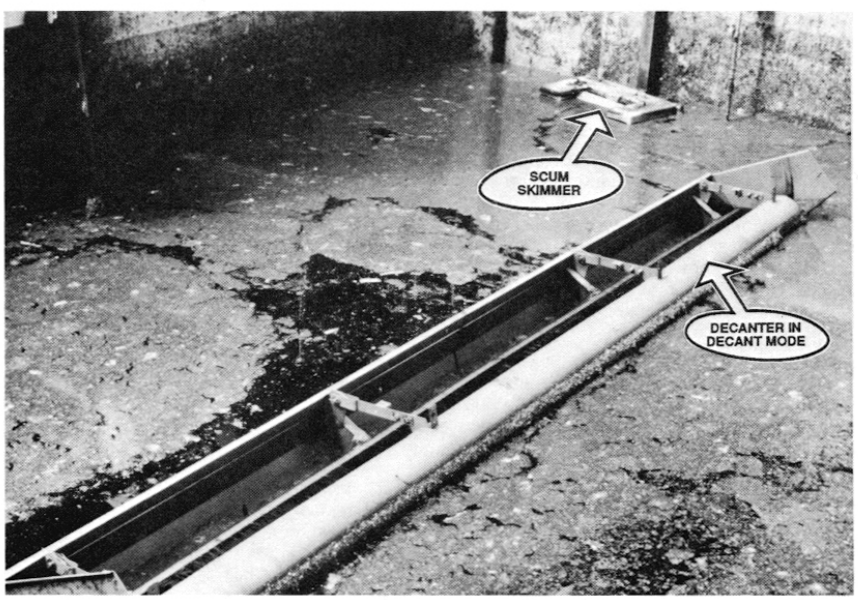
- Multiple tanks are required; the minimum is two.
  - One reactor fills and reacts while the other settles and decants.
- For best practice, use a minimum of three reactors to ensure that continuous operation is possible at all times.
- Tank configurations vary with manufacturers, but the most common configuration is rectangular.
- SBR reactors are usually deeper than conventional activated sludge aeration tanks.
- The maximum operating depth for typical SBR reactors ranges from 12 to 20 feet.

Decanters

- Decanter designs and configurations vary with the manufacturer.
- Decanters can be fixed-elevation or variable-elevation (floating) devices.
- Floating decanters are more expensive, but offer more flexibility in operation.



Decanter out of water during react (aeration) cycle



Decanter in water during settle cycle

Figure 2.3 Decanters3

Aeration and Mixing Equipment

- The same aeration and mixing equipment that is used for conventional activated sludge systems is used in the SBR systems.
- Mechanical mixers are commonly used in SBRs.
    - A submerged turbine aerator that uses mechanical mixing and optional aeration is often used for SBR systems.
- The use of air diffusers without mechanical mixers limits the flexibility of the SBR system.
    - Air diffusers alone are not used in SBR systems designed for nutrient removal because anoxic or anaerobic treatment cycles are required for nutrient removal.
- Jet aerators are used more often in SBR systems than in conventional activated sludge systems because of their ability to mix without aerating.
    - Jet aerators can be used with only a liquid motive force (for pumping mixed liquor), or with a combination of liquid and air streams to aerate.

Activated Sludge Wasting Components

- Sludge wasting is performed on an as-needed basis to manage the food to microorganism ratio in the SBR.
- Sludge wasting occurs intermittently, following the decant stage or during the idle stage of operation.
- Sludge is removed by gravity line or by pumps.

Sequencing Control

The PLC

- A Programmable Logic Controller (PLC) controls the sequencing of the reactor cycles.
- A battery backup should be installed to provide power to the PLC in case of power failure.
- Good practice requires that the PLC also be protected by an Uninterruptible Power Supply (UPS) to prevent PLC memory loss and to maintain normal operations during short power outages.

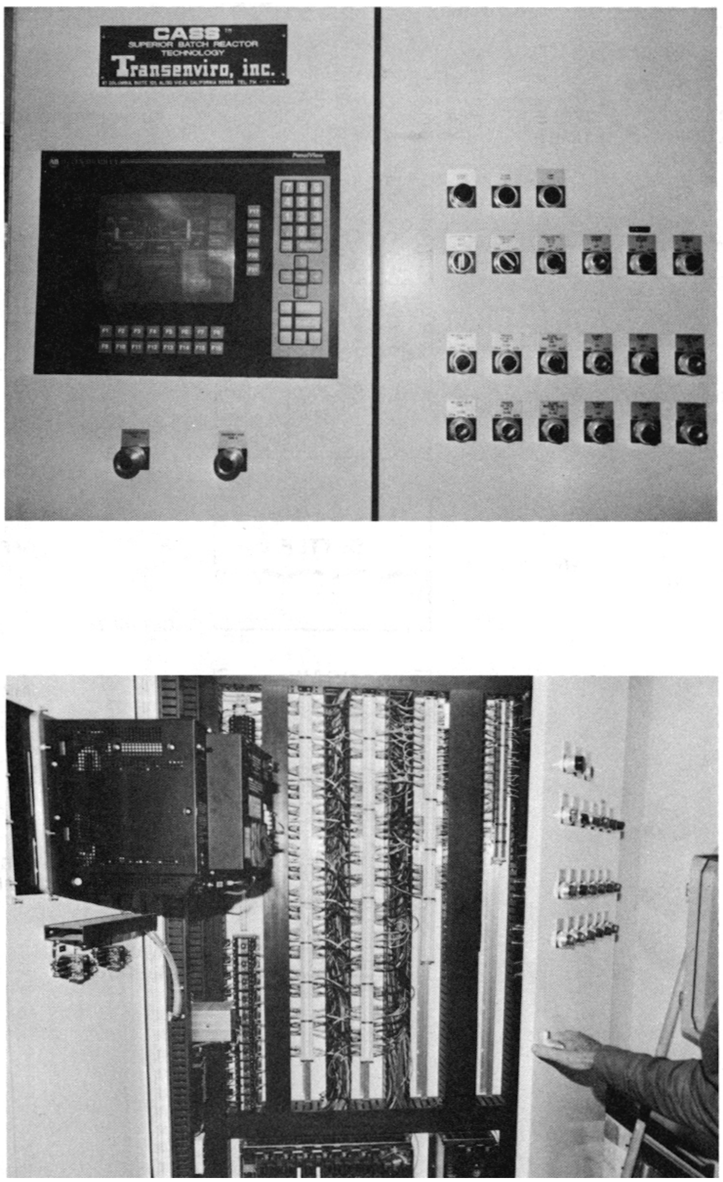


Figure 2.4 Programmable Logic Controller[4]

Automatically Actuated Valves

- Operations regulated or controlled by pneumatic, solenoid, or motorized valves can all be controlled from a centralized location with a PLC.

Instrumentation

- Motor starters, valves, level controls, timers, flow meters, and pressure switches are all controlled by the PLC.
- Display panels may be used to provide an operational overview and the status of individual instrumentation devices.

Software

- The PLC software is usually supplied by the PLC manufacturer.
- The software is unique for each individual SBR system manufacturer; it is one of the main features that differentiates between different SBR systems.

Ancillary Treatment

Post treatment can be used to disinfect the effluent or to process waste activated sludge.

Disinfection of Effluent

- Effective disinfection requires adequate contact time between the effluent and the disinfection chemical.
- Disinfection of SBR effluent requires special consideration because the effluent flow rate from an SBR is typically much greater than the average influent flow rate to the treatment facility, since the effluent is discharged as a batch, not continuously.
- If equalization of SBR effluent is not provided, the disinfection facilities must be sized to handle the SBR effluent flow rate, while still providing the requisite time for effective disinfection.

Processing of Waste Activated Sludge

- Waste activated sludge may be discharged directly to sludge drying beds.
- Alternately, some SBR facilities are supported by aerobic sludge digesters that process waste activated sludge from the SBRs.

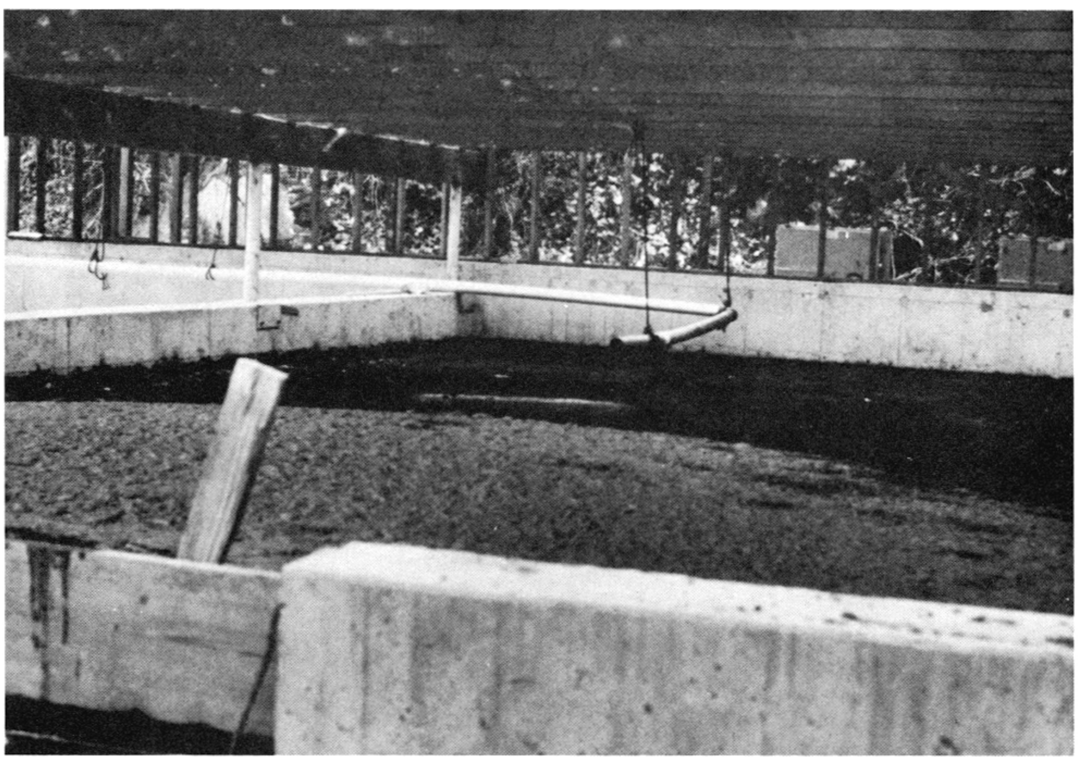
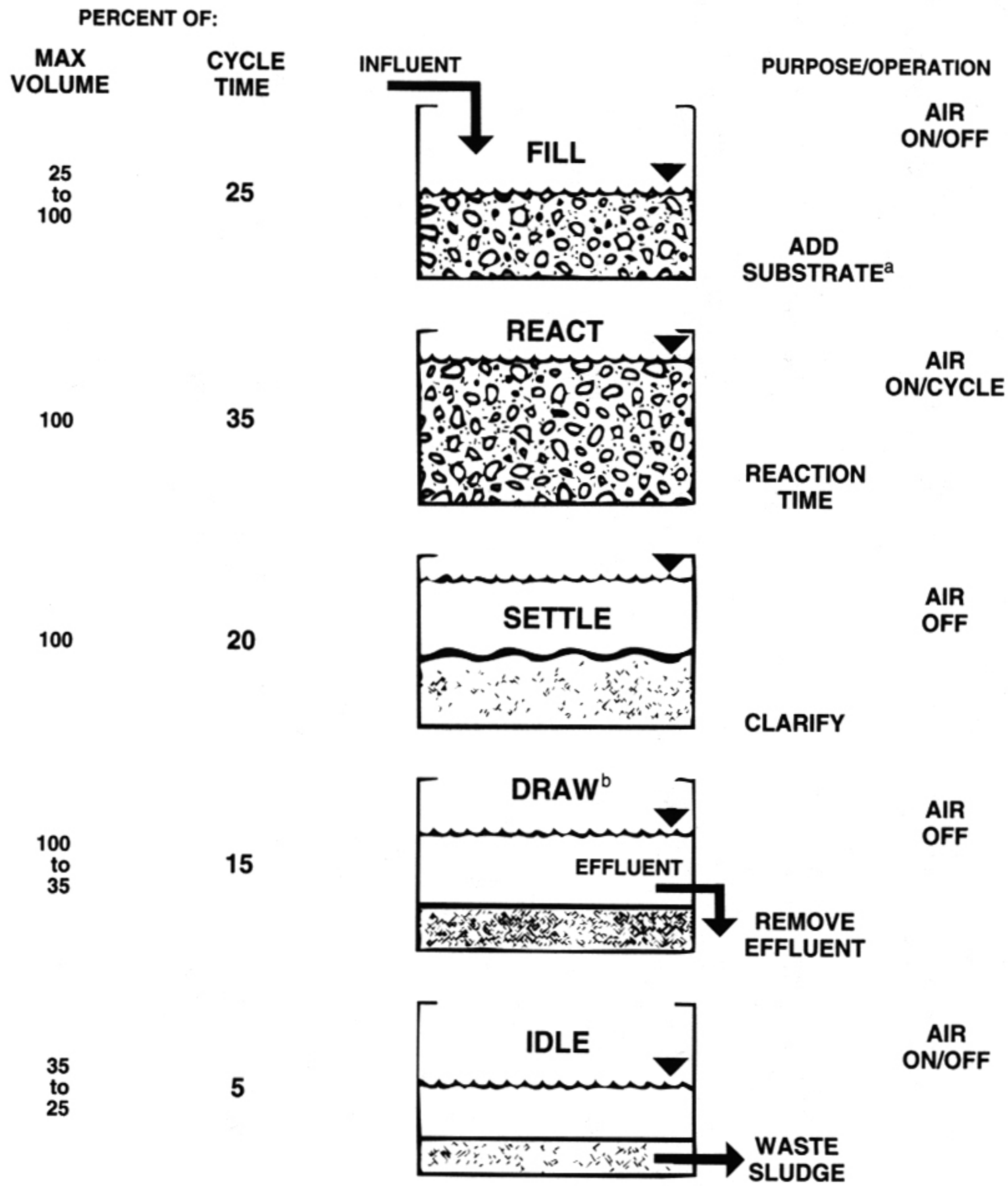


Figure 2.5 Processing of Waste Activated Sludge[5]

Stages of Operation



[a] Substrate—The base or food on which an organism lives.
[b] Draw—The decant or treated wastewater removal phase.

(Source: Irvine, Robert L., *TECHNOLOGY ASSESSMENT OF SEQUENCING BATCH REACTORS*, US EPA, Cincinnati, OH)

2.6 Stages of the SBR[6]

Fill

- During the fill stage, effluent from the preliminary treatment systems discharges to one or more of the SBR reactors.
- During this stage, the fluid level in the reactor is increased from the low water level (achieved after decanting) to the high water level.
- The fill cycle can be operated in a variety of ways, depending upon the treatment objective(s).
  - Fill can occur without any mixing or aeration; with mixing only; or with mixing and aeration.

React

- After the SBR is filled to the high fluid level, the react cycle typically begins.
- When the SBR is operating in the extended aeration mode, the react cycle is operated with full aeration and mixing to achieve the desired treatment.
  - Alternately, depending on the treatment objectives, the react stage may be operated with mixing but without aeration.

Settle

- Generally, settling occurs under quiescent conditions with no mixing or aeration.
  - Quiescent settling facilitates the formation of a sludge blanket, which produces a clear supernatant above the sludge blanket.
- In some situations, gentle mixing during the initial settling stage may encourage floc formation and produce a better quality effluent.
- Control of the settling stage duration is usually based on a timed cycle.

Decant

- During the decant stage, supernatant liquid is withdrawn from the top of the liquid surface in the reactor and is discharged as plant effluent.
  - Because there is no influent flow during the decant stage, the liquid level in the tank decreases as supernatant is withdrawn from the reactor.
- Baffles or weirs are typically used to prevent scum and other floating solids from entering the effluent discharge.

Idle

- Idle stage is not a required SBR operating stage.
- An idle stage, if needed, is used to allow the multiple SBR reactors to synchronize so that one SBR reactor can complete its fill stage before the plant influent is allowed to discharge to the idling reactor.
- The idle stage can be used for removal of waste sludge.

Operating Guidelines

Operating guidelines vary significantly, depending upon the treatment objective(s). Operating guidelines for industrial wastewaters will differ from guidelines for municipal wastewater. The following information is a generalized overview of operating guidelines.

F/M Ratio

- For municipal wastewater, with operation of the SBR as a typical aeration plant, the F/M ratio is 0.05 to 0.10.
- For municipal wastewater, if the objective is not to nitrify, an appropriate F/M ratio would be 0.15 to 0.4.

MLSS Concentration

- The MLSS concentration maintained in the SBR ranges from 2000 to 5000 milligrams per liter (mg/L), when there is a low liquid level in the SBR.
- Consistency is required in calculating the MLSS concentrations because the liquid level in the SBR reactor varies with time. Therefore the MLSS concentration must be sampled during the same phase every time.

Sludge Age

- SBRs are operated as extended aeration facilities and have a sludge age typical of those systems: from 25 to 45 days.

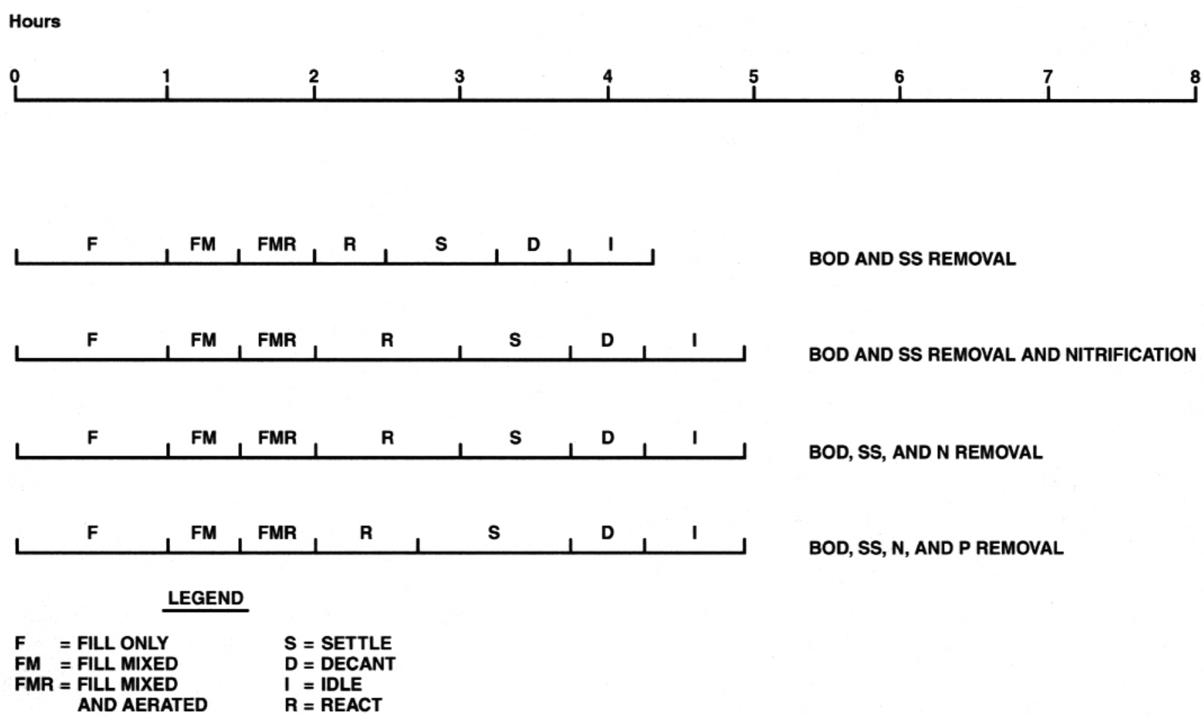
Reaction Stage Dissolved Oxygen (DO) Concentration

- During full aeration of the SBR reactor during the react stage, the DO concentration should not be limiting and should range from at least 1.0 mg/L to approximately 3.0 mg/L.
- Other modes of operation are possible; this could dictate DO concentrations during the react stage that would be different from that suggested above.

Process Control Considerations

Modifying the Stages of a Cycle to Affect Performance

- It is relatively easy to modify the stages of an SBR cycle by adjusting the timing for each treatment stage with the PLC.
  - New treatment cycles can be added, and the characteristics of each treatment cycle can be altered.
  - These changes require an operator who is knowledgeable about the PLC.
- Radical changes in the SBR cycles require prior knowledge of the required process parameters and/or close process monitoring to ensure the success of process changes.



(Source: Arora, Madan L. and Umphres, Peggy B., *TECHNICAL EVALUATION OF SEQUENCING BATCH REACTORS*, US EPA, Cincinnati, OH).

Figure 2.7 Typical Operational Strategies[7]

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

____

____

Monitoring Consistency

- Monitoring requirements for SBRs are very similar to those of other activated sludge systems.

- F/M ratio and dissolved oxygen concentrations are basic parameters that should be monitored for all activated sludge systems, including SBRs.
  - Since SBRs are somewhat unique, in that several processes occur in a single tank.
    - Monitoring activities must account for this uniqueness.
    - Effective monitoring will be done consistently at the same time in the cycle.
    - Measurement of the MLSS, in particular, is critical to process monitoring and must always be conducted at the same point in the process cycle.

Knowing Your PLC

- The PLC is the heart of the SBR operation because it controls the operation of the mechanical equipment and the timing of the treatment stages.

- Operators need to be familiar with the operation of the PLC in order to properly operate and control the SBR process.

- Operator knowledge should extend to being able to troubleshoot the PLC and to knowing how to return the PLC back into service if a power failure occurs and the uninterruptible power supply (UPS) is not online.

Key Points for Unit 2 – The Sequencing Batch Reactor (SBR)

- Typically, at least two Sequencing Batch Reactors (SBR) are needed to accommodate a system with continuous influent flow.
- A SBR system can typically finish from two to six complete processing cycles per day.
- A typical SBR cycle contains the following stages: fill, react, settle, decant and idle.
- SBR systems are usually deeper than conventional activated sludge aeration tanks.
- Sludge wasting occurs intermittently on an as needed basis in the SBR.
- A Programmable Logic Controller (PLC) controls the operation of the mechanical equipment and the timing of the treatment stages in a SBR process.

Exercise for Unit 2 – The Sequencing Batch Reactor

1. The maximum operating depth of a typical SBR system ranges from _________ to ___________ 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 _________________ __________________ ________________. 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.
   ____
   ____
   ____
   b.
   ____
   ____
   ____
   c.
   ____
   ____
   ____
   d.
   ____
   ____
   ____
   e.
   ____
   ____
   ____

[1] California State University, Sacramento, Department of Civil Engineering, *Operation of Wastewater Treatment Plants, Volume II, 5th ed.*, (Sacramento, CA: The California State University, Sacramento Foundation), page 95, figure 11.29.

[2] Operation *of Wastewater Treatment Plants*, p. 96, figure 11.30.

[3] Operation *of Wastewater Treatment Plants* page 98, figure 11.31.

[4] *Operation of Wastewater Treatment Plants*, p. 101, figure 11.34.

[5] *Operation of Wastewater Treatment Plants*, p. 100, figure 11.33.

[6] *Operation of Wastewater Treatment Plants*, p. 102, figure 11.35.

[7] Operation *of Wastewater Treatment Plants*, p. 104, figure 11.36.

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Unit 3 – Pure Oxygen Activated Sludge

Learning Objectives

- 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.

What is a Pure Oxygen Activated Sludge System?

Modifications of the Activated Sludge Process Using Oxygen

The Pure Oxygen System has the following characteristics, which are modifications of the Activated Sludge Process.

- It uses a high-purity oxygen gas rather than atmospheric air to dissolve oxygen in wastewater.
- It uses covered reactor tanks to maximize the use of the high purity oxygen.
- High purity oxygen gas must be created on site (from air) or shipped in and stored on site in large tanks.

Typical System Configuration

- The pure oxygen system uses covered reactor tanks so that more of the oxygen can be transferred to the wastewater and to maintain a small positive gas pressure over each reactor.
- Several reactors are used in series.
- Spent gas from the first stage reactor and each successive reactor stage is used as the feed gas in the next stage.
    - The concentration of oxygen remains very high throughout the stages.
    - Although the oxygen gas becomes diluted with carbon dioxide, nitrogen, and other stripped gases, it is typically reused until the oxygen concentration drops below a specified threshold.
- As spent gas is vented from the last reactor, pure oxygen is added to the first reactor to maintain the desired pressure in the system.

Figure 3.1, below, presents a schematic drawing of a typical pure oxygen system using surface aerators for oxygen transfer. Oxygen-rich gas can also be compressed and introduced into the wastewater beneath the surface.

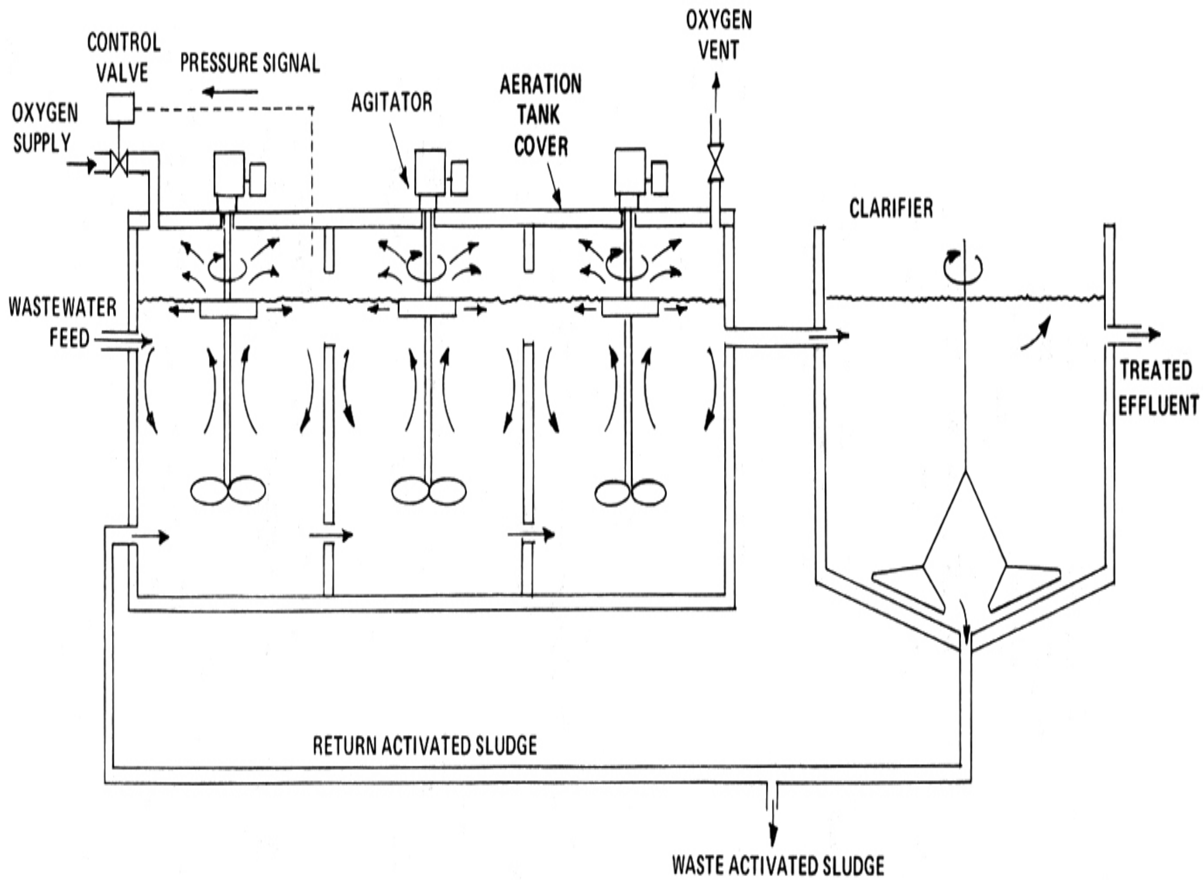


Figure 3.1 Schematic Drawing of a Pure Oxygen System using Surface Aerators[1]

Advantages of Pure Oxygen Systems

Some of the advantages of this system include:

- Providing greater wastewater oxygenation capacity.
- Allowing greater MLSS concentration.
- Allowing greater volumetric loading.
- Extending the useful life of overloaded facilities.
- Reducing air emissions.
- Providing better sludge settleability.

Disadvantages of Pure Oxygen Systems

As with all systems, there are some disadvantages to Pure Oxygen Systems, including:

- Creating higher capital costs.
- Having complexity in the system.
- Creating potential safety concerns.

System Components

The three components of the system include reactors, oxygen generating systems, and mixing equipment.

Reactors

Pure Oxygen Systems use a series of covered, complete-mix reactors to maximize the use of the high-purity oxygen gas. A small amount of gas pressure is maintained over each reactor.

- The aeration tank is baffled to create a series of complete-mix reactors. Oxygen gas that does not dissolve in the wastewater in one reactor is reused in the succeeding reactor.
- Although the oxygen gas becomes diluted with carbon dioxide, nitrogen, and other stripped gases, it is typically used until it drops below a 50% concentration. As spent gas is vented from the last reactor, pure oxygen is added to the first reactor to maintain the desired pressure in the system.

Oxygen Generating Systems

Two methods are commonly used to produce oxygen on site: PSA, or Pressure Swing Adsorption and Cryogenic Air Separation.

- PSA systems use a molecular sieve to separate all constituents out of atmospheric air, except for oxygen, which passes through.
- Cryogenic Air Separation systems use a very low temperature process to separate oxygen from air.

These oxygen generating systems are covered more fully in the next section.

Mixing Equipment

The dissolution of oxygen into the wastewater is facilitated by mixing equipment. The mixing is accomplished by mechanical or jet aerators.

Mechanical Aeration

- Mechanical surface aerators rely on surface turbulence and gas entrainment to dissolve the oxygen into the wastewater.
- Sparged turbines may also be used but these require the oxygen to be supplied under pressure to the submerged diffusers.

Jet Aeration

- Jet aerators combine a liquid motive force and a gas stream to mix and distribute gas directly into the subsurface of the wastewater. In this case, the oxygen must also be pressurized.

Proprietary Mixers

- Proprietary mixers, designed specifically for pure oxygen wastewater treatment, may have an oxygen dissolution efficiency of more than 90%.

Pressure Swing Adsorption

Remember that a constant supply of oxygen must be available for the Pure Oxygen Activated Sludge System.

Operating Principles

- PSA systems use a molecular sieve to separate all constituents out of atmospheric air, except for oxygen, which passes through.
  - For economic reasons, these systems are used in smaller treatment plants.
- Typically, multiple PSA modules are required so that one is in the supply mode while one or more are in the preparation mode.
- A PSA system has a wide operating range so that the system output can be adjusted to match the oxygenation requirements.
- A backup supply of liquid oxygen is generally used to handle the peak demand associated with smaller plants.

System Configuration

- Atmospheric air is compressed to 30-60 pounds per square inch (PSI), and then cooled to remove the heat of compression and condense out the moisture.
- The air stream then passes through a molecular sieve adsorber to separate oxygen from other components.
- Nitrogen and other impurities are retained on the adsorber, while oxygen passes through and is sent to the activated sludge process.

A three bed process is diagrammed on the next page for your review.

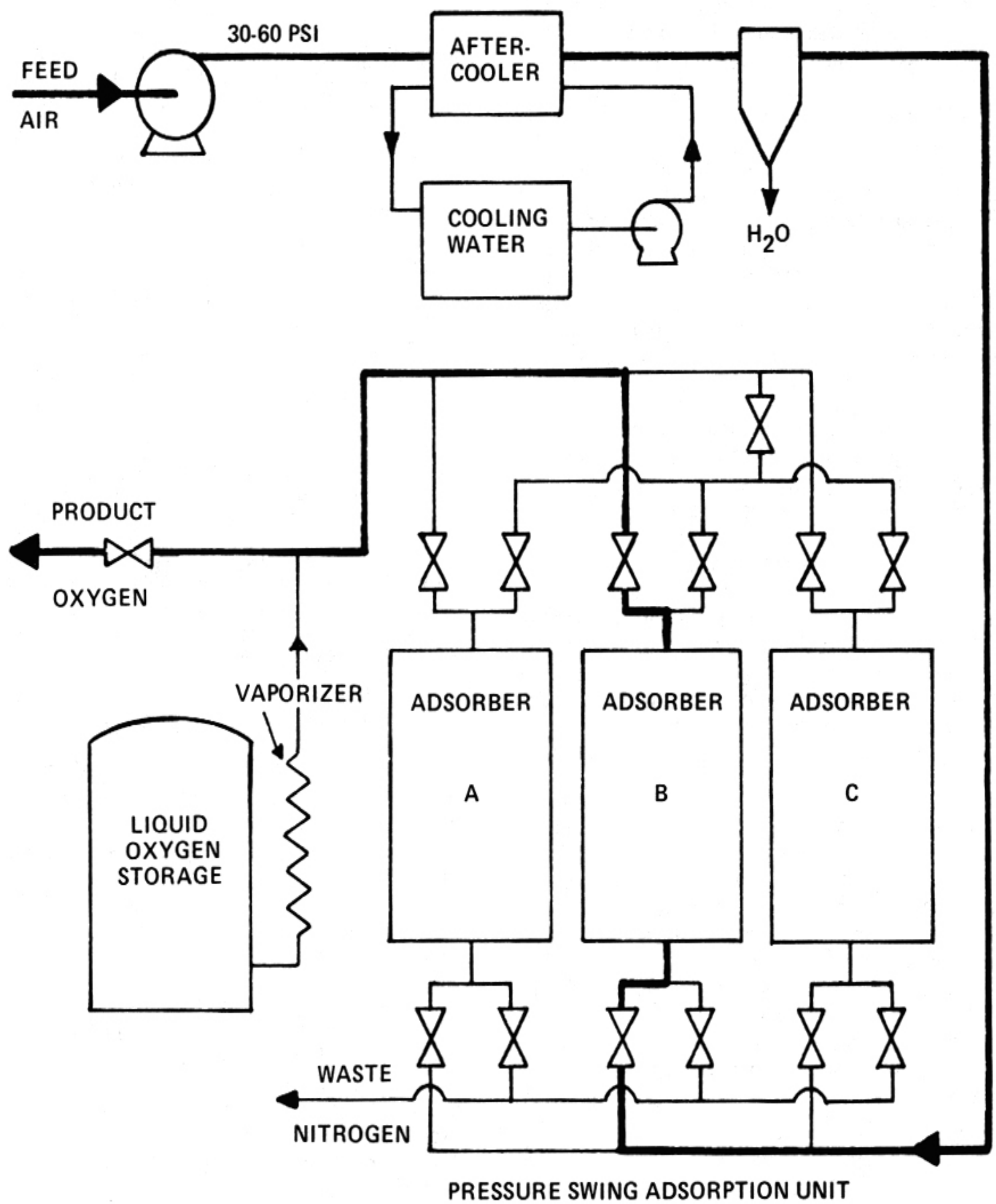


Figure 3.2 Three-Bed Pressure Swing Adsorption (PSA) Oxygen Generating System[2]

Cryogenic Air Separation

Remember that a constant supply of oxygen must be available for the Pure Oxygen Activated Sludge System.

Operating Principles

- Cryogenic Air Separation systems use a very low temperature process to separate oxygen from air.
  - Following initial purification, the air is liquefied, and then oxygen and nitrogen are separated by a fractional distillation process.
  - Before use, the oxygen, which is approximately 98% pure, is warmed.
- The process is complex and energy intensive.
- Cryogenic systems can produce liquid oxygen for on site storage when capacity exceeds demand.
- A backup supply of liquid oxygen is usually used to handle the peak demand or during cryogenic system maintenance.
- In large treatment plants, multiple cryogenic systems would be used to provide backup.

System Configuration

- Atmospheric air is filtered, compressed, and cooled to remove the heat of compression.
- Air is then reduced to a low temperature through the reversing heat exchanger where impurities are deposited. A nitrogen vapor stream removes the impurities during the reverse flow mode.
- The air stream then passes through a gel filter (molecular sieve) to remove residual impurities, including any residual water.
- Finally, the air is cooled until it liquefies; then a distillation column is used to separate liquid nitrogen from liquid oxygen.
  - The oxygen stream at this point is approximately 98% oxygen.
- Most of the oxygen is removed as a gas, warmed, and sent to the activated sludge process. Some liquid oxygen may be produced and sent to storage.

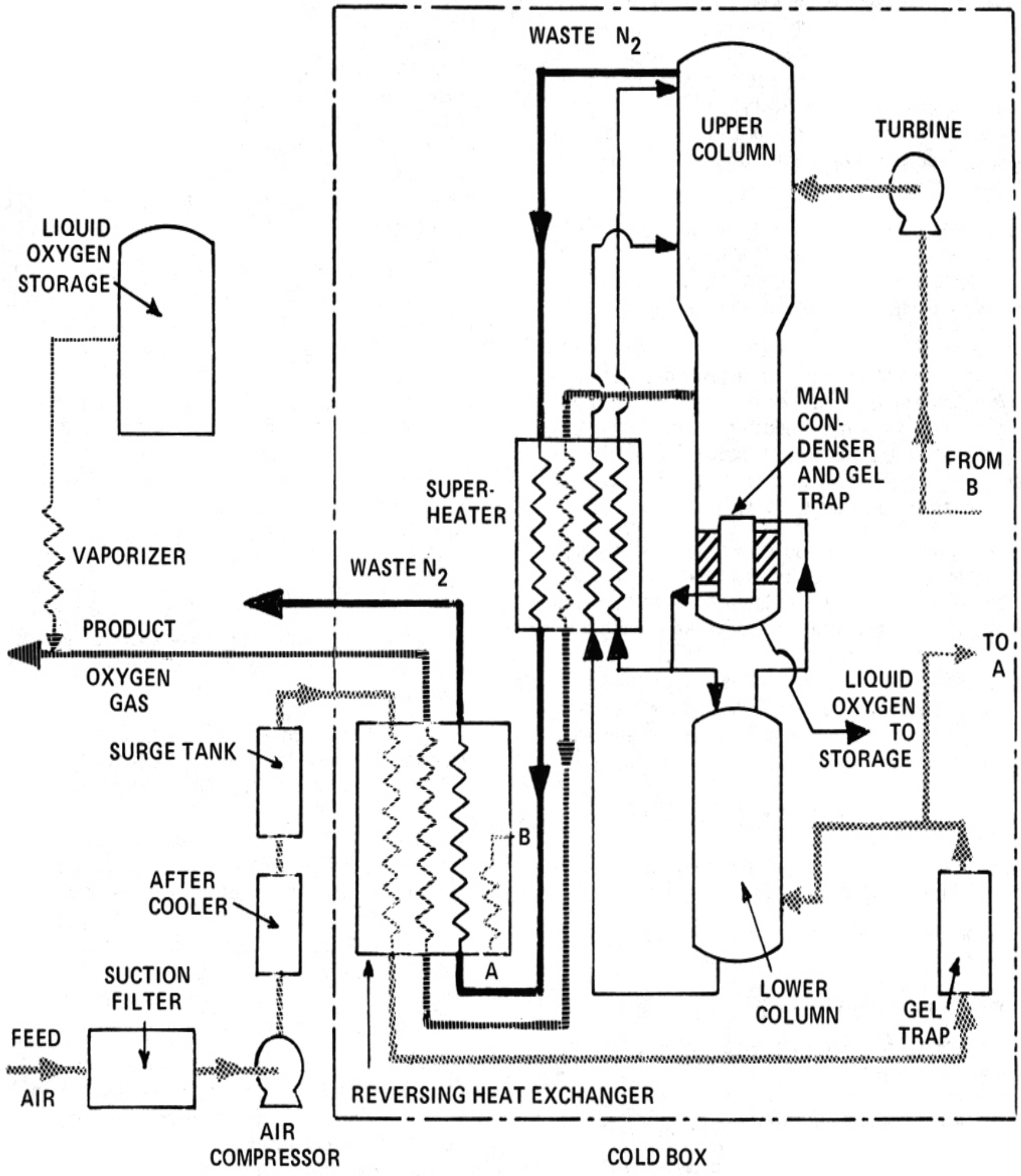


Figure 3.3 Cryogenic Oxygen Generating System[3]

The control parameters that are specific to the pure oxygen process include: reactor vent gas; reactor gas space pressure; and dissolved oxygen. These items are the focus of this section.

Reactor Vent Gas

Monitoring

- A mixture of unused oxygen, inert gases, and carbon dioxide is continually discharged from the last stage of the pure oxygen system.
- The percentage of oxygen in the discharge stream can be used to monitor the performance of the pure oxygen system.

Control

- The oxygen concentration will be allowed to fluctuate within a specified range, based upon the plant's operating history.
- If the situation warrants it, the operator can make manual valve adjustments to bring the system back into the normal operating range.

Reactor Gas Space Pressure

Monitoring

- The pressure of the gas in the space above each reactor, as well as the oxygen concentration, affects the performance of the pure oxygen system.
- The gas pressure normally is set at approximately two to four inches water column in the first stage reactor.
- The oxygen feed system is designed to maintain the pressure by increasing oxygen flow when the pressure is below the set point, and decreasing oxygen flow when the pressure is above the set point.

Control

- During periods of high loading, the operator may choose to increase the set point to dissolve more oxygen into the wastewater.

Dissolved Oxygen

Monitoring

- An oxygen probe is often used in the final stage reactor to monitor system performance.

- Pure oxygen systems operate with a usual dissolved oxygen concentration of approximately 4 milligrams per liter (mg/L) to 10 mg/L.

Control

- If the dissolved oxygen concentration drops below 4 mg/L, the operator might choose to open the vent valve wider, which would cause an increase in the flow of oxygen into the first stage of the system and would increase the dissolved oxygen concentration in the wastewater.

- Conversely, a sustained period above 10 mg/L might warrant closing the vent valve more to reduce the flow of oxygen to the system.

Process Safety

Oxygen atmospheres greater than normal increase the potential for development of explosive and flammable conditions.

Potentially Explosive Atmosphere

- The components of an explosive or flammable atmosphere include: oxygen; fuel; and an ignition source.

- To monitor the condition of the reactors, pure oxygen reactors are typically fitted with Lower Explosive Limit (LEL) combustible gas detectors.
    - If the LEL reading exceeds a certain threshold, the gas space in the reactors will be automatically purged with air to reduce the potential for explosion or fire.
    - If the condition should worsen, mixers may be shut down to minimize stripping of hydrocarbons from the wastewater while the purging of the gas space continues.

- To prevent an ignition source from developing, no electrical wiring is installed within the gas space, and equipment is designed to prevent metal-to-metal contact.

Liquid Oxygen (LOX) Storage

- Almost all pure oxygen activated sludge systems will have liquid oxygen storage.

- Liquid oxygen storage systems are equipped with alarms to monitor and shut down the liquid storage system in case out-of-specification conditions arise.

- A low temperature alarm is used to indicate when the temperature of the oxygen gas being sent to the activated sludge reactor has dropped below the threshold value. An alarm will sound if the vapor temperature falls below – 10^0 F (- 23^0 C). An alarm will sound and the system will shut down if the temperature reaches – 20^0 F (- 29^0 C).

- If the condition is not corrected, a further decrease in the temperature of the oxygen gas may cause the oxygen storage system to automatically shut down; manual restart would be required.

Alarms and Emergency Disconnects

- Oxygen generation systems are equipped with safety features that automatically operate to control system parameters within specified safety ranges.

- Alarms may be actuated to alert operators to conditions that are outside normal ranges.
- Emergency trip switches are provided that allow operators to manually shut down the oxygen generating system in the event of extreme emergency.

Operator Safety

Personnel Protection Equipment

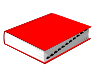
- Liquid oxygen is extremely cold; oxygen gas may also be very cold.

- Operators need to take special care to avoid contact with liquid oxygen, in particular, which can cause skin burns on contact and tissue damage with prolonged contact.

- When the potential for oxygen release exists, standard equipment should include:
  - Eye and face protection.
  - Clean insulated gloves.
  - Long sleeve shirts.
  - Long pants.

Material Handling Considerations

- A combustion hazard exists.
  - Pure oxygen supports and accelerates combustion more readily than air.
- Isolate combustible materials from liquid oxygen.
  - Operators performing maintenance must be familiar with special precautions required when servicing oxygen equipment.
  - Use only materials and tools specified by the manufacturer.
  - Use only authorized oxygen-handling equipment, which is designed to avoid the use of combustible materials and is intrinsically safe.



Intrinsically Safe refers to a device, instrument or component that will not produce any spark or thermal effects under any conditions that are normal or abnormal that will ignite a specified gas mixture. Electrical and thermal energy limits are at levels incapable of causing ignition. It is common practice to use external barriers with intrinsically safe installations.

  - The work area must be free of combustible materials, including asphalt.

- MSDS Data
  - Operators must be familiar with MSDS data for materials handled, especially related to oxygen interactions.

Liquid Oxygen Spill Response

Operators should be aware of and/or consult their site-specific procedures while keeping the following points in mind.

- *Avoid personal contact with spill area.*

  Contacting the spill area could introduce combustible materials and ignition sources (such as friction) into the area. This could create a fire or explosion hazard.

- *Frost marks from a spill indicate active danger.*

  Frost marks from a liquid oxygen spill indicate that liquid is still present on the surface; a fire or explosion hazard exists. While frost remains, avoid all contact with the area, including contact with the vapors.

- *Eliminate nearby ignition sources from vapor.*

  Ignition sources include more than just open flames and electrical equipment. Any spark or static electricity could provide the ignition source to set off a fire or explosion in a spill area.

- *Wait for natural dissipation of vapor.*

  In open areas, natural dissipation of oxygen vapors could occur rapidly. Dissipation can be checked using intrinsically safe monitoring equipment. If a fog develops from condensation of water vapors in the air, the area must be isolated and evacuated immediately and until the oxygen has dissipated.

- *Force ventilation of low-lying areas.*

  In some instances, forced ventilation might be required. This should only be done by using appropriate equipment and following specified protocol. Because oxygen is heavier than air, spills of liquid oxygen into low areas may not dissipate naturally.

- *Monitor the oxygen level in the air.*

  Throughout the activities associated with an oxygen spill, air monitoring should be conducted in order to track the progress of spill cleanup. Only appropriate, intrinsically safe equipment should be used.

Key Points for Unit 3 – Pure Oxygen Activated Sludge

- A Pure Oxygen System uses a high-purity oxygen gas rather than atmospheric air to dissolve oxygen in wastewater.
- The pure oxygen system uses covered reactor tanks so that more of the oxygen can be transferred to the wastewater and to maintain a small positive gas pressure over each reactor.
- Although the oxygen gas becomes diluted with carbon dioxide, nitrogen, and other stripped gases, it is typically reused until the oxygen concentration drops below a specified threshold.
- The three components of a pure oxygen activated sludge system include reactors, oxygen generating systems, and mixing equipment.
- Two methods are commonly used to produce oxygen on site: PSA, or Pressure Swing Adsorption and Cryogenic Air Separation.
- The dissolution of oxygen into the wastewater is facilitated by mixing equipment. The mixing is accomplished by mechanical or jet aerators.
- Remember that a constant supply of oxygen must be available for the Pure Oxygen Activated Sludge System.
- PSA systems use a molecular sieve to separate all constituents out of atmospheric air, except for oxygen, which passes through.
- Cryogenic Air Separation systems use a very low temperature process to separate oxygen from air.
- The control parameters that are specific to the pure oxygen process include: reactor vent gas; reactor gas space pressure; and dissolved oxygen
- Oxygen atmospheres greater than normal increase the potential for development of explosive and flammable conditions.
- Operators need to take special care to avoid contact with liquid oxygen, in particular, which can cause skin burns on contact and tissue damage with prolonged contact.
- Operators must be familiar with MSDS data for materials handled, especially related to oxygen interactions.
- Frost marks from a liquid oxygen spill indicate that liquid is still present on the surface; a fire or explosion hazard exists. While frost remains, avoid all contact with the area, including contact with the vapors.

The following case study is intended as a review of Module 17. Use the information presented in all three units of this module to consider a solution to the case study.

A wastewater treatment facility has an average daily influent flow rate of 5 million gallons, including the contribution from a local industry of 1.0 million gallons per day.

The aeration facilities are comprised of two conventional activated sludge aeration tanks operating in parallel; each tank is 40 feet wide by 125 feet long by 15 feet operating depth.

The municipal portion of the flow has a typical daily flow distribution; however, the industrial flow peaks in the early morning and again in the early evening. During each peak, approximately 40% of the industrial flow occurs over a 3 hour period.

The treatment facility has been experiencing general performance problems, but especially during the peak industrial flow periods. The blower capacity is maxed out during these periods, but still cannot overcome the performance problems (generally low DO).

The town council has been considering investigating an upgrade of the treatment facility. What recommendations would you make, what information would you need, and what are the pros and cons of your recommendation?

[1] California State University, Sacramento, Department of Civil Engineering, *Advanced Waste Treatment, 3rd ed.*, (Sacramento, CA: The California State University, Sacramento Foundation), p 56.

[2] *Advanced Waste Treatment,* p 58.

[3] *Advanced Waste Treatment*, p 59.