

# CHAPTER 7

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## ACTIVATED SLUDGE

### 7.1 General

#### 7.1.1 Applicability

The activated sludge process and its various modifications may be used where sewage is amenable to biological treatment. This process requires close attention and more competent operator supervision than some of the other biological processes. A treatability study may be required to show that the organics are amendable to the proposed treatment. For example, industrial wastewaters containing high levels of starches and sugars may cause interferences with the activated sludge process due to bulking.

Toxic loadings from industries and excessive hydraulic loadings must be avoided to prevent the loss or destruction of the activated sludge mass. If toxic influents are a possibility, a properly enforced industrial pretreatment program will prove extremely beneficial to the WWTP and will be required. It takes days and sometimes weeks for the plant to recover from a toxic overload and will likely result in permit violations. Flow equalization, as detailed in Chapter 4, may be required in some instances. These requirements shall be considered when proposing this type of treatment.

#### 7.1.2 Process Selection

The activated sludge process and its several modifications may be employed to accomplish varied degrees of removal of suspended solids and reduction of BOD and ammonia. Choice of the process most applicable will be influenced by the proposed plant size, type of waste to be treated, and degree and consistency of treatment required. All designs should provide for flexibility to incorporate as many modes of operation as is reasonably possible.

Calculations and/or documentation shall be submitted to justify the basis of design for the following:

- a. Process efficiency
- b. Aeration tanks
- c. Aeration equipment (including oxygen and mixing requirements)
- d. Operational rationale (including maintenance)
- e. Costs (capital and operating)

In addition, the design must comply with any requirements set forth in other chapters such as clarifiers, sludge processing, etc.

### 7.1.3 Pretreatment

Where primary settling tanks are not used, effective removal or exclusion of grit, debris, excessive oil or grease, and comminution or screening of solids shall be accomplished prior to the activated sludge process.

Where primary settling is used, provisions should be made for discharging raw sewage directly to the aeration tanks to facilitate plant start-up and operation during the initial stages of the plant's design life. Also, primary effluents are often low in D.O. This should be planned for in the design.

## 7.2 Types of Processes

Figure 7.1 shows the flow schematics of the major types of activated sludge processes, excluding pretreatment. The types that are simply modifications of these processes are not shown.

### 7.2.1 Conventional

Conventional activated sludge is characterized by introduction of influent wastewater and return activated sludge at one end of the aeration tank, a plug-flow aeration tank, and diffused aeration.

### 7.2.2 Complete Mix

Complete mix activated sludge is characterized by introduction of influent wastewater and return activated sludge throughout the aeration basin and the use of a completely mixed aeration tank. Complete mix aeration tanks may be arranged in series to approximate plug flow and conventional activated sludge.

### 7.2.3 Step Aeration

Step aeration activated sludge is characterized by introduction of the influent wastewater at two or more points in the aeration tank, use of a plug-flow aeration tank, and diffused aeration.

### 7.2.4 Tapered Aeration

Tapered aeration is similar to conventional activated sludge except that the air supply is tapered to meet the organic load within the tank. More air is added to the influent end of the tank where the organic loading and oxygen demand are the greatest.

### 7.2.5 Contact Stabilization

Contact stabilization activated sludge is characterized by the use of two aeration tanks for each process train, one to contact the influent wastewater and return activated sludge (contact tank) and the other to aerate the return activated sludge (stabilization tank) and promote the biodegradation of the organics absorbed to the bacterial flocs.

### 7.2.6 Extended Aeration

Extended aeration activated sludge is characterized by a low F/M ratio, long sludge age, and long aeration tank detention time (greater than 18 hours). For additional details on oxidation ditches see Section 7.7).

### 7.2.7 High-Rate Aeration

High-rate aeration activated sludge is characterized by high F/M ratio, low sludge age, short aeration tank detention time, and high mixed-liquor suspended solids. High-rate aeration should be followed by other BOD and suspended solids removal processes to provide secondary treatment.

### 7.2.8 High-Purity Oxygen

High-purity oxygen activated sludge is characterized by the use of high-purity oxygen instead of air for aeration.

### 7.2.9 Kraus Process

Kraus process activated sludge is characterized by use of an aeration tank to aerate a portion of the return activated sludge, digester supernatant, and digested sludge in order to provide nitrogen (ammonia) to a nitrogen-deficient wastewater.

### 7.2.10 Sequencing Batch Reactors (SBR)

The SBR process is a fill-and-draw, non-steady state activated sludge process in which one or more reactor basins are filled with wastewater during a discrete time period, and then operated in a batch treatment mode. SBR's accomplish equalization, aeration, and clarification in a timed sequence. For additional details see Section 7.6.

## 7.3 Aeration Tanks

### 7.3.1 Required Volume

The size of the aeration tank for any particular adaptation of the process shall be based on the food-to-microorganism (F/M) ratio, using the influent BOD (load per day) divided by the mixed-liquor volatile suspended solids. Alternatively, aeration tanks may be sized using sludge age. The calculations using the F/M ratio or sludge age shall be based on the kinetic relationships.

**APPENDIX 7A** shows the permissible range of F/M ratio, sludge age, mixed-liquor suspended solids, aeration tank detention time, aerator loading, and activated sludge return ratio for design of the various modifications of the activated sludge process. All design parameters shall be checked to determine if they fall within the permissible range for the selected F/M ratio or sludge area and the aeration tank size. Diurnal load variations and peak loadings must be considered when checking critical parameters.

### 7.3.2 Shape and Mixing

The dimensions of each independent mixed-liquor aeration tank or return sludge reaeration tank should be such as to maintain effective mixing and utilization of air when diffused air is used. Liquid depths should not be less than 10 feet or more than 30 feet except in special design cases. For plug-flow conditions using very small tanks or tanks with special configuration, the shape of the tank and/or the installation of aeration equipment should provide for elimination of short-circuiting through the tank.

Aerator loadings should be considered and the horsepower per 1,000 cubic feet of basin volume required for oxygen transfer should be limited to prevent excessive turbulence in the aeration basins, which might reduce activated sludge settleability.

### 7.3.3 Number of Units

Multiple tanks capable of independent operation may be required for operability and maintenance reasons, depending on the activated sludge process, size of the plant, and the reliability classification of the sewerage works (refer to Section 1.3.11).

## 7.3.4 Inlets and Outlets

### 7.3.4.1 Controls

Inlets and outlets for each aeration tank unit in multiple tank systems should be suitably equipped with valves, gates, stop plates, weirs, or other devices to permit control of the flow and to maintain reasonably constant liquid level. The hydraulic properties of the system should permit the maximum instantaneous hydraulic load to be carried with any single aeration tank unit out of service.

### 7.3.4.2 Conduits

Channels and pipes carrying liquids with solids in suspension should be designed to maintain self-cleaning velocities or should be agitated to keep such solids in suspension at all rates of flow within the design limits.

### 7.3.4.3 Hydraulics

Where multiple aeration tanks and secondary clarifiers are used, provisions should be made to divide the flow evenly to all aeration tanks in service and then recombine the flows, and to divide the flow evenly to all secondary clarifiers in service and then recombine the flows. Treatment plants using more than four aeration tanks and secondary clarifiers may divide the activated sludge systems into two or more process trains consisting of not less than two aeration tanks and secondary clarifiers per process train.

### 7.3.4.4 Bypass

When a primary settling tank is used, provisions shall also be made for discharging raw wastewater directly to the aeration tanks following pretreatment for start-ups.

## 7.3.5 Measuring Devices

For plants designed for less than 250,000 gallons per day, devices shall be installed for indicating flow rates of influent sewage, return sludge, and air to each aeration tank. For plants designed for greater than 250,000 gallons per day, devices shall be installed for totalizing, indicating, and recording influent sewage and returned sludge to each aeration tank. Where the design provides for all returned sludge to be mixed with the raw sewage (or primary effluent) at one location, the mixed-liquor flow rate to each aeration tank shall be measured, and the flow split in such a manner to provide even loading to each tank, or as desired by operations.

### 7.3.6 Freeboard and Foam Control

Aeration tanks shall have a freeboard of at least 18 inches. Freeboards of 24 inches are desirable with mechanical aerators.

Consideration shall be given for foam control devices on aeration tanks. Suitable spray systems or other appropriate means will be acceptable. If potable water is used, approved backflow prevention shall be provided on the water lines. The spray lines shall have provisions for draining to prevent damage by freezing.

### 7.3.7 Drain and Bypass

Provisions shall be made for dewatering each aeration tank for cleaning and maintenance. The dewatering system shall be sized to permit removal of the tank contents within 24 hours. If a drain is used, it shall be valved. The dewatering discharge shall be upstream of the activated sludge process.

Provisions shall be made to isolate each aeration tank without disrupting flow to other aeration tanks.

Proper precautions shall be taken to ensure the tank will not "float" when dewatered.

### 7.3.8 Other Considerations

Other factors that might influence the efficiency of the activated sludge process should be examined. Septic and/or low pH influent conditions are detrimental, particularly where primary clarifiers precede the activated sludge process or when the collection system allows the sewage to go septic. Often, the pH is buffered by the biological mass, but wide variations in the influent should be avoided and, if present, chemical addition may be necessary.

Aerobic organisms require minimum quantities of nitrogen and phosphorus. Domestic wastewater usually has an excess of nitrogen and phosphorus; however, many industrial wastewaters are deficient in these elements. A mass balance should be performed to see if the combined industrial and domestic influent contains sufficient nitrogen and phosphorus or if nutrient levels will have to be supplemented.

## 7.4 Aeration Equipment

### 7.4.1 General

Oxygen requirements generally depend on BOD loading, degree of treatment, and level of suspended solids concentration to be maintained in the aeration tank mixed liquor. Aeration equipment shall be designed to supply sufficient oxygen to maintain a minimum dissolved oxygen concentration of 2 milligrams per liter (mg/l) at average design load and 1.0 mg/l at peak design loads throughout the mixed liquor. In the absence of experimentally determined values, the design oxygen requirements for all activated sludge processes shall be 1.1 lbs oxygen per lb peak BOD<sub>5</sub> applied to the aeration tanks, with the exception of the extended aeration process, for which the value shall be 2.35. Aeration equipment shall be of sufficient size and arrangement to maintain velocities greater than 0.5 foot per second at all points in the aeration tank.

The oxygen requirements for an activated sludge system can be estimated using the following relationship:

$$O_2 = (a) (BOD) + b (MLVSS)$$

$$O_2 = \text{pounds of oxygen required per day}$$

$$BOD = \text{pounds of BOD removed per day (5-day BOD)*}$$

$$MLVSS = \text{pounds of mixed liquor volatile suspended solids contained in the aeration basin}$$

$$a = \text{amount of oxygen required for BOD synthesis. "a" will range from 0.5 to 0.75 pound of oxygen per pound of BOD removed}$$

$$b = \text{amount of oxygen required for endogenous respiration or decay. "b" will range from 0.05 to 0.20 pound of oxygen per pound of MLVSS}$$

\*BOD removal shall be calculated as influent BOD<sub>5</sub> minus soluble effluent BOD<sub>5</sub>.

For preliminary planning before process design is initiated, a rough estimate can be obtained by using 1.0 to 1.2 pounds of oxygen per pound of BOD removed (assuming no nitrification).

## 7.4.2 Diffused Air Systems

### 7.4.2.1 Design Air Requirements

The aeration equipment shall be designed to provide the oxygen requirements set forth above. Minimum requirements for carbonaceous removal are shown below. (Oxygen requirements for nitrification are in addition to that required for carbonaceous removal where applicable; i.e., low F/M.)

| <u>Process</u>                                                   | <u>Cubic Feet of Air Available per Pound of BOD Load Applied to Aeration Tank</u> |
|------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Conventional                                                     | 1,500                                                                             |
| Step Aeration                                                    | 1,500                                                                             |
| Contact Stabilization                                            | 1,500                                                                             |
| Modified or "High Rate"<br>(depending upon BOD removal expected) | 400 to 1,500                                                                      |
| Extended Aeration                                                | 2,100                                                                             |

Air required for channels, pumps, or other air-use demand shall be added to the air volume requirements.

Manufacturers' specifications must be corrected to account for actual operation conditions (use a worst case scenario). Corrections shall be made for temperatures other than 20°C and elevations greater than 2,000 feet.

### 7.4.2.2 Special Details

The specified capacity of blowers or air compressors, particularly centrifugal blowers, shall take into account that the air intake temperature might reach extremes and that pressure might be less than normal. Motor horsepower shall be sufficient to handle the minimum and maximum ambient temperatures on record.

The blower filters shall be easily accessible. Spare filters should be provided.

The blowers shall be provided in multiple units, arranged and in capacities to meet the maximum air demand with the single largest unit out of service. The design shall also provide for varying the volume of air delivered in proportion to the load demand of the plant.

The spacing of diffusers shall be in accordance with the oxygen and mixing requirements in the basin. If only one aeration tank is proposed, arrangement of

diffusers should permit their removal for inspection, maintenance, and replacement without de-watering the tank and without shutting off the air supply to other diffusers in the tank.

Individual units of diffusers shall be equipped with control valves, preferably with indicator markings, for throttling or for complete shutoff. Diffusers in each assembly shall have substantially uniform pressure loss. The adjustment of one diffuser should have minimal influence on the air supply rate to any other diffusers.

Flow meters and throttling valves shall be placed in each header. Air filters shall be provided as part of the blower assembly to prevent clogging of the diffuser system. Means shall be provided to easily check the air filter so that it will be replaced when needed.

#### 7.4.3 Mechanical Aeration Equipment

Power input from mechanical aerators should range from 0.5 to 1.3 horsepower per 1,000 cubic feet of aeration tank.

The mechanism and drive unit shall be designed for the expected conditions of the aeration tank in terms of the proven performance of the equipment.

Due to the high heat loss, consideration shall be given to protecting subsequent treatment units from freezing where it is deemed necessary. Multiple mechanical aeration unit installations shall be designed to meet the maximum oxygen demand with the largest unit out of service. The design shall normally also provide for varying the amount of oxygen transferred in proportion to the load demand on the plant.

A spare aeration mechanism shall be furnished for single-unit installations. Access to the aerators shall be provided for routine maintenance.

#### 7.4.4 Flexibility and Energy Conservation

The design of aeration systems shall provide adequate flexibility to vary the oxygen transfer capability and power consumption in relation to oxygen demands. Particular attention should be given to initial operation when oxygen demands may be significantly less than the design oxygen demand. The design shall always maintain the minimum mixing levels; mixing may control power requirements at low oxygen demands.

Dissolved oxygen probes and recording should be considered for all activated sludge designs. Consideration will be given to automatic control of aeration system oxygen transfer, based on aeration basin dissolved oxygen concentrations, provided manual back-up operation is available. A dissolved oxygen field probe and meter is to be provided for all activated sludge installations.

Watt-hour meters shall be provided for all aeration system drives to record power usage.

Energy conservation measures shall be considered in design of aeration systems. For diffused aeration systems, the following shall be considered:

- a. Use of small compressors and more units
- b. Variable-speed drives on positive-displacement compressors
- c. Intake throttling on centrifugal compressors
- d. Use of timers while maintaining minimum mixing and D.O. levels (consult with manufacturer's recommendations for proper cycling)
- e. Use of high-efficiency diffusers
- f. Use of separate and independent mixers and aerators

For mechanical aeration systems, the following shall be considered:

- a. Use of smaller aerators
- b. Variable aeration tank weirs
- c. Multiple-speed motors
- d. Use of timers

## **7.5 Additional Details**

### **7.5.1 Lifting Equipment and Access**

Provisions shall be made to lift all mechanical equipment and provide sufficient access to permit its removal without modifying existing or proposed structures.

### **7.5.2 Noise and Safety**

Special consideration shall be given to the noise produced by air compressors used with diffused aeration systems and mechanical aerators. Ear protection may be required. Silencers for blowers may be required in sensitive areas.

Handrails shall be provided on all walkways around aeration tanks and clarifiers.

The following safety equipment shall be provided near aeration tanks and clarifiers:

Safety vests  
Lifelines and rings  
Safety poles

Walkways near aeration tanks shall have a roughened surface or grating to provide safe footing and be built to shed water.

Guards shall be provided on all moving machinery in conformance with OSHA requirements.

Sufficient lighting shall be provided to permit safe working conditions near aerations tanks and clarifiers at night.

## **7.6 Sequencing Batch Reactors (SBRs)**

SBRs shall be designed to meet all the requirements set forth in preceding sections on activated sludge. Special consideration shall be given to the following:

- 7.6.1 A pre-aeration, flow-equalization basin is to be provided for when the SBR is in the settle and/or draw phases. If multiple SBR basins are provided, a pre-aeration basin will not be needed if each SBR basin is capable of handling all the influent peak flow while another basin is in the settle and/or draw phase.
- 7.6.2 When discharging from the SBR, means need to be provided to avoid surges to the succeeding treatment units. The chlorine contact tank shall not be hydraulically overloaded by the discharge.
- 7.6.3 The effluent from the SBRs shall be removed from just below the water surface (below the scum level) or a device which excludes scum shall be used. All decanters shall be balanced so that the effluent will be withdrawn equally from the effluent end of the reactor.
- 7.6.4 Prevailing winds must be considered in scum control.

## **7.7 Oxidation Ditch**

### **7.7.1 General**

The oxidation ditch is a complete-mixed, extended aeration, activated sludge process which is operated with a long detention time. Brush-rotor (or disk type) aerators are normally used for mixing and oxygen transfer. All requirements set forth in previous sections and/or chapters must be met, with the exception of those items addressed below.

## 7.7.2 Special Details

### 7.7.2.1 Design Parameters

The design parameters shall be in the permissible range as set forth in Table 7.1 for F/M, sludge age, MLSS, detention time, aerator loading, and activated sludge return ratio.

### 7.7.2.2 Aeration Equipment

Aeration equipment shall be designed to transfer 2.35 pounds of oxygen per pound of BOD at standard conditions. The oxygen requirement takes into account nitrification in a typical wastewater. Also, a minimum average velocity of one foot per second shall be maintained, based on the pumping rate of the aeration equipment and the aeration basin cross-sectional area.

A minimum of two aerators per basin is required.

### 7.7.2.3 Aeration Tank Details

#### a. Influent Feed Location

Influent and return activated sludge feed to the aeration tank should be located just upstream of an aerator to afford immediate mixing with mixed liquor in the channel.

#### b. Effluent Removal Location

Effluent from the aeration channel shall be upstream of an aerator and far enough upstream from the injection of the influent and return activated sludge to prevent short-circuiting.

#### c. Effluent Adjustable Weir

Water level in the aeration channel shall be controlled by an adjustable weir or other means. In calculating weir length, use peak design flow plus maximum recirculated flow to prevent excessive aerator immersion.

#### d. Walkways and Splash Control

Walkways must be provided across the aeration channel to provide access to the aerators for maintenance. The normal location is above the aerator. Splash guards shall be provided to prevent spray from the aerator on the walkway. Bridges should not be subject to splash from the rotors.

- e. Baffles  
Horizontal baffles, placed across the channel, may be used on all basins with over 6 feet liquid depth, and may be used where the manufacturer recommends them to provide proper mixing of the entire depth of the basin.

Baffles should be provided around corners to ensure uniform velocities.

### 7.7.3 45-Degree Sloping Sidewall Tanks

#### 7.7.3.1 Liquid Depth

Liquid depth shall be 7 to 10 feet, depending on aerator capability, as stated by the manufacturer.

#### 7.7.3.2 Channel Width at Water Level

The higher ratios (channel width at water level divided by aerator length) are to be used with smaller aerator lengths.

3- to 15-foot-long rotors, ratio 3.0 to 1.8.

16- to 30-foot-long rotors, ratio 2.0 to 1.3

Above 30-foot-long rotors, ratio below 1.5

#### 7.7.3.3 Center Island

When used, the minimum width of center island at liquid level, based on aerator length, should be as follows (with center islands below minimum width, use return flow baffles at both ends):

3- to 5-foot-long rotor, 14 feet

6- to 15-foot-long rotor, 16 feet

16- to 30-foot-long rotor, 20 feet

Above 30-foot-long rotors, 24 feet

#### 7.7.3.4 Center Dividing Walls

Center dividing walls can be used but return flow baffles at both ends are required. The channel width,  $W$ , is calculated as flat bottom plus  $1/2$  of sloping sidewall. Baffle radius is  $W/2$ . Baffles should be offset by  $W/8$ , with the larger opening accepting the flow and the smaller opening downstream compressing the flow.

#### 7.7.3.5 Length of Straight Section

Length of straight section of ditch shall be a minimum of 40 feet or at least two times the width of the ditch at liquid level.

#### 7.7.3.6 Preferred Location of Aerators

Aerators shall be placed just downstream of the bend, normally 15 feet, with the long straight section of the ditch downstream of the aerator.

### 7.7.4 Straight Sidewall Tanks

#### 7.7.4.1 Liquid Depth

Liquid depth shall be 7 to 12 feet, depending on aerators.

#### 7.7.4.2 Aerator Length

Individual rotor length shall span the full width of the channel, with necessary allowance required for drive assembly and outboard bearing.

#### 7.7.4.3 Center Island

Where center islands are used, the width should be the same as with 45-degree sloping sidewalls, or manufacturer's recommendation.

#### 7.7.4.4 Center Dividing Walls

When a center dividing wall is used, return flow baffles are required at both ends. Return flow baffle radius is width of channel,  $W$ , divided by 2,  $W/2$ . Baffles should be offset by  $W/8$ , with the larger opening accepting the flow and the smaller opening downstream compressing the flow.

#### 7.7.4.5 Length of Straight Section

Length of straight section downstream of aerator shall be near 40 feet or close to two times the aerator length. In deep tanks with four aerators, aerators should be placed to provide location for horizontal baffles.

#### 7.7.4.6 Preferred Location of Aerators

Aerators should be placed just downstream of the bend with the long straight section of the tank downstream of the aerator. Optimal placement of rotors will consider maintaining ditch center line distance between rotors close to equal.

#### APPENDIX 7-A