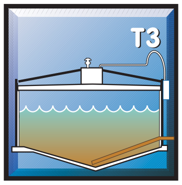

T3 Biological Treatment

This chapter describes biological treatment processes and includes design, construction, and operational considerations for these treatment processes. Suspended growth (continuous flow) using the activated sludge process, batch treatment (sequencing batch reactor) modification of the activated sludge process, and biological nutrient removal are the principal processes described in this chapter. The 2006 revision of this manual includes design information on membrane bioreactors (MBR) in a separate chapter (T6).

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T3-1 Objective

This chapter is intended to help engineers, operators, and local wastewater officials understand and efficiently implement biological treatment requirements. Because various professional societies and the US EPA develop and routinely update design manuals for wastewater treatment, this chapter will not address general design criteria contained in other design manuals, but will instead reference those manuals. It is the intention of this chapter to:

- Provide additional information pertinent to Washington State regulatory and environmental requirements.
- Illustrate and/or elaborate specific information.
- When appropriate, highlight items needing additional considerations applicable to smaller communities.
- Excerpt selected material to facilitate discussions and illustrate principles to assist local decision-makers.

T3-2 General Process Design

The general process design will provide the design considerations that should be reviewed when designing any biological treatment facilities.

T3-2.1 Mass Balances

T3-2.1.1 General Description and Objectives

A mass balance is a set of calculations used to account for the mass flows of various parameters among the different process units in a system. A mass balance model can be used to track such parameters as chemical oxygen demand (COD), total suspended solids (TSS), and total Kjeldahl oxygen (TKN) in the liquid and solids stream treatment processes in a wastewater treatment plant. Mass balances may be developed to assess equipment performance based on existing plant data or to project future solids loadings throughout an expanded facility.

T3-2.1.2 Application of Mass Balance

Mass balance calculations are typically applied based on steady-state plant operations. Although a treatment plant is never truly operating at steady state, pseudo-steady-state conditions can be assumed by using data averaged over a certain time period. The appropriate averaging time period for mass balances is plant-specific and may vary from year to year, even for the same plant. Annual or monthly average plant data are often used. The model is not suitable for assessing plant performance and predicting solids loads under short-term, highly variable conditions, such as during shock loading conditions or storm events. Therefore, plant data such as peak-day or peak-hour flow and loadings should not be used.

The mass balance for each process unit is written by equating the input minus the output to the conversion (removal or addition due to physical, chemical, or biological processes). The plant is assumed to be in equilibrium, so that there is no net accumulation or loss in each process unit.

Results of the mass balance calculations can only be as accurate as the values of the input variables. Because parameters such as TKN and total phosphorus are often not measured on a regular basis, especially in the solids handling area, developing the proper mass balances for these parameters may become difficult.

T3-2.1.3 Setup of Process Configurations

In order to accurately account for the mass flows of the tracked parameters, all unit processes that may either add to or reduce the mass flow should be incorporated. These may include primary sedimentation, secondary treatment (including biological treatment and secondary sedimentation), sludge thickening, sludge digestion, and sludge dewatering. Recycle streams such as thickener overflow, dewatering centrate/filtrate, and digester supernatant should be included. The routing of the recycle streams should be accurately represented in the mass balance model.

T3-2.1.4 Model Inputs

Inputs to the mass balance model generally consist of plant influent flow, influent loadings (i.e., BOD, TSS, and VSS), and effluent concentrations. Influent concentrations may also be used but should be converted first to mass loading rates in the model, since mass is a conserved property and is more appropriately tracked in mass balance calculations. The solids measurement method should be clarified to determine if a difference between total (TS, VS) and suspended solids (TSS, VSS) exists in the given data. In this text, it is assumed that TSS and VSS refer to the sum of the suspended and settleable solids. Sometimes the plant flow is measured just upstream of the primary clarifiers. In that case, the flow input to the model will be the primary influent flow, while the plant raw influent flow will be back-calculated from the primary influent flow and possibly any recycle flows. Mass balance models do not predict the effluent quality, which must be provided to calculate the waste sludge production rate or yield ratio.

T3-2.2 Process Flow Diagram

A process flow diagram shall be prepared to show the general, schematic interrelationship between major liquid and solids handling processes, beginning with influent wastewater conveyance and concluding with the final treated effluent. A typical process flow diagram is shown in Figure G1-2.

The level of detail for the process flow diagram will vary with the complexity of the treatment facility. The following guidelines shall apply to all process flow diagrams:

- The process flow diagram should be presented on a single sheet whenever possible. The diagram need not be drawn to scale.
- Treatment units and major equipment should be shown by schematic outline shapes and symbols. All major process units and flow streams shall be identified. Symbols and abbreviations used in the process flow diagram shall be defined in the drawings.
- The process flow diagram shall show the routine or normal routing of flows and solids streams along with important bypass routings. Arrowheads shall be used to indicate the normal direction of flow.

- The process flow diagram shall show a schematic representation of major interconnecting piping between treatment units. Varying line weights and styles shall be used to distinguish between liquid and solids process stream piping, gas piping, and other ancillary systems. Valves, gates, and similar flow controls need not be shown.
- Where provisions are made for the addition of future treatment units, the future process trains should be considered, and future tie-in points identified.

T3-2.3 Process and Instrumentation Diagrams

Plans for wastewater treatment facilities that involve automated controls, instrumentation systems, telemetry, and/or other remote monitoring or control shall include process and instrumentation diagrams (P&IDs). P&IDs shall show the interrelationships between mechanical equipment, local and remote controls, alarms, and instrumentation systems.

The level of detail for P&IDs will vary with the complexity of the treatment facility, controls, and instrumentation systems. The following guidelines shall apply to all P&IDs:

- Unlike process flow diagrams, P&IDs for a typical mechanical treatment plant may require multiple sheets. The diagrams need not be drawn to scale.
- Symbols and abbreviations shall comply with standards of ISA.
- Numbering conventions for equipment, alarms, instrumentation, and appurtenances shall utilize a system acceptable to the owner of the treatment facility.
- Treatment units and major equipment shall be shown by schematic outline shapes and symbols. All major process units and flow streams shall be identified. Piping shall be labeled with respect to diameter and type of conveyed fluid. Arrowheads shall be used to indicate the normal direction of flow.
- Valves (including any automated controls) should be shown schematically, and indicate normal positions.
- Symbols and abbreviations used in P&IDs shall be defined in the drawings.
- P&IDs shall show local and remote controls and protective devices/alarms for all mechanical equipment items, including interconnecting control signals and logic.
- The sampling locations and metering should allow for routine verification of the plant operating mass balance.

T3-2.4 Hydraulic Profile

A hydraulic profile drawing shall be prepared to show the water surface profile in cross-section view through the liquid treatment facilities. The hydraulic profile shall be calculated and shown for both peak hourly (or instantaneous) flow and design flow (maximum month) conditions. The peak hourly and average dry weather flow rates shall be clearly stated on the drawing, along with any critical assumptions used in developing the hydraulic profile. An excerpt of a hydraulic profile for a major mechanical treatment plant is presented in Figure T3-1.

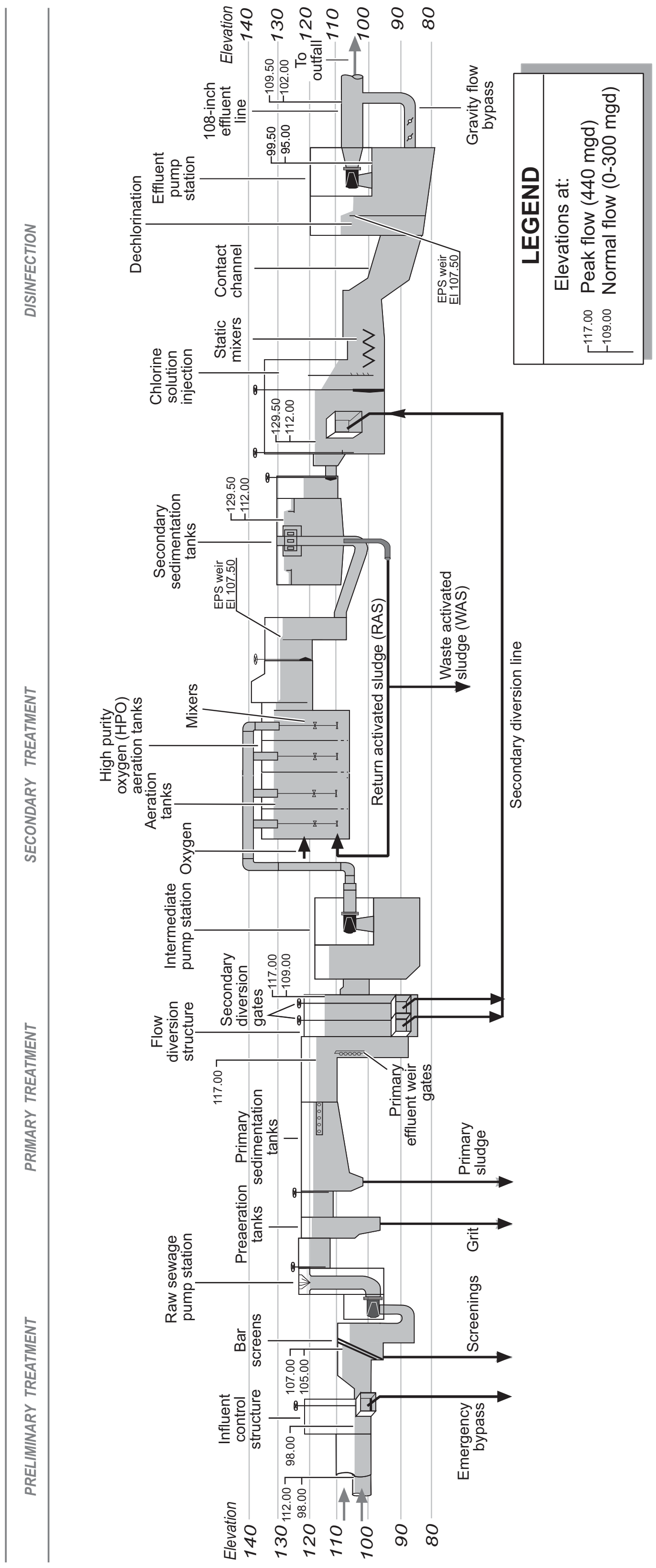

Figure T3-1. Hydraulic Profile for a Major Mechanical Treatment Plant

Hydraulic profile drawings shall be developed in accordance with the following criteria:

- The hydraulic profile should be presented on a single sheet if possible. An exaggerated vertical scale shall be used to emphasize water surface elevations. The hydraulic profile need not be drawn to accurate horizontal scale.
- For small or simple facilities, the hydraulic profile may be combined with other sheets, such as the listing of design criteria.
- Treatment units and flow control structures shall be shown schematically in cross-section views and labeled.
- Water surface elevations shall be calculated (and shown) to the nearest 0.01 foot. The hydraulic profile shall present water surface elevations at all major treatment units, flow control structures, weirs and gates, and the point of effluent discharge.
- Top of wall elevations for hydraulic structures shall be drawn to scale and labeled showing elevations.
- Where a treatment plant has multiple parallel process trains with similar hydraulics, the hydraulic profile need only show one typical train.

T3-2.5 Design Criteria

A complete detailed listing of design criteria shall be provided for the entire plant during wet-weather and dry-weather flow conditions, including the following:

- Flows (peak hour, maximum month, average daily).
- Loadings.
- Anticipated effluent quality.
- Treatment units, size, depth, detention, overflow, etc.
- Equipment HP, rated capacity, size, RPM, etc.
- Outfall length, material, diameter.
- Diffuser ports, depth, minimum dilution.
- Solids handling process units, equipment, metering, etc.
- Reliability class.
- Standby power type, capacity, fuel consumption and storage, etc.

T3-3 Design Guidelines (Rev. 11/2007)

This section is intended to provide guidance for a designer when designing biological treatment facilities.

T3-3.1 Activated Sludge

T3-3.1.1 Continuous Flow

A. Carbonaceous BOD Removal

1. Overview

This section provides design guidelines for carbonaceous BOD removal using the activated sludge process.

2. General Design Considerations

a. Specific Process Selection

The activated sludge process and its many modifications may be used to accomplish various degrees of removal of suspended solids and reduction of carbonaceous and/or nitrogenous oxygen demand.

Choosing the most applicable process will be influenced by the degree and consistency of treatment required, type of waste to be treated, proposed plant size, anticipated degree of operation and maintenance, and operating and capital costs. All designs shall provide for flexibility in operation and should provide for operation in various modes, if feasible.

For a discussion of characteristics and features of process modifications, refer to WEF Manual of Practice No. 8 or other textbooks.

b. Submittal of Calculations

Calculations shall be submitted, upon request, to justify the basis of design for the activated sludge process. The calculations shall show the basis for sizing the aeration tanks, aeration equipment, secondary clarifiers, return sludge equipment, and waste sludge equipment.

c. Primary Treatment

Where primary settling tanks are not used, effective removal or exclusion of grit, debris, excessive oil or grease (greater than 100 mg/l), and screening of solids shall be accomplished prior to the activated sludge process. Fine screens (6 mm or less) should always be used if primary clarifiers are not provided.

d. Winter Protection

In severe climates, consideration should be given to minimizing heat loss and protecting against freezing.

3. Process Design

Table T3-1 is a sample worksheet showing the data requirements typically necessary for designing biological systems processes.

Table T3-1. Sample Worksheet Showing Input Data Requirements for Biological Systems

Parameter	Units	Average Annual	Maximum Month	Maximum Day	Peak Hour
Flow	MGD				
BOD_5	lb/day				
COD (1)	lb/day				
TSS	lb/day				
VSS	lb/day				
TKN (2)	lb/day				
TP (2)	lb/day				
Minimum Temperature	°F				

(1) If COD:BOD_5 ratio is not 1.9-2.2:1.0, the conventional design equation can be in error. See WEF MOP No. 8, pgs. 11-20, notes on graphs 11.7a and 11.7b.

(2) If nutrient removal is required, TKN and/or TP will be needed.

a. Volume of Aeration Tanks

The volume of the aeration tanks for any adaptation of the activated sludge process shall be determined based on full scale experience, pilot plant studies, or rational calculations. Design equations based on mean-cell residence time (sludge age) can be found in WEF Manual of Practice No. 8, Chapter 11.

When aeration tanks are sized for carbonaceous BOD removal using rational calculations, the ability to maintain a flocculent, well settling mixed liquor must be considered. The use of selectors, as described in this chapter, may be desirable or necessary.

For carbonaceous BOD removal, sludge age values in the range of 5 to 15 days are typical, with the lower values used for high temperatures and the higher values used for low temperatures. Significant levels of nitrification will generally occur at 5-day SRT and temperatures of 61° F or greater.

Mixed liquor suspended solids (MLSS) concentrations in the range of 1,500 to 3,500 mg/L are often used. Because the mixed liquor concentration affects the solids loading on the secondary clarifiers, selection of the MLSS concentration must be coordinated with the secondary clarifier design.

b. Oxygen Requirements

Oxygen requirements for carbonaceous BOD removal include oxygen to satisfy the BOD of the wastewater plus the endogenous respiration of the microorganisms. Additional oxygen is required if nitrification occurs.

Oxygen requirements depend on the influent loading to the aeration tank as well as the process design and should be determined using rational calculations. Calculations should be based on the peak hourly BOD loading to the aeration tanks. Recycle flows from solids processing operations must be considered since these streams often have high BOD concentrations. Refer to WEF Manual of Practice No. 8, Chapter 11, for equations.

Oxygen requirements for carbonaceous BOD removal are dependent on the SRT and are typically 0.9 to 1.3 pounds of O_2 per pound of BOD removed. Provisions for nitrogenous oxygen demand should be considered separately and are typically 4.6 pounds of O_2 per pound of TKN applied.

c. Sludge Recycling Requirements

Sludge recycle rates can be calculated using the rational equations referenced above. The recycle rate deserves careful consideration since it affects the size of the secondary clarifiers without influencing the size of the aeration tanks. Because the recycle requirements also depend on the sludge settling and thickening characteristics, which may change, the rate of sludge recycle should be variable. The range is typically from 25 to 100 percent of the average design flow, though peak hourly flow needs must be accommodated.

d. Sludge Production and Wasting

When full scale or pilot plant data is not available, net sludge production can be estimated using the rational calculation procedures referenced above.

In order to obtain a reasonable estimate of the total sludge production, it is important to include solids present in the influent to the plant. Refer to WEF Manual of Practice No. 8 for more details.

Net sludge production increases with decreasing temperature and sludge age. In plants with primary sedimentation and operating at a sludge age of 15 days, net sludge production can be expected to be approximately 0.60 pounds of TSS per pound of BOD removed (0.48 lb VSS/lb BOD) at temperatures near 68° F. If the sludge age is decreased to 5 days, the net sludge production can be expected to increase slightly, to about 0.75 lbs/lb BOD removed (0.60 lb VSS/lb BOD).

In plants without primary sedimentation, net sludge production can be expected to range from 1.2 lbs TSS/lb BOD removed (0.92 lb VSS/lb BOD)to 1.0 lbs TSS/lb BOD removed (0.75 lb VSS/lb BOD) at sludge ages from 5 to 15 days at 68° F.

The net yields given in WEF Manual of Practice No. 8 are based on VSS. This value must be divided by the percent VSS/TSS in the mixed liquor to generate net yields of lb TSS/lb BOD. The values given in WEF Manual of Practice No. 8 are conservative and 85 to 90 percent of the facilities are expected to have lower yields. Net yields at existing facilities should be developed when plants are expanded.

4. Equipment Selection

a. Aeration Equipment

Aeration equipment must be selected to satisfy the maximum oxygen requirements and provide adequate mixing. In processes designed for carbonaceous BOD removal, oxygen requirements normally control aeration equipment design and selection. Consideration for aeration and mixing requirements should always be reviewed independently.

Aeration equipment should be designed to maintain a minimum dissolved oxygen concentration of 2 mg/L at maximum monthly design loadings and 0.5 mg/L at peak hourly loadings.

Because aeration consumes significant energy, careful consideration should be given to maximizing oxygen utilization and matching the output of the aeration system to the diurnal oxygen requirements.

b. Diffused Air Systems

Air requirements for diffused air systems should be determined based on the oxygen requirements and the following factors, using industry-accepted equations:

- Tank depth.
- Alpha value.
- Beta value of waste.
- Aeration-device standard oxygen-transfer efficiency.
- Minimum aeration tank dissolved oxygen concentration.
- Critical wastewater temperature.
- Altitude of plant.

Values for alpha and the transfer efficiency of the diffusers should be selected carefully to ensure an adequate air supply.

For all the various modifications of the activated sludge process, except extended aeration, the aeration system should be able to supply 1,500 cf of air (at standard conditions) per pound of BOD applied to the aeration tank. This aeration rate assumes the use of equipment capable of transferring at least 1.0 pound of oxygen per pound of BOD loading to the mixed liquor.

Air required for other purposes, such as aerobic digestion, channel mixing, or pumping, must be added to the air quantities calculated for the aeration tanks.

Multiple blowers must be provided. The number of blowers and their capacities must be such that the maximum air requirements can be met with the largest blower out of service. Because blowers consume considerable energy, the design should provide for varying the volume of air delivered in proportion to the demand.

Flow meters and throttling valves, where applicable, should be provided for air flow distribution and process control.

c. Mechanical Aeration Systems

In the absence of specific performance data, mechanical aeration equipment should be sized based on a transfer efficiency of 2.0 lbs of oxygen per hp/per hr in clean water under standard conditions.

Mechanical aeration devices must be capable of maintaining biological solids in suspension. In a horizontally mixed aeration tank, an average velocity of not less than 1 fps must be maintained.

Provisions to vary the oxygen transferred in proportion to the demand should be considered in order to conserve energy.

Protection from sprays and provisions for ease of maintenance should be included with any mechanical aeration system. Where extended cold weather conditions occur, the aeration device and associated structure should be protected from freezing due to splashing. Freezing in subsequent treatment units must also be considered due to the high heat loss resulting from mechanical aeration equipment agitation, i.e., splash and wave action.

d. Sludge Recycle Equipment

The sludge recycle rate should be variable over the range recommended in T3-3.1.1A.3.c. When establishing the flow range, initial operating conditions should be considered.

Sludge is normally recycled using pumps, and the most common method of controlling the sludge recycle rate is with variable speed pump motors. When pumps are used, the maximum sludge recycle flow shall be obtained with the largest pump out of service.

Sludge return pumps should operate with positive suction head and should have suction and discharge connections at least 3 inches in diameter. One pump should not be connected to two clarifiers for continuous withdrawal.

Air-lift pumps may also be used to return sludge. When air-lift pumps are used to pump sludge from the hopper in each clarifier, it is not practical to install standby units. Therefore, the design should provide for rapid and easy cleaning. Air-lift pumps should be at least 3 inches in diameter.

Flow meters should be provided for process control.

e. Waste Sludge Equipment

The sludge wasting rate will depend on the quantity of sludge produced and the process which receives the waste sludge.

Sludge is most commonly wasted using pumps. Waste sludge pumps could have capacity of up to 25 percent of the average daily flow. Minimum capacities in most smaller plants are governed by the practical turndown capabilities of the pumps. Variable speed drives and/or timers should be considered to control the wasting rate. Careful pump selection is also key in small flow-wasting applications (such as positive displacement vs. centrifugal).

Means should be provided for observing and sampling waste activated sludge. Flow meters with totalizers and recorders should be provided for process control and mass balance determinations.

B. Sedimentation

1. Overview

a. General

This section provides design guidelines for secondary sedimentation as a part of the activated sludge process.

b. Applicability

The activated sludge process requires separation of treatment organisms from the treated mixed liquor. In almost all activated sludge processes currently in use, this separation takes place in a gravity sedimentation tank or in a gravity sedimentation phase of a cyclic feed process. Since the effluent from the sedimentation process is the final step, sedimentation determines effluent quality for every activated sludge process.

2. Process Design Considerations

Design of sedimentation for activated sludge processes requires consideration of the overall process. Process loading parameters that determine the efficiency of the activated sludge sedimentation include overflow rate, solids loading rate, sludge settleability, underflow or return sludge pumping rate, and tank hydraulic characteristics. Design values should be identified for each of these process parameters.

a. Overflow Rate

The overflow rate is the rate of effluent flow from the sedimentation tank divided by the tank surface area. The overflow rate is the average upward velocity of process effluent from the sedimentation tank. Early researchers in sedimentation identified overflow rate as the critical factor in sedimentation tank design. By this early theory, a given size particle will be captured in the sedimentation tank if its settling velocity is more than the average tank overflow rate. Current design practice recognizes the hindering effect of high influent solids concentrations on settling in the activated sludge clarifier and includes overflow rate as only one of the factors used to determine sedimentation tank size. If, in overall activated sludge process design, the aeration tank size is determined to maintain MLSS concentration and settleability less than critical values for performance of the sedimentation tank, then the overflow rate may be the primary design parameter for the sedimentation tank. Table T3-2 gives values for design tank overflow rate during the peak sustained flow period that have proven effective under three different process configurations for the activated sludge process. Typical values for process variables—MLSS, sludge volume index (SVI), and RAS rate—are shown with corresponding values for design peak overflow rate. Overflow rate is given in units of gallons per day of effluent flow per square foot of total clarifier area. Some engineers subtract the influent area of the feed zone of the clarifier from the total sedimentation area. This practice may be considered as an additional safety factor in design and is not necessary as long as adequate safety factors are provided in the overall process design.

Table T3-2. Typical Process Design Values for Sedimentation Overflow Rate

Process Configuration	Typical MLSS, mg/L(1)	Typical SVI, mL/g	RAS rate, %	Peak Overflow Rate, gpd/sf(2)
Conventional Activated Sludge	1,500-3,500	150	50-75	1,200
Extended Aeration	2,500-3,500	200	100	500
Oxidation Ditch	2,500-3,500	150	100	700

(1) Not true if bioselectors are used.

(2) Depends on process parameters and tank design.

b. Solids Loading Rate

The solids loading rate is as important as overflow rate in determining the capacity of an activated sludge clarifier. The solids loading rate is the total mass rate of suspended solids into the clarifier divided by the tank cross-sectional area. The total mass rate to the clarifier is the sum of the tank effluent flow rate and the tank underflow or RAS pumping rate times the MLSS concentration. The limiting solids loading rate to an activated sludge clarifier should be no greater than the limiting solids flux in the clarifier. A factor of safety should also be applied that takes into consideration reasonably foreseen variations in design loading, settleability, and other variables.

$SF = G_L/SLR$, where

SF = Safety factor

G_L = Limiting solids flux, ppd

SLR = Solids loading rate, ppd

The limiting solids flux to an activated sludge clarifier is the limiting rate of solids loading to the clarifier that will reach the tank bottom. The limiting solids flux is a function of MLSS concentration, RAS rate, and sludge settleability. It can be calculated for given design conditions in a number of ways. Riddell, et al., in “Method for Estimating the Capacity of an Activated Sludge Plant” (1983), provides a procedure for direct calculation of limiting solids flux. Graphical procedures are provided in numerous references (see WEF Manual of Practice No. 8*)*. Rational designs should demonstrate that design assumptions for MLSS concentration, RAS rate, and sludge settleability have been taken into account in determining the size of activated sludge aeration tanks and clarifiers. The overflow rate values in Table T3-2 each yield a safety factor of approximately 1.5 when applied at the indicated values for MLSS, SVI, and RAS rate using the method of Riddell, et al.

For circular clarifiers, the SLR should not exceed 80 percent of the loading as a function of SVI (or DSVI) and return sludge concentration. See Daigger, "Development of Refined Clarifier Operating Diagrams Using an Updated Settling Characteristics Database" (1995).

c. Sludge Settleability

Sludge settleability determines the everyday capacity of an activated sludge clarifier since it partly determines the sludge settling rate against which the effluent overflow rate acts. The common measure of settleability in the activated sludge process is the SVI. Several models have been developed to relate SVI to sludge settling velocity. However, SVI is a poor procedure for MLSS of 3,000-4,000 mg/l and DSVI and SSVI tests should be used. Where possible, designs for activated sludge clarifiers should be based on field measurement of sludge settling velocity using batch settling tests at varying initial suspended solids concentration.

In order to eliminate high SVI conditions, bioselectors should be used in activated sludge plants.

d. Return Sludge Pumping Rate

Return sludge pumping is required to maintain a mass balance of solids in the secondary clarifier. The rate of sludge pumping as a ratio of the effluent flow from the clarifier is called the return sludge ratio. Values for this ratio have an inversely proportional effect on RAS concentration.

C. Bioselector

1. General

Bioselectors (also referred to as selective reactors) are biological reactor processes that are placed just ahead of the principal biological reactor (activated sludge, etc.). The selector process involves reacting the influent wastewater with return activated sludge from the secondary clarifiers. Selectors are of three types depending upon the degree of oxidation of the biological sludge: aerobic, anoxic, and anaerobic. The most prevalent application of selectors involves the anoxic process. For biological phosphorous removal, the aerobic selector is not used; the anaerobic mode is used. Only the anoxic selector is briefly addressed in this manual. The anoxic selector is most extensively applied to the treatment of both municipal and industrial wastewaters.

Anoxic selectors are a means of controlling SVI in the biological treatment of wastewater. In particular, selectors may be used in the treatment train of wastewater treatment plants using a suspended growth process as the principal biological treatment method.

Anoxic selectors can be used in an industrial wastewater treatment plant in which foaming or bulking problems may be expected. Industrial wastewaters, which are expected to produce a severe foaming problem during the main aeration step, may employ selectors just ahead of the aeration. Many industrial and some municipal treatment processes with short to long sludge ages, including extended aeration, experience bulking (nonsettling sludge) problems. Again, application of an anoxic selector just ahead of the main aeration step may be applied for the attenuation of potential bulking problems. Foaming and bulking conditions can be expected to exist for industrial wastewaters that consist of relatively simple sugars and other soluble substrates. These kinds of wastewaters are produced by pulp and paper mills, food processing facilities (fruit processing in particular), breweries with high alcohol content in the wastewater, and so on. Wastewater with elevated temperatures will exacerbate the problem of bulking and foaming. Temperatures to the bioreactor should not exceed 104° F, with temperatures below 100° F being more desirable.

The third application for anoxic selectors is for nutrient removal. Municipal wastewater treatment plants that employ a selector reactor system typically experience nitrogen compound and phosphorus reduction. Reactor designs that promote selective growth of certain microorganisms and which have enhanced nitrogen and/or phosphorus removal have been developed. In some cases, these proprietary processes are configured with a two (or more) stage biological reactor.

The design criteria may be different depending on the primary objective for the application. Selector design for bulking and foam control may use a somewhat different set of criteria than a selector with the principal objective of nutrient removal.

2. Foaming and Bulking Control

The purpose of including a selector in the treatment train for the reduction of foaming or bulking potential is to change the competitive environment among the various types of microorganisms that are present in the wastewater. In particular, the objective is to selectively remove the BOD_5 through absorption under conditions that are the least advantageous to filamentous types of microorganisms. Two phenomena have been reported as having an impact. The first is reduction in available BOD for the growth of filamentous microorganisms; the second is reduction in residual soluble BOD that remains towards the end of the aeration step. Both of these actions reduce the concentration of filamentous microbes in the activated sludge. In turn, these microbes, which are more likely to partition into the foam or float in the activated sludge, are reduced in concentration.

Design for this type of condition typically involves return of a portion of the RAS to the influent to the selector. Hydraulic detention times for this type of selector may be as short as 10 minutes and as long as 45 minutes. Typical sizing of a selector for this application involves hydraulic sizing for 30 minutes at the design flow, with detention times to be no less than 10 minutes under peak flow conditions. In addition, the selector should be compartmentalized into three or more equal volume tanks, each with a mixer capable of maintaining complete mix conditions. A high food-to-micro-organism ratio (F/M) ratio should be designed for the first stage selector tank. F/M values of 6 to over 30 have been reported as being successful designs. The designer should make provision for returning only a portion of the RAS to the influent of the selector process. The return flow to the selector should be selected by the operator from about 30 percent to 100 percent of the total RAS flow. In the absence of any pilot plant data, a design F/M value of 10 to 15 should be used initially. It should be anticipated that the operator will need to make adjustments to this value once the treatment plant is in operation.

3. Nutrient Control

The anoxic/oxic (A/O^{TM}) process for removal of phosphorus uses a selector reactor quite different from that described for bulking or foaming control. This process uses an anaerobic reactor followed by an aerobic reactor, with both tanks being about equal in volume. RAS full flow is returned to the influent to the anaerobic reactor. The mixed liquor is then piped into the aeration chamber. Nitrogen reduction typically does not occur with this process. For design parameters and conditions, the designer should consult with the WEF Manual of Practice No. 8. For this process, Metcalf & Eddy recommend an F/M ratio of 0.2 to 0.7 and an anaerobic reactor detention time of 0.5 to 1.5 hours followed by an aerobic reactor detention time of 1 to 3 hours.

Nitrogen reduction in a municipal wastewater can be accomplished with the inclusion of an anoxic selector just before the aeration process. Reductions of 50 to 80 percent of the TKN may be accomplished depending upon unit sizing, MLVSS and TKN concentration, etc. The design of an anoxic selector for denitrification is not straightforward. Both the anoxic reactor and the aerobic reactor are sized based on the desired effluent. When the treatment plant is required to produce very low residual TKN the designer should consider an alternative process, such as the Bardenpho™ process. When reductions of TKN are required to be on the order of 50 percent, an anoxic selector can be used ahead of the aeration reactor. With this type of process, the anoxic selector has a longer detention time and the full flow RAS is returned to the influent to the selector. Selector detention times for this type of application can exceed 2 hours, although this is rare. Metcalf & Eddy report a range of 0.2 to 2 hours as a typical detention time for the anoxic selector, with a detention time of 6 to 15 hours for the aeration chamber. Since much of the denitrification will occur from the sludge, all of the RAS is returned to the selector. Metcalf & Eddy present a rational approach to the design of this type of system.

Regardless of the objective for including an anoxic selector in the treatment train, some reduction in nutrients will occur. The rational approach cited above may be used to predict the amount of reduction. However, a number of assumptions are required to use the approach, or pilot study data must be developed for a more accurate prediction.

4. Discussion

Bioselectors control bulking, and can reduce capacity requirements by 30 to 50 percent.

Application of bioselectors in the treatment train should be used by the designer, either:

- To reduce the potential for bulking and/or foaming in the aeration chamber of an industrial or municipal wastewater treatment system, or
- For partial nutrient removal from a municipal or industrial wastewater treatment system.

T3-3.1.2 Batch Treatment (Sequencing Batch Reactor)

A. Overview: Process Description and Applicability

Sequencing Batch Reactors (SBRs) and continuous flow activated sludge systems use similar biological treatment principles. The primary difference is that SBRs alternately fill and-draw from a common tank. This sequencing may occur with fixed cycle times (time-based), or depend on the time needed to completely refill each tank (level-based). The basic process steps, and typical pattern for a three tank SBR system are shown below. With level based controls, there is also typically an idle period after decanting since the time it takes to fill the prior tank is variable.

Table T3-3. Basic Process Steps and Typical Pattern for Three Tank SBR System

	First third of Cycle	Second third of Cycle	Last third of Cycle
Tank 1	**Fill** (mixed and/or aerated)	**React** ----------------------------	→ **Settle, Decant/Waste**
Tank 2	---→ **Settle, Decant/Waste**	**Fill** (mixed and/or aerated)	**React** ------------------------
Tank 3	**React** -----------------------------	→ **Settle, Decant/Waste**	**Fill** (mixed and/or aerated)

Smaller municipalities with fewer technical resources to operate a complex system comprise the largest market for SBR systems. While the inherent complexity of SBRs has sometimes led to problems because of this, newer systems provide better control features and are more reliable.

Theoretically, engineers can design SBR systems for carbonaceous BOD removal, nitrification, denitrification, and biological phosphorus removal. Managing sludge age with the care needed to only remove carbonaceous BOD has proven an unrealistic expectation for most SBRs to date. Accordingly, SBR design guidance in this section is based on operating the systems for complete nitrification and, to the extent feasible, denitrification. The denitrification (mixed fill) step not only to remove nitrates, but to recovers alkalinity, which reduces the need for a chemical feed system. The mixed fill step also helps regulate filamentous bacteria growth.

Other References: Sequencing Batch Reactor Design and Operational Considerations, September 2005, New England Interstate Water Pollution Control Commission, www.neiwpcc.org contains recommended process control monitoring and a troubleshooting guide. These topics are not elsewhere covered in this section.

B. General Advantages and Disadvantages of SBRs:

While not all systems realize these advantages, and most of the disadvantages can be overcome, some of the typical advantages and disadvantages of the SBR process are:

Table T3-4. Typical Advantages and Disadvantages of SBRs

TYPICAL ADVANTAGES	TYPICAL DISADVANTAGES:
• Eliminates primary and secondary clarifiers and return sludge pumps.	• Needs three or more reactor tanks to meet redundancy requirements.
• Lowers the overall tank volume required per gallon treated.	• Needs larger disinfection and downstream components because of batch discharges.
• Reduces costs by using rectangular tank and common wall construction techniques.	• Has a more difficult review and purchase process due to proprietary parts & systems.
• Facilitates future expansion through modular construction.	• Has poorer settling floc because there are no selector zones.
• Reduces labor costs through highly automated process controls.	• Increases initial and maintenance costs by using complex control systems and valves.
• Provides perfectly quiescent settling.	• Needs a larger peak air supply.
• Maximizes use of small sites.	• Performs poorly at high peak flows.

C. Systems Available

1. System Types

Several manufacturers offer proprietary SBR systems. General SBR systems types include:

- **Batch systems using jet aerators and mixers.** These use a number of water "jets" with forced air, or venturi effect air injection spaced around each tank's perimeter. Operators may inspect and replace such jets without taking tanks offline, and without interfering with tank cleaning, inspection or maintenance. Sloped tank bottoms provide for easy maintenance. Jet aerators can mix to a distance of 30 to 40 feet. The same jets, without air, can provide mixing for denitrification.

- **Batch systems using independent mixers and diffused air.** These use diffuser arrays similar to other conventional secondary treatment systems, lowering costs and improving the availability of spare parts. Designers frequently array diffusers in banks so operators can isolate, retrieve, and service them without taking a tank off-line. Designs typically use separate mixers for the mixed fill cycle. These designs usually use less slope on the floor which helps with operator maintenance, but can make wasting sludge less efficient.

- **Continuous influent, batch discharge systems.** Engineers design these systems to continuously accept influent at one end while intermittently "batch" discharging from the other. These designs use influent baffles and a greater length to width ratio to make this possible. As with other designs, the aeration and mixing are turned off to allow settling prior to decanting. Designers may also use a partition and an internal sludge recycle loop to obtain some selector effect. These systems have redundancy with two tanks instead of three, but designers must evaluate the potential for short circuiting and solids washout during high flow periods.

2. Control Systems

Engineers could theoretically design SBR components such as decanters, aerators, valves, meters, and control logic to be interchangeable. However, most SBR systems come packaged together with proprietary controls designed to interface with their specific meters, valves, motors, and blowers. Control system technology is advancing rapidly, presenting an opportunity to economically retrofit existing SBR facilities with better controls and telemetry. This can improve economy and performance.

D. General Design Standards for SBRs

1. Basis of Design

a. General Design Basis

All designs must clearly identify the design loadings and appropriate flow and loading criteria based on peaking factors described in section G2-1.2. Designs must identify the following parameters: SVI, F:M ratio, MLVSS:MLSS ratio, decanter depth, high and low water levels, mean cell residence time, cycle times at various flow conditions, decant volume, and tank dimensions (see T3-3.1.2.D.3 for tank design guidance) . Project proponents must evaluate proprietary system designs and document how they meet the criteria of this section (T3-3.1.2). This analysis must include the calculations needed to support any performance claims.

b. Guarantees

Major SBR equipment manufacturers sometimes provide design calculations along with performance "guarantees". While guarantees may provide some important insurance to a community, Ecology's obligation to safeguard the environment prohibits accepting manufacturer guarantees in lieu of the engineering basis for the design.

c. General Reliability

Designs for SBR systems must provide the same reliability of treatment required for continuous flow through designs (see Chapter G2 sections 6, 7, and 8). Since each SBR reactor serves several functions, it must meet the most stringent of the reliability criteria for the various components it replaces (e.g.: primary clarifier, aeration basin, aerators, backup power, control logic, etc).

d. Comparison of Alternatives

Designers comparing the SBR option to other alternatives should do so on the basis of their comparative life cycle costs. The analysis must use a common cost basis comparison to determine which system most reliably and economically provides an effluent that will meet all anticipated requirements for discharge, disposal, or reuse over the useful service life of the project.

e. Solicitation Methods

Individual SBR equipment manufacturers often provide proprietary control system and process components. They will also specify optimum tank configurations that are unique for their process. As a result, early identification of a preferred SBR system may be necessary for efficient plant design. Proponents must ensure that any pre-selection or prequalification of a SBR system follows the current federal and state procurement laws. Section G1-2.7 provides information regarding Ecology grant and loan eligibility for components identified in plans and specifications based on a pre-selection process.

2. Required Number of Basins

- Designers must provide for more than two reactor vessels (basins) unless Ecology approves the system as a continuous flow-through system.
- Designers may request Ecology approve a two basin system if all other requirements for sizing are met and if design features ensure uninterrupted treatment with a malfunction in one tank. Designs for such systems must show how the operator can isolate, replace, or service a malfunctioning component with little or no reduction in treatment capacity. Such functionality typically requires an equalization basin(s) or removable components (diffuser grids, mixers, etc.). The design must provide a backup for all major assemblies, including motors, pumps, valves, blowers, and control logic. Plans for any two basin system must also show the location of a future third SBR basin. Plans should also provide for “stub outs” for a third basin if growth projections predict the need within twenty years.

3. Sizing Aeration Tanks

a. Basis for sizing

Engineers must size aeration tanks based on rational calculations which ensure compliance with anticipated permit limits.

b. Oxic Sludge Age

Designs must provide sufficient tank volume to operate at an “oxic” sludge age of 8 to 15 days (minimum). The oxic sludge age equals the mean cell residence time (MCRT) multiplied by the proportion of time the tank is in the react phase. The "oxic sludge age" for an SBR is the corollary to "sludge age" in a conventional activated sludge system. Designs must assess the need for longer sludge ages if reactors will operate below 15ºC.

c. Separation at end of Decant Cycle

Designs must provide an adequate zone of separation between the sludge blanket and the decanter(s) throughout the decant phase. Designers must estimate the clear water depth at the end of the decant cycle based upon a reasonable worst case Sludge Volume Index (SVI). Designers should use operating data from an existing SBR system with loading characteristics and operating goals similar to the proposed facility to estimate the facility's design SVI. If comparable site specific data is not available, designers should use a default SVI of 250 ml/g.

d. Minimum Decantable Volume

Designs must have a decantable volume (Vd) and decanter capacity that, with the largest basin out of service, will pass 75% or more of the design maximum day flow (Qd) without altering cycle time (ct, hours). Formula: $Vd > (.75*Qd*(ct/24))/(n-1)$ where 'n' is the total number of SBR tanks. Designs also may not specify a decantable volume of more than 1/3 of the total tank volume (Vt) per cycle ($Vt > Vd * 3$).

e. Maximum F:M Ratio

Designs must provide adequate tank volume to meet a nutrient loading rate limit. This limit is a food to micro-organism (F/M) ratio of 0.10 lb BOD5/day/lb MLVSS at the design maximum monthly average loading rate. The ratio of volatile suspended solids to total suspended solids within the mixed liquor (MLVSS:MLSS) should be based on rational calculations or data from similar facilities. Designers must provide operating examples to support design MLSS concentrations above 4,000 mg/l at full tank volume.

f. Mass Loading Rate

Designs must provide adequate tank volume to limit the mass loading rate to 15 lb BOD5/d/1000 ft3 [0.24 kg BOD5/d/m3]. Designers should evaluate this criteria using the tank volume at the normal low-water level and using the maximum monthly average loading for BOD5.

4. Sizing the Air Delivery System

a. General Process

Designs must supply the air needed for biological treatment under the range of anticipated conditions to maintain the proper mix of healthy biota. Designers must incorporate the following factors in their analysis:

- Peak loadings rates (carbonaceous and nitrogenous) at critical conditions (lower water depth, higher temperature)

- Diffuser specific oxygen transfer rates
- Specific motor and blower efficiency and pressure (head) losses through the air delivery system
- Optimization of the diffuser grid layout

Designers can find examples of aeration system design methods in:

- Design Manual - Fine Port Aeration Systems, USEPA, 1989, publication EPA/625/1-89/023.
- Design of Municipal Wastewater Treatment Plants, 4ed, MOP #8, WEF, 1998 (Ch.11)
- Wastewater Engineering Treatment and Reuse, Metcalf and Eddy, Fourth Edition, 2003 (Ch.5,8)

b. Standard Oxygen Transfer Efficiency

Designers must provide the diffuser manufacturer's estimated oxygen transfer efficiencies. Ecology encourages designers to verify such claims with an oxygen transfer test conducted in accordance with ASCE Procedures (ANSI/ASCE 2-19, Measurement of Oxygen Transfer in Clean Water). Ecology may require such verification for unfamiliar system, or atypical claims.

c. Adjustment Factors

Designers must typically multiply the standard oxygen transfer values (for clean water) for a diffuser by three separate factors to obtain oxygen transfer rates for a specific site. The factors include the alpha (oxygen mass transfer coefficient ratio from clean to wastewater), beta (salinity-surface tension correction factor), and fouling factors (diffuser specific decrease in efficiency over a specified period). Designers must provide the basis for selected factors, ideally using site specific data. Absent better data, designers should use alpha values of 0.5 for fine bubble diffusers, 0.75 for jet aerators, and 0.85 for coarse bubble diffusers.

d. Considering Nutrient Removal

SBR designs can achieve excellent conversion of ammonia to nitrates, and good removal of total nitrogen. SBR designs may also achieve phosphorus removal by creating alternating aerobic and anoxic reactor environments during the "react" phase of the process. Several sources report good total overall nitrogen removal with typical SBR cycle times of 6 -10 hours. If the system must achieve low effluent total nitrogen levels, the designer may need to employ additional treatment steps.

E. Equipment Design Features Required for SBR Systems:

1. Flow Equalization Basins

Designs must include an evaluation of the cost and benefits of an influent flow equalization basin to equalize diurnal flow and facilitate operation while one SBR basin is off-line for necessary repairs and maintenance.

2. Screens

Designs must include an appropriate method of removing grit, rags, floatables, and other solid waste. Designers should give preference to screens over comminutors. Designs not incorporating preliminary treatment must include an acceptable justification.

3. Scum Control

Designs must provide scum removal features. Where designs employ scum troughs, they may either be fixed or floating (such as attached to the decant boom). Designs may specify manual scum removal if it is not needed more than every third day.

4. Foam Control

Designs should include spray bars supplied with chlorinated non-potable water for foam suppression and to facilitate scum collection.

5. Mixing Equipment

Designs for mixing equipment must include the capacity for anoxic mixing (without supplying air). Designs must provide for complete mixing of the contents of the basin so that solids concentrations vary less than 10% after the first five minutes.

6. Diffuser Anti-Clogging Features

Designs must specify whether the aerators chosen require continuous positive pressure to avoid clogging, and if so, how the system will meet this requirement.

7. Alkalinity Addition Systems

Designs must include an evaluation of the potential need to add alkalinity to maintain a neutral effluent pH and residual alkalinity of 50 mg/l. The analysis must presume that the SBR system will achieve complete nitrification (whether required or not). Designs must show an accessible location for an alkalinity addition system. Where alkalinity addition is anticipated, designers should give preference to an alkalinity source or mix of chemicals which supplies carbonate ions.

8. Tank Maintenance

Designs must include provisions for cleaning such as a sloped bottoms and sumps, ladders, and features to facilitate the removal of waste activated sludge. Designers should give preference to systems which use pumps to positively control the rate of removal of waste solids rather than decanting waste solids by gravity. Designs must provide a means for the operator to transfer activated sludge from one SBR to the other(s) to bring a tank online after cleaning or to recover after an upset.

9. Decanting Equipment

Designs for decanters must include an evaluation of their ability to pass the peak-day flow in the allocated decant time without resuspending settled mixed liquor or decanting scum. Decant mechanisms should draw the treated effluent along a horizontal plane below the scum level. Designs for decanting equipment should also keep solids from accumulating in the decanting mechanisms during the react phase. Decanting equipment must require at least two independent control signals or valves to open for decanting to occur (one may be a manual valve).

10. Disinfection Equipment

Designs must ensure disinfection systems will meet permit limits and meet the disinfection criteria of Chapter T-5 at the flow rates and conditions which occur at the start of a decant cycle. Follow-on processes (pipes, filters, or effluent pumps and diffusers) must not cause a backup at these rates. Designs should include a comparative life cycle cost analysis of post treatment equalization basins, their amortized cost weighed against the higher power and larger disinfection system needed without it.

11. Valve Positioning

Designs must show valves are positioned in easily serviceable locations, avoiding areas subject to flooding or freezing (unless protected). Designs must protect electronics from electrical power surges. Plans and O&M manuals must reinforce the need to maintain spare valve actuators for each size of automatic valve used.

12. Blower Turndown Features

Designs must show that blowers can meet air demands at the anticipated range of flows and loadings without significant loss of efficiency.

13. Sampling Equipment

Designs must specify flow-paced composite samplers for the effluent because effluent flows are not continuous. Samplers must draw sample aliquots at the beginning and end of decant cycles on a representative basis. Designs must show sampling ports at the locations relevant for process control.

14. Freeze Thaw Protection

Designs must include features to protect exposed components and pipes from freezing in areas where freezing might be reasonably anticipated. Designs must anticipate that exposed pipes of SBR systems are at greater risk of freezing than flow through systems.

F. Reliability Requirements for SBR Systems

1. Diffuser Features

Designs must provide for retrievable aeration equipment, or an alternate method of cleaning or backflushing the diffusers. In systems with only two reactor tanks, designers must configure diffusers in multiple banks that can be independently isolated and repaired. Reactor basins must provide sufficient aeration with a diffuser section or jet aerator out of service.

2. Motor Operated Valve Features

Designs must include automatically controlled, motor-operated (or hydraulic cylinder-operated) valves for influent, decant, and air control valves. All motor-operated valves should have the ability to be manually operated should the electronics fail, or the design must include a manual backup valve. Influent valves must pass solids.

3. Blowers

Engineers must size air blowers for SBR systems, as with other conventional secondary treatment systems, to supply the design oxygen requirements with the largest unit out of service. Where this requires valves to divert air from one tank to another, the valves must be electronically switchable.

4. Backup Power Systems

Designs must supply an uninterruptible power supply with electrical surge protection for each Programmable Logic Controller (PLC) or computer in computer controlled systems. The system must retain program memory in event of a power loss or fluctuation (e.g. the process control program, last-known set points, valve positions, cycle state, and equipment run hours and status.).

5. Sensitive Discharge Area Protection

Where the facility must meet category 1 reliability standards, or where discharges to shellfish beds, designs must provide online TSS meters on the decant lines from each SBR tank. Designs must integrate these meters into the plant's control system. Excessive TSS values must cause an alarm that triggers prompt operator attention or halts the discharge until the operator corrects the problem.

G. Control System Requirements for SBR Systems:

1. General Control Functions

The control system must monitor key information and control routine operations of the SBR process. Key information includes system status, valve positions, tank levels, monitoring probe values, and equipment status. Routine operations include valve operation, aeration, mixing, decanting, sludge wasting, and disinfection. Designs may base operation on the tank's fill level (flow-based) or a fixed schedule (time-based) with level overrides. Both must allow operator adjustment of the cycle structure.

2. Load Equalization

Designs should give flow-based operation priority over time-based schemes to give more consistent loadings and better use capacity. When time based cycles are used, the cycle times must be staggered so alternating basins accept peak daily loads.

3. Control System Redundancy

Designs must provide both an automatic programmable logic controller (PLC) or computer-based control system and a manual interface in case the automated system is inoperable. Designs must provide a redundant control system, and incorporate reasonable redundant control features (e.g. having computer based control systems loaded on multiple computers).

4. Process Optimization and Efficiency Features

Designs should employ telemetry from probes continuously monitoring levels of dissolved oxygen, oxidation reduction potential, pH, and alkalinity (when alkalinity addition is needed). Control logic should use this information to control aerator output and cycle times. Systems should vary blower run time, output, or the number of blowers operating to keep oxygen levels within a range determined by control logic or the operator.

5. Alternative Operation for High Flows

Designs must address the operational strategy for high flow situations. For time-based operation, the control system should automatically and progressively adjust cycle times when influent flows exceed what “normal” cycle times can handle. The control strategy for flow-based operation should adjust to faster fill rates with shorter cycles, greater decant volumes, and/or higher high-water levels, with control settings adjusted in turn. Designs must include a level-based high water alarm and cycle structure override. Control logic must always provide at least 20 minutes between react and decant phases.

6. Manual Override Features

Designs must include both automatic and manual controls to allow independent operation of each tank. Manual controls should also prevent decant with less than 20 minutes of settling unless emergency bypass procedures are employed.

7. Sludge Wasting Features

Designs must use waste activated sludge pumps rather than wasting by gravity unless the flow of waste sludge is metered. The volume of sludge flowing by gravity in a given time is otherwise too great for good process control. Designs must describe how to determine the volume and frequency of settled sludge to waste to ensure the stability of the system. Designs should automate sludge wasting as needed for stable performance considering weekend staffing levels.

8. Valve Telemetry

Electronic controls must include feedback to ensure confirmation of proper valve operation. Critical valve failures must cause an alarm traceable to the specific valve. The control logic should make a record of each valve’s operating history.

9. Alarm and Backup Features

Alarm features must provide audible alarms to immediately alert the operator to any critical fault, and provide a visual signal until the fault is corrected. After hours alarms must trigger an auto-dialer to call a sequential list of staff with an alarm message. The control system must display the status of the process and equipment (ideally both numerically and graphically). The control system should maintain an operational history of the facility and regularly and automatically store this in non-volatile format. This information should allow restoring the system, estimating when services are due, and allow for warranty claims.

T3-3.1.3 Extended Aeration

Extended aeration is one form of the various forms of suspended growth or “activated sludge” type treatment. The process is so named because the wastewater is held under aeration for an extended period of time. The extended aeration process is characterized by having long hydraulic detention times and very long mixed liquor (MLSS) detention times (longer sludge age than necessary to meet effluent criteria). The process is designed to operate in the “endogenous” phase of the microbial growth-death curve.

The extended aeration treatment process may be found in a number of different physical configurations that may include smaller (hydraulically) mechanical “package” treatment systems, “race track” or oxidation ditch systems for treatment of municipal wastewater, sequencing batch reactors (SBR), and large industrial treatment systems. Generally, when the extended aeration process is used for wastewater treatment, the treatment objective is to produce low residual BOD in the treated effluent, minimize the amount of sludge solids which must ultimately be disposed, and/or provide a more stable process that is easier to perform.

The objective of the extended aeration process in this case is to minimize costs. This is accomplished by retaining the solids in the treatment system as long as possible to allow the organic solids to oxidize in the aeration step. The BOD to MLSS ratio, typically referred to as the F/M ratio, is on the order of 0.1 or less. This means that the influent BOD to the treatment process is barely able to keep the existing microbes alive, and therefore a portion of the microbes die. For this application, the hydraulic detention time of the aeration chamber should be no less than 24 hours under peak hour flow conditions, with a design maximum monthly flow detention time of no less than 48 hours.

A. Application for Municipal and Industrial Treatment Systems

For small to moderate sized municipal treatment systems, the oxidation ditch or “race track” treatment process has been commonly applied to the treatment of wastewater. Depending upon the specific design and operation conditions, this type of system should be classified as an extended aeration system. The objectives in this application are generally somewhat more complex and include the following:

- Minimize operator attention and effort.
- Minimize waste sludge sent to the ultimate disposal process.
- Maximize the probability that effluent standards will be met.

To meet these combined objectives, the hydraulic detention time may not be as long as indicated above. Sludge age may be in the range of 30 days or longer, provided that such a long sludge age does not cause additional operating problems (foaming, bulking, high effluent TSS, etc.).

Industrial applications of the extended aeration process generally have the same objectives as municipal treatment systems. Such treatment plants tend to have serious operational problems such as frequent bulking, foaming, etc., even when safeguards are designed and built into the system.

B. Design Considerations

1. General Design Considerations

As indicated above, the extended aeration system is characterized by a long hydraulic detention time, typically 24 hours or longer, and a long solids retention time. The F/M is around 0.1 or less. This parameter is inversely related to the sludge retention time. See also textbooks or WEF manuals of practice on the subject for the quantitative relationship between F/M ratio and sludge age (sludge retention time).

A significant operational problem associated with extended aeration is that of sludge “bulking” or high-suspended solids in the effluent. The designer should include a selector system before the aeration basin, for suppression of microbes that cause a “bulking” condition in the secondary clarifiers. Depending upon wastewater characteristics, some form of chemical addition could be included in the sludge return system. Depending upon specific site conditions and which chemicals are readily available, chlorine, hydrogen peroxide, or a similar oxidant may be used to suppress “bulking” organisms, but this approach results in lower effluent quality.

2. Consideration of Oxygen Transfer

Sizing the oxygen transfer system involves multiple considerations. Oxygen must be supplied to satisfy the change in BOD between the influent and effluent from the aeration basin. This portion of the oxygen demand is standard for all biological treatment processes. In addition to this demand, oxygen for the demand created by the oxidation of biological solids will also need to be supplied to the system. Finally, due to the long detention times, some nitrification of the wastewater is likely to occur and requires evaluation to determine oxygen requirements. The reader is again referred to textbooks and the WEF manuals of practice for the methods of sizing oxygen transfer devices. Also, determining oxygen requirements for BOD and nitrogen are described in the same references. Determining oxygen requirements for biological solids is not well described. The following guidelines are recommended for determining oxygen requirements for an extended aeration system:

- Determine total BOD to be oxidized.
- Assume that the yield for conversion of BOD to solids is at least 0.5.

- Biological solids will typically have a 12- to 25-percent inert fraction.
- Of the remaining 75 to 88 percent, about 20 percent will be refractory and impose a very slow oxygen demand rate.
- The remaining solids, on the order of 60 to 70 percent, will impose an oxygen demand at the same rate as the BOD and at a ratio of one pound of decomposed solids per one pound of oxygen demand.

For this type of system, special consideration of the selected alpha should be made. Due to higher solids in the wastewater, the "fouled alpha" is somewhat lowered. Values as low as 0.25 have been observed at municipal plants, which include an industrial contribution to the wastewater. Sizing the oxygen transfer system for an extended aeration system will probably require significant additional aeration capacity compared to other types of biological treatment process. The above recommended guideline does not include consideration of the wasted solids, and therefore is slightly conservative in the estimation of oxygen demand. The degree of conservatism in the application of the above guideline will be a function of the sludge age and the influent BOD concentration. The lower the sludge age and more dilute the influent BOD, the more conservative the above calculation result will be.

3. Consideration of Secondary Clarification

Extended aeration will likely produce an effluent with a higher suspended solids concentration compared to other suspended growth (activated sludge) type processes. Loading rates for secondary clarifiers applied to an extended aeration plant should be on the lower end of the recommend range for both hydraulic loading rates and solids loading rates. If SVI is controlled, higher loading rates are possible.

Sludge "bulking" and high solids loss in the secondary effluent can be problematic with an extended aeration plant. Once the treatment plant is operational, the plant operator should consider continuous measurement of the activated sludge VSS and TSS in the mixed liquor. The VSS/TSS ratio should be observed on a frequent basis, as this parameter may provide a clue to an impending or virtual upset condition. Provided the plant has been designed with methods for adding chemicals to "kill off" the "bulking" organisms, the operator can take corrective action prior to an actual noncompliance condition.

T3-3.2 Biological Nutrient Removal

Biological nutrient removal processes remove nutrients from the wastewater effluent using biological systems. Sub-sections below provide a brief description of the nutrient removal objective and the various processes available. For more extensive information and guidelines on nutrient removal technologies, the following references are recommended: *Biological Nutrient Removal (BNR) Operation in Wastewater treatment Plants*, Water Environment Federation, MOP 30, October 2005; and *Factors Influencing* *the Reliability of Enhanced Biological Phosphorus Removal*, Water Environment Research Foundation, 2003. (NOTE: Above two references added Nov/2007.)

T3-3.2.1 Objective

Nutrients (including nitrogen and phosphorous) are removed from the wastewater effluent because these nutrients tend to stimulate weed growth and algal blooms in the receiving water body.

T3-3.2.2 Processes Available

A. Activated Sludge Plants

Activated sludge plants may be modified or built to provide NDN (nitrification denitrification) in the aeration basins by adding selector and anoxic zones in the plant as the primary effluent. Return from the end of the aeration basin is sent back to the front of the aeration basin to enter and mix in the front of the basin in an anaerobic zone. It then flows into an anoxic zone. The anoxic zone is then followed by an aerobic zone. The sizing of the zones is dependent on the flows and solids entering the basins and the return flows from the aeration basin recycle pump.

Depending upon the designer’s intent, the ammonia in the incoming waste stream will be converted to nitrate, nitrite, and/or nitrogen gas, depending on the size of the zones, the recycle rate in the aeration basin, and the alkalinity available in the wastewater.

The above process will also reduce phosphorous.

B. Oxidation Ditches

Oxidation ditches will remove nitrogen from the waste stream by putting the wastewater through anoxic and aerobic phases as the wastewater is circulated through the oxidation ditch.

C. Trickling Filters

Trickling filters remove ammonia by recirculating the wastewater through the trickling filter. A modification can be made to the trickling filter plant by adding a solids contactor basin (small aeration tank) that utilizes the aerobic section of the tank to remove ammonia and BOD to reduce the loading on the trickling filter.

D. Rotating Biological Contactors (RBC)

As with trickling filters, achieving ammonia and/or a higher level of nitrogen removal requires an increase in recirculation of the effluent from the RBCs. If the plant is in the design phase, this can generally be accommodated; but in existing plants, the plant’s rated hydraulic capacity will be impacted because of the increased recirculation requirements to meet the nitrogen removal need. Other processes might be considered.

E. Lagoons

Lagoons reduce the nitrogen in the incoming wastewater. This is done through the long detention time normally found in lagoons. Lagoons can be retrofitted with baffles, pumps, and aeration systems to replicate the activated sludge plants with selectors as noted above.

F. A/O Process

In activated sludge plants, the process is designed into the aeration basin to provide an anaerobic zone and an aerobic zone (A/O process). This process removes both phosphorous and nitrogen. Existing plants can be retrofitted with an A/O process.

G. Phostrip Process

This is an offline separate process that removes sludge from the final clarifiers and pumps it to a separate process train. From there, elutriant and anaerobic stripper is combined in a tank, with the water fraction being subjected to lime. Then the sludge is removed in a separate clarifier where the phosphorous is removed, with the overflow returning to the front of the aeration tank. The sludge from the elutriant/anaerobic stripper tank is recycled to the front of the aeration tank.

T3-4 Construction Considerations

T3-4.1 Objective

This section identifies some construction considerations related to secondary treatment. Problems related to items mentioned below can become a source of trouble for wastewater treatment plant operation and maintenance. Construction deficiencies are at the root of many common operational problems, which with appropriate attention can be avoided. The engineer is generally encouraged to recognize the integral link between design, construction, and operation and provide a prudent level of control to safeguard against these and other common problems. Possible measures include specific mention in the plans and specifications, submittal requirements, general oversight during construction, special inspection, and inclusion as specific topics for construction meetings.

By being aware of common problem areas, the engineer can apply the appropriate level of precaution to help ensure operational characteristics consistent with the design intent. Several common problem areas are discussed in the remainder of T3-4.

T3-4.2 Settling and Uplift

This section discusses some considerations associated with the construction, initial filling, and dewatering of large process tanks. These considerations include settling and uplift, which are a concern during both initial construction and subsequent plant expansion or maintenance.

Even with aggressive measures taken to reduce settling, such as dynamic compaction and preloading, some settling at the time of initial tank filling may occur as a result of immense loads associated with large tanks. Loads resulting from initial tank filling will be particularly large when tanks are constructed in banks or connected through a mat foundation. In this case settling can be sufficient to cause cracking in architectural features such as masonry. In those cases, particularly when it is unlikely that once placed into service all tanks will be simultaneously empty again, it may be appropriate to postpone application of architectural features until after the initial tanks fill in order to avoid this type of cracking.

Settling is a familiar concern and most obvious during initial tank filling. However, settling can also occur to existing facilities as a result of construction dewatering. The reduced hydraulic static pressure may affect neighboring process facilities causing them to settle. The effect on existing structures of dewatering for new construction must be carefully considered.

Any settling, either immediate or long term, will place stress on rigid connections to the structure. To reduce stress as a result of settling on piping at connections, two flexible joints, connected by a short spool piece, should be located just outside the wall face. The flexible joints provide points of rotation and allow the spool piece to provide for vertical displacement.

Uplift is an equally important concern for buried tanks and other subterranean structures. Uplift occurs when the buoyant forces caused by hydraulic static pressure are greater than the downward gravitational forces. This is a concern whenever a buried structure is at, or below, ground water elevation, particularly if a normally full tank is empty. Schemes to mitigate uplift include locating pressure relief valves in the tank floor to relieve excess hydraulic pressure and placing subterranean wings on the structure to balance uplift forces with the weight of backfill soil. The pressure relief valves are designed to relieve upward buoyant forces by letting water pass through the floor and into the tank. If this system is used the valves should be immediately and closely inspected to ensure they are properly installed and operational. If the wing system is used the structure is at risk until backfill is placed. Consequently, any change in ground water elevation, such as the halting of construction dewatering, may affect the structure. Factors that can quickly affect ground water elevation include heavy rain, mechanical or electrical failure of the dewatering system, and environmental factors that overwhelm the capacity of the dewatering system installed.

Uplift is a concern any time a buried tank is emptied. The potential for uplift is greater with deeper structures and in areas of high ground water.

T3-4.3 Secondary Clarifier Slab

Since the primary function of a secondary clarifier is to provide separation of solids from the effluent, an effective solids-removal process is essential. Typically, solids are allowed to settle and then are removed from the clarifier floor with a sweeping collector. To ensure effective solids removal, it is important that the collector maintain a minimum separation or even contact with the floor slab. This helps ensure that solids are consistently removed from the tank.

It is important that the secondary clarifier slab be finished straight, without depressions or high spots. Warps in the floor slab can impair the solids removal process by creating pockets where the settled solids are not removed. These solids are retained in the tank until they denitrify. Contrary to the desired removal process, denitrification causes the solids to become buoyant and float. These solids come to the surface and carry over the weirs, degrading effluent quality.

Since a true surface is essential for consistent solids removal, often topping grout will be used as the final surface to improve ability to meet close tolerances. The topping grout surface can be better controlled than the initial slab pour. If no topping grout pour is called for and the structural slab is to remain the collector contact surface, it is essential that the slab itself be finished true, free of depressions or high spots.

T3-4.4 Aeration Piping

Piping used to convey compressed gas to aeration tanks may be either buried or exposed, and can be located outside, in a gallery, or in a pipe chase. The cost effectiveness and hidden nature of buried piping can be attractive; however, the reduced accessibility of such a configuration may become problematic for aeration piping. With time, aeration piping can develop leaks as a result of either settling, construction defects, or deterioration. Buried piping is particularly subject to these problems and the reduced accessibility makes repair more difficult. Air expelled from the piping will exfiltrate through cover soil and cracks in paving to the surface, becoming a nuisance.

Consequently, it is recommended that aeration piping receive special attention during construction, especially if buried. The engineer should encourage or provide aggressive construction inspection in conjunction with leak testing to help ensure proper installation, soil compaction, and joint integrity, and to avoid future air leakage and exfiltration problems. Piping located in a gallery or exposed is somewhat easier to repair and may not need the same level of attention during construction recommended for buried piping.

T3-4.5 Control Strategy

This section discusses problems with a common secondary-treatment process control strategy. This strategy relies on flow metering downstream of the primary tanks to control secondary process variables. The strategy uses primary effluent flow to flow pace secondary process variables. Typically, the flow signal is sent to a programmable logic controller (PLC) or other controller, which processes the flow information and returns a control signal to secondary process elements. Since the secondary process is relatively sensitive, accurate flow information is required to maintain proper process parameters. However, relying on a flow meter for accurate information can be problematic.

Flow meters inherently have limited accuracy, which can further be reduced by poor field hydraulics, improper installation, poor calibration, flows at the extreme ends of the meter’s accuracy, flows outside the range of calibration, etc. Problems with flow meter accuracy are compounded during startup and initial operation when flows are much less than design flows. Inaccurate readings cause operation of the secondary system to be problematic. It is essential that a flow meter not only be selected that can accurately measure the range of flows anticipated, but also that it be properly installed, tested, and calibrated. Initial calibration should strive for accuracy over the lower range of flows initially experienced, rather than the entire design range anticipated. Understanding the sensitivity of this control strategy on the secondary process and providing the appropriate care will help to ensure a more accurate and less problematic secondary control system.

T3-5 Operational Considerations

T3-5.1 Objective

The objective of this section is to discuss practical process design issues that are vital to the proper performance of the facility.

T3-5.2 Plant Hydraulics

T3-5.2.1 Flow Splitting

Flow splitting refers to dividing a flow stream into two or more smaller streams of a predetermined proportional size. Flow splitting allows unit processes such as aeration basins or secondary clarifiers to be used in parallel fashion. The flow is typically divided equally, although there are circumstances where this is not the case. For example, if the parallel unit processes do not have equal capacity, then the percentage of total flow feeding that unit might be equal to the capacity of that unit relative to the total capacity of all the parallel units. Flow splitting applies mainly to liquid streams but can also be an issue in sludge streams. See Chapters G2 and T2 for additional information.

T3-5.2.2 Activated Sludge Pumping/Conveyance

This section describes return activated sludge (RAS) pumping and conveyance; however, many of the issues addressed in this section also apply to waste activated sludge (WAS).

A. Purpose

RAS pumping/conveyance is designed to withdraw settled activated sludge from the secondary clarifier and return it to the aeration basin(s) at a controlled rate. The RAS rate maintains a mass balance between the aeration basin(s) and the secondary clarifier(s). This is done to keep the total solids inventory distributed in a certain proportion between the aeration basin(s) where sorption takes place and the secondary clarifier(s) where maintaining quiescent conditions allows flocculation, clarification, zone settling, and thickening to occur. To allow all of the above to occur requires special care in designing the RAS pumping/conveyance system.

B. Types and Their Application

1. Centrifugal Pumps

Centrifugal pumps are used most often to convey RAS. The pumps can be designed to handle the debris and stringy material typically found in activated sludge. One of the most common kinds of pump for this purpose is called a vortex pump. Raised vanes on a flat plate rotate in a recess adjacent to the volute case. The rotating vanes indirectly stir the fluid in the volute, generating a centrifugal pumping action. The advantage of this type of pump is that the volute remains fully open to pass RAS debris. Since the pump has large clearances between the impeller and the volute case, it requires a significant (10 feet is recommended) positive suction head to achieve a prime.

2. Gravity Flow

Gravity flow to convey RAS relies on available head pressure to “push” the flow along. A typical design would consist of a withdrawal pipe situated in a sludge hopper at the bottom of the clarifier. The pipe would convey the RAS back to either (1) a lift station that would lift it back to the aeration basin(s), or (2) flow directly back to the aeration basin(s) if lower than the secondary clarifier. The latter situation requires that the mixed liquor is pumped from the aeration basin(s) to the secondary clarifier(s) since the clarifiers would be higher than the aeration basin(s). The RAS flow from each sludge hopper can be controlled by a manual or automatic valve.

3. Combination

A combination system uses elements of a gravity conveyance system with a pumped system. The gravity portion of the system contains an adjustable weir, adequate head upstream, a wetwell, and pump. The adjustable weir can be a flat plate or circular (telescoping valve). The flow quantity is controlled by the gravity device.

C. Problems

1. Inadequate Suction Head

If not enough suction head is available for the RAS pump, it will not prime or will lose its prime, and therefore will not pump the RAS. To ensure adequate suction head, generally speaking allow the full tank depth as suction head. Also, keep the length of the suction lines to the pump at a minimum to reduce head loss.

2. Inadequate Head

For gravity RAS conveyance systems, available head is crucial for proper operation. Minimal head can result in plugging of the RAS lines and channels. Even if the RAS is flowing initially, thixotropic property of the sludge can cause the sludge to slow and eventually stop.

3. RAS Lines Not Hydraulically Independent (Common Header and Line)

If the RAS lines from two or more clarifiers are manifolded together, it creates a more difficult control problem because the lines are not pressure-flow independent. Increasing the flow in one of the lines feeding the common line can create more back pressure on the other lines, reducing their flow. The dynamics are further complicated when the concentration of the sludge changes, changing the viscosity of the fluid. Under these circumstances, the only control system that will work is to have flow meters on each separate feeder line. The flow-generated signals from these meters then provide input to a controller regulating the speed of each RAS pump to match the flow target for each RAS line. If proper response times and delays are not preset, the system flows can vary in an oscillating pattern among the various RAS lines. If the RAS lines are kept separate and pressure/flow independent, that is, discharge to a tank, box, or channel open to the atmosphere (zero gauge pressure), the control scheme can be simpler and more reliable. The latter system could be simplified to manual speed control on the RAS pumps and either a visual check or flow measurement on each RAS line.

4. **Plugging of Gravity Systems**

   Plugging of gravity RAS conveyance systems is primarily a function of the thixotropic properties of the RAS sludge. Unlike a positive pumped system, the driving force does not increase with increasing resistance to flow, but remains the same. The increased resistance caused by thickening sludge settling out in lines and channels slows the flow, which in turn causes more thickening and more slowing until the flow eventually stops. This can cause extensive problems for an activated sludge system. Sludge can pile up in the secondary clarifiers overnight, causing an upset and degraded effluent for several days.

5. **Lack of Turndown Capability**

   RAS conveyance systems need turndown capability in order for activated sludge systems to run optimally. For many plants, the secondary clarifier is a crucial sludge thickening device prior to aerobic digestion. Without prethickening to 1 percent solids or so, the waste sludge flow rate would be too high. The digester would fill with too much water or the required volume would be uneconomical. The problem this presents to the operator is that the required decant volume for the next days' wasting overloads the plant hydraulically. To slowly decant over a longer period would reduce the amount of aeration below the minimum required between decant cycles. Also, for small plants that have day shifts only, it becomes a staffing and budget issue.

6. **Flow Range**

   In municipal plants, diurnal flows with low nighttime flows should be incorporated into the design by reviewing the design flows and control strategy for handling low flows.

T3-5.3 Reactor Issues

T3-5.3.1 Feed/Recycle Flexibility

For varying loading and flow conditions, it is advantageous to add feed/recycle flexibility to activated sludge systems. Aeration basins can be constructed either long and narrow to promote plug flow conditions or in a series as separate compartments. The raw or primary effluent and/or RAS can be introduced into the aeration basin flow path at various strategic points to promote more efficient treatment and/or resistance to storm flow washout. In step feeding, the raw or primary effluent flow is routed to one or more regions or compartments of the aeration basin flow path. In this way the F/M ratio can be controlled along the basin to maximize treatment efficiency. If the F/M is kept the same in all regions/compartments, the system approximates a complete mix basin. Because the load is distributed evenly, complete mix systems can handle shock loads well. However, because the sewage is diluted over the entire contents of the aeration basin, this mode of operation can promote low F/M filaments to predominate. By introducing the feed at the head of the basin or in the first compartment, plug flow can be achieved. This mode can inhibit the growth of filaments by providing a high F/M environment at the front of the aeration train which selects faster growing, better settling floc forms over the slower metabolizing filaments. If the RAS is introduced to various points along the aeration train, the aerator sludge detention time can be manipulated to control and enhance settling characteristics to respond to changes in flows and loading. The advantage of this scheme is that aeration basins do not have to be dewatered to reduce the oxidation pressure on the microorganisms to respond to a drop in the organic load and/or flow.

T3-5.3.2 Tank Dewatering/Cleaning

To greatly reduce manpower and time required to dewater and clean aeration basins, dewatering lines should be provided for each compartment. The drawoff point(s) should come off recesses in the floor to ensure that as much mixed liquor as possible can be pumped out. The floors should be sloped to the drain hopper(s).

T3-5.3.3 Multiple Tanks for Seasonal Load Variation

Two or more process tanks/units should be constructed if the influent load and flow vary seasonally or periodically. In this way the process can run optimally without process failure. For example, an extended aeration basin may be adequately sized for summer operation. During winter flows, however, the detention time of the basin may be cut in half. Continuing to run the basin in extended aeration mode at a short detention time results in massive quantities of sludge particles rising in the secondary clarifiers. The sludge can form a brown foam on the surface that can cover the secondary clarifier, chlorine contact chamber, and any other downstream tankage. The result is a severe maintenance and odor problem for the operator.

T3-5.3.4 Suspended Growth Back Mixing

For aeration basins in activated sludge systems that are intended as plug flow basins, back mixing must be minimized. For large plants, constructing the basins with a length to width ratio of 40:1 mitigates the impact of back mixing. For small plants, the basins would be too narrow and difficult to maintain if the 40:1 standard were used. A better approach with small facilities is to construct separate compartments in a series to achieve plug flow benefits and characteristics. This latter option is the surest way to prevent back mixing in any activated sludge aeration basin.

The compartments should be constructed with submerged (overflow) baffle walls with an allowance for bottom drains to prevent scum accumulation. The head loss of maximum flow should be about one-half inch (water) per baffle.

T3-5.3.5 Fixed Film Prescreening

For fixed film systems it is critical that adequate prescreening of the wastewater is provided to prevent plugging of the media.

T3-5.4 Secondary Clarifier Issues

Better performance is achieved if the clarifier capacity online can be matched with the flow, settleability, and solids loading. To do this, at least two clarifiers should be constructed. It is harder to control the thickening process in underloaded clarifiers because the sludge blanket is so thin that water can be sucked into the RAS along with the sludge. Also, the RAS cannot be turned down as low because at least two RAS pumps must be in operation. Not enough capacity online for the given conditions can result in a solids washout, producing a degraded effluent lasting from several days to several weeks.

T3-6 Reliability

Reliability related to this chapter is addressed here; see Chapter G2 for additional general information on reliability.

T3-6.1 General

In accordance with the requirements of the appropriate reliability class, capabilities shall be provided for satisfactory operation during power failures, flooding, peak loads, equipment failure, and maintenance shutdown. As defined in EPA's publication, "Design Criteria for Mechanical, Electrical, and Fluid System Component Reliability," reliability is "a measurement of the ability of a component or system to perform its designated function without failure... Reliability pertains to mechanical, electrical, and fluid systems and components. Reliability of biological processes, operator training, process design, or structural design is not addressed here."

Except as modified below, unit operations in the main wastewater treatment system shall be designed so that, with the largest-flow-capacity unit out of service, the hydraulic capacity (not necessarily the design-rated capacity) of the remaining units shall be sufficient to handle the peak wastewater flow. There shall be system flexibility to enable the wastewater flow to any unit out of service to be routed to the remaining units in service.

Equalization basins or tanks will not be considered a substitute for process component backup requirements.

Below are requirements for each reliability classification for the common components of biological treatment. Reliability requirements for the other wastewater treatment plant components and general site considerations are elsewhere in this manual. Requirements are also described in EPA's technical bulletin cited above.

Definitions of the three reliability classes are given in Chapter G2.

T3-6.2 Secondary Process Components

T3-6.2.1 Aeration Basins

A. Reliability Class I and Class II

A backup basin will not be required; however, at least two equal-volume basins shall be provided. (For the purpose of this criterion, the two zones of a contact stabilization process are considered only one basin.)

B. Reliability Class III

A single basin is permissible.

T3-6.2.2 Aeration Blower and Mechanical Aerators

A. Reliability Class I and Class II

There shall be a sufficient number of blowers or mechanical aerators to enable the design oxygen transfer to be maintained with the largest-capacity-unit out of service. It is permissible for the backup unit to be an uninstalled unit, provided the installed units can be easily removed and replaced. However, at least two units shall be installed.

B. Reliability Class III

There shall be at least two blowers, mechanical aerators, or rotors available for service. It is permissible for one of the units to be uninstalled, provided that the installed unit can be easily removed and replaced. Aeration must be provided to maintain sufficient DO in the tanks to maintain the biota.

T3-6.2.3 Air Diffusers

Reliability Class I, Class II, and Class III. The air diffusion system for each aeration basin shall be designed so that the largest section of diffusers can be isolated without measurably impairing the oxygen transfer capability of the system.

T3-6.2.4 Sequencing Batch Reactors

Sequencing batch reactors serve as both aeration basin and clarifier. The standard reliability requirements for both aeration basins and final sedimentation shall be used unless justification can be provided to Ecology of alternative means of providing reliability through design and/or operation of mechanical components.

T3-7 References

Albertson, O.E. *Bulking Sludge Control—Progress, Practices and Problems.* Water Science and Technology, 23(4/5):835-846. 1991.

ASCE Procedures. *Measurement of Oxygen Transfer in Clean Water*. ANSI/ASCE2-19.

Daigger, Grant T. “Development of Refined Clarifier Operating Diagrams Using an Updated Settling Characteristics Database.” *Water Environment Research Foundation (WERF).* 67(1); 95-100, 1995.

Metcalf & Eddy, Inc. *Wastewater Engineering—Treatment, Disposal, and Reuse*. Third Edition. NewYork, NY: McGraw Hill, Inc., 1991.

Riddell, M.D.R., J.S. Lee, and T.E. Wilson. “Method for Estimating the Capacity of an Activated Sludge Plant.” *Journal of the Water Pollution Federation*. 55 (4); 360-368, 1993.

US Environmental Protection Agency. *Design Criteria for Mechanical, Electrical, and Fluid System Component Reliability*. EPA 430-99-74-001. 1974.

Wanner, Jiri. *Activated Sludge Bulking and Foaming Control*. Lancaster, PA: Technomic Publishing Company, 1994.

Water Environment Federation. *Design of Municipal Wastewater Treatment Plants. Volume II. WEF Manual of Practice No. 8*. 1998