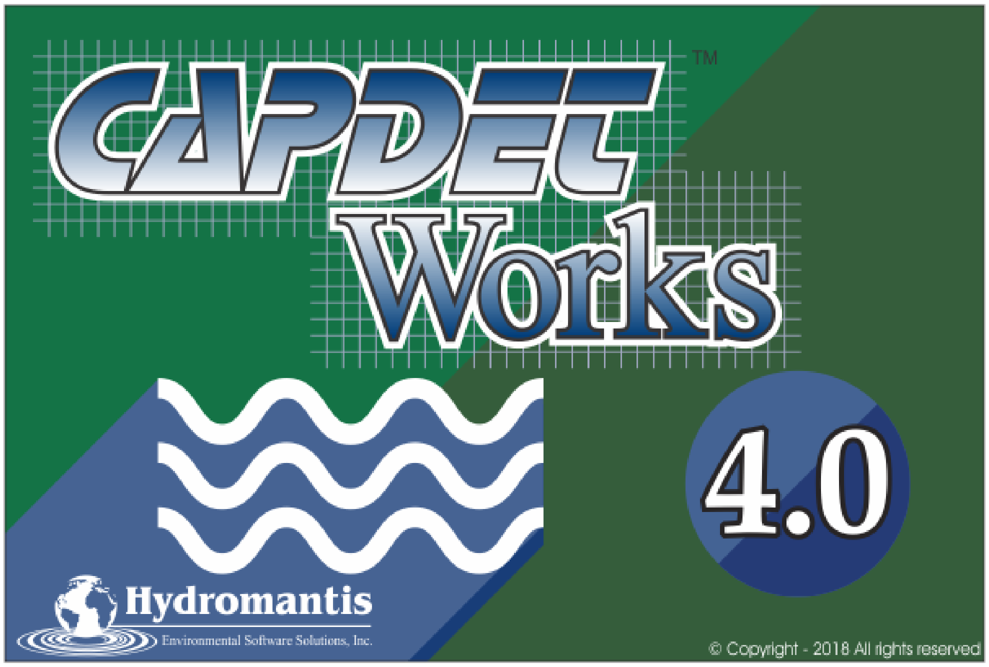
CapdetWorks V4.0

State-of-the-art Software for the Design and Cost Estimation of Wastewater Treatment Plants



Supplemental Technical Reference

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Table of Contents

BIOLOGICAL NITROGEN REMOVAL

Discharge of ammonia nitrogen to a receiving stream causes depletion of the stream's dissolved oxygen content as the ammonia nitrogen is oxidized to nitrate. In addition, ammonia nitrogen can adversely affect fish life under certain environmental conditions. As a result, many wastewater treatment plants employ nitrification to convert ammonia nitrogen to nitrate nitrogen prior to discharge. However, the nitrogen in nitrate is available as a nutrient for biological growth. Thus, the discharge of nitrate can contribute to biostimulation of surface waters, resulting in effects such as algal blooms and eutrophication. As a result, denitrification must be used at certain treatment plants. The biological process of denitrification involves the conversion of nitrate nitrogen to gaseous nitrogen. The gaseous product, primarily nitrogen gas, is not available for biological growth.

Denitrification is a two-step biological process. Nitrate is converted to nitrite, which in turn is reduced to nitrogen gas. This two-step process is termed "dissimilation". A broad range of bacteria, including *Pseudomonas*, *Micrococcus*, *Achromobacter* and *Bacillus*, can accomplish denitrification. These bacteria can use either nitrate or oxygen to oxidize organic material. As the use of oxygen is more energetically favorable than nitrate, denitrification must be conducted in the absence of oxygen (anoxic condition) to ensure that nitrate, rather than oxygen, is used in the oxidation of the organic material. For denitrification to occur, a carbon source must be available for oxidation. If the carbonaceous material in the raw wastewater has been removed, an external carbon source may have to be added to the denitrification system.The theoretical methanol requirement for nitrate reduction and cell synthesis is 2.86 mg methanol-COD per mg nitrate-nitrogen. However, additional methanol is needed to ensure the complete reduction of any nitrite present and the elimination of any remaining oxygen.

Step 1: Determine the minimum aerobic SRT for nitrification based on the winter temperature.

Nitrifier Growth Rate

$$\mu_{maxA,T_{winter}} = \mu_{maxA,20} \times \Theta_{\mu A,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{1}$$

where: T_{winter} = winter temperature (°C)

$\mu_{maxA,T_{winter}}$ = maximum specific growth rate at temperature, T_{winter} (1/d)

$\mu_{maxA,20}$ = maximum specific growth rate at 20°C (1/d)

$\Theta_{\mu A,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.123 in version 1.0

Nitrifier Decay Rate

$$b_{a,T_{winter}} = b_{a,20} \times \Theta_{ba,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{2}$$

where: T_{winter} = winter temperature (°C)

$b_{a,T_{winter}}$ = decay rate at temperature, T_{winter} (1/d)

$b_{a,20}$ = decay rate at 20°C (1/d)

$\Theta_{ba,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 1.0

Minimum Aerobic SRT

$$SRT_{aerobic} = \frac{1}{\mu_{maxA,T_{winter}} - b_{a,T_{winter}}} \tag{3}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for nitrification at temperature, T_{winter}

Allowing for an SRT safety factor:

$$SRT_{aerobic,safe} = SRT_{aerobic} * SRT_{sf} \tag{4}$$

where: $SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
SRT_{sf} = safety factor for SRT

Step 2: Calculate the Aerobic Basin Volume

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20} \times \Theta_{kd,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{5}$$

where: T_{winter} = winter temperature (°C)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, Twinter (1/d)
$k_{d,20}$ = oxygen decay coefficient at 20°C (1/d)
$\Theta_{kd\,,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.040 in version 1.0

BOD Removal

$$BOD_{removed} = BOD_{T,in} - BOD_{S,eff} \tag{6}$$

where: $BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$BOD_{T,in}$ = total BOD entering the unit process (g BOD/m^3)
$BOD_{S,eff}$ = effluent soluble BOD (g BOD/m^3)

Aerobic Volume

$$V_{aerobic} = \frac{SRT_{aerobic,safe} \times Q_{in} \times Y_h \times BOD_{removed} \times 0.8}{VSS \times (1 + k_{d,T_{winter}} \times SRT_{aerobic,safe})} \tag{7}$$

where: $V_{aerobic}$ = aerobic volume (m^3)
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
Q_{in} = the unit process influent flow rate (m^3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
0.8 = assumed removal factor which is used to calculate the aerobically removed BOD from the total BOD removed (80% assumed)
VSS = volatile suspended solids concentration [= Suspended solids * ‘VSS/SS ratio’] (g/m^3)

$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

Step 3: Check on Aerobic HRT

Aerobic Hydraulic Retention Time

$$HRT_{aerobic} = \frac{V_{aerobic}}{Q_{in}} \times 24 \tag{8}$$

where: $HRT_{aerobic}$ = aerobic hydraulic retention time (hr) - minimum allowable $HRT_{aerobic}$ = 3 hours

Resizing Aerobic Tank (if necessary)

If the calculated $HRT_{aerobic}$ is less than 3 hours, then the aerobic tank must be resized and the VSS and SS concentrations are recalculated.

$$HRT_{aerobic} = 3 \text{ hours} \tag{9}$$

$$V_{aerobic} = \frac{HRT_{aerobic} \times Q_{in}}{24} \tag{10}$$

If the aerobic tank needs to be resized to satisfy an HRT limitation then the user-defined VSS concentration needs to be overridden and new VSS & SS concentrations need to be calculated.

$$VSS = \frac{SRT_{aerobic,safe} \times Q_{in} \times Y_h \times BOD_{removed} \times 0.8}{V_{aerobic} \times (1 + k_{d,T_{winter}} \times SRT_{aerobic,safe})} \tag{11}$$

$$SS = \frac{VSS}{ivt} \tag{12}$$

where: ivt = VSS/SS ratio

Step 4: Determine the Volume of the Anoxic Basins

Influent BOD to TKN ratio

$$BN_{inf} = \frac{BOD_{T,in}}{TKN_{T,in}} \tag{13}$$

where: BN_{inf} = influent BOD to TKN ratio

Using a ladder logic type approach, the volume of the anoxic basins and the total SRT can be calculated.

BN_{inf}	$Size_f$
$BN_{inf} \geq 6.5$	0.8
$6.5 > BN_{inf} \leq 5.0$	0.7
$5.0 > BN_{inf} < 4.0$	0.6
$BN_{inf} \leq 4.0$	0.6 - warning printed

where: $Size_f$ = sizing factor

System Sizing

$$V_{total} = \frac{V_{aerobic}}{Size_f} \tag{14}$$

$$V_{anoxic} = (1 - Size_f) \times V_{total} \tag{15}$$

$$SRT_{total} = \frac{SRT_{aerobic,safe}}{Size_f} \tag{16}$$

Step 5: Determine the Number of Batteries, Process Trains & Number of Tanks-In-Series

Influent Flow in U.S. Units

$$Q_{in,us} = \frac{Q_{in}}{3785} \tag{17}$$

where: $Q_{in,us}$ = unit process influent flow rate in U.S. units (MGD)
3785 = volume conversion (m^3/Mgal)

Batteries

$$NB = \text{int}\left(\frac{Q_{in,us}}{100} + 1.0\right) \tag{18}$$

where: NB = number of batteries

$$Q_{PB} = \frac{Q_{in,us}}{NB} \tag{19}$$

where: Q_{PB} = flow per battery (MGD)

Number of Process Trains

Using a ladder logic-type approach, the number of process trains can be calculated.

Q_{PB} (MGD)	NT
$Q_{PB} > 70$	16
$70 \geq Q_{PB} < 50$	14
$50 \geq Q_{PB} < 40$	12
$40 \geq Q_{PB} < 30$	10
$30 \geq Q_{PB} < 20$	8
$20 \geq Q_{PB} < 10$	6
$10 \geq Q_{PB} < 4$	4
$4 \geq Q_{PB} < 2$	3
$Q_{PB} \leq 2.0$	2

where: NT = number of process trains

Number of Aerobic Tanks-in-Series

Given the number of process trains to be designed, the number of aerobic tanks in series per process train must be calculated.

$$V_{aerobic,nt} = \frac{V_{aerobic}}{NT \times NB} \tag{20}$$

where: $V_{aerobic,nt}$ = aerobic volume per process stream (m^3)

$V_{aerobic,nt}$ (m^3)	$T_{aerobic,nt}$
$V_{aerobic,nt} < 300$	1
$300 \leq V_{aerobic,nt} < 600$	2
$V_{aerobic,nt} \geq 600$	3

where: $T_{aerobic,nt}$ = number of aerobic tanks per process train

$$V_{aerobic,i} = \frac{V_{aerobic,nt}}{T_{aerobic,nt}} \tag{21}$$

where: $V_{aerobic,i}$ = volume of individual aerobic tanks (m^3)

Number of Anoxic Tanks-in-Series

Given the number of process trains to be designed, the number of anoxic tanks in series per process train must be calculated.

$$V_{anoxic,nt} = \frac{V_{anoxic}}{NT \times NB} \tag{22}$$

where: $V_{anoxic,nt}$ = anoxic volume per process stream (m^3)

$V_{anoxic,nt}$ (m^3)	$T_{anoxic,nt}$
$V_{anoxic,nt} \leq V_{aerobic,i}$	1
$V_{aerobic,i} < V_{anoxic,nt} \leq 2*V_{aerobic,i}$	2
$V_{anoxic,nt} > 2*V_{aerobic,i}$	3

where: $T_{anoxic,nt}$ = number of anoxic tanks per process train

Volume of Each Anoxic Tank

$$V_{anoxic,i} = \frac{V_{anoxic}}{(T_{anoxic,nt} \times NT \times NB)} \tag{23}$$

where: $V_{anoxic,i}$ = volume of each anoxic tank (m^3)

Step 6: Calculate Air Requirements

Nitrogen Requirement for Growth

$$FNR = Min(TKN_{T,in}, 0.05 \text{ x } BOD_{removed}) \tag{24}$$

where: FNR = nitrogen requirement for growth (gN/m^3)

$$TPR = Min(TP_{in}, 0.01 \text{ x } BOD_{removed}) \tag{25}$$

where: TPR = phosphorus requirement for growth (gP/m^3)

Nitrifiable Nitrogen

$$N_N = TKN_{T,in} - FNR \tag{26}$$

where: N_N = nitrifiable nitrogen (gN/m^3)

Effluent Nitrogen

It is assumed that all influent TKN is available and that the effluent soluble TKN is ammonia.

$$NH_{3,eff} = TKN_{T,inf} - FNR - N_N \text{ x } 0.8 \tag{27}$$

$$NO_{3,eff} = N_N \text{ x } 0.8 - (0.8 - 0.8 \text{ x } 0.7) \text{ x } N_N \tag{28}$$

$$TKN_{eff} = NH_{3,eff} \tag{29}$$

Required Oxygen for Average Influent Load (assuming 80% nitrification)

$$O_{req} = Q_{in} \text{ x } (0.75 \text{ x } BOD_{removed} + 4.3 \text{ x } 0.8 \text{ x } N_N - 2.83 \text{ x } (0.8 - 0.8 \text{ x } 0.7) \text{ x } N_N) \text{ x } 1000 \tag{30}$$

where: O_{req} = oxygen required (kgO_2/d)

Required Air Flow for Average Influent Load

$$Q_{air} = \frac{O_{req}}{\alpha \times \frac{SOTE}{100}} \times \frac{1}{(1.2 \times 0.21)} \tag{31}$$

where: Q_{air} = required air flow (m^3/d)
$SOTE$ = standard oxygen transfer efficiency (%)
α = alpha factor for oxygen transfer into wastewater

1.2 = unit conversion (kgO_2/m^3)
0.21 = partial pressure of oxygen in air

Step 7: Calculate Number of Baffles Required

Total Number of Baffles

$$Baff_T = (1+(T_{anoxic,nt} - 1) + (T_{aerobic,nt} - 1)) \text{ x } NT \text{ x } NB \tag{32}$$

where: $Baff_T$ = total number of baffles
$T_{anoxic,nt}$ = number of anoxic tanks in series per process train
$T_{aerobic,nt}$ = number of aerobic tanks in series per process train

Step 8: Calculate Mixing Requirements

Anoxic Tank Mixing Power

$$Power_{anoxic,mix} = \text{int}\left(\frac{V_{anoxic,i} \times 30.0}{1000} + 1.0\right) \tag{33}$$

where: $Power_{anoxic,mix}$ = required mixing power (kW)

Number of Mixers

$$Mixers_{anoxic} = T_{anoxic,nt} \text{ x } NT \text{ x } NB \tag{34}$$

where: $Mixers_{anoxic}$ = number of required anoxic mixers

Step 9: Size pumps

Internal recycling pumps and return sludge pumps are sized according to the general pumping algorithm that can be found in the CapdetWorks Technical Reference. The recycle pumps are sized to have a maximum pumped flow of 2 x $Q_{in,nt}$, and minimum pumped flow of $Q_{in,nt}$. The return sludge pumps are sized to have a maximum pumped flow of $Q_{in,nt}$ and a minimum pumped flow of 0.35 x $Q_{in,nt}$.

Step 10: Determine Sludge Production

Sludge Production

$$Sludge_{total} = \frac{(V_{total} \times SS)}{SRT_{total} \times 1000} \tag{35}$$

$$Sludge_{weir} = \frac{SS_{out} \times Q_{in}}{1000} \tag{36}$$

$$Sludge_{wasted} = Sludge_{total} - Sludge_{weir} \tag{37}$$

where: SS_{out} = concentration of suspended solids in the effluent (g/m^3)
SS = concentration of suspended solids in the reactor (g/m^3)
$Sludge_{wasted}$ = mass of sludge to be disposed of (kg/d)

$Sludge_{weir}$ = mass of sludge going over the weir (kg/d)
$Sludge_{total}$ = sludge produced (kg/d)

Step 11: Determine Sludge Recycle Ratio

Clarifier Mass Balance

If SS_{out} is assumed to be negligible in comparison to the solids loading to the clarifier, then a mass balance around the clarifier can be established and solved for Q_{ras}.

$$(Q_{in} + Q_{ras}) \text{ x } SS = Q_{ras} \text{ x } UC \text{ x } 10000 \qquad (38)$$

$$\downarrow$$

$$Q_{ras} = \frac{Q_{in} \times SS}{UC \times 10000 - SS} \qquad (39)$$

where: UC = underflow concentration (%)
Q_{ras} = recycle activated sludge flow rate (m^3/d)

Sludge Recycle Ratio

$$SRR = \frac{Q_{ras}}{Q_{in}} \qquad (40)$$

where: SRR = sludge recycle ratio

Step 12: Determine Effluent Oxygen Demand

Effluent BOD

$$BOD_{T,eff} = BOD_{S,eff} + 0.84 \text{ x } f_{VSS,bio} \text{ x } SS_{out} \text{ x } ivt \qquad (41)$$

where: $BOD_{T,eff}$ = effluent BOD (g/m^3)
$f_{VSS,bio}$ = degradable fraction of MLVSS
0.84 = degradable VSS to BOD conversion factor

Effluent COD

$$COD_{T,eff} = BOD_{T,eff} \text{ x} 1.5 \qquad (42)$$

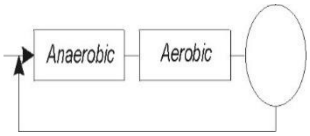
where: $COD_{T,eff}$ = effluent COD (g/m^3)

BIOLOGICAL NUTRIENT REMOVAL

Biological nutrient removal encompasses both denitrification (described previously) and excess biological phosphorus removal (EBPR) separately, or in combination. EBPR is a biologically mediated process used within activated sludge systems to achieve phosphorus removal from wastewater. The process involves cultivating within the mixed community, microorganisms (termed polyphosphate accumulating organisms or PAOs) which have the ability to take up more phosphorus than they require for growth. The net effect of this uptake is a reduced wastewater concentration to a level of residual phosphorus which can be less than 1mg/L.

Experience has shown that significant biological nutrient removal (BNR) activity does not occur in strictly aerobic systems. Rather, BNR behavior is achieved by incorporating an unaerated zone into the process design. For denitrification, an anoxic stage (nitrate present, no oxygen) is included and for EBPR, an anaerobic stage (neither nitrate nor oxygen present) must be included in the reactor configuration.

BIOLOGICAL NUTRIENT REMOVAL – 2-STAGE



This reactor configuration includes an anaerobic/unaerated stage ahead of an aerobic reactor. These reactors are followed by a secondary clarifier that is used to concentrate the sludge and return it to the unaerated stage.

Step 1: Determine the aerobic SRT based on temperature.

System SRT

If the winter temperature is above 10°C and the summer temperature is above 20°C then:

$$SRT = 3\text{ days} \tag{1}$$

Otherwise:

$$SRT = 5\text{ days} \tag{2}$$

where: SRT = design SRT (d)

Step 2: Calculation of the Aerobic Basin Volume

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20} \times \Theta_{kd,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{3}$$

where: T_{winter} = winter temperature (°C)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)
$k_{d,20}$ = oxygen decay coefficient at 20°C (1/d)
$\Theta_{kd,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.040 in version 1.0

BOD Removal

$$BOD_{removed} = BOD_{T,in} - BOD_{S,eff} \tag{4}$$

where: $BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$BOD_{T,in}$ = total BOD entering the unit process (g BOD/m^3)
$BOD_{S,eff}$ = effluent soluble BOD (g BOD/m^3)

Aerobic Volume

$$V_{aerobic} = \frac{SRT \times Q_{in} \times Y_h \times BOD_{removed}}{VSS \times (1 + k_{d,T_{winter}} \times SRT)} \tag{5}$$

where: $V_{aerobic}$ = aerobic volume (m^3)
SRT = design SRT (d)
Q_{in} = the unit process influent flow rate (m^3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
VSS = volatile suspended solids concentration [= Suspended solids * ‘VSS/SS ratio’] (g/m^3)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

Aerobic Hydraulic Retention Time

$$HRT_{aerobic} = \frac{V_{aerobic}}{Q_{in}} \times 24 \tag{6}$$

where: $HRT_{aerobic}$ = aerobic hydraulic retention time (hr) - minimum allowable $HRT_{aerobic}$ = 3 hours

Resizing Aerobic Tank (if necessary)

If the calculated $HRT_{aerobic}$ is less than 3 hours, then the aerobic tank must be.

$$HRT_{aerobic} = 3 \text{ hours} \tag{7}$$

$$V_{aerobic} = \frac{HRT_{aerobic} \times Q_{in}}{24} \tag{8}$$

Step 3: Check on Loading

F/M Ratio

$$F/M_{calc} = \frac{Q_{in} \times BOD_{T,in}}{VSS \times V_{aerobic}} \tag{9}$$

where: F/M_{calc} = calculated F/M ratio (g BOD g VSS^{-1} d^{-1})

*F/M_{calc} is bounded by between $F/M_{user,min}$ [$F/M_{user,min}$ is the user-specified ‘F/M Ratio - Minimum’] and $F/M_{user,max}$ [$F/M_{user,max}$ is the user-specified ‘F/M Ratio - Maximum’].

If the calculated F/M_{calc} falls outside these boundaries, then the user-defined VSS concentration needs to be overridden and new VSS & SS concentrations need to be calculated. Based on these calculations, the SRT also must be recalculated.

$$VSS = \frac{Q_{in} \times BOD_{removed}}{V_{aerobic} \times F/M_{user}} \tag{10}$$

$$SS = \frac{VSS}{ivt} \tag{11}$$

where: ivt = VSS/SS ratio
F/M_{user} = either $F/M_{user,min}$ or $F/M_{user,max}$, i.e. whichever boundary has been violated

$$SRT = \frac{V_{aerobic} \times VSS}{Q_{in} \times Y_h \times BOD_{removed} - V_{aerobic} \times VSS \times k_{d,T_{winter}}} \tag{12}$$

Step 4: Determine the Anaerobic Basin Volume

Influent BOD to TP ratio

$$BP_{inf} = \frac{BOD_{T,in}}{TP_{T,in}} \tag{13}$$

where: BP_{inf} = influent BOD to TP ratio

Using a ladder logic type approach, the anaerobic retention time can be calculated subject to minimum boundaries.

BP_{inf}	$HRT_{anaerobic}$ *(hr)*	*Minimum Boundaries (all apply)*	
$BP_{inf} > 35$	$\frac{(TP_{in} - TP_{out}) - 2}{5}$	$HRT_{anaerobic} \geq 1.0$	$HRT_{anaerobic} \geq 0.15 \text{ x } HRT_{aerobic}$
$BP_{inf} \leq 35$	0.88 x (TP_{in} - TP_{out}) - 2.5	$HRT_{anaerobic} \geq 1.5$	$HRT_{anaerobic} \geq 0.25 \text{ x } HRT_{aerobic}$

$$V_{anaerobic} = \frac{HRT_{anaerobic} \times Q_{in}}{24} \tag{14}$$

where: $HRT_{anaerobic}$ = anaerobic hydraulic retention time (hr)
$V_{anaerobic}$ = anaerobic volume (m^3)

Total Volume

$$V_{total} = V_{anaerobic} + V_{aerobic} \tag{15}$$

Step 5: Determine the Number of Batteries, Process Trains & Number of Tanks-In-Series

Influent Flow in U.S. Units

$$Q_{in,us} = \frac{Q_{in}}{3785} \tag{16}$$

where: $Q_{in,us}$ = unit process influent flow rate in U.S. units (MGD)
3785 = volume conversion (m^3/Mgal)

Batteries

$$NB = \text{int}\left(\frac{Q_{in,us}}{100} + 1.0\right) \tag{17}$$

where: NB = number of batteries

$$Q_{PB} = \frac{Q_{in,us}}{NB} \tag{18}$$

where: Q_{PB} = flow per battery (MGD)

Number of Process Trains

Using a ladder logic-type approach, the number of process trains can be calculated.

Q_{PB} (MGD)	NT
$Q_{PB} > 70$	16
$70 \geq Q_{PB} < 50$	14
$50 \geq Q_{PB} < 40$	12
$40 \geq Q_{PB} < 30$	10
$30 \geq Q_{PB} < 20$	8
$20 \geq Q_{PB} < 10$	6
$10 \geq Q_{PB} < 4$	4
$4 \geq Q_{PB} < 2$	3
$Q_{PB} \leq 2.0$	2

where: NT = number of process trains

Number of Aerobic Tanks-in-Series

Given the number of process trains to be designed, the number of aerobic tanks in series per process train must be calculated.

$$V_{aerobic,nt} = \frac{V_{aerobic}}{NT \times NB} \tag{19}$$

where: $V_{aerobic,nt}$ = aerobic volume per process stream (m^3)

$V_{aerobic,nt}$ (m^3)	$T_{aerobic,nt}$
$V_{aerobic,nt} < 300$	1
$300 \leq V_{aerobic,nt} < 600$	2
$V_{aerobic,nt} \geq 600$	3

where: $T_{aerobic,nt}$ = number of aerobic tanks per process train

$$V_{aerobic,i} = \frac{V_{aerobic,nt}}{T_{aerobic,nt}} \tag{20}$$

where: $V_{aerobic,i}$ = volume of individual aerobic tanks (m^3)

Number of Anaerobic Tanks-in-Series

Given the number of process trains to be designed, the number of anoxic tanks in series per process train must be calculated.

$$V_{anaerobic,nt} = \frac{V_{anaerobic}}{NT \times NB} \tag{21}$$

where: $V_{anaerobic,nt}$ = anaerobic volume per process stream (m^3)

$V_{anaerobic,nt}$ (m^3)	$T_{anaerobic,nt}$
$V_{anaerobic,nt} \leq V_{aerobic,i}$	1
$V_{aerobic,i} < V_{anaerobic,nt} \leq 2{*}V_{aerobic,i}$	2
$V_{anaerobic,nt} > 2{*}V_{aerobic,i}$	3

where: $T_{anaerobic,nt}$ = number of anaerobic tanks per process train

Volume of Each Anaerobic Tank

$$V_{anaerobic,i} = \frac{V_{anaerobic}}{(T_{anaerobic,nt} \times NT \times NB)} \tag{22}$$

where: $V_{anaerobic,i}$ = volume of each anaerobic tank (m^3)

Step 6: Calculate Number of Baffles Required

Total Number of Baffles

$$Baff_T = (1 + (T_{anaerobic,nt} - 1) + (T_{aerobic,nt} - 1)) \text{ x } NT \text{ x } NB \tag{23}$$

where: $Baff_T$ = total number of baffles
$T_{anaerobic,nt}$ = number of anaerobic tanks in series per process train

$T_{aerobic,nt}$ = number of aerobic tanks in series per process train

Step 7: Calculate Mixing Requirements

Anaerobic Mixing Power

$$Power_{anaerobic,mix} = \mathrm{int}\left(\frac{V_{anaerobic,i} \times 30.0}{1000} + 1.0\right) \quad (24)$$

where: $Power_{anaerobic,mix}$ = required anaerobic mixing power (kW)

Number of Mixers

$$Mixers_{anaerobic} = T_{anaerobic,nt} \text{ x } NT \text{ x } NB \quad (25)$$

where: $Mixers_{anaerobic}$ = number of required anoxic mixers

Step 8: Calculate Air Requirements

Nitrogen Requirement for Growth

$$FNR = Min(TKN_{T,in}, 0.05 \text{ x } BOD_{removed}) \quad (26)$$

where: FNR = nitrogen requirement for growth (gN/m^3)

Degree of Nitrification

The assumed degree of nitrification is assessed based on the summer temperature according to the following criteria.

Summer Temperature Constraint	SRT < 3 days	N $3 \leq$ SRT < 5	SRT $\geq$ 5 days
$T_{summer} \geq 20^oC$	0.4	0.8	1.0
$T_{summer} < 20^oC$	0.4	0.6	0.6

where: N = degree of nitrification

Effluent Nitrogen

It is assumed that all influent TKN is available and that the effluent soluble TKN is ammonia.

$$NH_{3,eff} = TKN_{T,inf} - FNR - (TKN_{T,in} - FNR) \text{ x } N \quad (27)$$

$$NO_{3,eff} = (TKN_{T,in} - FNR) \text{ x } N - (N - N \text{ x } 0.7) \text{ x } (TKN_{T,in} - FNR) \quad (28)$$

$$TKN_{eff} = NH_{3,eff} \quad (29)$$

Required Oxygen for Average Influent Load (with complete nitrification)

$$O_{req} = Q_{in} \text{ x } (0.75 \text{ x } BOD_{removed} + 4.3 \text{ x } (TKN_{T,in} - FNR) - 2.83 \text{ x } (1.0 - 0.7) \text{ x } (TKN_{T,in} - FNR)) \text{ x } 1000 \quad (30)$$

where: O_{req} = oxygen required (kgO$_2$/d)

Required Air Flow for Average Influent Load

$$Q_{air} = \frac{O_{req}}{\alpha \times \frac{SOTE}{100}} \times \frac{1}{(1.2 \times 0.21)} \qquad (31)$$

where:
Q_{air} = required air flow (m^3/d)
$SOTE$ = standard oxygen transfer efficiency (%)
α = alpha factor for oxygen transfer into wastewater
1.2 = unit conversion (kgO$_2$/m^3)
0.21 = partial pressure of oxygen in air

Step 9: Size pumps

Internal recycling pumps and return sludge pumps are sized according to the general pumping algorithm that can be found in the CapdetWorks Technical Reference. The return sludge pumps are sized to have a maximum pumped flow of $Q_{in,nt}$ and a minimum pumped flow of 0.35 x $Q_{in,nt}$.

Step 10: Determine Sludge Production

Sludge Production

$$Sludge_{total} = \frac{(V_{total} \times SS)}{SRT \times 1000} \qquad (32)$$

$$Sludge_{weir} = \frac{SS_{out} \times Q_{in}}{1000} \qquad (33)$$

$$Sludge_{wasted} = Sludge_{total} - Sludge_{weir} \qquad (34)$$

where:
SS_{out} = concentration of suspended solids in the effluent (g/m^3)
SS = concentration of suspended solids in the reactor (g/m^3)
$Sludge_{wasted}$ = mass of sludge to be disposed of (kg/d)
$Sludge_{weir}$ = mass of sludge going over the weir (kg/d)
$Sludge_{total}$ = sludge produced (kg/d)

Step 11: Determine Sludge Recycle Ratio

Clarifier Mass Balance

If SS_{out} is assumed to be negligible in comparison to the solids loading to the clarifier, then a mass balance around the clarifier can be established and solved for Q_{ras}.

$$(Q_{in} + Q_{ras}) \text{ x } SS = Q_{ras} \text{ x } UC \text{ x } 10000 \qquad (35)$$

$$\downarrow$$

$$Q_{ras} = \frac{Q_{in} \times SS}{UC \times 10000 - SS} \qquad (36)$$

where: UC = underflow concentration (%)
Q_{ras} = recycle activated sludge flow rate (m^3/d)

Sludge Recycle Ratio

$$SRR = \frac{Q_{ras}}{Q_{in}} \tag{37}$$

where: SRR = sludge recycle ratio

Step 12: Determine Effluent Oxygen Demand

Effluent BOD

$$BOD_{T,eff} = BOD_{S,eff} + 0.84 \text{ x } f_{VSS,bio} \text{ x } SS_{out} \text{ x } ivt \tag{38}$$

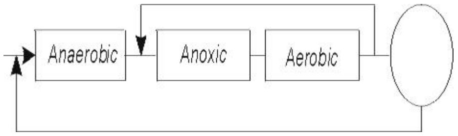
where: $BOD_{T,eff}$ = effluent BOD (g/m^3)
$f_{VSS,bio}$ = degradable fraction of MLVSS
0.84 = degradable VSS to BOD conversion factor

Effluent COD

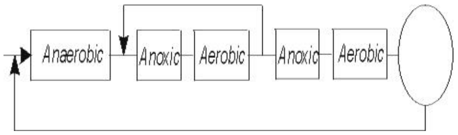
$$COD_{T,eff} = BOD_{T,eff} \text{ x } 1.5 \tag{39}$$

where: $COD_{T,eff}$ = effluent COD (g/m^3)

BIOLOGICAL NUTRIENT REMOVAL – 3/5 STAGE



The 3-stage biological nutrient removal configuration includes an anaerobic stage, followed by an anoxic stage followed by an aerobic stage. One internal recycle is used to recycle nitrate from the aerobic stage to the anoxic stage and a return activated sludge (RAS) recycle is used to recycle thickened sludge from the clarifier to the anaerobic stage.



The 5-stage configuration (also termed a 'modified Bardenpho') is similar to the 3-stage configuration in that the first three reactors are similar and one internal recycle recycles nitrate to the anoxic stage. However, to increase the nutrient removal capacity, two additional stages are placed after the aerobic stage and before the clarifier. The first of these stages is anoxic for more denitrification, and the second is aerobic for effluent polishing.

Step 1: Determine the minimum aerobic SRT for nitrification based on the winter temperature.

Nitrifier Growth Rate

$$\mu_{maxA,T_{winter}} = \mu_{maxA,20} \times \Theta_{\mu A,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{1}$$

where: T_{winter} = winter temperature (°C)

$\mu_{maxA,T_{winter}}$ = maximum specific growth rate at temperature, T_{winter} (1/d)

$\mu_{maxA,20}$ = maximum specific growth rate at 20°C (1/d)

$\Theta_{\mu A,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.123 in version 1.0

Nitrifier Decay Rate

`

$$b_{a,T_{winter}} = b_{a,20} \times \Theta_{ba,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{2}$$

where: T_{winter} = winter temperature (°C)

$b_{a,T_{winter}}$ = decay rate at temperature, T_{winter} (1/d)

$b_{a,20}$ = decay rate at 20°C (1/d)

$\Theta_{ba,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 1.0

Minimum Aerobic SRT

$$SRT_{aerobic} = \frac{1}{\mu_{maxA,T_{winter}} - b_{a,T_{winter}}} \tag{3}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for nitrification at temperature, T_{winter}

Allowing for an SRT safety factor:

$$SRT_{aerobic,safe} = SRT_{aerobic} * SRT_{sf} \tag{4}$$

where: $SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
SRT_{sf} = safety factor for SRT

Step 2: Calculation of the Aerobic Basin Volume

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20} \times \Theta_{kd,arrhenius}{}^{(T_{winter} - 20^{o}C)} \tag{5}$$

where: T_{winter} = winter temperature (°C)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)
$k_{d,20}$ = oxygen decay coefficient at 20°C (1/d)
$\Theta_{kd,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.040 in version 1.0

BOD Removal

$$BOD_{removed} = BOD_{T,in} - BOD_{S,eff} \tag{6}$$

where: $BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$BOD_{T,in}$ = total BOD entering the unit process (g BOD/m^3)
$BOD_{S,eff}$ = effluent soluble BOD (g BOD/m^3)

Aerobic Volume

$$V_{aerobic} = \frac{SRT_{aerobic,safe} \times Q_{in} \times Y_h \times BOD_{removed} \times 0.8}{VSS \times (1 + k_{d,T_{winter}} \times SRT_{aerobic,safe})} \tag{7}$$

where: $V_{aerobic}$ = aerobic volume (m^3)
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
Q_{in} = the unit process influent flow rate (m^3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
0.8 = assumed removal factor which is used to calculate the aerobically removed BOD from the total BOD removed (80% assumed)
VSS = volatile suspended solids concentration
[= Suspended solids * ‘VSS/SS ratio’] (g/m3)

$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

Step 3: Check on Aerobic HRT

Aerobic Hydraulic Retention Time

$$HRT_{aerobic} = \frac{V_{aerobic}}{Q_{in}} \times 24 \qquad (8)$$

where: $HRT_{aerobic}$ = aerobic hydraulic retention time (hr) - minimum allowable $HRT_{aerobic}$ = 3 hours

Sizing Aerobic Tank (if necessary)

If the calculated $HRT_{aerobic}$ is less than 3 hours, then the aerobic tank must be resized and the VSS and SS concentrations are recalculated.

$$HRT_{aerobic} = 3 \text{ hours} \qquad (9)$$

$$V_{aerobic} = \frac{HRT_{aerobic} \times Q_{in}}{24} \qquad (10)$$

If the aerobic tank needs to be resized to satisfy an HRT limitation then the user-defined VSS concentration needs to be overridden and new VSS & SS concentrations need to be calculated.

$$VSS = \frac{SRT_{aerobic,safe} \times Q_{in} \times Y_h \times BOD_{removed} \times 0.8}{V_{aerobic} \times (1 + k_{d,T_{winter}} \times SRT_{aerobic,safe})} \qquad (11)$$

$$SS = \frac{VSS}{ivt} \qquad (12)$$

where: ivt = VSS/SS ratio

Step 4: Determine the Anoxic Basin Volume

Influent BOD to TKN ratio

$$BN_{inf} = \frac{BOD_{T,in}}{TKN_{T,in}} \qquad (13)$$

where: BN_{inf} = influent BOD to TKN ratio

Using a ladder logic type approach, the anoxic volume can be calculated.

BN_{inf}	$Size_f$
$BN_{inf} \geq 6.5$	0.7
$6.5 > BN_{inf} \leq 5.0$	0.6
$5.0 > BN_{inf} < 4.0$	0.35
$BN_{inf} \leq 4.0$	0.35 - warning printed

$$V_{anoxic} = (1 - Size_f) \times V_{aerobic} \tag{14}$$

where: $Size_f$ = sizing factor

Step 5: Determine the Anaerobic Basin Volume

Influent BOD to TP ratio

$$BP_{inf} = \frac{BOD_{T,in}}{TP_{T,in}} \tag{15}$$

where: BP_{inf} = influent BOD to TP ratio

Using a ladder logic type approach, the anaerobic retention time can be calculated subject to minimum boundaries.

BP_{inf}	$HRT_{anaerobic}$ (hr)	Minimum Boundaries (all apply)	
$BP_{inf} > 35$	$\frac{(TP_{in} - TP_{out}) - 2}{5}$	$HRT_{anaerobic} \geq 1.0$	$HRT_{anaerobic} \geq 0.15 \times HRT_{aerobic}$
$BP_{inf} \leq 35$	$0.88 \times (TP_{in} - TP_{out}) - 2.5$	$HRT_{anaerobic} \geq 1.5$	$HRT_{anaerobic} \geq 0.25 \times HRT_{aerobic}$

$$V_{anaerobic} = \frac{HRT_{anaerobic} \times Q_{in}}{24} \tag{16}$$

where: $HRT_{anaerobic}$ = anaerobic hydraulic retention time (hr)
$V_{anaerobic}$ = anaerobic volume (m^3)

**Note: $V_{anaerobic}$ is subject to a minimum boundary such that $V_{anaerobic} \leq V_{anoxic}$.

Step 6: Determine the Total Solids Retention Time

Total Volume

$$V_{total} = V_{anaerobic} + V_{anoxic} + V_{aerobic} \tag{17}$$

Aerobic Fraction

$$f_{aerobic} = \frac{V_{aerobic}}{V_{total}} \tag{18}$$

where: $f_{aerobic}$ = aerobic fraction of the total volume

System Solids Retention Time

$$SRT_{system} = \frac{SRT_{aerobic,safe}}{f_{aerobic}} \tag{19}$$

where: SRT_{system} = system solids retention time (d)

Step 7: Determine the Number of Batteries, Process Trains & Number of Tanks-In-Series

Influent Flow in U.S. Units

$$Q_{in,us} = \frac{Q_{in}}{3785} \tag{20}$$

where: $Q_{in,us}$ = unit process influent flow rate in U.S. units (MGD)
3785 = volume conversion (m^3/Mgal)

Batteries

$$NB = \text{int}\left(\frac{Q_{in,us}}{100} + 1.0\right) \tag{21}$$

where: NB = number of batteries

$$Q_{PB} = \frac{Q_{in,us}}{NB} \tag{22}$$

where: Q_{PB} = flow per battery (MGD)

Number of Process Trains

Using a ladder logic-type approach, the number of process trains can be calculated.

Q_{PB} (MGD)	NT
$Q_{PB} > 70$	16
$70 \geq Q_{PB} < 50$	14
$50 \geq Q_{PB} < 40$	12
$40 \geq Q_{PB} < 30$	10
$30 \geq Q_{PB} < 20$	8
$20 \geq Q_{PB} < 10$	6
$10 \geq Q_{PB} < 4$	4
$4 \geq Q_{PB} < 2$	3
$Q_{PB} \leq 2.0$	2

where: NT = number of process trains

Number of Aerobic Tanks-in-Series

Given the number of process trains to be designed, the number of aerobic tanks in series per process train must be calculated.

$$V_{aerobic,nt} = \frac{V_{aerobic}}{NT \times NB} \tag{23}$$

where: $V_{aerobic,nt}$ = aerobic volume per process stream (m^3)

$V_{aerobic,nt}$ (m^3)	$T_{aerobic,nt}$ (3 stage)	$T_{aerobic,nt}$ (5 stage)
$V_{aerobic,nt} < 300$	1	2
$300 \leq V_{aerobic,nt} < 600$	2	2
$V_{aerobic,nt} \geq 600$	3	3

where: $T_{aerobic,nt}$ = number of aerobic tanks per process train

$$V_{aerobic,i} = \frac{V_{aerobic,nt}}{T_{aerobic,nt}} \tag{24}$$

where: $V_{aerobic,i}$ = volume of individual aerobic tanks (m^3)

Number of Anoxic Tank- in-Series

Given the number of process trains to be designed, the number of anoxic tanks in series per process train must be calculated.

$$V_{anoxic,nt} = \frac{V_{anoxic}}{NT \times NB} \tag{25}$$

where: $V_{anoxic,nt}$ = anoxic volume per process stream (m^3)

$V_{anoxic,nt}$ (m^3)	$T_{anoxic,nt}$ (3 stage)	$T_{anoxic,nt}$ (5 stage)
$V_{anoxic,nt} \leq V_{aerobic,i}$	1	2
$V_{aerobic,i} < V_{anoxic,nt} \leq 2*V_{aerobic,i}$	2	2
$V_{anoxic,nt} > 2*V_{aerobic,i}$	3	3

where: $T_{anoxic,nt}$ = number of anoxic tanks per process train

Volume of Each Anoxic Tank

$$V_{anoxic,i} = \frac{V_{anoxic}}{(T_{anoxic,nt} \times NT \times NB)} \tag{26}$$

where: $V_{anoxic,i}$ = volume of each anoxic tank (m^3)

Number of Anaerobic Tanks-in-Series

Given the number of process trains to be designed, the number of anoxic tanks in series per process train must be calculated.

$$V_{anaerobic,nt} = \frac{V_{anaerobic}}{NT \times NB} \quad (27)$$

where: $V_{anaerobic,nt}$ = anaerobic volume per process stream (m^3)

$V_{anaerobic,nt}$ (m^3)	$T_{anaerobic,nt}$
$V_{anaerobic,nt} \leq V_{aerobic,i}$	1
$V_{aerobic,i} < V_{anaerobic,nt} \leq 2*V_{aerobic,i}$	2
$V_{anaerobic,nt} > 2*V_{aerobic,i}$	3

where: $T_{anaerobic,nt}$ = number of anaerobic tanks per process train

Volume of Each Anaerobic Tank

$$V_{anaerobic,i} = \frac{V_{anaerobic}}{(T_{anaerobic,nt} \times NT \times NB)} \quad (28)$$

where: $V_{anaerobic,i}$ = volume of each anaerobic tank (m^3)

Step 8: Calculate Air Requirements

Nitrogen Requirement for Growth

$$FNR = Min(TKN_{T,in}, 0.05 \text{ x } BOD_{removed}) \quad (29)$$

where: FNR = nitrogen requirement for growth (gN/m^3)

Nitrifiable Nitrogen

$$N_N = TKN_{T,in} - FNR \quad (30)$$

where: N_N = nitrifiable nitrogen (gN/m^3)

Effluent Nitrogen

It is assumed that all influent TKN is available and that the 3/5 stage BNR process achieves 90% nitrification and partial denitrification.

$$NH_{3,eff} = TKN_{T,inf} - FNR - 0.9 \text{ x } N_N \tag{31}$$

$$NO_{3,eff} = 0.9 \text{ x } N_N - 0.9 \text{ x } (1.0 - 0.7) \text{ x } N_N \tag{32}$$

$$TKN_{eff} = NH_{3,eff} \tag{33}$$

Required Oxygen for Average Influent Load (with complete nitrification)

$$O_{req} = Q_{in} \text{ x } (0.75 \text{ x } BOD_{removed} + 4.3 \text{ x } N_N - 2.83 \text{ x } (1.0 - 1.0 \text{ x } 0.7) \text{ x } N_N) \text{ x } 1000 \tag{34}$$

where: O_{req} = oxygen required (kgO_2/d)

Required Air Flow for Average Influent Load

$$Q_{air} = \frac{O_{req}}{\alpha \times \frac{SOTE}{100}} \times \frac{1}{(1.2 \times 0.21)} \tag{35}$$

where: Q_{air} = required air flow (m^3/d)
$SOTE$ = standard oxygen transfer efficiency (%)
α = alpha factor for oxygen transfer into wastewater
1.2 = unit conversion (kgO_2/m^3)
0.21 = partial pressure of oxygen in air

Step 9: Calculate Number of Baffles Required

Total Number of Baffles

$$Baff_T = (2 + (T_{anaerobic,nt} - 1) + (T_{anoxic,nt} - 1) + (T_{aerobic,nt} - 1)) \text{ x } NT \text{ x } NB \tag{36}$$

where: $Baff_T$ = total number of baffles
$T_{anaerobic,nt}$ = number of anaerobic tanks in series per process train
$T_{anoxic,nt}$ = number of anoxic tanks in series per process train
$T_{aerobic,nt}$ = number of aerobic tanks in series per process train

Step 10: Calculate Mixing Requirements

Anoxic Mixing Power

$$Power_{anoxic,mix} = \text{int}\left(\frac{V_{anoxic,i} \times 30.0}{1000} + 1.0\right) \tag{37}$$

where: $Power_{anoxic,mix}$ = required anoxic mixing power (kW)

Anaerobic Mixing Power

$$Power_{anaerobic,mix} = \text{int}\left(\frac{V_{anaerobic,i} \times 30.0}{1000} + 1.0\right) \tag{38}$$

where: $Power_{anaerobic,mix}$ = required anaerobic mixing power (kW)

Number of Mixers

$$Mixers_{anoxic} = T_{anoxic,nt} \text{ x } NT \text{ x } NB \tag{39}$$

$$Mixers_{anaerobic} = T_{anaerobic,nt} \text{ x } NT \text{ x } NB \tag{40}$$

$$Mixers_{total} = Mixers_{anoxic} + Mixers_{anaerobic} \tag{41}$$

where: $Mixers_{anaerobic}$ = number of required anoxic mixers
$Mixers_{anoxic}$ = number of required anoxic mixers
$Mixers_{total}$ = number of required anoxic mixers

Step 11: Size pumps

Internal recycling pumps and return sludge pumps are sized according to the general pumping algorithm that can be found in the CapdetWorks Technical Reference. The recycle pumps are sized to have a maximum pumped flow of 2 x $Q_{in,nt}$, and minimum pumped flow of $Q_{in,nt}$. The return sludge pumps are sized to have a maximum pumped flow of $Q_{in,nt}$ and a minimum pumped flow of 0.35 x $Q_{in,nt}$.

Step 12: Determine Sludge Production

Sludge Production

$$Sludge_{total} = \frac{(V_{total} \times SS)}{SRT_{system} \times 1000} \tag{42}$$

$$Sludge_{weir} = \frac{SS_{out} \times Q_{in}}{1000} \tag{43}$$

$$Sludge_{wasted} = Sludge_{total} - Sludge_{weir} \tag{44}$$

where: SS_{out} = concentration of suspended solids in the effluent (g/m^3)
SS = concentration of suspended solids in the reactor (g/m^3)
$Sludge_{wasted}$ = mass of sludge to be disposed of (kg/d)
$Sludge_{weir}$ = mass of sludge going over the weir (kg/d)
$Sludge_{total}$ = sludge produced (kg/d)

Step 13: Determine Sludge Recycle Ratio

Clarifier Mass Balance

If SS_{out} is assumed to be negligible in comparison to the solids loading to the clarifier, then a mass balance around the clarifier can be established and solved for Q_{ras}.

$$(Q_{in} + Q_{ras}) \text{ x } SS = Q_{ras} \text{ x } UC \text{ x } 10000 \tag{45}$$

$$\downarrow$$

$$Q_{ras} = \frac{Q_{in} \times SS}{UC \times 10000 - SS} \tag{46}$$

where: UC = underflow concentration (%)
Q_{ras} = recycle activated sludge flow rate (m^3/d)

Sludge Recycle Ratio

$$SRR = \frac{Q_{ras}}{Q_{in}} \tag{47}$$

where: SRR = sludge recycle ratio

Step 14: Determine Effluent Oxygen Demand

Effluent BOD

$$BOD_{T,eff} = BOD_{S,eff} + 0.84 \times f_{VSS,bio} \times SS_{out} \times ivt \tag{48}$$

where: $BOD_{T,eff}$ = effluent BOD (g/m^3)
$f_{VSS,bio}$ = degradable fraction of MLVSS
0.84 = degradable VSS to BOD conversion factor

Effluent COD

$$COD_{T,eff} = BOD_{T,eff} \times 1.5 \tag{49}$$

where: $COD_{T,eff}$ = effluent COD (g/m^3)

SEQUENCING BATCH REACTOR

This object is similar to the SRT-based plug flow activated sludge process in that it is based on a University of Cape Town plug flow tank algorithm and is consistent with the idea of influent fractionation to more accurately predict the mass of solids that will be present in the tank. The algorithm for the Sequencing Batch Reactor (SBR) has been developed based on the premise that where plug flow tanks are designed in space (i.e. reactors of a certain volume with a certain hydraulic retention time), SBRs are designed in time (i.e. aerobic cycle time). Nevertheless, the biology of the two approaches is assumed to be the same and hence the mass of solids generated is expected to be similar. This approach is also consistent with the dynamic wastewater treatment model known as ASM1 (Henze *et al.* 1986) published as an International Water Association Scientific and Technical Report. This object is recommended for those who hope to export the final design to GPS-X, Hydromantis dynamic process simulator, and perform further dynamic analysis of the design.

Step 1: Determine the Minimum Aerobic SRT (based on the winter temperature)

Nitrifier Growth Rate

$$\mu_{\max A,T_{winter}} = \mu_{\max A,20}\Theta_{\mu A,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (1)$$

where:
T_{winter} = winter temperature (°C)
$\mu_{maxA,T_{winter}}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxA,20}$ = maximum specific growth rate at 20°C (1/d)
$\Theta_{\mu A,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.096 in version 2.1

Nitrifier Decay Rate

$$b_{a,T_{winter}} = b_{a,20}\Theta_{ba,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (2)$$

where:
$b_{a,Twinter}$ = decay rate at temperature, T_{winter} (1/d)
$b_{a,20}$ = decay rate at 20°C (1/d)
$\Theta_{ba,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 2.1

Heterotrophic Growth Rate

$$\mu_{\max H,T_{winter}} = \mu_{\max H,20}\Theta_{\mu H,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (3)$$

where:
$\mu_{maxH,T_{winter}}$ = maximum heterotrophic specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxH,20}$ = maximum heterotrophic specific growth rate at 20°C (1/d)
$\Theta_{\mu H,arrhenius}$ = arrhenius heterotrophic temperature coefficient that has a value of 1.072 in version 2.1

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20}\Theta_{kd,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (4)$$

where:
$k_{d,T_{winter}}$ = endogenous respiration rate coefficient at temperature, T_{winter} (1/d)
$k_{d,20}$ = endogenous respiration rate coefficient at 20°C (1/d)
$\Theta_{kd,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.04 in version 2.1

Minimum Aerobic SRT

If Carbon Removal Only:

$$SRT_{aerobic} = \frac{1}{\mu_{\max H,T_{winter}} - k_{d,T_{winter}}} \qquad (5a)$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for carbon removal at temperature, T_{winter} (d)

Otherwise for all other designs:

$$SRT_{aerobic} = \frac{1}{\mu_{\max A,T_{winter}} - b_{a,T_{winter}}} \qquad (5b)$$

Allowing for an SRT safety factor:

$$SRT_{aerobic,safe} = SRT_{aerobic} SRT_{sf} \qquad (6)$$

where: $SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
SRT_{sf} = safety factor for SRT

Step 2: Calculate the Influent and Effluent Concentrations, Removals and Solids Masses

Influent Speciation

$$VSS_{in} = SS_{in} * ivt \qquad (7)$$

$$ISS_{in} = SS_{in} - VSS_{in} \qquad (8)$$

where: SS_{in} = influent total suspended solids (mg/L)
VSS_{in} = influent volatile suspended solids (mg/L)
ISS_{in} = influent inert inorganic solids (mg/L)
ivt = influent VSS to SS ratio (-)

$$uVSS_{in} = F * VSS_{in} \qquad (9)$$

$$uCOD_{in} = 1.5 * uVSS_{in} \qquad (10)$$

$$uSS_{in} = ISS_{in} + uVSS_{in} \qquad (11)$$

$$bCOD_{in} = COD_{in} - uCOD_{in} \qquad (12)$$

where: F = fraction of influent VSS that is unbiodegradable
$uVSS_{in}$ = influent unbiodegradable VSS (mg/L)
$uCOD_{in}$ = influent unbiodegradable COD (mg COD/L)
uSS_{in} = influent unbiodegradable suspended solids (mg/L)
$bCOD_{in}$ = influent biodegradable COD (mg COD/L)
COD_{in} = total influent COD (mg COD/L)

Reactor Solids Masses

$$M(X_a) = \frac{SRT_{aerobic,safe} Q_{in} Y_h BOD_{removed}}{(1 + k_{d,T_{winter}} SRT_{aerobic,safe})} \qquad (13)$$

$$M(X_e) = 0.2 k_{d,T_{winter}} SRT_{aerobic,safe} M(X_a) \qquad (14)$$

$$M(X_i) = uVSS_{in} Q_{in} SRT_{aerobic,safe} \qquad (15)$$

$$M(VSS) = M(X_a) + M(X_e) + M(X_i) \qquad (16)$$

$$M(ISS) = ISS_{in} Q_{in} SRT_{aerobic,safe} \tag{17}$$

$$M(SS) = M(VSS) + M(ISS) \tag{18}$$

where: $M(X_a)$ = total mass of active biomass in the reactor (g)
$M(X_e)$ = total mass of inert endogenous biomass products in the reactor (g)
$M(X_i)$ = total mass of inert volatile solids in the reactor (g)
$M(VSS)$ = total mass of volatile solids in the reactor (g)
$M(ISS)$ = total mass of inert inorganic solids in the reactor (g)
$M(SS)$ = total mass of solids in the reactor (g)
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
Q_{in} = the unit process influent flow rate (m_3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$K_{d,Twinter}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

BOD Removal

$$BOD_{removed} = BOD_{in} - BOD_{S,eff} \tag{19}$$

where: BOD_{in} = the greater of $bCOD_{in}$ or (BOD_{in} *1.5)
$BODS,eff$ = effluent soluble BOD (mg/L)

F:M ratio

$$F:M = \frac{Q_{in} BOD_{removed}}{M(VSS)} \tag{20}$$

where: $F:M$ = food-to-micro-organism ratio (g BOD/(g VSS•d))

Aeration Hydraulic Retention Time

$$HRT = \frac{V_{oxic} 24}{Q_{avg}} \tag{21}$$

where: HRT = hydraulic retention time (d)

Sludge Volume per Day

$$V_{sludge} = Q_{in} SRT_{aerobic,safe} \tag{22}$$

where: V_{sludge} = daily sludge volume (m^3)

Step 3 : Determine the SBR Volume

Cycle Time

$$T_{cycle} = T_{aerobic} + T_{anaerobic} + T_{settle,decant} \tag{23}$$

where: $T_{aerobic}$ = aerobic cycle time (hr)
$T_{anaerobic}$ = anaerobic cycle time (hr)
$T_{settle,decant}$ = settle & decant time (hr)

T_{cycle} = cycle time (hr)

Volume per Cycle

$$Cycles = \frac{24}{T_{cycle}} SBRs \tag{24}$$

$$V_{Cycle} = \frac{Q_{in}}{Cycles} \tag{25}$$

where:
$Cycles$ = number of cycles per day
$SBRs$ = number of SBRs to be designed
V_{Cycle} = volume per cycle

Decant Pump Size

$$Pump_{d,size} = \frac{V_{Cycle}\,24}{\frac{T_{settle,decant}}{3}} \tag{26}$$

where: $Pump_{d,size}$ = decant pump capacity (m^3/d)

SBR Volume

$$V_{total} = \frac{V_{Cycle}\,SBRs}{\frac{V_{exchange}}{100}} \tag{27}$$

$$V_{SBR} = \frac{V_{total}}{SBRs} \tag{28}$$

where:
V_{total} = total SBR volume (m^3)
$V_{exchange}$ = exchange volume (%)
V_{SBR} = volume per SBR (m^3)

Reactor Solids

$$SS_{reactor} = \frac{M(SS)}{V_{total}} \tag{29}$$

$$VSS_u = \frac{M(X_i) + M(X_e)}{V_{total}} \tag{30}$$

$$VSS_b = \frac{M(X_a)}{V_{total}} \tag{31}$$

$$VSS_{reactor} = VSS_u + VSS_b \tag{32}$$

$$ivt_{reactor} = \frac{VSS}{SS} \tag{33}$$

where: $SS_{reactor}$ = reactor total suspended solids (g/m^3)
VSS_u = unbiodegradable volatile suspended solids (g/m^3)
VSS_b = biodegradable volatile suspended solids (g/m^3)
$VSS_{reactor}$ = reactor volatile suspended solids (g/m^3)
$ivt_{reactor}$ = reactor volatile to total suspended solids ratio (-)

Step 4: Determine the Unaerated Cycle Time (only used if C, N & P removal required)

Influent BOD to TP ratio

$$BP_{\inf} = \frac{BOD_{removed}}{TP_{T,in}} \tag{34}$$

where: BP_{inf} = influent BOD to TP ratio

Using a ladder logic type approach, the anaerobic cycle time (T_{ana}) can be calculated subject to minimum boundaries.

BP_{inf}	$HRT_{anaerobic}$ *(hr)*	*Minimum Boundaries (all apply)*
$BP_{inf} > 35$	$((Tp_{in} - TP_{out}) - 2)/5$	$T_{ana} \geq 0.15 * T_{aerobic}$
$BP_{inf} \leq 35$	$0.88 * (TP_{in} - TP_{out}) - 2.5$	$T_{ana} \geq 1.5 * (V_{exchange})/100$

Influent BOD to TKN ratio

$$BN_{\inf} = \frac{BOD_{T,in}}{TKN_{T,in}} \tag{35}$$

where: BN_{inf} = influent BOD to TKN ratio

Using a ladder logic type approach, the anoxic cycle time (T_{anoxic}) can be calculated subject to minimum boundaries.

BN_{inf}	*Minimum Boundaries (all apply)*
$BN_{inf} \geq 6.5$	0.3 x $T_{aerobic}$
$6.5 > BN_{inf} \geq 5.0$	0.4 x $T_{aerobic}$
$5.0 > BN_{inf} \geq 4.0$	0.65 x $T_{aerobic}$
$BN_{inf} \leq 4.0$	0.65 x $T_{aerobic}$ (warning printed)

$$T_{unaerated} = T_{anoxic} + T_{ana} \tag{36}$$

where: $T_{unaerated}$ = calculated unaerated cycle time (hr)
Note: warning printed if $T_{unaerated}$ is greater than T_{ana} (anaerobic) specified by the user

Step 5: Calculate Air Requirements

Phosphorus Requirement for Growth

$$TPR = \min\left((TP_{in} - TP_{out}), 0.01BOD_{removed}\right) \tag{37}$$

where: TPR = phosphorus requirement for growth (g P/m^3)

TP_{in} = influent total phosphorus (g P/m^3)

TP_{out} = effluent total phosphorus (g P/m^3)

Nitrogen Requirement for Growth

$$FNR_{total} = \min(TKN_{in,} 0.05BOD_{removed}) \tag{38}$$

where: FNR_{total} = nitrogen requirement for growth
TKN_{in} = influent total Kjeldahl nitrogen (g N/m^3)

Nitrifiable Nitrogen (not performed if Carbon Only Design)

$$NH3_{eff} = Min\left(0, TKN_{in} - FNR, 0.5 * \frac{b_{a,T_{winter}} + \dfrac{1}{SRT_{aerobic,safe}}}{\mu_{\max A,T_{winter}} - \left(b_{a,T_{winter}} + \dfrac{1}{SRT_{aerobic,safe}}\right)}\right) \tag{39a}$$

$$NO3_{eff} = TKN_{T,in} - FNR - NH3_{eff} \tag{39b}$$

where: $NH3_{eff}$ = effluent ammonia (g N/m^3)
$NO3_{eff}$ = effluent nitrate nitrogen (g N/m^3)

Required Oxygen for Average Influent Load

Carbon Removal only:

$$O_2 = Q_{in}\left(BOD_{removed} - 1.42\frac{M(X_a)}{SRT_{aerobic,safe}Q_{in}}\right) * 0.001 \tag{40}$$

where O_2 = Oxygen requirement, kg O_2/d

For nitrification:

$$O_2 = Q_{in}\left(BOD_{removed} + 4.57NO3 - 1.42\frac{M(X_a)}{SRT_{aerobic,safe}Q_{in}}\right) * 0.001 \tag{41}$$

If Carbon, Nitrogen and Phosphorus Removal:

$$O_2 = Q_{in}\left(BOD_{removed} + 4.57NO3 - 2.86(1 - \frac{V_{exchange}}{100})NO3 - \frac{1.42M(X_a)}{SRT_{aerobic,safe}Q_{in}} \right) * 0.001 \tag{42}$$

where $V_{exchange}$ = Q_{in} (%)
2.86 = oxygen credit in denitrification (g O_2/g NO_3-N)

Required Air Flow for Average Influent:

If aerated whole period

$$Q_{air} = \frac{O_2}{\alpha \frac{SOTE}{100}} \left(\frac{1}{1.2 * 0.21} \right) \tag{43}$$

where Q_{air} = required air flow (m^3/d)
SOTE = standard oxygen transfer efficiency (%)
α = alpha-factor for oxygen transfer into wastewater (-)
1.2 = conversion factor (kg O_2/m^3)
0.21 = partial pressure of oxygen in air

Otherwise, at average influent load

$$Q_{air} = \frac{O_2}{\alpha \frac{SOTE}{100}} \left(\frac{1}{1.2 * 0.21} \right) \left(\frac{24}{T_{aerobic} Cycles} \right) SBRs \tag{44}$$

Step 6: Calculate Mixing Requirements

Mixing Power Required

$$Power_{mix} = \text{int}\left(\frac{V_{total} * 13}{1000} \right) \tag{45}$$

Where: $Power_{mix}$ = required mixing power (kW)
13 = power requirement factor (13 kW/1000 m^3)

Number of mixers

$$Mixers_{unaerated} = SBRs \tag{46}$$

Where: $Mixers_{unaerated}$ = number of required mixers (kW)

Step 7: Determine Sludge Production

Sludge Production

$$WAS = \frac{V_{total} SS_{reactor}}{SRT_{aerobic,safe} 1000} \tag{47}$$

Where: WAS = waste biomass production rate (kg/d)

$$Q_{waste} = WAS - \left(\frac{\frac{Q_{in} SS_{decant}}{1000}}{\frac{SS_{waste} 10000}{1000} - \frac{SS_{decant}}{1000}} \right) \tag{48}$$

where: WAS = waste sludge produced (kg/d)
Qwaste = flow of waste sludge (m^3/d)
SSdecant = suspended solids in decanted effluent
SSwaste = biomass concentration after decant (%)

Step 8: Determine Effluent Oxygen Demand

Effluent BOD

$$BOD_{T,eff} = BOD_{S,eff} + \frac{0.25 VSS_b * ivt * decantSS}{VSS} \tag{49}$$

where: $BOD_{T,eff}$ = effluent total BOD (g/m^3)
VSS_b = biodegradable VSS = M(X_a) / V_{total} (mg/L)
decantSS = total suspended solids in reactor decant (mg/L)
ivt = M(VSS) / M(SS) (-)
= effluent BOD to bCOD ratio (-) (Copp *et al.* 2002)

Effluent COD

$$COD_{S,eff} = 1.5 BOD_{S,eff} \tag{50}$$

$$COD_{T,eff} = COD_{S,eff} + 1.5(ivt)(SS_{waste})10000 \tag{51}$$

where: $COD_{T,eff}$ = effluent COD (g/m^3)
1.5 = effluent ratio (Copp *et al.* 2001)

SRT-BASED PLUG FLOW TANK

The SRT-based plug flow activated sludge process uses an aeration tank, a settling tank, and a sludge return line to treat wastewater. Wastewater and returned sludge from the secondary clarifier enter the head of the aeration tank to undergo a specified period of aeration. Diffused aeration is used to provide the necessary oxygen and adequate mixing of the influent waste and recycled sludge. Absorption, flocculation, and synthesis of the organic matter take place during aeration. The mixed liquor (sludge floc plus liquid in the aeration tank) is settled in the secondary clarifier, and sludge is returned at a sufficient rate.

This object is similar to the plug flow activated sludge process, but this SRT-based algorithm is simply another approach. This algorithm is based on a University of Cape Town algorithm and is consistent with the idea of influent fractionation to more accurately predict the mass of solids that will be present in the tank. This approach is also consistent with the dynamic wastewater treatment model known as ASM1 (Henze *et al.* 1986) published as an International Water Association Scientific and Technical Report. This object is recommended for those who hope to export the final design to GPS-X, Hydromantis' dynamic process simulator, and perform further dynamic analysis of the design.

Step 1: Determine the Minimum Aerobic SRT (based on the winter temperature).

Nitrifier Growth Rate

$$\mu_{maxA,T_{winter}} = \mu_{maxA,20} \times \Theta_{\mu A,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{1}$$

where:
T_{winter} = winter temperature (^{o}C)
$\mu_{maxA,T_{winter}}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxA,20}$ = maximum specific growth rate at 20^{o}C (1/d)
$\Theta_{\mu A,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.123 in version 1.0

Nitrifier Decay Rate

$$b_{a,T_{winter}} = b_{a,20} \times \Theta_{ba,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{2}$$

where:
T_{winter} = winter temperature (^{o}C)
$b_{a,T_{winter}}$ = decay rate at temperature, T_{winter} (1/d)
$b_{a,20}$ = decay rate at 20^{o}C (1/d)
$\Theta_{ba,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 1.0

Heterotrophic Growth Rate

$$\mu_{max,T_{winter}} = \mu_{max,20} \times \Theta_{\mu,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{1}$$

where:
T_{winter} = winter temperature (^{o}C)
$\mu_{max,T_{winter}}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{max,20}$ = maximum specific growth rate at 20^{o}C (1/d)
$\Theta_{\mu,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.072 in version 1.0

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20} \times \Theta_{kd,arrhenius}^{(T_{winter} - 20^{o}C)} \tag{3}$$

where:
T_{winter} = winter temperature (^{o}C)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)
$k_{d,20}$ = oxygen decay coefficient at 20^{o}C (1/d)
$\Theta_{kd,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 1.0

Minimum Aerobic SRT

If ‘Carbon Removal Only’:

$$SRT_{aerobic} = \frac{1}{\mu_{max,T_{winter}} - k_{d,T_{winter}}} \tag{4a}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for nitrification at temperature, T_{winter}

Otherwise for all other designs:

$$SRT_{aerobic} = \frac{1}{\mu_{maxA,T_{winter}} - b_{a,T_{winter}}} \tag{4b}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for nitrification at temperature, T_{winter}

Allowing for an SRT safety factor:

$$SRT_{aerobic,safe} = SRT_{aerobic} * SRT_{sf} \qquad (5)$$

where: $SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
SRT_{sf} = safety factor for SRT

Step 2: Calculate the Influent Loads

Influent Speciation

$$VSS_{in} = SS_{in} * ivt \qquad (6)$$

$$ISS_{in} = SS_{in} - VSS_{in} \qquad (7)$$

where: SS_{in} = influent total suspended solids (mg/L)
VSS_{in} = influent volatile suspended solids (mg/L)
ISS_{in} = influent inert inorganic solids (mg/L)
ivt = influent VSS to SS ratio (-)

$$uVSS_{in} = F * VSS_{in} \qquad (8)$$

$$uCOD_{in} = 1.5 * uVSS_{in} \qquad (9)$$

$$uSS_{in} = ISS_{in} + uVSS_{in} \qquad (10)$$

$$bCOD_{in} = COD_{in} - uCOD_{in} \qquad (11)$$

where: F = fraction of influent VSS that is unbiodegradable
$uVSS_{in}$ = influent unbiodegradable VSS (mg/L)
$uCOD_{in}$ = influent unbiodegradable COD (mg COD/L)
uSS_{in} = influent unbiodegradable suspended solids (mg/L)
$bCOD_{in}$ = influent biodegradable COD (mg COD/L)

BOD Removal

$$BOD_{removed} = BOD_{in} - BOD_{S,eff} \qquad (12)$$

where: BOD_{in} = the greater of $bCOD_{in}$ or (BOD_{in} *1.5)
$BOD_{S,eff}$ = effluent soluble BOD (mg/L)

Solids Calculations (in VSS units)

$$M(X_a) = \frac{SRT_{aerobic,safe} \times Q_{in} \times Y_h \times BOD_{removed}}{(1 + k_{d,T_{winter}} \times SRT_{aerobic,safe})} \tag{13}$$

$$M(X_e) = 0.2 \text{ x } k_{d,Twinter} \text{ x } SRT_{aerobic,safe} \text{ x } M(X_a) \tag{14}$$

$$M(X_i) = uVSS_{in} \text{ x } Q_{in} \text{ x } SRT_{aerobic,safe} \tag{15}$$

$$M(VSS) = M(X_a) + M(X_e) + M(X_i) \tag{16}$$

$$M(ISS) = ISS_{in} \text{ x } Q_{in} \text{ x } SRT_{aerobic,safe} \tag{17}$$

$$M(SS) = M(VSS) + M(ISS) \tag{18}$$

where: $M(X_a)$ = total mass of active biomass in the reactor (g)
$M(X_e)$ = total mass of inert endogenous biomass products in the reactor (g)
$M(X_i)$ = total mass of inert volatile solids in the reactor (g)
$M(VSS)$ = total mass of volatile solids in the reactor (g)
$M(ISS)$ = total mass of inert inorganic solids in the reactor (g)
$M(SS)$ = total mass of solids in the reactor (g)
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
Q_{in} = the unit process influent flow rate (m^3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

Step 3: Determine the Basin Volume

Basin Volume

$$V_{basin} = \frac{M(SS)}{SS_{reactor}} \tag{19}$$

where: V_{total} = basin volume (m^3)
$SS_{reactor}$ = user-specified reactor suspended solids (g/m^3)

Reactor Solids

$$VSS_{reactor} = \frac{M(VSS)}{V_{total}} \tag{20}$$

$$ivt_{reactor} = \frac{M(VSS)}{M(SS)} \tag{21}$$

where: $VSS_{reactor}$ = reactor volatile suspended solids (g/m^3)
$ivt_{reactor}$ = reactor volatile to total suspended solids ratio (-)

Step 4: Determine the Number of Batteries, Process Trains & Number of Tanks-In-Series

Influent Flow in U.S. Units

$$Q_{in,us} = \frac{Q_{in}}{3785} \tag{22}$$

where: $Q_{in,us}$ = unit process influent flow rate in U.S. units (MGD)

3785 = volume conversion (m^3/Mgal)

Batteries

$$NB = \text{int}\left(\frac{Q_{in,us}}{100} + 1.0\right) \tag{23}$$

where: NB = number of batteries

$$Q_{PB} = \frac{Q_{in,us}}{NB} \tag{24}$$

where: Q_{PB} = flow per battery (MGD)

Number of Process Trains

Using a ladder logic-type approach, the number of process trains can be calculated.

Q_{PB} (MGD)	NT
$Q_{PB} > 70$	16
$70 \geq Q_{PB} < 50$	14
$50 \geq Q_{PB} < 40$	12
$40 \geq Q_{PB} < 30$	10
$30 \geq Q_{PB} < 20$	8
$20 \geq Q_{PB} < 10$	6
$10 \geq Q_{PB} < 4$	4
$4 \geq Q_{PB} < 2$	3
$Q_{PB} \leq 2.0$	2

where: NT = number of process trains

Number of Aerobic Tanks-in-Series

Given the number of process trains to be designed, the number of aerobic tanks in series per process train must be calculated.

$$V_{nt} = \frac{V_{total}}{NT \times NB} \tag{25}$$

where: V_{nt} = volume per process stream (m^3)

V_{nt} (m^3)	T_{nt}
$V_{nt} < 300$	1
$300 \leq V_{nt} < 600$	2
$V_{nt} \geq 600$	3

where: T_{nt} = number of aerobic tanks per process train

$$V_i = \frac{V_{nt}}{T_{nt}} \tag{26}$$

where: $V_{aerobic,i}$ = volume of individual aerobic tanks (m^3)

Step 5: Calculate Air Requirements

Nitrogen Requirement for Growth

$$FNR = Min(TKN_{T,in}, 0.05 \text{ x } BOD_{removed}) \tag{27}$$

where: FNR = nitrogen requirement for growth (gN/m^3)

$$TPR = Min(TP_{in}, 0.01 \text{ x } BOD_{removed}) \tag{28}$$

where: TPR = phosphorus requirement for growth (gP/m^3)

Nitrifiable Nitrogen (not performed if Carbon Only Design)

$$NH3_{eff} = Min\left(0, TKNin - FNR, 0.5 \times \frac{b_{a,T_{winter}} + \frac{1}{SRT_{aerobic,safe}}}{\mu_{maxA,T_{winter}} - \left(b_{a,T_{winter}} + \frac{1}{SRT_{aerobic,safe}}\right)}\right) \tag{29}$$

$$NO3_{eff} = TKN_{T,in} - FNR - NH3_{eff} \tag{30}$$

where: $NO3_{eff}$ = effluent nitrate nitrogen (gN/m^3)
$NH3_{eff}$ = effluent ammonia (gN/m^3)

Required Oxygen for Average Influent Load – Carbon Design

$$O_{req} = Q_{in} \times \frac{BOD_{removed}}{1000} \tag{31}$$

Required Oxygen for Average Influent Load – Nitrification Design

$$O_{req} = Q_{in} \times \frac{BOD_{removed} + 4.57 \times N_N}{1000} \tag{32}$$

where: O_{req} = oxygen required (kgO_2/d)

Required Air Flow for Average Influent Load

$$OTE = STE \times \frac{O_{sat} \times \beta - 2.0}{9.17} \times \alpha \times 1.024^{(T_{winter} - 20)} \tag{33}$$

$$Q_{air} = \frac{O_{req}}{\frac{OTE}{100}} \times \frac{1}{(1.2 \times 0.21)} \tag{34}$$

where: Q_{air} = required air flow (m^3/d)
STE = standard oxygen transfer efficiency (%)
O_{sat} = oxygen saturation (mg/L)
α = alpha factor for oxygen transfer into wastewater
□ = beta factor for oxygen saturation in wastewater
1.2 = unit conversion (kgO_2/m^3)
0.21 = partial pressure of oxygen in air

Step 6: Determine Sludge Production

Sludge Production

$$Sludge_{total} = \frac{(V_{total} \times SS_{reactor})}{SRT_{aerobic,safe} \times 1000} \tag{35}$$

where: $Sludge_{total}$ = sludge produced (kg/d)

Step 7: Determine Effluent Oxygen Demand

Effluent BOD

$$BOD_{T,eff} = BOD_{S,eff} + 0.25 \times \frac{M(X_a)}{V_{total}} \tag{36}$$

where: $BOD_{T,eff}$ = effluent BOD (g/m^3)
0.25 = effluent BOD to bCOD ratio (Copp *et al.* 2001)

Copp J.B. editor (2001) *The COST Simulation Benchmark: Description and Simulator Manual*, Office for Official Publications of the European Communities, Luxembourg.

Effluent COD

$$COD_{T,eff} = 1.5 \text{ x } (BOD_{S,eff} + VSS_{reactor}) \tag{37}$$

where: $COD_{T,eff}$ = effluent COD (g/m^3)

OXIDATION DITCH

Step 1: Determine the Minimum Aerobic SRT (based on the winter temperature)

Nitrifier Growth Rate

$$\mu_{\max A,T_{winter}} = \mu_{\max A,20}\Theta_{\mu A,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (1)$$

where:
T_{winter} = winter temperature (^{o}C)
$\mu_{maxA,Twinter}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxA,20}$ = maximum specific growth rate at 20^{o}C (1/d)
$\Theta_{\mu A,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.096 in version 2.1

Nitrifier Decay Rate

$$b_{a,T_{winter}} = b_{a,20}\Theta_{ba,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (2)$$

where:
$b_{a,Twinter}$ = decay rate at temperature, T_{winter} (1/d)
$b_{a,20}$ = decay rate at 20^{o}C (1/d)
$\Theta_{ba,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 2.1

Heterotrophic Growth Rate

$$\mu_{\max H,T_{winter}} = \mu_{\max H,20}\Theta_{\mu H,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (3)$$

where:
$\mu_{maxH,T_{winter}}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxH,20}$ = maximum specific growth rate at 20^{o}C (1/d)
$\Theta_{\mu H,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.072 in version 2.1

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20}\Theta_{kd,arrhenius}^{(T_{winter}-20^{o}C)} \qquad (4)$$

where:
$k_{d,T_{winter}}$ = endogenous respiration rate coefficient at temperature, T_{winter} (1/d)
$k_{d,20}$ = endogenous respiration rate coefficient at 20^{o}C (1/d)
$\Theta_{kd,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.04 in version 2.1

Minimum Aerobic SRT

If Carbon Removal Only:

$$SRT_{aerobic} = \frac{1}{\mu_{\max H,T_{winter}} - k_{d,T_{winter}}} \qquad (5a)$$

where:
$SRT_{aerobic}$ = minimum aerobic SRT for carbon removal at temperature, T_{winter}

Otherwise for all other designs:

$$SRT_{aerobic} = \frac{1}{\mu_{\max A,T_{winter}} - b_{a,T_{winter}}} \tag{5b}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for nitrification at temperature, T_{winter}

Allowing for an SRT safety factor:

$$SRT_{aerobic,safe} = SRT_{aerobic} SRT_{sf} \tag{6}$$

where:
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
SRT_{sf} = safety factor for SRT

Step 2: Calculate the Influent Loads, BOD Removed and Reactor Masses

Influent Speciation

$$VSS_{in} = SS_{in} * ivt \tag{7}$$

$$ISS_{in} = SS_{in} - VSS_{in} \tag{8}$$

where:
SS_{in} = influent total suspended solids (mg/L)
VSS_{in} = influent volatile suspended solids (mg/L)
ISS_{in} = influent inert inorganic solids (mg/L)
ivt = influent VSS to SS ratio (-)

$$uVSS_{in} = F * VSS_{in} \tag{9}$$

$$uCOD_{in} = 1.5 * uVSS_{in} \tag{10}$$

$$uSS_{in} = ISS_{in} + uVSS_{in} \tag{11}$$

$$bCOD_{in} = COD_{in} - uCOD_{in} \tag{12}$$

where:
F = fraction of influent VSS that is unbiodegradable
$uVSS_{in}$ = influent unbiodegradable VSS (mg/L)
$uCOD_{in}$ = influent unbiodegradable COD (mg COD/L)
uSS_{in} = influent unbiodegradable suspended solids (mg/L)
$bCOD_{in}$ = influent biodegradable COD (mg COD/L)
COD_{in} = total influent COD (mg COD/L)

BOD Removal

$$BOD_{removed} = BOD_{in} - BOD_{S,eff} \tag{13}$$

where:
BOD_{in} = the greater of $bCOD_{in}$ or (BOD_{in} *1.5)
$BOD_{S,eff}$ = effluent soluble BOD (mg/L)

Reactor Solids Masses

$$M(X_a) = \frac{SRT_{aerobic,safe} Q_{in} Y_h BOD_{removed}}{(1 + k_{d,T_{winter}} SRT_{aerobic,safe})} \tag{14}$$

$$M(X_e) = 0.2 k_{d,T_{winter}} SRT_{aerobic,safe} M(X_a) \tag{15}$$

$$M(X_i) = uVSS_{in}Q_{in}SRT_{aerobic,safe} \tag{16}$$

$$M(VSS) = M(X_a) + M(X_e) + M(X_i) \tag{17}$$

$$M(ISS) = ISS_{in}Q_{in}SRT_{aerobic,safe} \tag{18}$$

$$M(SS) = M(VSS) + M(ISS) \tag{19}$$

where:
$M(X_a)$ = total mass of active biomass in the reactor (g)
$M(X_e)$ = total mass of inert endogenous biomass products in the reactor (g)
$M(X_i)$ = total mass of inert volatile solids in the reactor (g)
$M(VSS)$ = total mass of volatile solids in the reactor (g)
$M(ISS)$ = total mass of inert inorganic solids in the reactor (g)
$M(SS)$ = total mass of solids in the reactor (g)
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
Q_{in} = the unit process influent flow rate (m^3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$k_{d,Twinter}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

Step 3: Calculate Nutrient and Air Requirements

Phosphorus Requirement for Growth

$$TPR = \min\left(TP_{in}, \frac{0.02M(VSS)}{Q_{in}SRT_{aerobic,safe}}\right) \tag{20}$$

where:
TPR = phosphorus requirement for growth (g P/m^3)
TP_{in} = influent total phosphorus (g P/m^3)

Nitrogen Requirement for Growth

$$FNR = \min\left(TKN_{in}, \frac{0.1M(VSS)}{Q_{in}SRT_{aerobic,safe}}\right) \tag{21}$$

where:
FNR = nitrogen requirement for growth (g N/m^3)
TKN_{in} = influent total Kjeldahl nitrogen (g N/m^3)

Effluent Nitrogen (Carbon Removal only)

$$NH3_{eff} = \min(0, NH3_{in} - FNR) \tag{22}$$

where:
$NH3_{eff}$ = effluent ammonia (g N/m^3)

Nitrifiable Nitrogen (not performed if Carbon Only Design)

$$NH3_{eff} = Min\left(0, NH3_{in} - FNR, 0.5 * \frac{b_{a,T_{winter}} + \frac{1}{SRT_{aerobic,safe}}}{\mu_{\max A,T_{winter}} - \left(b_{a,T_{winter}} + \frac{1}{SRT_{aerobic,safe}}\right)}\right) \tag{23}$$

$$NO3_{eff} = TKN_{T,in} - FNR - NH3_{eff} \tag{24}$$

where: $NO3_{eff}$ = effluent nitrate nitrogen (g N/m^3)

Required Oxygen for Average Influent Load

$$O_2 = Q_{in}\left(BOD_{removed} + 4.57 NO3 - 1.42\frac{M(X_a)}{SRT_{aerobic,safe} Q_{in}}\right) * 0.001 \tag{25}$$

where: O_2 = Oxygen requirement, kg O$_2$/d

Step 4: Determine the Ditch (Basin) Volume and Equipment Selection

Volume of oxidation ditch

$$V_{oxic} = \frac{M(SS)}{SS} \tag{26}$$

where: V_{oxic} = *aeration volume (m^3)*
$M(SS)$ = *total mass of solids (g)*
SS = *suspended solids (g/m^3)*

Number of Batteries per Total Plant Volume

$$N_{batteries} = \frac{Q_{avg}}{100} + 1 \tag{27a}$$

or

$$N_{batteries} = Integer.roundup(V_{oxic} \div 17000) \tag{27b}$$

where: $N_{batteries}$ = *the number of batteries rounded up to the nearest integer*

The maximum volume per battery in a plant is 17,000 m^3. The value used for $N_{batteries}$ is the larger of the two values from equations 27a and 27b.

Number of Tanks per Battery

The software is programmed so that there are no more than two (2) tanks per battery. The number of tanks and/or the number of batteries may need to be adjusted to meet this criterion.

Volume per Tank

$$V_{\tan k} = \frac{V_{oxic}}{N_{batteries} N_{\tan ks}} \qquad (28)$$

where: V_{tank} = *volume of individual tanks* (m^3)
N_{tanks} = *the number of tanks per battery (either 1 or 2)*

Rotor Selection

$$RLFA = O_2 / STE / 24.0 \qquad (29)$$

where: *RLFA* = *length of rotor required for oxygenation (ft)*
STE = *3.74 =oxygen transfer of 42 inch diameter rotor with 8 inch submergence* ((lb O_2 /hr)/ft)
O_2 = Oxygen requirement, lb O_2/d

$$RLFM = V_{oxic,US} / \text{mixing requirement} \qquad (30)$$

where: $V_{oxic,US}$ = *volume of ditch converted to US gallons*
RLFM = *length of rotor required for mixing (ft)*
mixing requirement = *21,000 gal/ft of rotor length*

The design length of rotor (RLF) is the larger of RLFA and RLFM values.

Number of Rotors per Tank

Using a ladder-logic-type approach, the number of rotors is determined by the total volume of each tank.

Total Volume of Each Tank (m^3)	*Number of Rotors per Tank, K*
0 – 9,400	*2*
9,400 – 14,100	*3*
> 14,100	*4*

Selection of length of individual rotor

$$LRTK = \frac{RLF}{N_{\tan ks} * N_{batteries} * N_{rotors}} \qquad (31)$$

where: *LRTK* = *individual rotor length (m)*

If LRTK > 15.25 m use one more rotor

Motor Horsepower Required for Rotor

Using a ladder-logic-type approach, the motor horsepower required for each rotor can be calculated.

LRTK (m)	*HPK (HP)*
$LRTK \leq 3.05$	15
$3.05 < LRTK \leq 4.0$	20
$4.0 < LRTK \leq 4.9$	30
$4.9 < LRTK \leq 6.7$	40
$6.7 < LRTK \leq 8.2$	50
$8.2 < LRTK \leq 9.1$	60
$LRTK > 9.1$	75

where: *HPK* = *individual motor horsepower (HP)*

Step 5: Basin Design and Calculations (programmed in U.S. units)

Width of ditch bottom

The rotor length is first converted from metric units (m) to U.S. units (ft).

$$LRTK_{US} = 3.2808 * LRTK \tag{32}$$

The width if the ditch bottom is determined by length of rotor.

$LRTK_{US}$ (ft)	*W_b (ft)*
$LRTK_{US} > 15.5$	$LRTK + 4$
$LRTK_{US} <= 15.5$	$LRTK + 1$

where: W_b = *ditch bottom width (ft)*

Single Basin Design

Assumed basin depth is 6 ft.

Volume of circular ends

$$V_e = 18.85 W_b^2 + 150.8 W_b + 282.7 \tag{33}$$

where: V_e = *volume of circular ends (ft^3)*

Length of straight sections

$$L_s = \frac{V_{\tan k} - V_e}{36 + 12 W_b} \tag{34}$$

where: L_s = *length of straight sections (ft)*
V_{tank} = *tank volume (ft^3)*

Volume of straight sections

$$V_s = 36 L_s + 12 L_s W_b \tag{35}$$

where: V_s = *volume of straight sections (ft^3)*

Two Basin Design

Assumed basin depth is 12 ft.

Volume of circular ends

$$V_e = 37.7W_b^2 + 18.9W_b \tag{36}$$

Volume of straight sections

$$V_s = V_{\tan k} - V_e \tag{37}$$

Length of straight sections

$$L_s = \frac{V_s}{2*12*W_b} \tag{38}$$

Length of Effluent Weir

$$FLW = \frac{3*Q_{avg}*10^6}{N_{\tan ks}*N_{batteries}*66.1*1440} \tag{39}$$

where:
FLW = *length of adjustable floating weir*
66.1 = *flow that can be handled by one foot of weir (gpm)*
Q_{avg} = *average daily flow of wastewater (MGD)*
N_{tanks} = *number of tanks*
$N_{batteries}$ = *number of batteries*

Aeration Hydraulic Retention Time

$$HRT = \frac{V_{oxic}24}{Q_{avg}} \tag{40}$$

where: *HRT* = *hydraulic retention time (h)*

F:M ratio

$$F:M = \frac{Q_{in}BOD_{in}}{M(VSS)} \tag{41}$$

where: *F:M* = *food-to-micro-organism ratio (g BOD/(g VSS•d))*

Volumetric BOD loading

$$BOD_{load} = \frac{Q_{in}BOD_{in}}{V_{oxic}} \tag{42}$$

where: BOD_{load} = *BOD loading to aeration (g BOD/(m^3•d))*

Aerobic Biomass Solids Yield

$$TSS_{yield} = \frac{M(SS)1.5}{SRT_{aerobic,safe} Q_{in} BOD_{rem}} \tag{43}$$

$$Y_h = TSS_{yield} * ivt_{reactor} \tag{44}$$

where: TSS_{yield} = *solids yield coefficient, (g TSS/g BOD)*
1.5 = *assumed bCOD/BOD ratio*
Y_h = *aerobic biomass yield (g VSS/g BOD)*

Step 6: Determine Sludge Production

Reactor Solids

$$SS_{reactor} = \frac{M(SS)}{V_{oxic}} \tag{45}$$

$$VSS_{reactor} = \frac{M(VSS)}{V_{oxic}} \tag{46}$$

$$ivt_{reactor} = \frac{M(VSS)}{M(SS)} \tag{47}$$

where: $SS_{reactor}$ = *reactor total suspended solids (g/m^3)*
$VSS_{reactor}$ = *reactor volatile suspended solids (g/m^3)*
$ivt_{reactor}$ = *reactor volatile to total suspended solids ratio (-)*

Sludge Production

$$WAS = \frac{SS_{reactor} V_{oxic}}{1000 SRT_{aerobic,safe}} \tag{48}$$

where: WAS = *waste activated sludge produced (kg/d)*

Step 7: Determine Effluent Oxygen Demand

Effluent BOD

$$BOD_{s,eff} = \frac{k_s\left(1 + k_d T_{winter} * SRT_{aerobic,safe}\right)}{SRT_{aerobic,safe} * (\mu_{\max H, T_{winter}} - k_d T_{winter}) - 1} \tag{49}$$

where: $BOD_{s,eff}$ = effluent BOD (mg/L)
k_s = Monod half velocity constant (mg/L)

EXTENDED AERATION

Step 1: Determine the Minimum Aerobic SRT (based on the winter temperature)

Nitrifier Growth Rate

$$\mu_{\max A,T_{winter}} = \mu_{\max A,20}\Theta_{\mu A,arrhenius}^{(T_{winter}-20^{o}C)} \tag{1}$$

where: T_{winter} = winter temperature (^{o}C)
$\mu_{maxA,Twinter}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxA,20}$ = maximum specific growth rate at 20^{o}C (1/d)
$\Theta_{\mu A,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.096 in version 2.1

Nitrifier Decay Rate

$$b_{a,T_{winter}} = b_{a,20}\Theta_{ba,arrhenius}^{(T_{winter}-20^{o}C)} \tag{2}$$

where: $b_{a,Twinter}$ = decay rate at temperature, T_{winter} (1/d)
$b_{a,20}$ = decay rate at 20^{o}C (1/d)
$\Theta_{ba,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.029 in version 2.1

Heterotrophic Growth Rate

$$\mu_{\max H,T_{winter}} = \mu_{\max H,20}\Theta_{\mu H,arrhenius}^{(T_{winter}-20^{o}C)} \tag{3}$$

where: $\mu_{maxH,Twinter}$ = maximum specific growth rate at temperature, T_{winter} (1/d)
$\mu_{maxH,20}$ = maximum specific growth rate at 20^{o}C (1/d)
$\Theta_{\mu H,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.072 in version 2.1

Endogenous Respiration Rate

$$k_{d,T_{winter}} = k_{d,20}\Theta_{kd,arrhenius}^{(T_{winter}-20^{o}C)} \tag{4}$$

where: $k_{d,Twinter}$ = endogenous respiration rate coefficient at temperature, T_{winter} (1/d)
$k_{d,20}$ = endogenous respiration rate coefficient at 20^{o}C (1/d)
$\Theta_{kd,arrhenius}$ = arrhenius temperature coefficient that has a value of 1.04 in version 2.1

Minimum Aerobic SRT

If Carbon Removal Only:

$$SRT_{aerobic} = \frac{1}{\mu_{\max H,T_{winter}} - k_{d,T_{winter}}} \tag{5a}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for carbon removal at temperature, T_{winter}

Otherwise for all other designs:

$$SRT_{aerobic} = \frac{1}{\mu_{\max A,T_{winter}} - b_{a,T_{winter}}} \tag{5b}$$

where: $SRT_{aerobic}$ = minimum aerobic SRT for nitrification at temperature, T_{winter}

Allowing for an SRT safety factor:

$$SRT_{aerobic,safe} = SRT_{aerobic} SRT_{sf} \tag{6}$$

where:
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
SRT_{sf} = safety factor for SRT

Step 2: Calculate the Influent Loads, BOD Removed and Reactor Solids Masses

Influent Speciation

$$VSS_{in} = SS_{in} * ivt \tag{7}$$
$$ISS_{in} = SS_{in} - VSS_{in} \tag{8}$$

where:
SS_{in} = influent total suspended solids (mg/L)
VSS_{in} = influent volatile suspended solids (mg/L)
ISS_{in} = influent inert inorganic solids (mg/L)
ivt = influent VSS to SS ratio (-)

$$uVSS_{in} = F * VSS_{in} \tag{9}$$
$$uCOD_{in} = 1.5 * uVSS_{in} \tag{10}$$
$$uSS_{in} = ISS_{in} + uVSS_{in} \tag{11}$$
$$bCOD_{in} = COD_{in} - uCOD_{in} \tag{12}$$

where:
F = fraction of influent VSS that is unbiodegradable
$uVSS_{in}$ = influent unbiodegradable VSS (mg/L)
$uCOD_{in}$ = influent unbiodegradable COD (mg COD/L)
uSS_{in} = influent unbiodegradable suspended solids (mg/L)
$bCOD_{in}$ = influent biodegradable COD (mg COD/L)
COD_{in} = total influent COD (mg COD/L)

Effluent BOD

$$BOD_{s,eff} = \frac{k_s\left(1 + k_d T_{winter} * SRT_{aerobic,safe}\right)}{SRT_{aerobic,safe} * (\mu_{\max H,T_{winter}} - k_d T_{winter}) - 1} \tag{13}$$

where:
$BOD_{s,eff}$ = effluent BOD (mg/L)
k_s = Monod half velocity constant (mg/L)

BOD Removal

$$BOD_{removed} = BOD_{in} - BOD_{S,eff} \tag{14}$$

where:
BOD_{in} = the greater of $bCOD_{in}$ or (BOD_{in} *1.5)
$BOD_{S,eff}$ = effluent soluble BOD (mg/L)

Reactor Solids Mass Calculations

$$M(X_a) = \frac{SRT_{aerobic,safe} Q_{in} Y_h BOD_{removed}}{(1 + k_{d,T_{winter}} SRT_{aerobic,safe})} \tag{15}$$

$$M(X_e) = 0.2 k_{d,T_{winter}} SRT_{aerobic,safe} M(X_a) \tag{16}$$

$$M(X_i) = uVSS_{in} Q_{in} SRT_{aerobic,safe} \tag{17}$$

$$M(VSS) = M(X_a) + M(X_e) + M(X_i) \tag{18}$$

$$M(ISS) = ISS_{in} Q_{in} SRT_{aerobic,safe} \tag{19}$$

$$M(SS) = M(VSS) + M(ISS) \tag{20}$$

where:
$M(X_a)$ = total mass of active biomass in the reactor (g)
$M(X_e)$ = total mass of inert endogenous biomass products in the reactor (g)
$M(X_i)$ = total mass of inert volatile solids in the reactor (g)
$M(VSS)$ = total mass of volatile solids in the reactor (g)
$M(ISS)$ = total mass of inert inorganic solids in the reactor (g)
$M(SS)$ = total mass of solids in the reactor (g)
$SRT_{aerobic,safe}$ = calculated minimum aerobic SRT after safety factor correction (d)
Q_{in} = the unit process influent flow rate (m^3/d)
Y_h = biomass yield (gVSS/gBOD)
$BOD_{removed}$ = BOD removed in the unit process (g BOD/m^3)
$k_{d,T_{winter}}$ = oxygen decay coefficient at temperature, T_{winter} (1/d)

Reactor Solids Concentrations

$$SS_{reactor} = \frac{M(SS)}{V_{oxic}} \tag{21}$$

$$VSS_{reactor} = \frac{M(VSS)}{V_{oxic}} \tag{22}$$

$$ivt_{reactor} = \frac{M(VSS)}{M(SS)} \tag{23}$$

where:
$SS_{reactor}$ = reactor total suspended solids (g/m^3)
$VSS_{reactor}$ = reactor volatile suspended solids (g/m^3)
$ivt_{reactor}$ = reactor volatile to total suspended solids ratio (-)

Step 3: Calculate Nutrient and Air Requirements

Phosphorus Requirement for Growth

$$TPR = \min\left(TP_{in}, \frac{0.02 M(VSS)}{SRT_{aerobic,safe} Q_{in}} \right) \tag{24}$$

where:
TPR = phosphorus requirement for growth (g P/m^3)

Nitrogen Requirement for Growth

$$FNR = \min\left(TKN_{in}, \frac{0.1M(VSS)}{SRT_{aerobic,safe} Q_{in}} \right) \tag{25}$$

where: FNR = nitrogen requirement for growth (g N/m^3)

Nitrifiable Nitrogen (not performed if Carbon Only Design)

$$NH3_{eff} = Min\left(0, TKN_{in} - FNR, 0.5 * \frac{b_{a,T_{winter}} + \frac{1}{SRT_{aerobic,safe}}}{\mu_{\max A,T_{winter}} - \left(b_{a,T_{winter}} + \frac{1}{SRT_{aerobic,safe}} \right)} \right) \tag{26}$$

$$NO3_{eff} = TKN_{T,in} - FNR - NH3_{eff} \tag{27}$$

where: $NH3_{eff}$ = effluent ammonia (g N/m^3)
$NO3_{eff}$ = effluent nitrate nitrogen (g N/m^3)

Required Oxygen for Average Influent Load

Carbon Removal only:

$$O_2 = Q_{in}\left(BOD_{removed} - 1.42 \frac{M(X_a)}{SRT_{aerobic,safe} Q_{in}} \right) * 0.001 \tag{28}$$

where O_2 = Oxygen requirement, kg O_2/d

For nitrification:

$$O_2 = Q_{in}\left(BOD_{removed} + 4.57 NO3 - 1.42 \frac{M(X_a)}{SRT_{aerobic,safe} Q_{in}} \right) * 0.001 \tag{29}$$

Step 4: Calculate Basin Volumes and Equipment Requirements (coded in U.S. units)

Number of Batteries

$$N_{batteries} = \frac{Q_{avg}}{100} + 1 \tag{30}$$

where: $N_{batteries}$ = *number of batteries*
Q_{avg} = *average daily wastewater flow (MGD)*

Flow per Battery

$$Q_{battery} = \frac{Q_{avg}}{N_{batteries}} \tag{31}$$

where: $Q_{battery}$ = *average flow per battery(MGD(US))*

Number of Parallel Trains per Battery

Using a ladder logic type approach, number of parallel trains per battery (N_{trains}) can be calculated subject to minimum boundaries.

$Q_{battery}$ MGD(US)	N_{trains}
$2 < Q_{battery} \leq 4$	3
$4 < Q_{battery} \leq 10$	4
$10 < Q_{battery} \leq 20$	6
$20 < Q_{battery} \leq 30$	8
$30 < Q_{battery} \leq 40$	10
$40 < Q_{battery} \leq 50$	12
$50 < Q_{battery} \leq 70$	14
$Q_{battery} > 70$	16

where: N_{trains} = *number of parallel trains per battery*

Number of Aerators per Train (Mechanical Aeration)

$Q_{battery}$ MGD(US)	$N_{aerators}$
$10 < Q_{battery} \leq 30$	2
$30 < Q_{battery} \leq 70$	3
$Q_{battery} > 70$	4

where: $N_{aerators}$ = *number of aerators per train*

Mechanical Aerator Power Requirements

$$HP_{aerator} = \frac{HP_{design}}{N_{batteries} N_{trains} N_{aerators}} \tag{32}$$

where: $HP_{aerator}$ = *horse power per aerator (HP)*
HP_{design} = *total design horse power (HP)*

If $HP_{aerator} > 150$ and $N_{trains} = < 4$, then repeat above with $N_{trains} = N_{trains} + 1$
If $HP_{aerator} > 150$ and $N_{trains} \geq 4$, then repeat above with $N_{trains} = N_{trains} + 2$

Total Number of Parallel Trains

$$NT_{trains} = N_{batteries} N_{trains} N_{aerators} \tag{33}$$

where: N_{trains} = *number of parallel trains*

Tank Sidewater Depth

If HP ≤ 100,

$$D_t = 4.816 HP_{aerator}^{0.2467} \tag{34a}$$

If HP > 100,

$$D_t = 15 \tag{34b}$$

where: D_t = *tank sidewater depth (ft)*

Aeration volume

$$V_{oxic} = \frac{M(SS)}{SS} \tag{35}$$

where:
V_{oxic} = *aeration volume* (m^3)
$M(SS)$ = *total mass of solids (g)*
SS = *suspended solids* (g/m^3)

Volume of Each Aeration Tank

$$V_n = \frac{V_{oxic}}{N_{batteries} N_{trains}} \tag{36}$$

where: V_n = volume of each aeration tank (m^3)

and

$$V_{n,US} = V_n * 35.314 \tag{37}$$

where: $V_{n,US}$ = volume of each aeration tank (ft^3)

Width of Each Tank

$$W_t = \left(\frac{V_{n,US}}{D_t N_{aerators}} \right)^{0.5} \tag{38}$$

where: W_t = *width of tank (ft)*

Length of Each Tank, Lt

$$L_t = \frac{V_{n,US}}{W_t D_t} \tag{39}$$

where: L_t = *length of tank rounded to the nearest ft (ft)*

If $L_t > 133$ and $NT \leq 3$, then repeat above two equations with NT = NT + 1

If L_t >133 and NT > 3, then repeat above two equations with NT = NT + 2

Diffused Aeration:

Air Flow Rate

$$A_s = L_{\tan k} W_t N_{batteries} N_{trains} \tag{40}$$

where: A_s = *tank surface area (m^2)*

For fine bubble pore size:

$$AFR = \frac{AFR_{fine} A_s 60}{V_{oxic}} \tag{41a}$$

where: AFR = *air flow required (L air/m^3 basin volume/min)*
AFR_{fine} = *fine air bubble diffuser rate, either user-defined or default value of 0.61 L/s/m^2 basin surface area*

For coarse bubble pore size:

$$AFR = AFR_{coarse} \tag{41b}$$

where: $AFRcoarse$ = *coarse air bubble diffuser rate, either user-defined or default value of 0.33 L/s/m^3 basin volume * 60 s/min*

Number of Cells per Aeration Train

Diffused Aeration

Using a ladder logic type approach, number of aeration cells within one train (C_{oxic}) can be calculated subject to minimum boundaries.

V_{oxic} / (NT * NB)	C_{oxic}
$V_{oxic} / (NT * NB) < 1000$	1
$1000 \leq V_{oxic} / (NT * NB) < 2000$	2
$V_{oxic} / (NT * NB) \geq 2000$	3

where: C_{oxic} = *number of cells within one train*

Mechanical Aeration

C_{oxic} is the minimum of C_{oxic} and $N_{aerators}$

Step 5: Determine Aerobic HRT, Organic Loadings and Biomass Yields

Aeration Hydraulic Retention Time

$$HRT = \frac{V_{oxic}}{Q_{avg}} \tag{42}$$

where: *HRT* = *hydraulic retention time (d)*

F:M ratio

$$F:M = \frac{Q_{in} BOD_{in}}{M(VSS)} \tag{43}$$

where: *F:M* = *food-to-micro-organism ratio (g BOD/(g VSS•d))*

Volumetric BOD loading

$$BOD_{load} = \frac{Q_{in} BOD_{in}}{V_{oxic}} \tag{44}$$

where: BOD_{load} = *BOD loading to aeration (g BOD/(m^3•d))*

Aerobic Biomass Solids Yield

$$TSS_{yield} = \frac{M(SS)1.5}{SRT_{aerobic,safe} Q_{in} BOD_{rem}} \tag{45}$$

$$Y_h = TSS_{yield} * ivt_{reactor} \tag{46}$$

where: TSS_{yield} = *solids yield coefficient, (g TSS/g BOD)*
1.5 = *assumed bCOD/BOD ratio*
Y_h = aerobic biomass yield (gVSS/gBOD)

Step 6: Determine Sludge Production

Sludge Production

$$WAS = \frac{SS_{reactor} V_{oxic}}{1000 SRT_{aerobic,safe}} \tag{47}$$

where: *WAS* = waste activated sludge produced (kg/d)