ANOXIC BIOREACTOR SIZING
ANOXIC BIOREACTORS

- Anoxic Reactor
  - As Selector for enhanced sludge settleability
  - For Denitrification
    - Single Anoxic Reactor
    - Multiple Anoxic Reactors
    - Intermittent Operation Aerobic/Anoxic Reactor
    - Simultaneous Nitrification/Denitrification
SELECTOR TANK

- Small tanks located upstream of the aeration tanks that receive the wastewater for treatment and the returned RAS to limit the growth of organisms that do not settle well. They are called selectors because they select the floc forming organisms.
- Selectors are naturally incorporated into the biological nitrogen and phosphorus removal processes.

Purpose
- Provides initial zone of high F/M ratio.
- Encourages rapid uptake of substrate
- Promotes growth of floc formers
- Anoxic or anaerobic conditions inhibit growth of filamentous bacteria.
- Improve the settlement
The biggest cause of sludge bulking is that caused by the growth of filamentous bacteria in the aeration tank.

The filamentous bacteria grow because they have the correct environmental conditions to favor their growth. Most filaments can only grow in aerobic conditions.

The best remedial methods involve changing the conditions so that other bacteria, the floc forming bacteria, are encouraged to grow.

It has been found that to encourage the growth of floc formers the F/M ratio at the beginning of treatment needs to be high.
• Anoxic selector shall be sized on the assumption that all biodegradable substrate be removed within the selector volume under high F/M ratio.
• Recommended design F/M=2 to 5 Kg BOD$_5$/kg MLSS.d.
• Multiple zones within the selector are recommended to provide an F/M gradient and to reduce the potential for substrate breakthrough.
• Selectors can be aerobic where it has the advantage that the volume is part of the carbon removal and/or nitrification aerobic volume.
DENITRIFICATION CAPACITY/POTENTIAL

• The maximum denitrification capacity is determined by:
  – The available amount of bsCOD or BOD in influent wastewater to the anoxic zone.
  – Amount of bsCOD or BOD required for nitrate reduction (bsCOD/NO₃-N ratio).

\[
\frac{bsCOD}{NO₃-N} = \frac{2.86}{1-1.42Y_n}
\]

\[
Y_n = \frac{Y}{1 + k_d SRT}
\]

Where
bsCOD/NO₃-N = required ratio of bsCOD to NO₃-N, g bsCOD/g NO₃-N.
Y_n = net biomass yield, g VSS/g bsCODr
Y = biomass yield for heterotrophic bacteria (0.4 g VSS/g bsCOD).
k_d = endogenous decay coefficient for heterotrophic bacteria, g VSS/g VSS.d.

A general rule of thump is that 4 kg of wastewater BOD is needed per kg of NO₃-N to be removed through biological treatment (EPA Nutrient Control Design Manual). As-Samra WWTP is designed for average value of 3 g.
MAXIMUM DENITRIFICATION CAPACITY

\[
\text{Maximum Denitrification Capacity} = \frac{rbCODa}{\text{Required ratio of } bsCOD / \text{NO}_3 - N}
\]

\[
DC_m = \left[ \frac{rbCOD_a}{bsCOD} \right] \left[ \frac{\text{bsCOD}}{\text{NO}_3 - N} \right]
\]

Where
- \( bsCOD / \text{NO}_3 - N \) = required ratio of bsCOD to NO\(_3\)-N, g bsCOD/g NO\(_3\)-N.
- \( rbCOD_a \) = available rbCOD in the influent, mg/l, kg/day.
- \( DC_m \) = maximum denitrification capacity, mg NO\(_3\)-N/l, kg NO\(_3\)-N/day.

\[
bsCOD = \frac{2.86}{1 - 1.42Y_n}
\]

\[
\text{NO}_3 - N
\]
**ANOXIC REACOR SIZING**
**DESKTOP DESIGN APPROACH**

\[
NO_r = V_{nox} \times SDNR \times MLVSS
\]

\[
V_{nox} = \frac{NO_r}{SDNR \times MLVSS}
\]

\[
SDNR = \frac{NO_{rr}}{MLVSS}
\]

\[
NO_{rr} = \frac{NO_r}{V_{nox}}
\]

SDNR is the nitrate reduction rate in the anoxic tank normalized to the MLVSS concentration or it is the mass of nitrate-N denitrified in the anoxic zone per unit time per unit biomass in the reactor.

Multiply \(NO_{rr}\) in mg N/l.h by 24 to get g N/m3.d

**Where:**
- \(NO_r\) = amount of nitrate removed in the anoxic tank, g/d.
- \(NO_{rr}\) = nitrate removal rate in the anoxic tank, g/m₃.d.
- \(SDNR\) = specific denitrification rate, g NO3-N/g MLVSS.d
- \(MLVSS\) = mixed liquor volatile suspended solids concentration, mg/l, g/m3.
- \(V_{nox}\) = anoxic tank volume, m3.
### REPORTED TYPICAL SDNR VALUES

<table>
<thead>
<tr>
<th>Type</th>
<th>Metcalf &amp; Eddy</th>
<th>EPA Nutrient Control Design Manual</th>
<th>AS-Samra WWTP Design @ 17°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g NO₃-N/g MLVSS.d</td>
<td>mg NO₃-N/g MLVSS.h</td>
<td>g NO₃-N/g MLVSS.d</td>
</tr>
<tr>
<td>Pre-anoxic tanks</td>
<td>0.04 - 0.42</td>
<td>1.67 - 17.50</td>
<td>0.05 - 0.15</td>
</tr>
<tr>
<td>Post-anoxic tanks</td>
<td>0.01 - 0.04</td>
<td>0.42 - 1.67</td>
<td>0.01 - 0.04</td>
</tr>
<tr>
<td>With methanol added</td>
<td></td>
<td></td>
<td>0.10 - 0.25</td>
</tr>
</tbody>
</table>

\[
\text{SDNR}_{20} = 3.85 \text{ mg NO}_3-\text{N/g MLVSS.h} \\
\text{SDNR20} = \frac{3.85 \times 24}{1000} = 0.09 \text{ g NO}_3-\text{N/g MLVSS.d}
\]
**EMPIRICAL RELATIONSHIP FOR SDNR CALCULATIONS**

Where:

- **SDNR**\(_{20}\) = specific denitrification rate at 20 °C, g NO3-N/g MLVSS.d
- **F/M** = anoxic zone food to microorganisms ratio, g BOD applied/g MLVSS.d in the anoxic zone
- **F_b** = active biomass fraction of MLVSS
- **Y_H** = heterotrophic biomass synthesis yield, g VSS/g VSS.d.
- **k_d** = endogenous decay rate at 20 °C, g VSS/g VSS.d
- **k_{dt}** = endogenous decay rate at MLVSS temperature, g VSS/g VSS.d
- **Y_I** = Influent inert VSS fraction, g VSS inert/g BOD.

**For Bardenpho process at 18 °C with no primary treatment**

\[
SDNR = 0.03 \times \left[ \frac{F}{M} \right] + 0.029
\]

**Adjusted for SRT and wastewater characteristics**

\[
SDNR_{20} = 0.03 \times \left[ \frac{F}{M} \right] \times \left[ \frac{F_b}{0.3} \right] + 0.029
\]

\[
F_b = \frac{Y_H}{1 + k_{dt} \times SRT} + Y_I
\]

\[
k_{dt} = k_d \times 1.029^{(T-20)}
\]

**Influent inert VSS(Y_I) typical values**

<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>With primary treatment</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td>Without primary treatment</td>
<td>0.3-0.5</td>
</tr>
</tbody>
</table>
SDNR CORRECTION FOR TEMPERATURE & IR

\[ SDNR_T = SDNR_{20} \times \theta^{(T - 20)} \]

\[ SDNR_{adj} = SDNR_{IR1} - 0.0166 \ln \left( \frac{F}{M_b} \right) - 0.0078 \quad \text{For IR = 2} \]

\[ SDNR_{adj} = SDNR_{IR1} - 0.029 \ln \left( \frac{F}{M_b} \right) - 0.012 \quad \text{For IR = 3-4} \]

- \[ \theta \] = temp. Coefficient (1.026)
- \[ F/M_b \] = BOD F/M ratio based on anoxic volume and active biomass concentration, g/g.d.
- \[ T \] = Temperature
- \[ SDNR_T \] = specific denitrification rate at T temperature, g NO3-N/g MLVSS.d
- \[ SDNR_{20} \] = specific denitrification rate at 20 °C, g NO3-N/g MLVSS.d
- \[ SDNR_{adj} \] = SDNR adjusted for the effect of internal recycle, g NO3-N/g MLVSS.d
- \[ SDNR_{IR1} \] = SDNR value at internal recycle ratio of 1, g NO3-N/g MLVSS.d
The curves are a result of model simulations using ASM1 Model which couldn’t be verified based on BioWin simulation.

\[
\frac{F}{M_b} = \frac{Q S_o}{(V_{nox}) X_b}
\]

Where
- \( F/M_b \) = BOD F/M ratio based on active biomass concentration, g BOD/g biomass d
- \( Q \) = influent flowrate, m3/d.
- \( S_o \) = Influent BOD concentration, mg/l
- \( X_b \) = anoxic zone biomass concentration, mg/l.
CONCERNS OVER USING EMPIRICAL SDNR EQUATIONS

- Empirical relationships are limited in applications and can provide only rough estimate of SDNR, because SDNR depends on the following factors that are site and design specific:
  - Fraction of active biomass in the mixed liquor.
  - rbCOD concentration in the anoxic zone.
  - Temperature.
  - SRT.

- The use of Stensel equations has resulted in over sizing of anoxic tanks. Simulation models provide an alternative method for SDNR estimation and anoxic reactor sizing. The simulation model methodology eliminates many of the limitations of the empirical methods.

- It is recommended to use the empirical methods for conceptual stage of the projects and to use simulation model beyond the conceptual stage.
POSTANOXIC ENDOGENOUS DENITRIFICATION

- After nitrification the rbCOD is depleted, and depending upon SRT, most of the bpCOD is likely to be depleted.
- The electron donor that creates the demand for nitrate reduction is mainly form activated sludge endogenous respiration.
- SDNR ranged from 0.01 to 0.04 g NO3-N/g MLVSS under endogenous respiration.

$$SDNR_b = \frac{1.42 \times k_d \times \eta}{2.86} = 0.5 \times k_d \times \eta$$

Where:
- 1.42 = g O2/g biomass VSS
- 2.86 = g O2 equivalent /g NO3-N
- $\eta$ = fraction of biomass that can use NO3-N in place of O2 as an electron acceptor, 0.5-0.85.
- $k_d$ = biomass endogenous decay coefficient, 1/d.
The nitrogen removal and effluent nitrate-N concentration that can be achieved by a single anoxic zone is limited by the practical limits of the MLSS recycle(IR). IR ratios above 4 are impractical.

MLSS recycle returns most of this nitrate to anoxic zone.

\[
IR = \frac{NO_x}{N_e} - 1 - R
\]

\[
% N\text{removal} = \left[\frac{NO_x - N_e}{NO_x}\right] \times 100
\]

\[
% N\text{removal} = \frac{IR + R}{IR + R + 1} \times 100
\]

For example:
IR = 3, R = Q

\[
% N\text{removal} = \frac{3 + 1}{3 + 1 + 1} \times 100 = \frac{400}{5} = 80\%
\]
% N REMOVAL VERSUS IR & RAS

\[ \% N_{\text{removal}} = \left( \frac{N_{e} - N_{o}}{N_{o}} \right) \times 100 \]

\[ \% N_{\text{removal}} = \frac{IR + R}{IR + R + 1} \times 100 \]
EFFECT OF INTERNAL RECYCLE RATIO (IR) ON EFFLUENT NITRATE CONCENTRATION

\[ IR = \frac{NO_x}{N_e} - 1 - R \]

\[ N_e = \frac{NO_x}{IR + R + 1} \]
• MLE Configuration is probably simplest configuration for Biological Nitrogen Removal
• Provides nitrification and denitrification (through Anoxic Zone and Internal MLSS recycle)
• Energy Recovery as Nitrate Provides An Alternative Oxygen Source
• Denitrification capacity is function of the of readily available carbon material (BOD, COD) and the practical return MLSS.
5-STAGE BARDENPHO PROCESS WITH BIOLOGICAL PHOSPHORUS REMOVAL

- Includes biological P removal
- Key to Bio-P removal is the anaerobic zone.
- Nitrification and Denitrification
- Second Anoxic zone relies on carbon material produced in the endogenous phase.
NITROGEN MASS BALANCE

- The mass balance should be based on the influent TKN to the activated sludge process.
- Ammonia available for nitrification is equal to the TKN to the secondary treatment minus the following:
  - Soluble organic nitrogen exiting the aeration tank. Estimation of the soluble organic nitrogen was discussed in the wastewater characterization lectures. In the absence of data it can be assumed as 1.5% of the TKN in the raw wastewater.
  - Effluent particulate TKN
  - Nitrogen used for growth of the carbonaceous removing bacteria. This is estimated about 10% of the volatile fraction of the mixed liquor solids.
- Denitrified nitrogen is equal to the nitrified nitrogen less the effluent NO\textsubscript{3-}N.

\[ TN_e = NH_4^- N_e + NO_3^- N_e + pTKN + nbsON \]

\[ TKN_e = NH_4^- N_e + pTKN + nbsON \]

\[ TKN_a = 0.1 \times Y \times BOD_x \times (VSS/TSS) \]

\[ NH_4^- N_n (nitrified) = TKN_i - nbsON - NH_4^- N_e - TKN_a \]

\[ NO_3^- N (denitrified) = NH_4^- N_n - NO_3^- N_e \]
NITROGEN BALANCE
WHERE DOES NITROGEN END UP IN A NITRIFYING PLANT

- In the sludge
- In the effluent
- In the atmosphere
HOW MUCH NITROGEN IS IN THE SLUDGE?

Rule of Thumb

Primary Sludge - About 2.5% of total solids is Nitrogen

Secondary Sludge - 10% of total solids is Nitrogen on VSS basis.
<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent Flow</td>
<td>m³/day</td>
<td>12,433</td>
</tr>
<tr>
<td>Influent TKN to Bioreactor</td>
<td>mg/l</td>
<td>170.0</td>
</tr>
<tr>
<td>NO₃ in Final Effluent</td>
<td>mg/l</td>
<td>30</td>
</tr>
<tr>
<td>NO₃-N in Final Effluent</td>
<td>mg/l</td>
<td>6.8</td>
</tr>
</tbody>
</table>

**Residual TKN**
*(Nonbiodegradable Soluble Organic Nitrogen)*

- Assumed Percentage of the influent TKN: mg/l, 1.5%
- Calculated Concentration: mg/l, 2.6
- Assumed concentration: mg/l, 2.6

**Residual Ammonia**

- Effluent NH₄-N limit: mg/l, 1.0

**TKN in Effluent SS**

- Effluent TSS: mg/l, 10
- VSS/TSS: 0.85
- Effluent VSS: mg/l, 8.5
- Nitrogen content of biomass (VSS): mg N/mg VSS, 0.1
- TKN in SS Effluent: mg/l, 0.85

**Nitrogen used for growth of the carbonaceous removing organisms**

- Total BOD Removed in the Bioreactor: Kg BOD/day, 11960
- Net Yield: Kg TSS/Kg BOD removed, 0.6
- Total waste sludge volatile suspended solids: Kg VSS/day, 6100
- Nitrogen content of biomass (VSS): mg N/mg VSS, 0.1
- TKN load assimilated in waste sludge: Kg N/day, 610
- TKN concentration assimilated in waste Sludge: mg/l, 49.1
- NH₄-N available for Nitrification: mg/l, 117.4
- NO₃-N available for Denitrification: mg/l, 110.6
- % N removal required: 94.2%
NITROGEN MASS BALANCE
CONCENTRATION (mg/l)

\[ \text{Nitrified TKN} = 117.35 \text{ mg/l} \]
\[ \text{Denitrified TKN} = 110.55 \text{ mg/l} \]

\[ \text{NH}_4-N_n \text{ (nitrified)} = TKN_i - nbsON - NH_4-N_e - TKN_a \]

\[ \text{NO}_3-N \text{ (denitrified)} = NH_4-N_n - NO_3-N_e \]
NITROGEN MASS BALANCE LOADS (kg/day)

Nitrified TKN: 1460.00 kg/day
Denitrified TKN: 1375.00 kg/day

\[
\begin{align*}
\text{NH}_4^- N_n (\text{nitrified}) &= \text{TKN}_i - nbsON - \text{NH}_4^- N_e - \text{TKN}_a \\
\text{NO}_3^- N (\text{denitrified}) &= \text{NH}_4^- N_n - \text{NO}_3^- N_e
\end{align*}
\]
EXAMPLE
AEROBIC & ANOXIC REACTORS SIZING

AEROBIC (AERATED) BIOREACTOR SIZING

MLSS := 3000
MLVSS := MLSS × %MLVSS
= 3000 × %MLVSS
= 2250.0

SRT := 5.5

\[ V_{aerobic} = \frac{BOD_{Load_{rMM}} \times Y_{obs} \times SRT}{MLSS \times 0.001} \]

= \frac{36854.0 \times 0.65 \times 5.5}{3000 \times 0.001}
= 43917.0

Assumed Mixed liquor suspended solids, mg/l
Calculated Mixed liquor volatile suspended solids, mg/l
Sludge age calculated/assumed above
Volume of the aerobic zone of the bioreactors, m³
Thank you for your attention.
For further information

Website
www.swim-h2020.eu  E: info@swim-h2020.eu

LinkedIn Page
SWIM-H2020 SM LinkedIn

Facebook Page
SWIM-H2020 SM Facebook
APPENDIX
# Activated Sludge Processes Classification

<table>
<thead>
<tr>
<th></th>
<th>Low Rate</th>
<th>Conventional Rate</th>
<th>High Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volumetric Loading</strong></td>
<td>Kg BOD/m³.d</td>
<td>10 000</td>
<td>20 000</td>
</tr>
<tr>
<td><strong>MLSS</strong></td>
<td>mg/l</td>
<td>6 000</td>
<td>3 000</td>
</tr>
<tr>
<td><strong>Sludge Age</strong></td>
<td></td>
<td>30.0</td>
<td>20.0</td>
</tr>
<tr>
<td><strong>F/M</strong></td>
<td>Kg BOD/Kg MLVSS.d</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Land Area Required</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power Required</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hyd. Ret. Time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sludge Production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nitrogen Removal</strong></td>
<td></td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
</table>
TWO-STEP NITRIFICATION DENITRIFICATION SHARON PROCESS

Single Reactor High Activity Ammonia Removal Over Nitrite

Advantages:
- 25% Reduction in Oxygen Demand
- 40% Reduction in Carbon
- Reduced Biomass Production
### ACTIVATED SLUDGE KINETIC COEFFICIENTS FOR HETEROTROPHIC BACTERIA

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Unit</th>
<th>Value @ 20 °C</th>
<th>Temp. Correction (θ Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Typical</td>
</tr>
<tr>
<td>Maximum specific bacterial growth rate</td>
<td>( \mu_m )</td>
<td>3-13.2</td>
<td>6</td>
</tr>
<tr>
<td>Half-velocity constant</td>
<td>( K_s )</td>
<td>25-100</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>mg BOD/l</td>
<td>10-60</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>mg bsCOD/l</td>
<td>5-40</td>
<td>20</td>
</tr>
<tr>
<td>True yield (Synthesis yield coefficient)</td>
<td>( Y )</td>
<td>0.4-0.8</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>mgVSS/mg BOD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mgVSS/mg bCOD</td>
<td>0.3-0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Endogenous decay coefficient</td>
<td>( k_d )</td>
<td>0.06-0.2</td>
<td>0.12</td>
</tr>
<tr>
<td>Cell debris fraction</td>
<td>( f_d )</td>
<td>Unitless</td>
<td>0.08-0.2</td>
</tr>
</tbody>
</table>

**Source:** Tale 8-10, Metcalf & Eddy, page 705.
# Activated Sludge Kinetic Coefficients for Nitrifying Bacteria

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Unit</th>
<th>Value @ 20 °C</th>
<th>Temp. Correction (θ Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Typical</td>
<td>Range</td>
</tr>
<tr>
<td>Maximum specific growth rate of nitrifying bacteria</td>
<td>$\mu_{mn}$</td>
<td>gVSS/g VSS.d</td>
<td>0.2-0.9</td>
</tr>
<tr>
<td>Half-velocity constant for ammonia concentration</td>
<td>$K_n$</td>
<td>mg NH4-N/l</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Biomass true yield /Synthesis yield coefficient)</td>
<td>$Y_n$</td>
<td>mgVSS/mg NH4-N</td>
<td>0.1-0.15</td>
</tr>
<tr>
<td>Endogenous decay coefficient for nitrifying organisms</td>
<td>$k_{dn}$</td>
<td>g VSS/g VSS.day</td>
<td>0.05-0.15</td>
</tr>
<tr>
<td>Half-velocity constant for dissolved -oxygen concentration</td>
<td>$K_o$</td>
<td>mg/l</td>
<td>0.40-0.60</td>
</tr>
</tbody>
</table>

Source: Tale 8-11 Metcalf & Eddy, page 705.
### Updated Kinetic Parameters for BOD Removal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Metcalf &amp; Eddy/AECOM Fifth Edition</th>
<th>Metcalf &amp; Eddy Fourth Edition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Typical</td>
<td>Range</td>
</tr>
<tr>
<td>Maximum specific substrate utilization rate</td>
<td>k</td>
<td>bsCOD/g VSS.d</td>
<td>4-12</td>
</tr>
<tr>
<td>Half-velocity constant</td>
<td>Ks</td>
<td>mg/l BOD</td>
<td>20-60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mg/l bsCOD</td>
<td>5-30</td>
</tr>
<tr>
<td>True yield (Synthesis yield coefficient)</td>
<td>Y</td>
<td>mg VSS/mg BOD</td>
<td>0.4-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mg VSS/mg COD</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Endogenous decay coefficient</td>
<td>b,kd</td>
<td>g VSS/g VSS.d</td>
<td>0.06-0.15</td>
</tr>
</tbody>
</table>

Source: Metcalf & Eddy/Aecom
Table 7-8, page 593 Fifth Edition
Table 7-9, page 585 Fourth Edition
## UPDATED KINETIC PARAMETERS FOR NITRIFICATION & BOD REMOVAL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cryptic Name</th>
<th>Unit</th>
<th>Metcalf &amp; Eddy/AECOM Fifth Edition</th>
<th>Metcalf &amp; Eddy Fourth Edition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>COD Oxidation</td>
<td>NH4 Oxidation</td>
</tr>
<tr>
<td>Maximum specific growth rate</td>
<td>( \mu_{\text{max}} )</td>
<td>g VSS/g VSS.d</td>
<td>6</td>
<td>0.9</td>
</tr>
<tr>
<td>Half-velocity constant</td>
<td>( K_s )</td>
<td>mg/l</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( K_{\text{NH4}} )</td>
<td>mg/l</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>( K_{\text{NO2}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True yield /Synthesis yield coefficient</td>
<td>( Y )</td>
<td>g VSS/g substrate oxidised</td>
<td>0.45</td>
<td>0.15</td>
</tr>
<tr>
<td>Endogenous decay coefficient</td>
<td>( b, k_{\text{dn}} )</td>
<td>g VSS/g VSS.d</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>Fraction of biomass that remains as cell debri</td>
<td>( f_d )</td>
<td></td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Half-velocity constant for dissolved oxygen concentration</td>
<td>( K_{\text{CO2}} )</td>
<td>mg/l</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Temp. Correction ( \mu_{\text{max}} )</td>
<td></td>
<td></td>
<td>1.07</td>
<td>1.072</td>
</tr>
<tr>
<td>Temp. Correction ( b, k_{\text{dn}} )</td>
<td>(( \Theta ) Value)</td>
<td></td>
<td>1.04</td>
<td>1.029</td>
</tr>
<tr>
<td>Temp. Correction ( K_n )</td>
<td></td>
<td></td>
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<td>1</td>
</tr>
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</table>

Source: Metcalf & Eddy/Aecom
Table 8-14, page 755  Fifth Edition
Table 6-8-11, page 705  Fourth Edition
EFFECT OF TEMPERATURE ON KINETIC COEFFICIENTS

\[ k_T = k_{20} \times \theta^{(T-20)} \]

Where
- \( k_T \) = reaction rate coefficient at temperature \( T \), oC.
- \( k_{20} \) = reaction rate coefficient at 20 oC.
- \( \theta \) = temperature coefficient (1.02-1.25).
- \( T \) = temperature, oC.
NITROGEN REMOVAL MASS BALANCE

\[
\begin{align*}
Q_{IR} \left[ \frac{\text{NO}_3 - m}{Q + Q_{IR} + Q_R} \right] &= Q_{IR} \left[ \frac{\text{NO}_3 - m}{Q + IR \times Q + R \times Q} \right] = Q_{IR} \left[ \frac{\text{NO}_3 - m}{1 + IR + R} \right] = IR \left[ \frac{\text{NO}_3 - m}{1 + IR + R} \right]
\end{align*}
\]

NO3 mass = \(Q_e \times \text{NO}_3 - c\)

\[
\begin{align*}
Q_e \left[ \frac{\text{NO}_3 - m}{Q + Q_e + Q_e} \right] &= Q_e \left[ \frac{\text{NO}_3 - m}{Q + IR \times Q + R \times Q} \right] = Q_e \left[ \frac{\text{NO}_3 - m}{1 + IR + R} \right] = R \left[ \frac{\text{NO}_3 - m}{1 + IR + R} \right]
\end{align*}
\]

NO3 mass = \(Q_e \times \text{NO}_3 - c\)

\[
\begin{align*}
N_e &= \frac{\text{NO}_3 - m}{Q + Q_{IR} + Q_R}
\end{align*}
\]

mass of nitrate produced in aerobic zone

\[
\begin{align*}
Q \times NQ - c &= N_e \times Q + N_e \times Q_{IR} + N_e \times Q_R \\
Q \times NO_3 - c &= N_e (Q + Q_{IR} + Q_R) \\
Q \times NO_3 - c &= N_e (Q + IR \times Q + R \times Q)
\end{align*}
\]

IR = \(\frac{Q_{IR}}{Q}\)

R = \(\frac{Q_e}{Q}\)

IR = \(\frac{\text{NO}_3 - c}{N_e} - 1 - R\)
RASSS

\[ RASSS = \left( 1 + \frac{Q_r}{Q} \right) \times MLSS - ESS \approx \left( 1 + \frac{R}{R} \right) \times MLSS \]

\[ R = \frac{Q_r}{Q} \]

Where:
RASSS: Return activated sludge concentration
Q: Influent flow
ESS: Effluent suspended solids, negligible
Qw: Waste activated sludge flow, negligible
AEROBIC BIOLOGICAL OXIDATION

Oxidation & Synthesis

\[ \text{COHNS} + O_2 + \text{nutrients} \xrightarrow{\text{bacteria}} CO_2 + NH_3 + C_5H_7NO_2 + \text{other products} \]

Organic matter

Endogenous respiration

cells

\[ C_5H_7NO_2 + 5O_2 \xrightarrow{\text{bacteria}} 5CO_2 + 2H_2O + NH_3 + \text{energy} \]

mw= 113  mw= 160  160/113= 1.42

New cells
DERIVATION OF PRE-ANOXIC TANK VOLUME EQUATION

\[ NO_r = V_{nox} \times SDNR_t \times MLVSS \]

\[ SDNR_{20} = 0.03 \times \left[ \frac{F}{M} \right] \times \left[ \frac{F_b}{0.3} \right] + 0.029 \]

\[ F / M = \frac{Q \times BOD_i}{V \times MLVSS} \]

\[ T_c = \theta^{(T-20)} \]

\[ SDNR_t = SDNR_{20} \times \theta^{(T-20)} \]

\[ NO_r = V \times \left[ 0.03 \times \left( \frac{Q \times BOD_i}{V \times MLVSS} \right) \times \left[ \frac{F_b}{0.3} \right] + 0.029 \right] \times T_c \times MLVSS \]

\[ V = \frac{0.0345 \times (1 \times 10^6 \times NO_r - 100 \times BOD_i \times F_b \times Q \times T_c)}{MLVSS \times T_c} \]

Where:
F/M = anoxic zone food to microorganisms ratio, g BOD applied/g MLVSS.d in the anoxic zone
F_b = active biomass fraction of MLVSS
BOD_i = influent BOD5 concentration mg/l
NO_r = Denitrified nitrogen kg/day.
T_c = Temperature correction for SDNR
BOD REMOVAL

\[ \frac{1}{SRT} = \left[ \frac{F}{M} \right] \times Y_{obs} \]
Where

\( \mu_n = \) specific growth rate for nitrifiers

\( k_{dn} = \) specific decay rate for nitrifiers

\( \mu_{mn} = \) maximum specific growth rate for nitrifiers

\( N = \) ammonia concentration in the effluent

\( K_N = \) half-velocity constant for ammonia conc.

\( DO = \) DO concentration

\( K_o = \) half-velocity constant for DO concentration
### SDNR FOR OXIDATION DITCHES DENITRIFICATION

\[
SDNR_b = \frac{\eta \times A_n}{2.86 \times Y_n} \left( \frac{1}{SRT} \right)
\]

\[
Y_n = \frac{Y}{1 + k_d \times SRT}
\]

\[
A_n = 1 - 1.42 \times Y + \frac{1.42 \times k_d \times Y \times SRT}{1 + k_d \times SRT}
\]

Where:
- \(SDNR_o\) = SDNR in anoxic zones following nitrification & with no exogenous carbon addition, g NO\(_3\)-N/g MLVSS.d
- \(A_n\) = net oxygen requirement by heterotrophs, g O\(_2\)/g bCOD removed
- \(Y_n\) = net heterotrophic biomass yield, g VSS/g bCOD removed.
- \(\eta\) = fraction of biomass that can use NO\(_3\)-N in place of O\(_2\) as an electron acceptor, 0.5-0.85, typical 0.5.
- \(k_d\) = biomass endogenous decay coefficient, 1/d.
- \(SRT\) = sludge age, days

Source: M&E chapter 8, page 777
# DESIGN SRT FOR NITRIFICATION (METHOD-1 METCALF & EDDY FIFTH EDITION)

**Fifth Edition Metcalf & Eddy**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Parameter</th>
<th>Value at 20°C</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/day</td>
<td>μ&lt;sub&gt;mn&lt;/sub&gt;</td>
<td>0.9</td>
<td>1.072</td>
</tr>
<tr>
<td>1/day</td>
<td>k&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>mg/l</td>
<td>K&lt;sub&gt;N&lt;/sub&gt;</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>mg/l</td>
<td>K&lt;sub&gt;O&lt;/sub&gt;</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>mg/l</td>
<td>N</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>DO</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

\[ \mu_n = \mu_{mn} \times \frac{N}{K_N + N} \times \frac{DO}{K_O + DO} \]

\[ k_T = k_{20} \times \theta^{(T-20)} \]

\[ SRT_a = \frac{1}{\mu_n - k_d} \]

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>(\mu_{mnT})</th>
<th>k&lt;sub&gt;d&lt;/sub&gt;</th>
<th>(\mu_n)</th>
<th>Theoretical SRT SRTa (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.449</td>
<td>0.128</td>
<td>0.239</td>
<td>8.9</td>
</tr>
<tr>
<td>11</td>
<td>0.481</td>
<td>0.131</td>
<td>0.257</td>
<td>8.0</td>
</tr>
<tr>
<td>12</td>
<td>0.516</td>
<td>0.135</td>
<td>0.275</td>
<td>7.1</td>
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<tr>
<td>13</td>
<td>0.553</td>
<td>0.139</td>
<td>0.295</td>
<td>6.4</td>
</tr>
<tr>
<td>14</td>
<td>0.593</td>
<td>0.143</td>
<td>0.316</td>
<td>5.8</td>
</tr>
<tr>
<td>15</td>
<td>0.636</td>
<td>0.147</td>
<td>0.339</td>
<td>5.2</td>
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<tr>
<td>16</td>
<td>0.681</td>
<td>0.152</td>
<td>0.363</td>
<td>4.7</td>
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<td>17</td>
<td>0.731</td>
<td>0.156</td>
<td>0.390</td>
<td>4.3</td>
</tr>
<tr>
<td>18</td>
<td>0.783</td>
<td>0.161</td>
<td>0.418</td>
<td>3.9</td>
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<tr>
<td>19</td>
<td>0.840</td>
<td>0.165</td>
<td>0.448</td>
<td>3.5</td>
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<tr>
<td>20</td>
<td>0.900</td>
<td>0.170</td>
<td>0.480</td>
<td>3.2</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Design SRT (days) For Safety Factor =</th>
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<tbody>
<tr>
<td>1.2</td>
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<tr>
<td>10.7</td>
</tr>
<tr>
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<tr>
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<td>6.9</td>
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<tr>
<td>5.7</td>
</tr>
<tr>
<td>5.1</td>
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<td>4.7</td>
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<tr>
<td>4.2</td>
</tr>
<tr>
<td>3.9</td>
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</table>
## DESIGN SRT FOR NITRIFICATION (METHOD-2 WASHOUT SRT)

### Method-2

<table>
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<tr>
<th>Unit</th>
<th>Parameter</th>
<th>Value at 20°C</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/day</td>
<td>$\mu_{mn}$</td>
<td>0.9</td>
<td>1.072</td>
</tr>
<tr>
<td>1/day</td>
<td>$k_{dn}$</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>mg/l</td>
<td>$K_N$</td>
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<tr>
<td>mg/l</td>
<td>$K_o$</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>mg/l</td>
<td>N</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>DO</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

### Formulas

\[
\mu_n = \mu_{mn} \times \frac{DO}{K_o + DO}
\]

\[
k_T = k_{20} \times \theta^{(T-20)}
\]

\[
SRT_w = \frac{1}{\mu_n - k_{dn}}
\]

### Table

<table>
<thead>
<tr>
<th>Temp. °C</th>
<th>$\mu_{mnT}$ Maximum Specific Growth Rate</th>
<th>$k_{dn}$ Specific Decay Rate</th>
<th>$\mu_n$ Specific Growth Rate</th>
<th>Washout SRT SRTw (days)</th>
<th>Design SRT (days) For Safety Factor =</th>
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</thead>
<tbody>
<tr>
<td>10</td>
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<td>0.128</td>
<td>0.359</td>
<td>4.3</td>
<td>2.5</td>
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<tr>
<td>11</td>
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