



ENVE 302

Environmental Engineering Unit Processes

CHAPTER: 9

DENITRIFICATION

Assist. Prof. Bilge Alpaslan Kocamemi

Marmara University

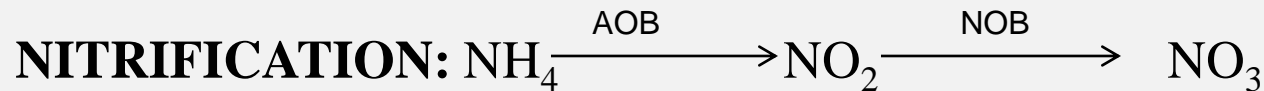
Department of Environmental Engineering

Istanbul, Turkey

BIOLOGICAL NITROGEN-REMOVAL FROM DOMESTIC WASTEWATER

Nitrification + denitrification

- To prevent eutrophication
- To protect groundwater against elevated NO_3^- N concentrations



BIOLOGICAL DENITRIFICATION

➤ Biological oxidation of many organic substrates using nitrate (NO_3^-) or NO_2^- (nitrite) as e^- acceptor instead of oxygen (Anoxic conditions)



➤ If both NO_3^- (or NO_2^-) and N_2 are present, the bacteria will use oxygen in the oxidation of organic matter because it yields more energy

Thus, for denitrification to proceed \longrightarrow no molecular oxygen must exist (anoxic conditions)

e^- acceptor = NO_3 or NO_2

e^- donor = organic substrate

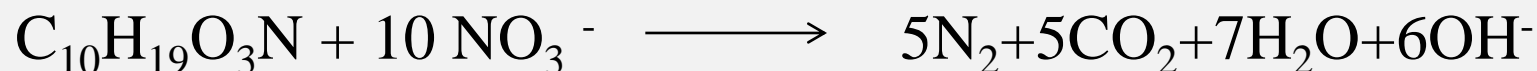
- bs COD in the influent
- bs COD produced during endogenous decay
- An exogeneous source such as methanol

Relatively broad range of hetetrophic bacteria (facultative) can accomplish denitrification

Recent researches —→ denitrification by autotrophic bacteria
 e^- donor = hydrogen or reduced sulfur

DENITRIFICATION RXN STOICHIOMETRY FOR DIFFERENT ELECTRON DONORS

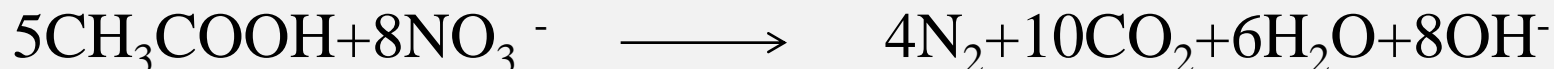
➤ Biodegradable organic matter in ww ($C_{10}H_{19}O_3N$)



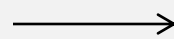
➤ Methanol



➤ Acetate

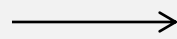


$$\frac{1 \text{ eq alkalinity produced}}{1 \text{ eq } \text{NO}_3 - \text{N}}$$



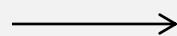
$$3.57 \frac{\text{g of alkalinity as } \text{CaCO}_3}{\text{g nitrate nitrogen reduced}}$$

In nitrification



$$7.14 \frac{\text{g of alkalinity as } \text{CaCO}_3 \text{ reduced}}{\text{g } \text{NH}_4 - \text{N} \text{ oxidized}}$$

In denitrification



$$3.57 \frac{\text{g of alkalinity as } \text{CaCO}_3 \text{ produced}}{\text{g } \text{NO}_3 - \text{N} \text{ reduced}}$$

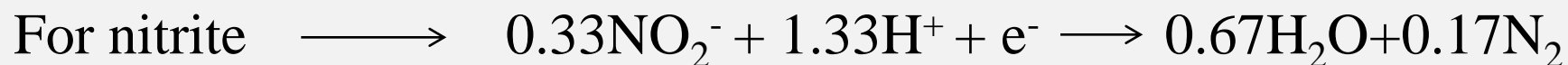
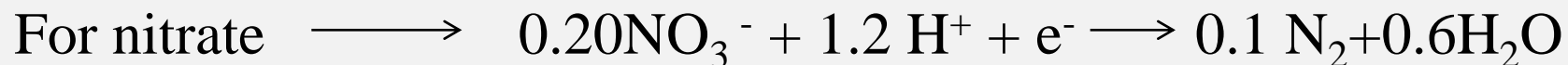
About one half of the alkalinity amount destroyed in nitrified can be recovered through denitrification

OXYGEN CALCULATIONS

Combined C removal, nitrification, denitrification \longrightarrow O_2 saving
(for the case of pre-anoxic configuration)

Because some of the organic C will be used for denitrification and in
denitrification e^- acceptor = NO_3 or NO_2 not O_2

Oxidation-Reduction half rxns;



From the above oxidation-reduction half rxns;

0.25 mole oxygen is equivalent to 0.2 mole nitrate
0.33 mole nitrite for e^- transfer

$$0.25 \text{ mole } O_2 \times \frac{32 \text{ g}}{1 \text{ mole}} = 8 \text{ g } O_2$$

$$0.2 \text{ mole } NO_3 \times \frac{62 \text{ g}}{1 \text{ mole}} = 12.4 \text{ g } NO_3 \longrightarrow 2.8 \text{ g } NO_3\text{-N}$$

$$0.33 \text{ mole } NO_2 \times \frac{46 \text{ g}}{1 \text{ mole}} = 15.8 \text{ g } NO_2 \longrightarrow 4.62 \text{ g } NO_2\text{-N}$$

$$\longrightarrow \frac{8 \text{ g } O_2}{2.8 \text{ g } NO_3\text{-N}} = 2.86 \frac{\text{g } O_2}{\text{g } NO_3\text{-N}} \quad \text{Oxygen eq of } NO_3\text{-N}$$

$$\longrightarrow \frac{8 \text{ g } O_2}{4.62 \text{ g } NO_2\text{-N}} = 1.7 \frac{\text{g } O_2}{\text{g } NO_2\text{-N}} \quad \text{Oxygen eq of } NO_2\text{-N}$$

Example:

$$Q = 22464 \text{ m}^3/\text{d}$$

$$\text{bsCOD influent} = 224 \text{ g/m}^3$$

$$P_{x, \text{bio}} = 1154.7$$

$$\text{TKN influent} = 35 \text{ g/m}^3$$

$$\text{NH}_4\text{-N influent} = 25 \text{ g/m}^3$$

$$\text{Influent alkanity} = 140 \text{ g/m}^3 \text{ as CaCO}_3$$

$$\text{NH}_4\text{-N effluent} = 0.5 \text{ g/m}^3$$

$$\text{bCOD effluent} = 1 \text{ g/m}^3$$

$$\text{Alkanity conc.to maintain ph in the range of 6.8 - 7} = 80 \text{ g/m}^3$$

a) Find O_2 requirement

- i) If the system includes carbon removal, nitrification
- ii) If the system includes carbon removal, nitrification, denitrification ($\text{NO}_3\text{-N effluent} = 6 \text{ g/m}^3$)

b) Find the alkalinity requirement

- i) If the system includes carbon removal, nitrification
- ii) If the system includes C removal, nitrification and denitrification ($\text{NO}_3\text{-N} = 6 \text{ g/m}^3$)

C REQUIREMENT FOR DENITRIFICATION

Important design parameter
for denitrification process →

Amount of bsCOD or BOD
to provide sufficient amount of
 e^- donor for nitrate removal

As a general rule
(Barth et al., 1968) →

4 g of BOD is needed per g of NO_3
reduced

The actual value depends on;

- The system operating conditions
- Type of e^- donor used

bsCOD/NO₃-N ratio —→ related to the system biomass yield

From a steady-state COD balance;

$$\underbrace{\text{bsCOD}_R}_{\substack{\text{bsCOD} \\ \text{utilized} \\ \text{g bsCOD/d}}} = \underbrace{\text{bsCOD}_{\text{syn}}}_{\substack{\text{bsCOD} \\ \text{incorporated} \\ \text{into cell synthesis} \\ \text{g bsCOD/d}}} + \underbrace{\text{bsCOD}_o}_{\substack{\text{bsCOD oxidized} \\ \text{g bsCOD/d}}}$$

$\text{bsCOD}_{\text{syn}}$ —→ is calculated from the net biomass yield and the ratio of 1.42 g O₂/g VSS.

The oxygen equivalent of the biomass = bsCOD incorporated into biomass

$$bsCOD_{syn} = 1.42 \frac{g O_2}{g VSS} \times Y_n \frac{g VSS}{g bsCOD_R} \times bsCOD_R \frac{g}{d}$$

$$\text{Net Biomass Yield: } Y_n = \frac{Y}{1 + (k_{dn})SRT}$$

$$bsCOD_R = 1.42 Y_n bsCOD_R + bsCOD_0$$

$$bsCOD_0 = (1 - 1.42 Y_n) bsCOD_R$$

COD oxidized equals to the oxygen equivalent of NO_3 -N used for bsCOD oxidation

$$bsCOD_0 = 2.86 NO_x$$

\downarrow
 O_2 equivalent of
 NO_3 -N
 $(g O_2 / g NO_3\text{-N})$

\searrow
 NO_3 -N reduced (g/d)

$$2.86 NO_3 = (1 - 1.42 Y_n) bsCOD_R$$

$$\frac{bsCOD}{NO_3 - N} = \frac{2.86}{1 - 1.42 Y_n}$$

GROWTH KINETICS OF DENITRIFICATION

Denitrification \longrightarrow Heterotrophic bacteria (facultative)
 e^- donor = organic
 e^- acceptor = $\text{NO}_3\text{-N}$

Heterotrophic bacterial growth occurs \longrightarrow with O_2 consumption in aerobic zone
with $\text{NO}_3\text{-N}$ consumption in anoxic zone

The mixed liquor biomass concentration can be calculated based on the total amount of BOD removed, but only a portion of that biomass can use both nitrate and oxygen as e^- acceptor.

Therefore, r_{su} expression derived for heterotrophic biomass is modified by a term to account for the fact that only a portion of the biomass is active in the anoxic zone.

$$r_{su} = -\frac{kXS\eta}{K_s + S}$$

n = Fraction of denitrifying bacteria in the biomass
(g VSS/ g VSS)

Denitrifying bacteria \longrightarrow facultative hetetrophs
can use both NO_3 and O_2 e^- acceptor

Other portion of $\xrightarrow{\eta}$ strictly aerobic
hetetrophs

$n = 0.2 - 0.8$ (For preanoxic denitrification reactors fed domestic ww for

For postanoxic process \rightarrow biomass consists of mainly denitrifying
bacteria $\rightarrow n$ term is necessary

EFFECTS OF NITRATE AND DO CONCENTRATION

DO \longrightarrow can inhibit nitrate reduction

DO > 0.2 mg/l inhibits denitrification

$$r_{su} = -\left(\frac{kXS}{K_s + S}\right)\left(\frac{NO_3}{K_{sNO_3} + NO_3}\right)\left(\frac{K_{O'}}{K_{O'} + DO}\right)n$$

K_o = DO inhibition coefficient for nitrate reduction (mg/l)

System specific (0.1 – 0.2 mg/l)


ENVIRONMENTAL FACTORS

Alkanity → produced in denitrification rxn

pH is generally elevated

In contrast to nitrifying organisms → less concern about pH influences on denitrification rate

No significant effect on denitrification rate has been reported for pH between 7 and 8.

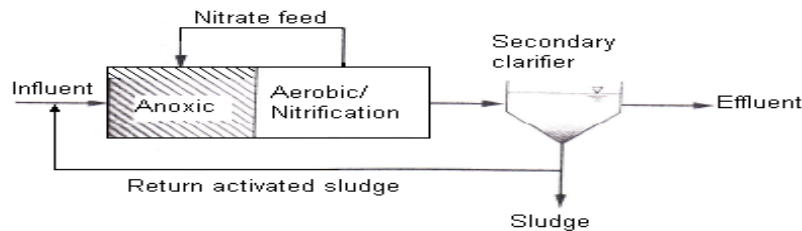


Temperature —→ as with any microbial activity ,
denitrification rate can be effected
significantly by temperature

inhibitors —→ denitrifiers are much less sensitive to
inhibitory compounds then nitrifiers

Types of denitrification Processes

a) PRE-ANOXIC DENITRIFICATION

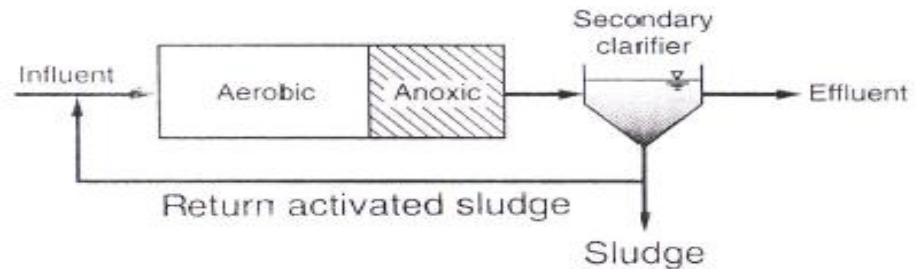


Organic substrate; from the influent ww

$NO_3^- \rightarrow$ Produced in the aeration tank through nitrification is recycled back to the anoxic tank

Carbon source in anoxic zone :

b) POST-ANOXIC DENITRIFICATION



- Denitrification occurs after carbon removal and nitrification in aerobic zone.
- Carbon necessary for denitrification is depleted in aerobic zone through carbon removal

Carbon source in anoxic zone:

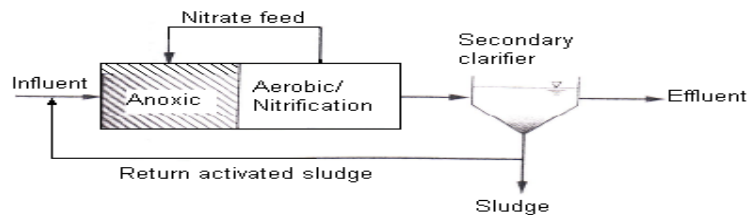
Endogenous decay

(slow denitrif. rate by a factor of 3-8)

Exogenous carbon source (methanol, acetate etc)

Nitrogen Removal Process Configurations

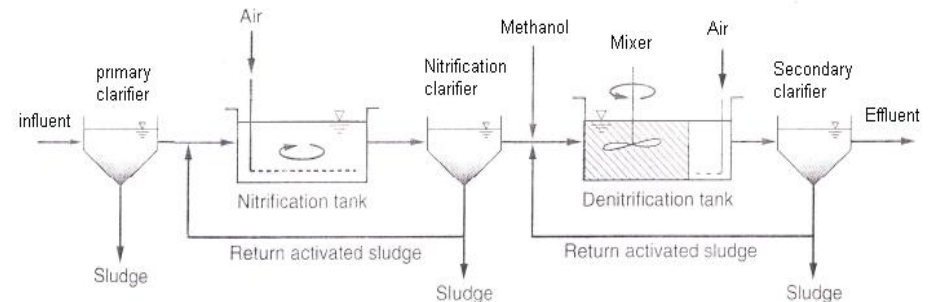
a) Single Sludge Systems



➤ Only one solid separation device

➤ The activated sludge tank may be divided into different zones of anoxic and oxic conditions and mixed liquor may be pumped from one zone to another (internal recycle) but the liquid-solid separation occurs only once

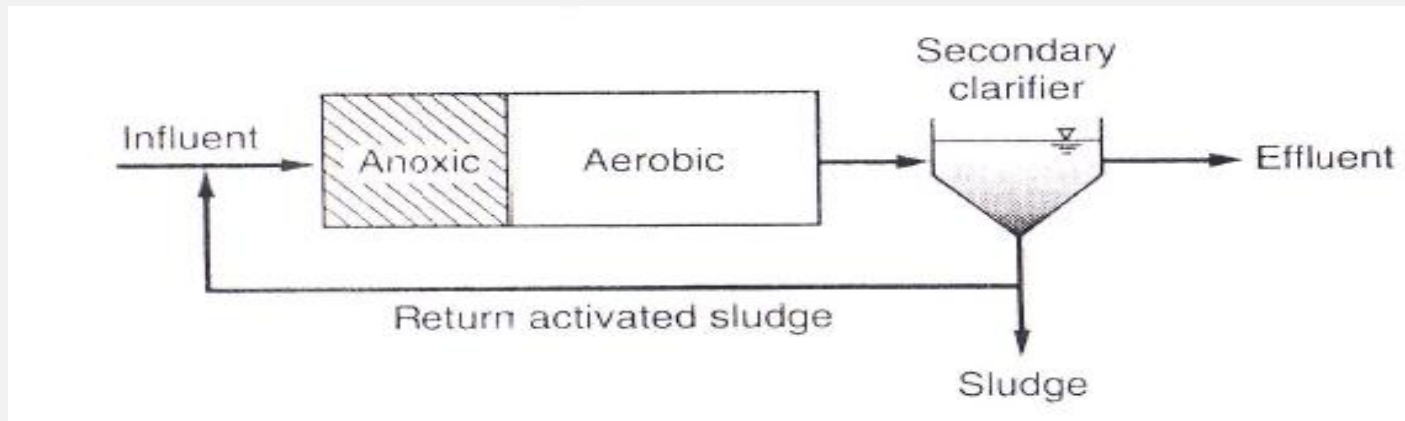
b) Two Sludge Systems



➤ Aerobic process (for nitrification) followed by an anoxic process (for denitrification) each with its own clarifier, thus producing two sludges

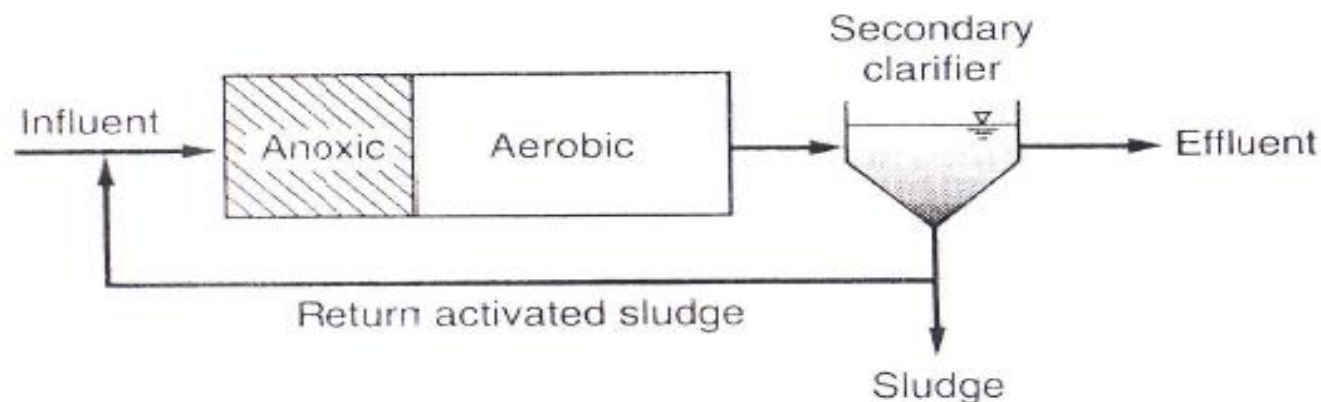
Single-sludge Nitrogen Removal Process Configurations

a) Ludzack-Ettinger (Pre-anoxic)



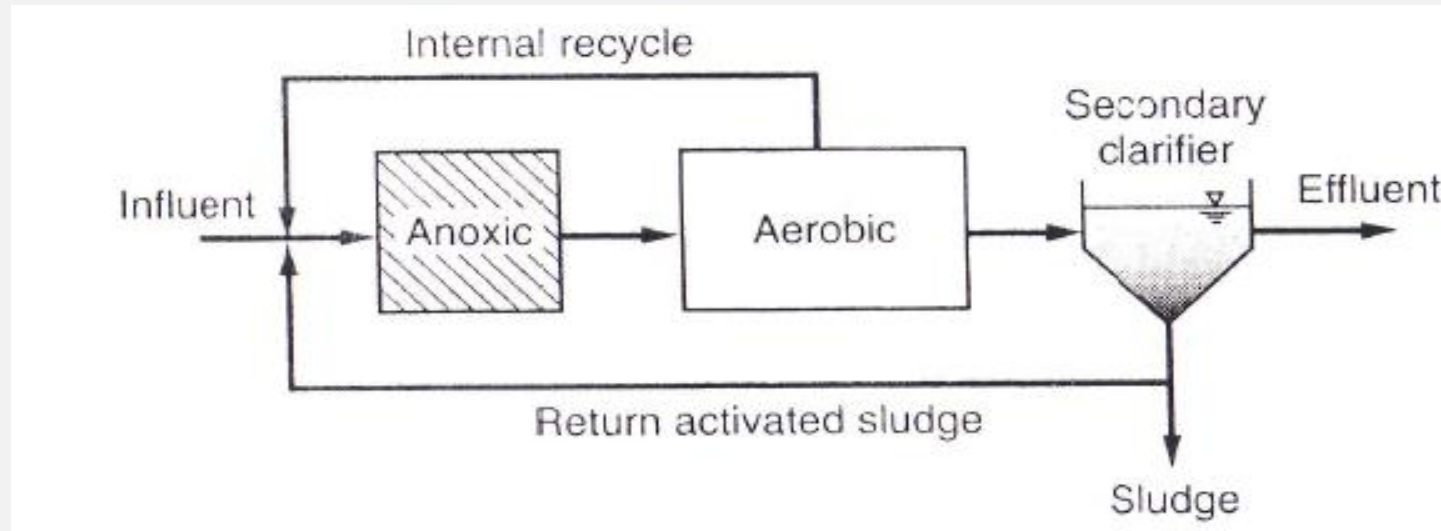
NO_3^- formed in the aerobic zone being returned via RAS to the anoxic zone

Denitrification rate is limited by the RAS recycle ratio



The first concept of a preanoxic BNR was an anoxic-aerobic operating sequence by Ludzack and Ettinger (1962). The influent wastewater was fed to an anoxic zone, which was followed by an aerobic zone. The process relies on the nitrate formed in the aerobic zone being returned via the RAS to the anoxic zone. Because the only nitrate fed to the anoxic zone is that in the RAS, denitrification is limited greatly by the RAS recycle ratio. However, more recently, this process has been used with increased RAS recycle rates to prevent rising sludge in the secondary clarifiers due to denitrification

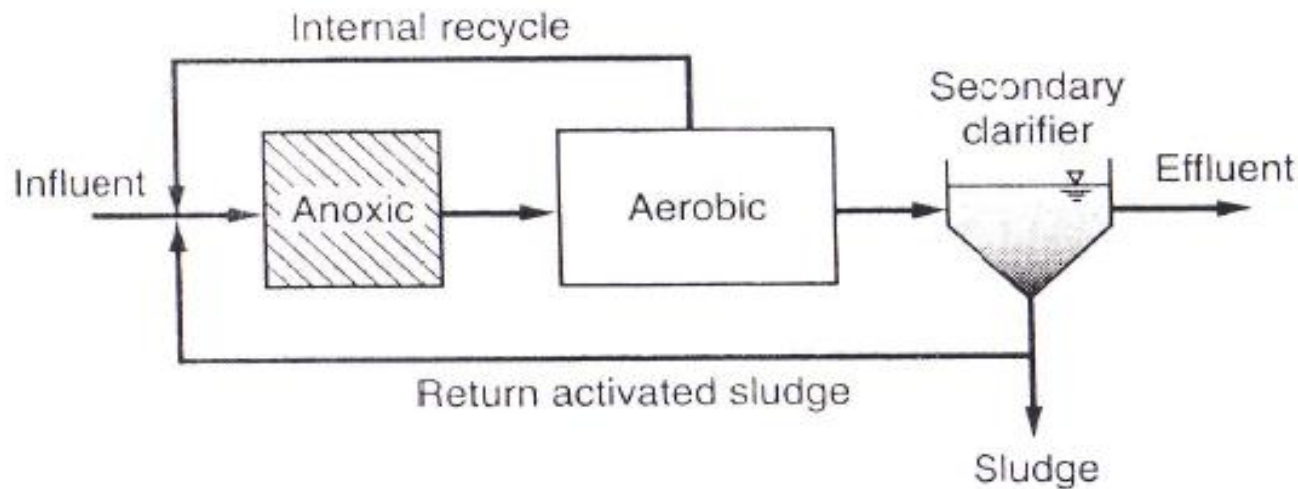
b) Modified Ludzack-Ettinger (MLE) (Pre-anoxic)



- Internal recycle is provided to feed more NO_3^- to the anoxic zone directly from aerobic zone
- Denitrification rate and overall nitrogen removal rate increase

$$IR = \frac{\text{Internal_recycle_flowrate}}{\text{Influent_flowrate}} = 2-4$$

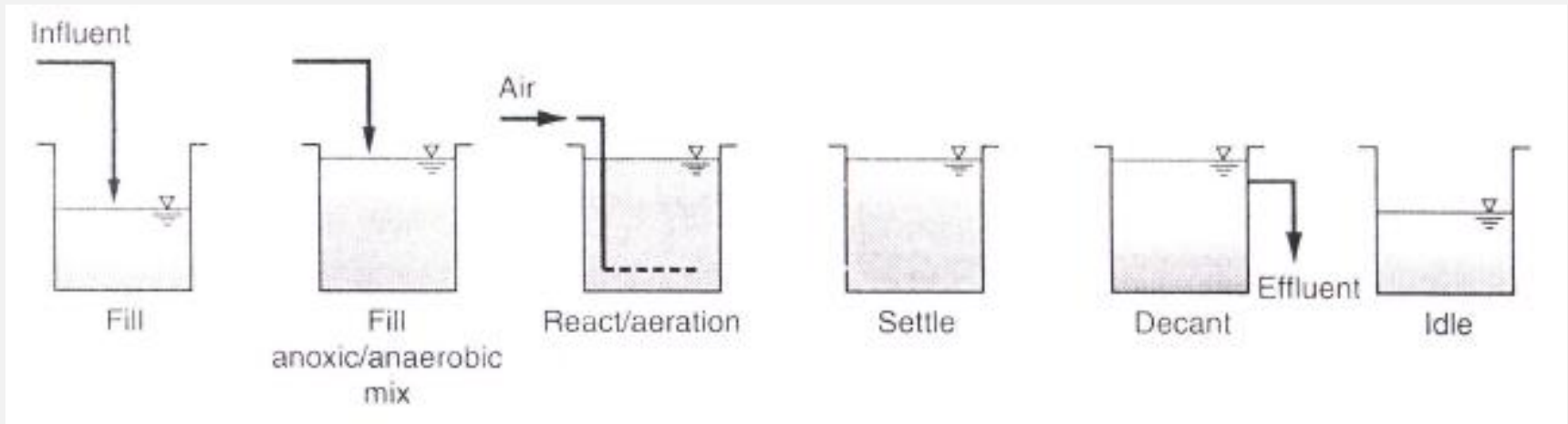
- A BOD / TKN = 4:1 in the influent ww
- This is usually sufficient for effective NO_3^- reduction by preanoxic processes
- for domestic ww $NO_3\text{-}N_{\text{eff}} = 4\text{-}7\text{mg/L}$
- very adaptable to existing activated sludge processes



One of the most commonly used BNR processes is the modified Ludzack-Ettinger (MLE) process. Barnard (1973) improved on the original Ludzack-Ettinger design by providing the internal recycle to feed more nitrate to the anoxic zone directly from the aerobic zone. Both the denitrification rate and overall nitrogen-removal efficiency are increased. The internal recycle flow ratio (recycle flowrate divided by influent flowrate) typically ranges from 2 to 4. With sufficient influent BOD and anoxic contact time, these recycle ratios result in an average effluent $\text{NO}_3\text{-N}$ concentration from 4 to 7 mg/L when treating domestic wastewater. The MLE process is very adaptable to existing activated-sludge facilities and can easily meet a common effluent standard of <10mg/L total nitrogen.

A BOD/TKN ratio of 4:1 in the influent wastewater is usually sufficient for effective nitrate reduction by preanoxic processes. Typical anoxic tank detention times for the MLE process range from 2 to 4 h, but when the anoxic zone is divided into 3 to 4 stages in series, denitrification kinetic rates are increased and the total detention time needed may then be 50 to 70 percent of the single-stage design. Another modification of the MLE process, termed "eMLE," uses an additional set of anoxic/aeration basins to enhance nutrient removal

d) Sequencing Batch Reactors (SBR) (Pre-anoxic)



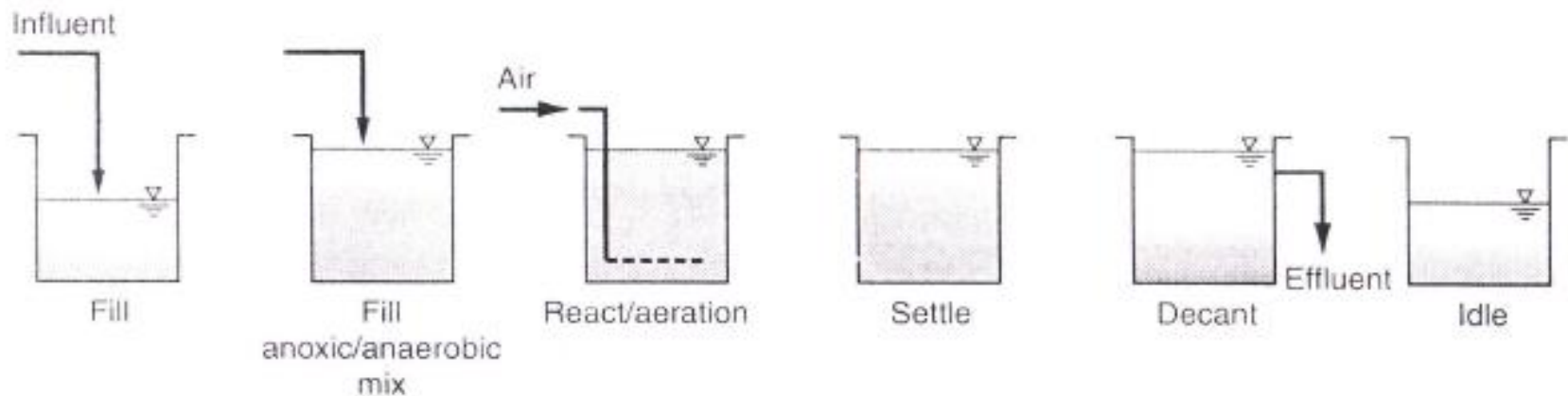
- Cycling aeration on/off during the react period

OR

- Using a mixed non-aerated fill period

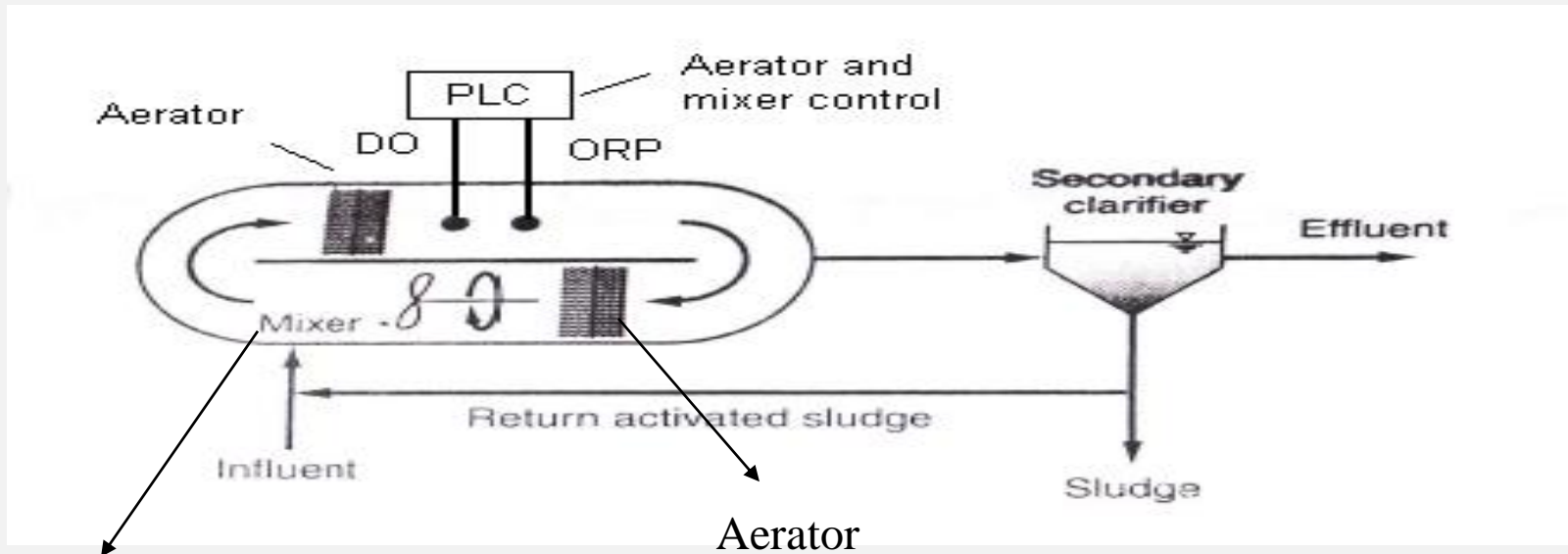
Effluent $\text{NO}_3\text{-N} = 5\text{-}8\text{mg/L}$

- Preanoxic denitrification; using BOD in the influent ww and remaining in the mixed liquor after the settle and decant phases
- Most of the NO_3^- produced during the previous aerobic cycle remains in the SBR tank because decant volume is 20-30% of total volume



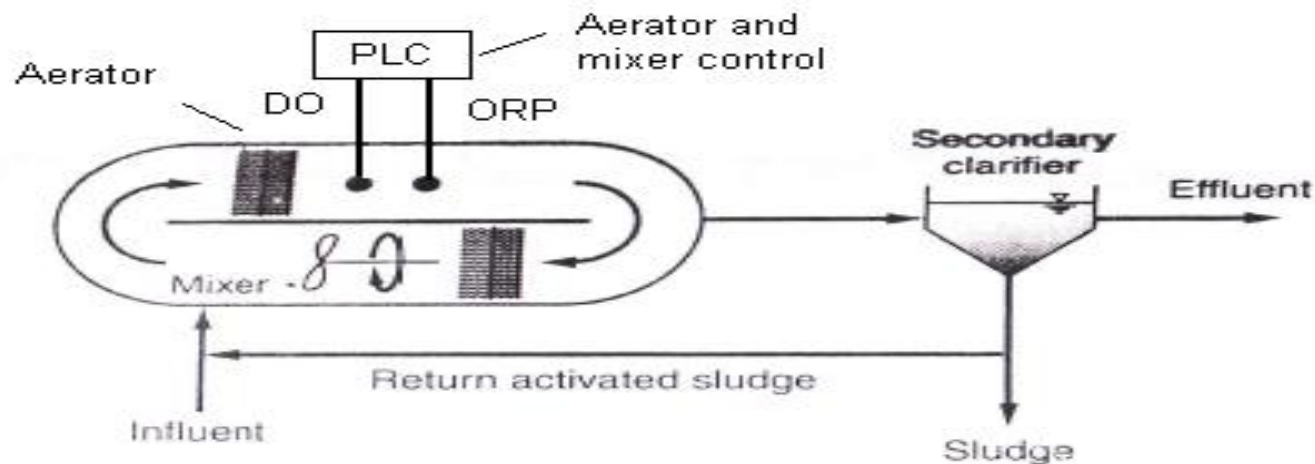
The SBR system (see Table 8-15) also employs preanoxic denitrification using BOD in the influent wastewater. Mixing is used during the fill period to contact the mixed liquor with the influent wastewater. For many domestic applications, depending on the wastewater strength, sufficient BOD and fill time are available to remove almost all of the nitrate remaining in the mixed liquor after the settle and decant steps. Some nitrate removal also occurs during the nonaerated settle and decant periods. Separate mixing provides operating flexibility and is useful for anoxic operation during the aeration period, as well as anaerobic or anoxic contacting during the fill period. Mixing without aeration during the fill period is effective in improving sludge-settling properties in addition to nitrogen removal. Many facilities have reported effluent $\text{NO}_3\text{-N}$ concentrations of less than 5 mg/L.

f) Nitrox (Pre-anoxic)



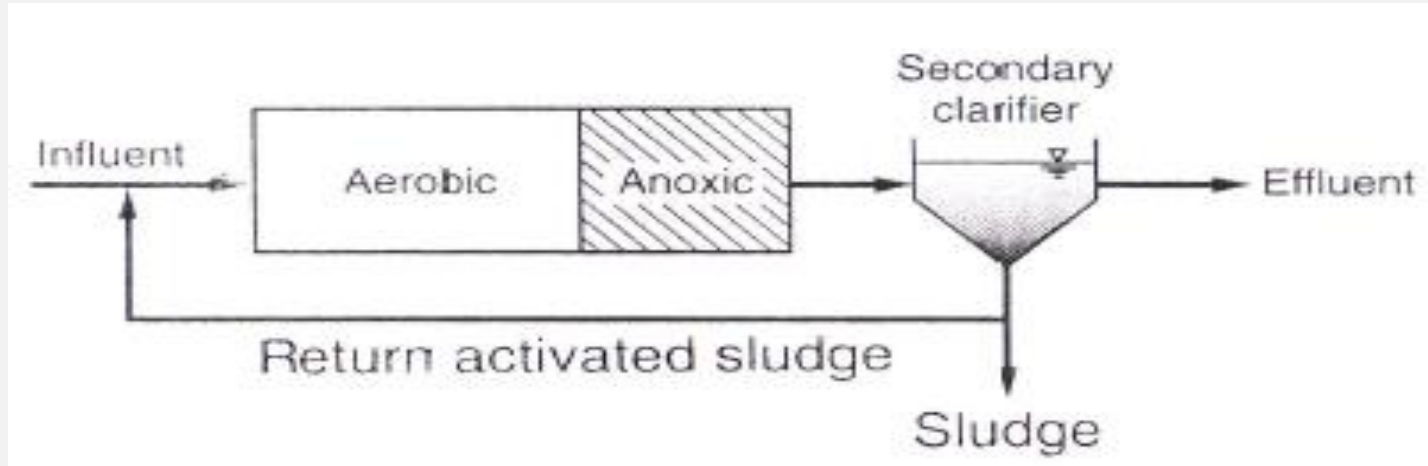
to maintain channel velocity of 0-3m/sec

- The oxidation ditch operation is switched from an aerobic operation to anoxic operation condition by turning off the aeration
- ORP control → to determine when NO_3^- is depleted and to restart aeration
- When the nitrate is depleted in the aeration off period, the ORP drops dramatically
- Effluent $\text{NO}_3\text{-N} < 8\text{mg/L}$

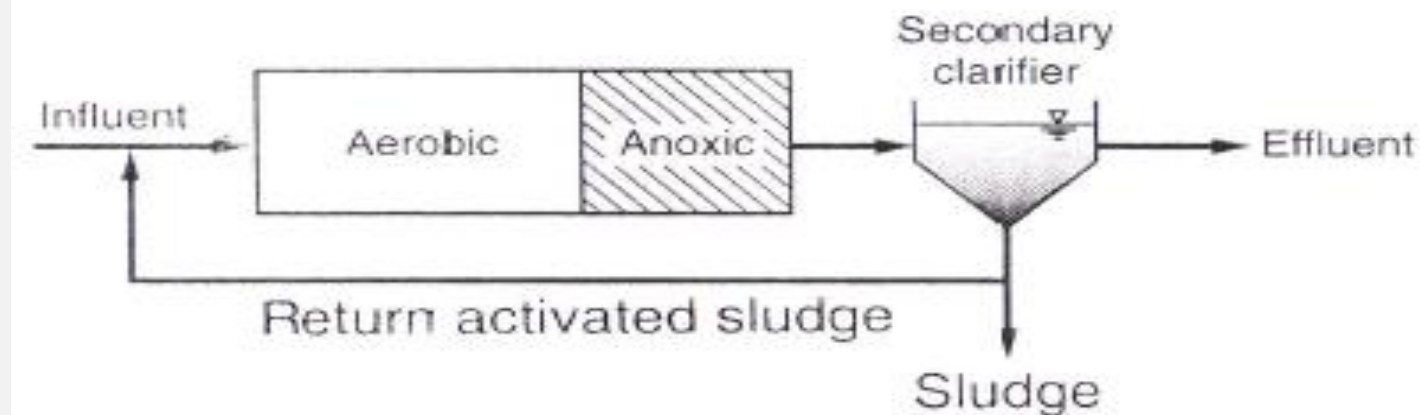


In the Nitrox process, the oxidation ditch operation is switched from an aerobic to an anoxic operating condition by turning off the aeration and operating a submerged mixer to maintain channel velocity. The process depends on the use of oxidation-reduction potential (ORP) control to (1) determine when the nitrate is depleted during the anoxic operation and (2) restart aeration. At selected times, the aerators are turned off and the mixer is turned on. When the nitrate is depleted in the aeration OFF period, the ORP drops dramatically. The ORP data is interpreted by a PC, which starts the aeration. A typical operating condition for the Nitrox™ process is to turn the aerators off at least twice per day, usually in the morning when the load is increasing and then in the early evening hours (Stensel and Coleman, 2000). The off-time for the nitrate depletion usually lasts 3 to 5 h depending on the plant load and amount of nitrate in the oxidation ditch. Effluent $\text{NO}_3\text{-N}$ concentrations of less than 8 mg/L and $\text{NH}_4\text{-N}$ concentrations ranging from 1.0 to 1.5 mg/L have been reported

Wuhrmann process (Postanoxic)

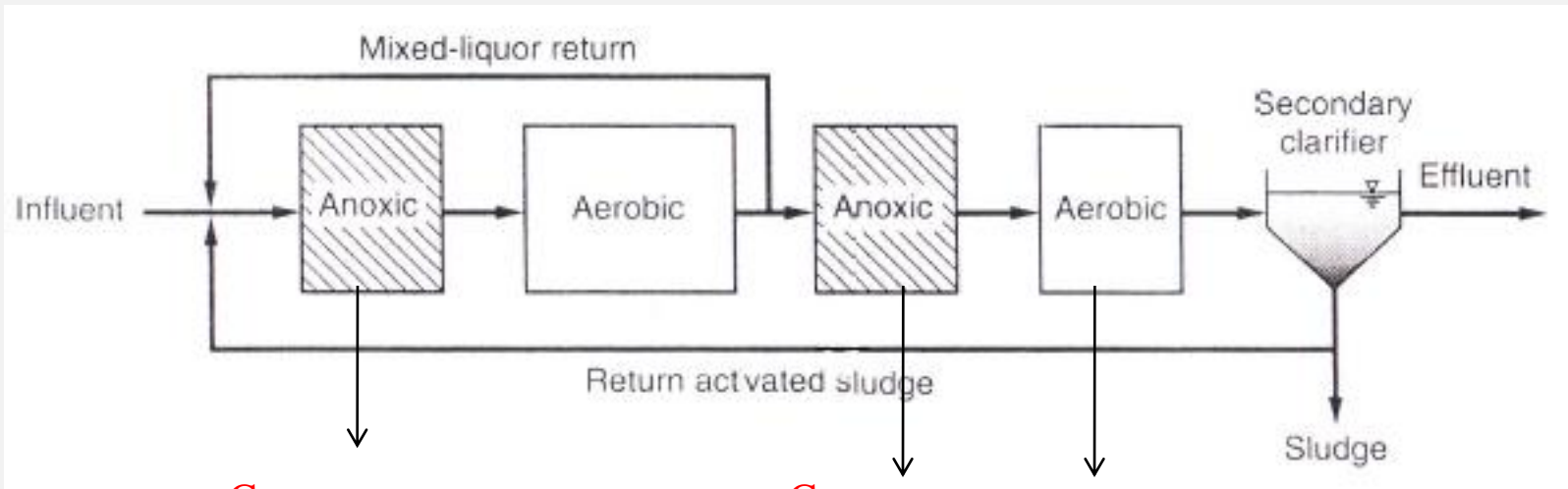


- Denitrification rate is proportional to the endogenous respiration rate in the mixed liquor
- Long detention time required in the postanoxic tank
- Exogenous C may be added
- Higher operating cost due to purchase of methanol



In the single-sludge process (developed by Wuhrmann), nitrogen removal was accomplished in the activated-sludge process by adding a mixed anoxic tank after aerobic nitrification. To achieve high nitrate-removal efficiency, a long detention time is required in the postanoxic tank because the denitrification rate is proportional to the endogenous respiration rate in the mixed liquor

h) Bardenpho (4-stage) (Pre-anoxic + Postanoxic)

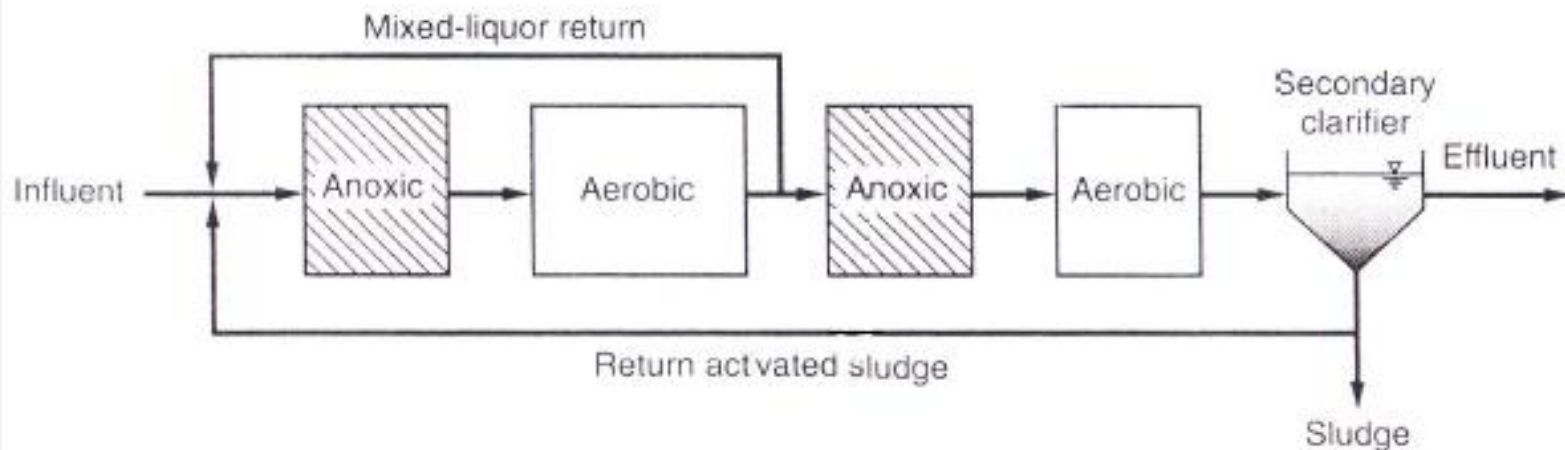


C source
influent
wastewater

C source
endogenous
respiration

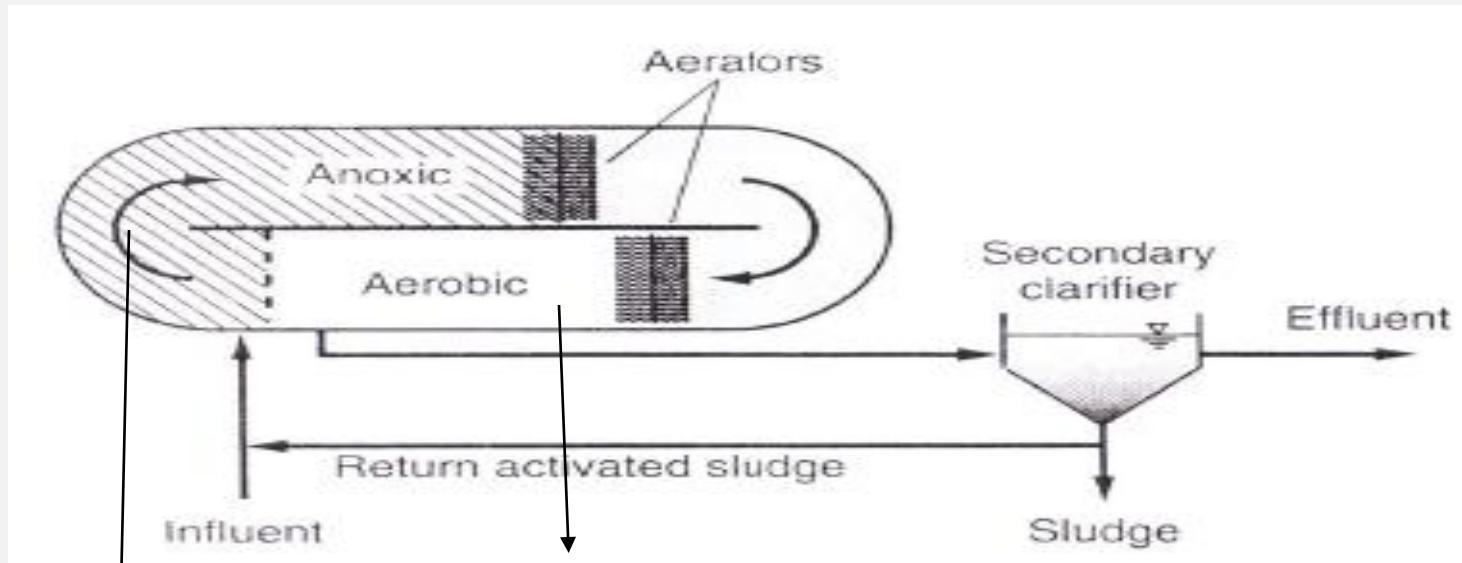
to release N_2
in clarifier ;
 N_2 causes sludge
bulking

- Capable of achieving effluent nitrogen level less than 3mg/L
- Large reactor volumes required



Both preanoxic and postanoxic denitrification are incorporated in the Bardenpho process, which was developed and applied at full-scale facilities in South Africa in the mid-1970s, before making its way to the United States in 1978. The detention time of the postanoxic stage is about the same as or larger than that used for the preanoxic zone. In the postanoxic zone, the $\text{NO}_3\text{-N}$ concentration leaving the aeration zone is typically reduced from about 5 to 7 mg/L to less than 3 mg/L. During pilot-plant testing with higher-strength wastewaters, Barnard (1974) found that biological phosphorus removal occurred as well as nitrogen removal, hence the basis for the process name (the name comes from the first three letters of the inventor's name, Barnard; denitrification; and phosphorus)

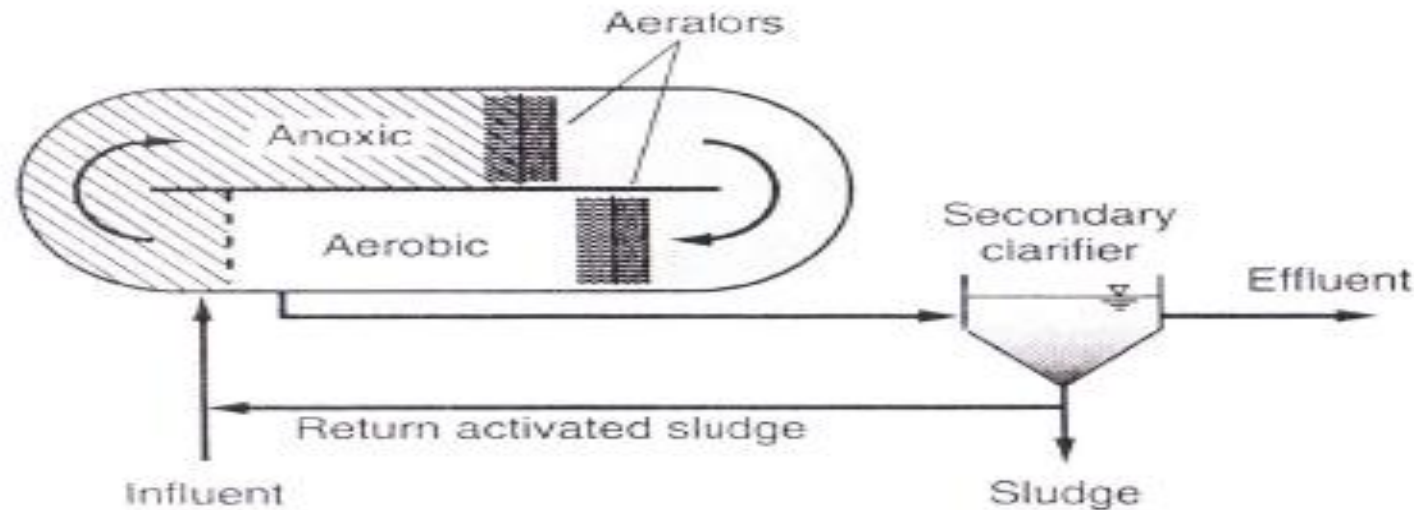
i) Oxidation ditch (Postanoxic)



DO depletion due
to microorganism
activity

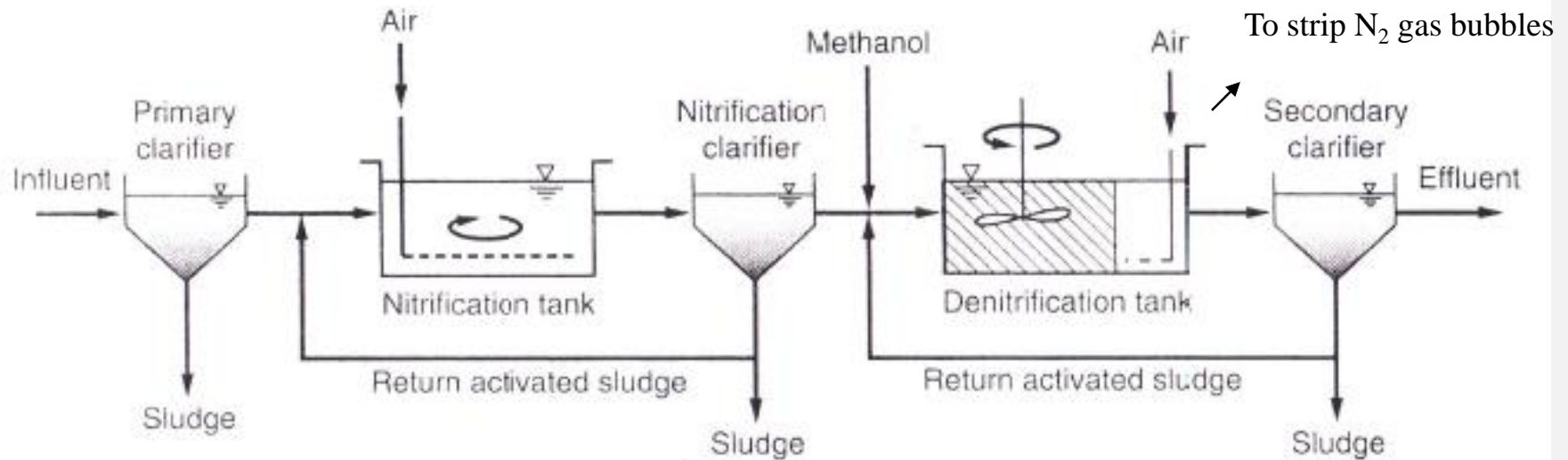
Nitrate will be used for
endogenous respiration
activity

- Large tank volume
- Long SRT
- $TN_{eff} < 10\text{mg/L}$

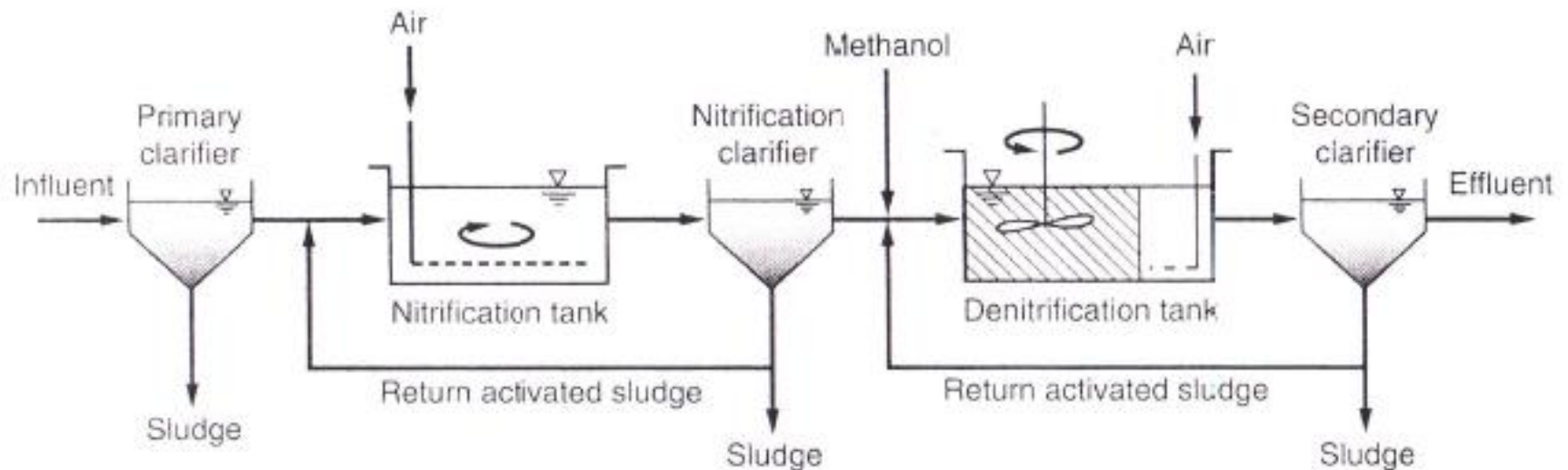


Depending on the aeration design and length of the oxidation ditch channel, anoxic denitrification zones can be established in oxidation ditches to accomplish biological nitrogen removal in a single tank. An aerobic zone exists after the aerator, and as the mixed liquor flows down the channel away from the aerator, the DO concentration decreases due to oxygen uptake by the biomass. At a point where the DO is depleted, an anoxic zone is created in the ditch channel and the nitrate will be used for endogenous respiration activity by the mixed liquor. Most of the readily degradable BOD had been consumed previously in the aerobic zone. Because of the large tank volumes and long SRTs used in oxidation ditch processes, sufficient capacity is available to accommodate nitrification and denitrification zones. DO control is necessary, however, to maintain a sufficient anoxic zone volume to allow for significant nitrogen removal

j) Two-stage (two-sludge) with an external carbon source (Post anoxic)



- **Methanol:** It is more effective than other substrates (glucose or acetate) in terms of cost per unit of nitrate removed
- Methanol is a flammable substance and requires special storage
- Typical ratios of methanol / nitrate: 3 to 4 g/g depending on the amount of DO in the influent ww and the anoxic system SRT
- Longer SRT; greater amount of endogenous respiration which consumes nitrate. Thus, influent methanol / nitrate ratio may be lower



An approach that was most popular in the 1970s and is occasionally used today is a postanoxic design with exogenous external carbon addition, usually methanol. The activated-sludge anoxic zone (1 to 3 h) is mixed and a short aeration time (<30 min) follows to strip nitrogen gas bubbles from the floc and to provide aerobic conditions to improve liquid-solids separation in the clarifier. Methanol is a commonly used substrate because it is more effective than other substrates for denitrification in terms of cost per unit of nitrate removed. Though its absolute cost may be higher than glucose or acetate, methanol is less expensive overall because it has a relatively low biomass yield. The lower yield means that a greater portion of the methanol is oxidized to result in a higher ratio of nitrate used per g of substrate provided. Typical ratios of methanol to nitrate removal are 3.0 to 4.0 g/g depending on the amount of DO in the influent wastewater and the anoxic system SRT. Longer SRT designs have greater amounts of biomass oxidized by endogenous respiration, which consumes nitrate, and thus the influent methanol to nitrate ratio can be lower. **The use of methanol requires special storage and monitoring precautions as it is a flammable substance. Because** methanol is flammable, other substances, such as acetate, have been considered. Attached growth denitrification reactors with methanol addition have also been used for postanoxic nitrogen removal.

In the design of anoxic volume → SDNR
(specific denitrification rate)

$$NO_R = V_{NO_X} (SDNR)(MLVSS)$$

NO_R = nitrate removed(g/d)

V_{NO_X} = anoxic tank volume(m^3)

SDNR = specific denitrification rate (g NO_3 -N/gMLVSS.d)

SDNR observed for preanoxic tanks in full scale applications;
= 0.04 -0.42 g NO₃-N/g MLVSS.d

SDNR observed for postanoxic tanks (w/o exogeneous source)
= 0.01-0.04 g NO₃-N/g MLVSS.d

SDNR calculation :

- Empirical approach
- Graphical approach

SDNR calculation by empirical approach

$$SDNR = 0.03(F / M) + 0.025$$

$$\frac{F}{M} = \frac{gBOD_{applied}}{gMLVSS_d}$$

This empirical relationship based on data collected for anoxic/aerobic processes at mixed liquor temp. 20-25 °C

SDNR calculation by graphical approach

Specific Denitrification Rates (SDNR) at 20° C

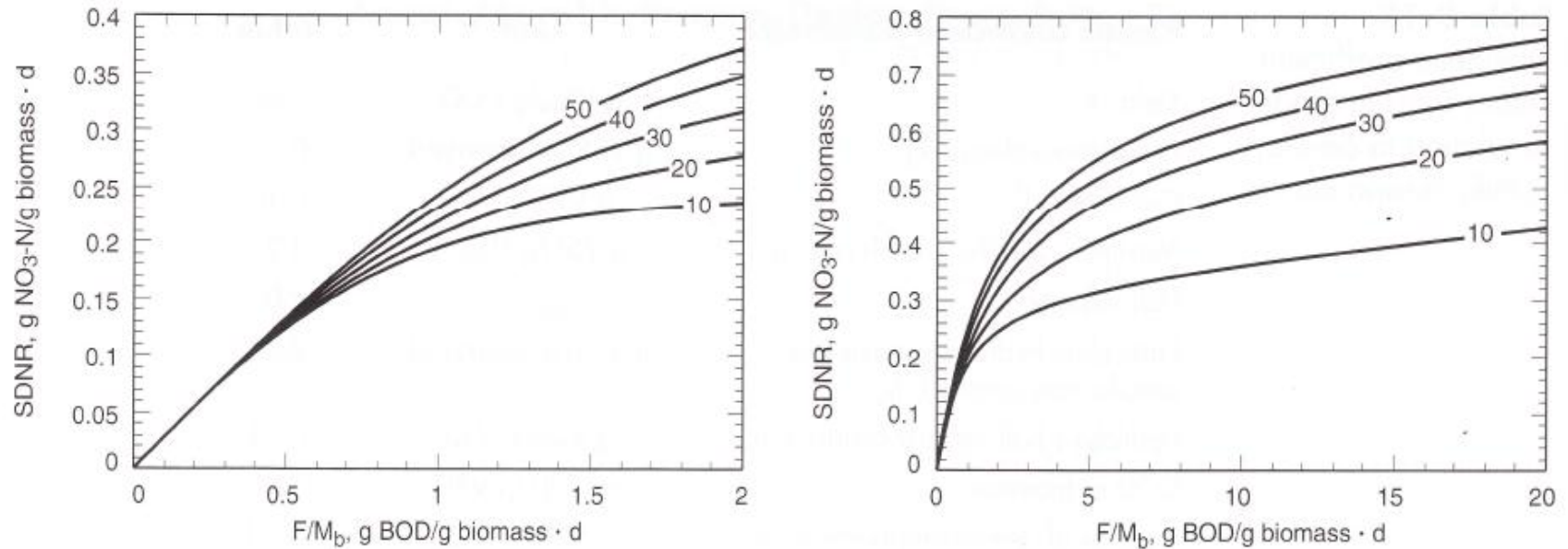
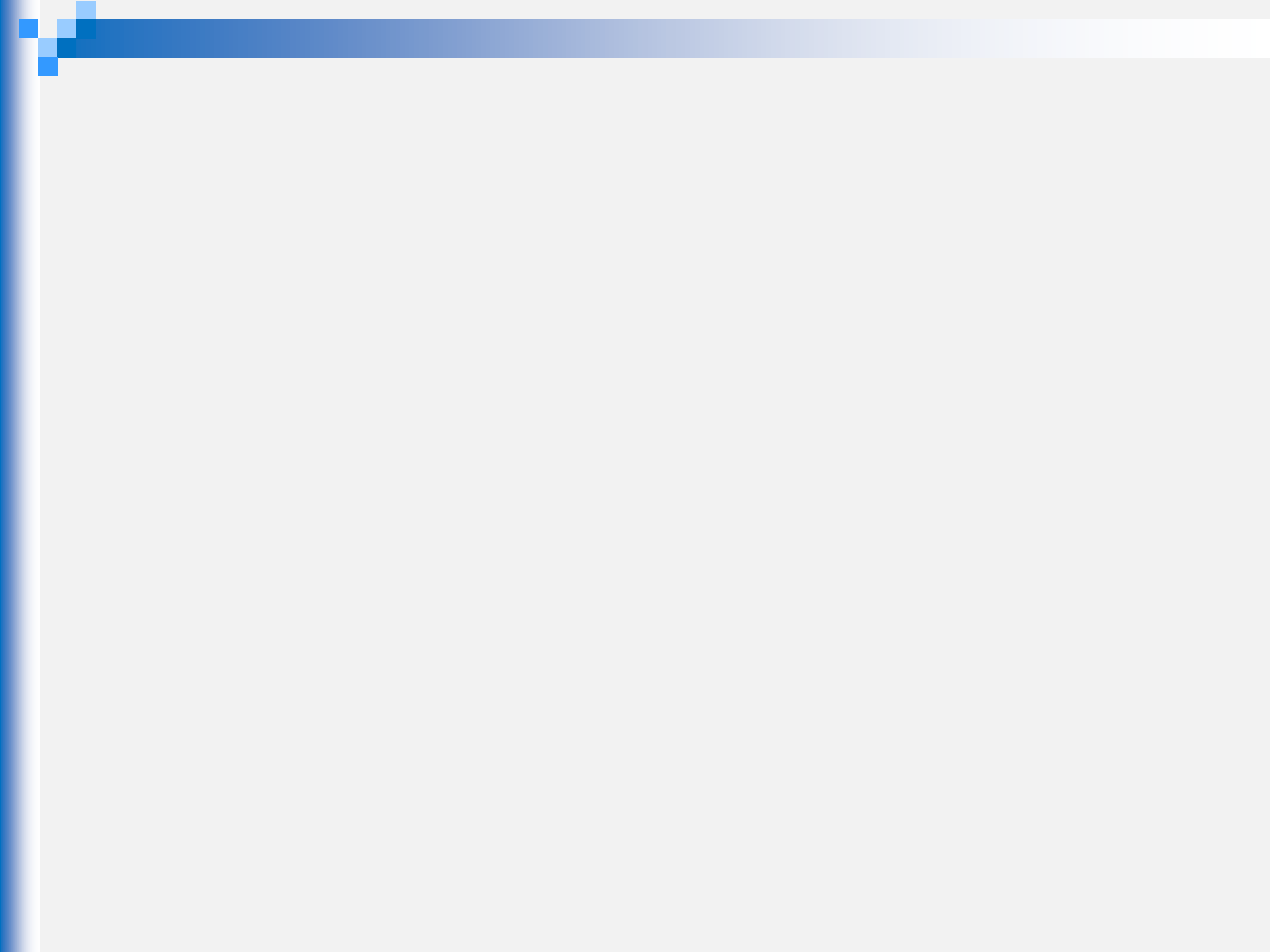


Figure 8-23

Ref: Metcalf & Eddy, 2004

Plot of specific denitrification rates (SDNR_b) based on biomass concentration at 20°C versus food to biomass (F/M_b) ratio for various percentages of rbCOD relative to the biodegradable COD of the influent wastewater.



SDNR calculation by graphical approach

Specific Denitrification Rates (SDNR) at 20° C

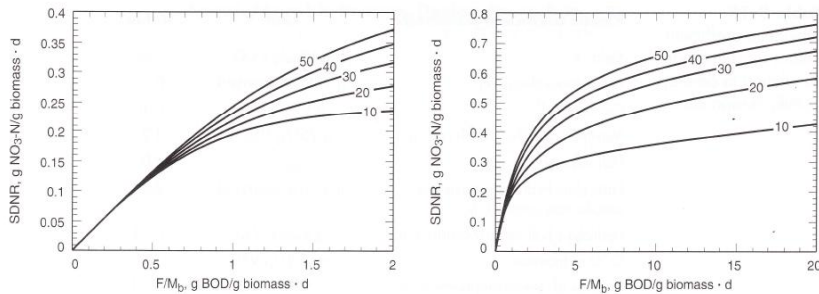


Figure 8-23

Plot of specific denitrification rates (SDNR_b) based on biomass concentration at 20°C versus food to biomass (F/M_b) ratio for various percentages of rbCOD relative to the biodegradable COD of the influent wastewater.

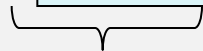
- based on the results of model simulations in the anoxic tank
- internal recycle rates from the aerobic zone and temperature effects were accounted for

To use SDNR_b values in the above figures



Calculation of active biomass VSS concentration in the mixed liquor is necessary.

$$\frac{F}{M_b} = \frac{QS_0}{(V_{NO_x})X_b}$$



F/M ratio based on active biomass concentration
g BOD / g biomass-d

- Q= influent flowrate, m³/day
- S₀ = influent BOD concentration, mg/L
- V_{NO_x} = anoxic volume, m³
- X_b = anoxic zone biomass concentration, mg/L

SDNR calculation by graphical approach

Specific Denitrification Rates (SDNR) at 20° C

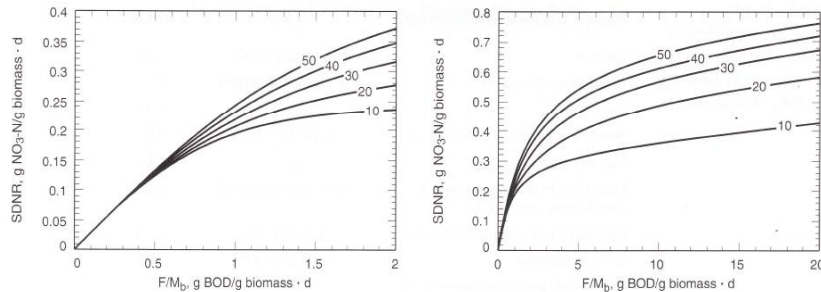


Figure 8-23

Plot of specific denitrification rates (SDNR_b) based on biomass concentration at 20°C versus food to biomass (F/M_b) ratio for various percentages of rbCOD relative to the biodegradable COD of the influent wastewater.

Temperature correction for SDNR_b values from above figures:

$$\text{SDNR}_T = \text{SDNR}_{20} \theta^{T-20}$$

$$\Theta = 1.026$$

$$T = \text{°C}$$

SDNR calculation by graphical approach

Specific Denitrification Rates (SDNR) at 20° C

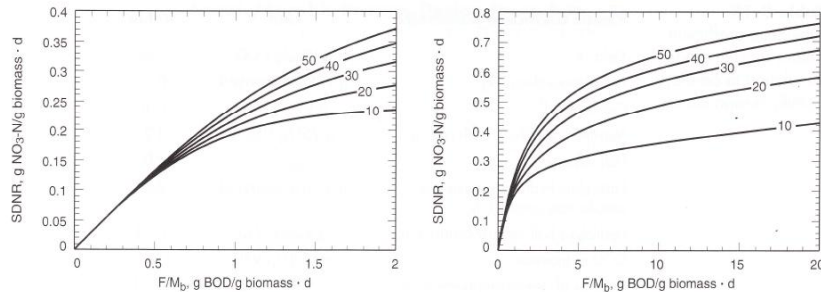


Figure 8-23

Plot of specific denitrification rates ($SDNR_b$) based on biomass concentration at 20°C versus food to biomass (F/M_b) ratio for various percentages of rbCOD relative to the biodegradable COD of the influent wastewater.

IR (Internal Recycle ratio) Correction for $SDNR_b$ values from above figures:

$F/M \leq 1 \longrightarrow$ No correction is required

IR = 2 \longrightarrow $SDNR_{adj} = SDNR_{IR1} - 0.0166Ln(F/M_b) - 0.0078$

IR = 3-4 \longrightarrow $SDNR_{adj} = SDNR_{IR1} - 0.029Ln(F/M_b) - 0.012$

SDNR adjusted
for the effect of
internal recycle

SDNR value at internal
recycle ratio = 1

F/M ratio based on anoxic
zone volume and active
biomass concentration

At high IR ratios \longrightarrow Influent rbCOD is diluted \longrightarrow Resulting lower denitrification rate 44

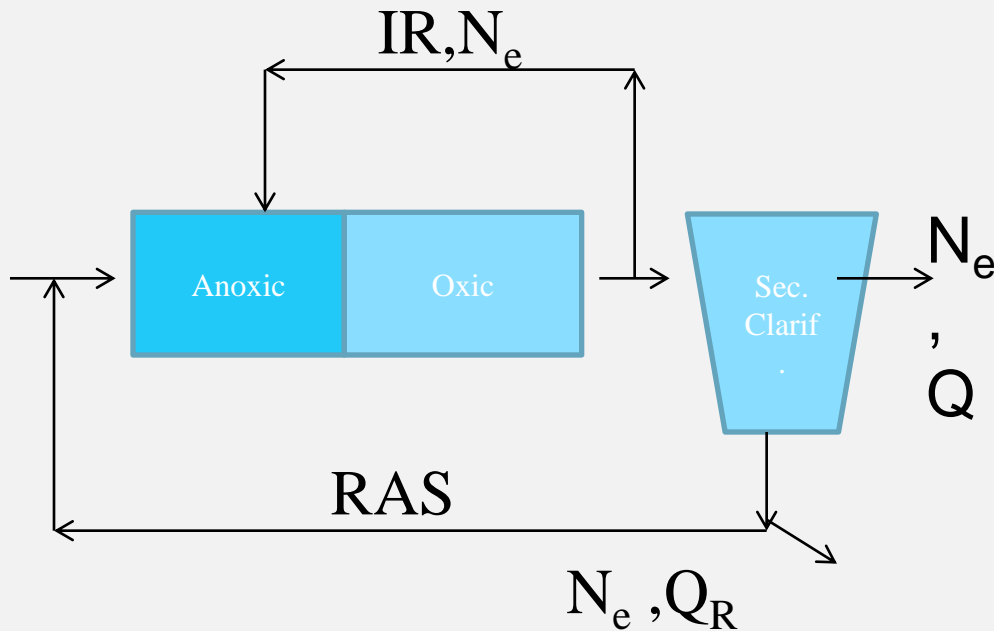
kg/d of nitrate produced in aerobic zone = nitrate in effluent + nitrate in internal cycle + nitrate in RAS

$$QNO_X = N_e (Q + IRQ + RQ)$$

$$IR = \frac{NO_x}{N_e} - 1 - R$$

- IR = internal cycle ratio (internal recycle flowrate / influent flowrate)
- R = RAS recycle ratio (RAS flowrate / influent flowrate)
- NO_X = nitrate produced in aeration zone
- N_e = effluent NO_3 -N conc. , mg/l

Mass Balance to Find Internal Recycle Ratio (IR)



- IR = internal cycle ratio
(internal recycle flow / influent flow)
- R = RAS recycle ratio
(RAS flowrate / influent flowrate)
- NO_x = nitrate produced in aeration zone
- N_e = effluent NO_3 -N conc. , mg/l

kg/d of nitrate produced in aerobic zone = nitrate in effluent + nitrate in internal recycle + nitrate in RAS

$$QNO_x = N_e (Q + IRQ + RQ)$$

→

$$IR = \frac{NO_x}{N_e} - 1 - R$$

An $IR = 3-4$ is typical

$IR = 2-3$ applied for ww with lower ww TKN conc.



Example:

Design a preanoxic basin for the CMAS nitrification system process described in a previous example in Section 6 to produce in effluent $\text{NO}_3\text{-N}$ concentration of 6 g/m^3 .

$$Q = 22.464 \text{ m}^3/\text{d}$$

WW characteristics:

$$\text{BOD} = 140 \text{ g/m}^3$$

$$\text{bCOD} = 224 \text{ g/m}^3$$

$$\text{rbCOD} = 80 \text{ g/m}^3$$

$$\text{NO}_x = 28.3 \text{ g/m}^3$$

$$\text{TN} = 6 \text{ g/m}^3$$

$$\text{Alk} = 140 \text{ as CaCO}_3$$

$$\text{RAS ratio} = 0.6$$

Design conditions:

$$Q = 22464 \text{ m}^3/\text{d}$$

$$T = 12 \text{ }^\circ\text{C}$$

$$\text{MLSS} = 3000 \text{ g/m}^3$$

$$\text{MLVSS} = 2370 \text{ g/m}^3$$

$$\text{Aerobic } \theta_c = 12.5 \text{ d}$$

$$\text{Aeration volume} = 8466 \text{ m}^3$$