Denitrification in Activated Sludge Processes

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Organisms and Their Sources of Energy (or Food)

- Heterotrophic - use organic carbon
  - CBOD removing organisms
  - Denitrifying organisms
  - Bio-P organisms

- Autotrophic - use inorganic carbon
  - Nitrifying organisms

Organisms and Their Means of Respiration

- Aerobic - use elemental oxygen
- Anoxic - use nitrate (NO_3) or nitrite (NO_2)
- Anaerobic - use other terminal electron acceptors (SO_4 , CO_2) or none at all
- Facultative - two or more means of respiration
- Fermentative - no terminal electron acceptor

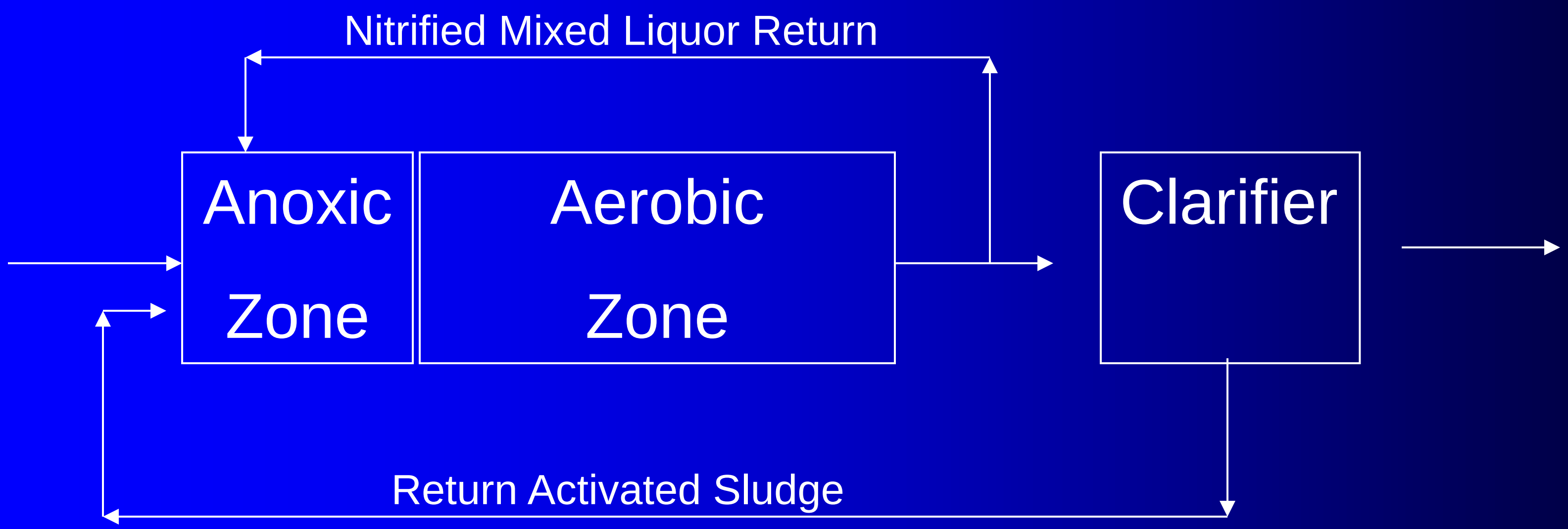
Terminal Electron Acceptors and Their Products

- Oxygen (O_2) $\rightarrow$ H_2O and CO_2
- Nitrate (NO_3^-) $\rightarrow$ N_2 , H_2O, and CO_2
- Sulfate ($SO_4^=$) $\rightarrow$ H_2S, H_2O, and CO_2
- Carbon dioxide (CO_2) $\rightarrow$ CH_4 , H_2O, and CO_2

Denitrification

- Heterotrophic
- Anoxic (facultative)

Adding an Anoxic Zone



Comments about Anoxic Zone

Requirements:

- Mixed, but un-aerated
- Nitrification in aerobic zone
- Mixed liquor recycle

Comments about Anoxic Zone

Uses:

- Nitrogen removal
- Alkalinity recovery
- CBOD removal (some)

Biological Nitrogen Removal is Optimized by an Environment that ...

- Provides the right source of energy
- Ensures the right means of respiration

Minimizing DO in Anoxic Zone

- Avoid aeration at the inlet zone
  - ♦ don’t allow a cascading influent
  - ♦ eliminate primary effluent flow splitting turbulence
- Eliminate mixer vortex if possible
- Avoid back mixing from the aerobic zone

Effect of DO on Denitrification Rates

DO Conc, mg/L	Denitrification Rate
0.0	100%
0.1	40%
0.2	20%
0.3	10%
> 0.3	Negligible

Denitrification: Biochemical Reactions

Methanol as external carbon source:

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

Denitrification Reactions

For one gram of NO_3-N that is denitrified:

2.47 g of methanol (~3.7 g of COD) are consumed

0.45 g of new cells are produced

3.57 g of alkalinity are formed

Denitrification: Biochemical Reactions

Sewage as carbon source:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + 10\ OH^- + NH_3$$

Factors Affecting Denitrification

- Substrate degradability
- pH
- Dissolved oxygen
- Temperature

Oxygen Savings with Denitrification

For every gram of NO_3-N that is reduced to nitrogen gas, 2.86 grams of oxygen are saved.

Comments about Denitrification

- Rate of denitrification depends on nature and concentration of the carbonaceous organics being degraded

$$Rate_{methanol} \geq Rate_{sewage} >> Rate_{endog\ resp}$$

- Denitrification is a zero order reaction with respect to nitrate down to very low nitrate concentrations

Single-Sludge Denitrification

- To avoid the operating costs of using methanol as the carbon source, it is more cost-effective to use the organics available in raw sewage.
- These systems are referred to as “combined carbon oxidation / nitrification / denitrification” or “single-sludge.”
- These systems have lower capital and operating costs than separate stage nitrification / denitrification systems

Single-Sludge Denitrification

Two carbon sources are used:

- Endogenous decay of the activated sludge microbes
- Wastewater influent to the activated sludge process

Single-Sludge Denitrification

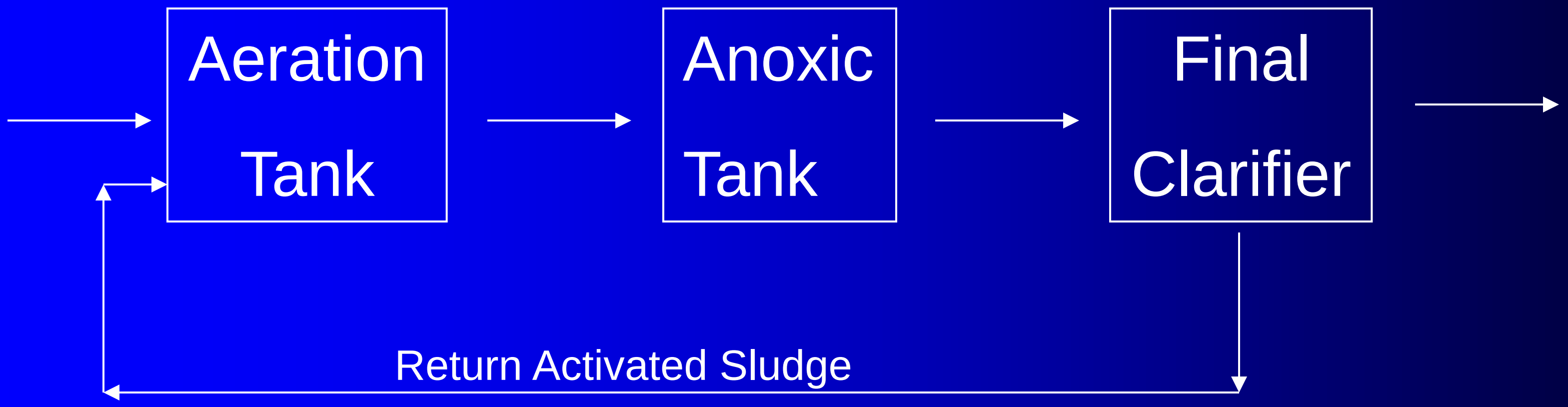
Advantages:

- It uses only one clarifier
- No external carbon source is required
- It has lower neutralization chemical requirements
- It has lower oxygen requirements

Disadvantage:

- Need for pumping equipment and energy for recycling high volumes of mixed liquor

Single-Sludge Denitrification Using Endogenous Decay

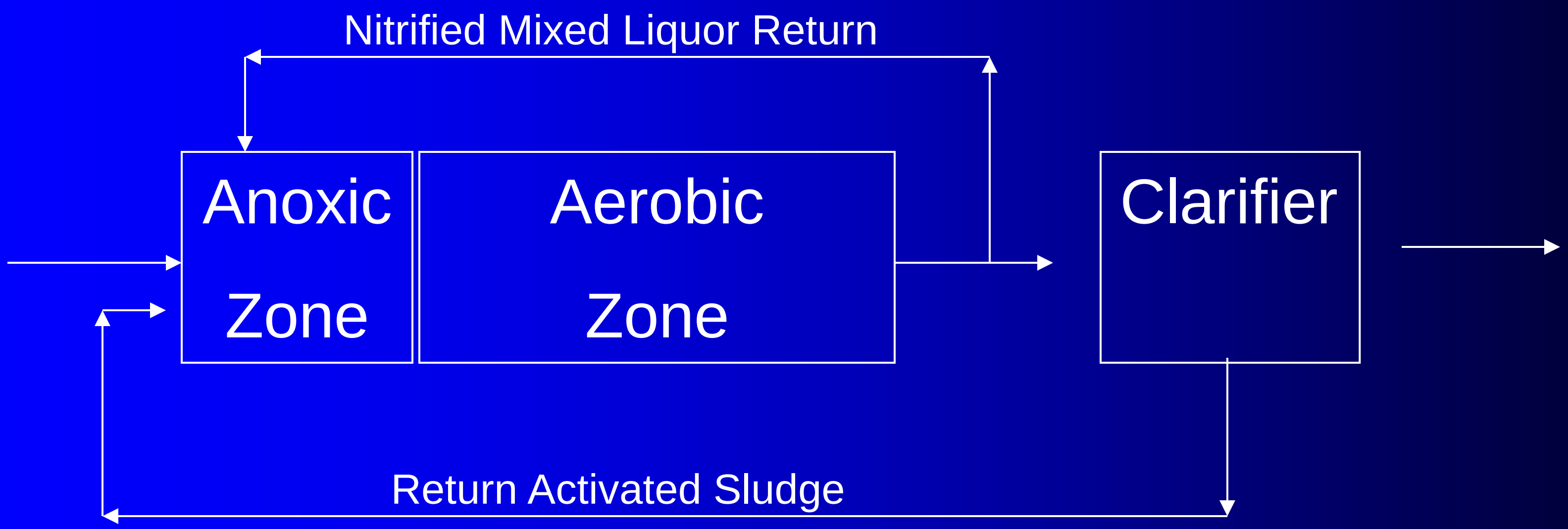


Single-Sludge Denitrification Using Endogenous Decay

Disadvantages:

- Very low denitrification rate due to relatively low availability of carbon from endogenous decay and in the secondary effluent
- Potential for some ammonia-N release due to the decay and lysis of biomass
- Need a large anoxic reactor because of low denitrification rate

Single-Sludge Denitrification Using Influent Organic Content



Single-Sludge Denitrification Using Influent Organic Content

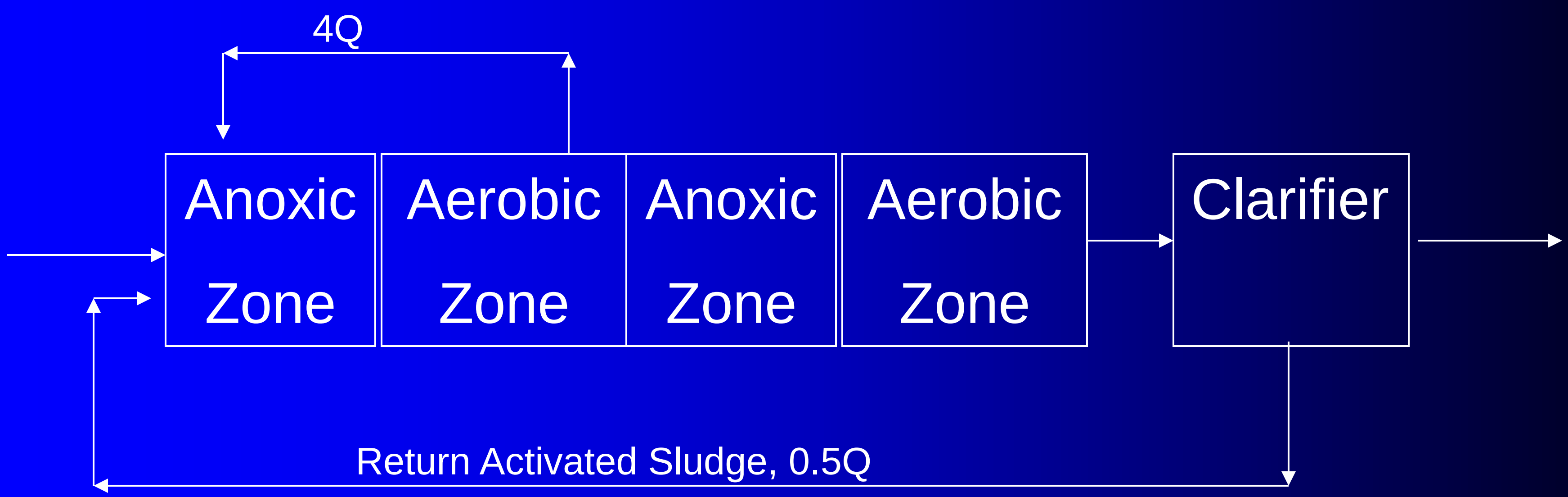
- Many process configurations
- Minimizes ammonia-N release
- Higher denitrification rate
- Uses alternating aerobic/anoxic zones

Single-Sludge Denitrification Using Influent Organic Content

Expected Effluent Quality:

BOD_5	5 - 15 mg/L
TSS	10 - 20 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	5 - 7 mg/L
Total N	6 - 10 mg/L

Four Stage Bardenpho Process



Four Stage Bardenpho Process

- Uses both wastewater carbon and endogenous decay carbon for denitrification
- Carbon present in raw waste is used to denitrify the recycled nitrate in first anoxic zone
- Ammonia in raw waste passes through first anoxic zone to be nitrified in first aerobic zone
- Nitrified mixed liquor flows from first aerobic zone to be denitrified at lower rate in second anoxic zone (endog resp)
- Final aerobic zone allows release of N_2 gas, improves sludge settleability, and oxidizes residual ammonia-N

Four Stage Bardenpho Process

Expected Effluent Quality:

BOD_5	5 - 15 mg/L
TSS	10 - 20 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	1 - 3 mg/L
Total N	2 - 5 mg/L

Modifying Existing WWTPs to Achieve Nitrogen Removal

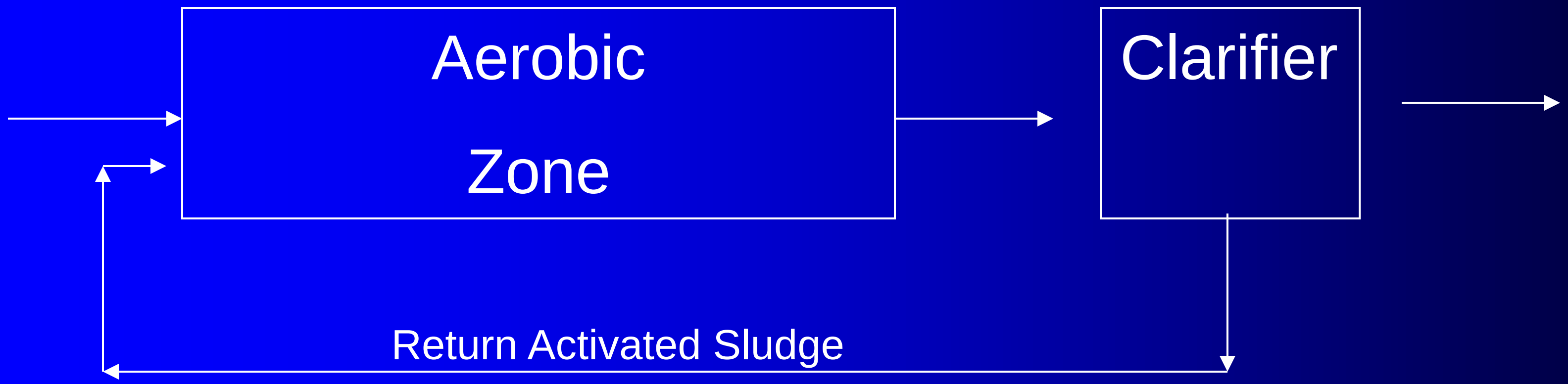
Performance of Single-Sludge Denitrification

- Can achieve high N removals (85% to 95%)
- Does not necessarily enhance sludge settleability in final clarifier
- Uses carbon source in influent
- Reduces the energy requirements for BOD removal from the wastewater (2.86 lb O_2 equivalent per lb of NO_3-N removed)
- About one-half of alkalinity required for nitrification is produced in anoxic zone

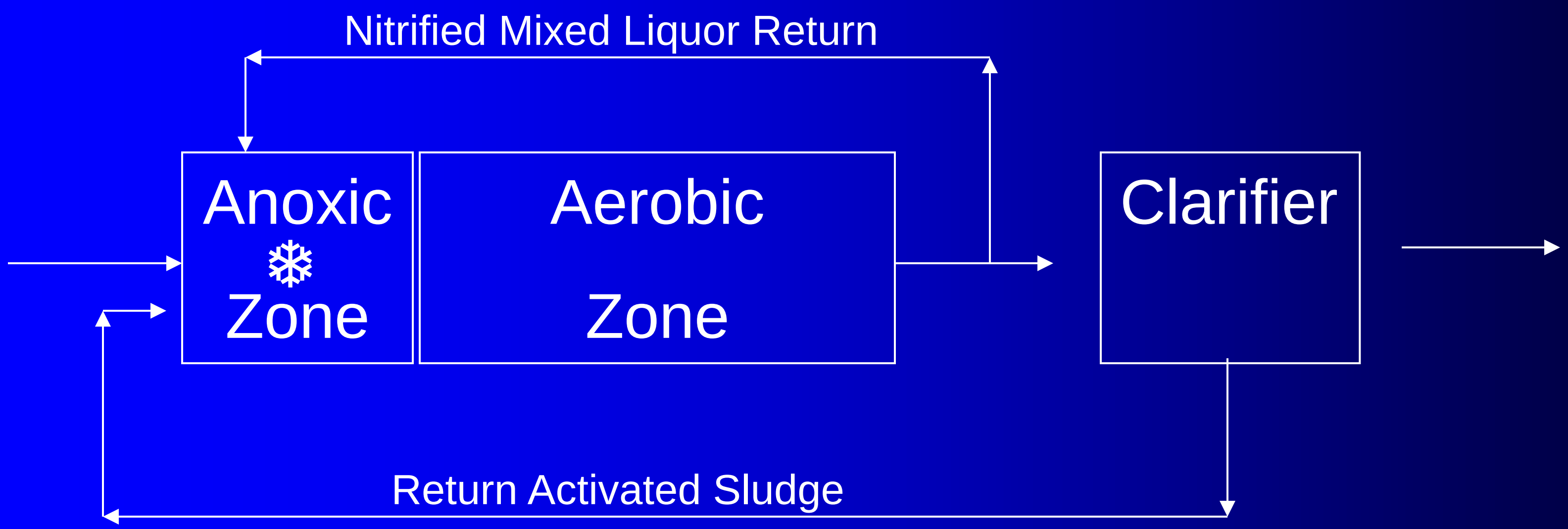
WWTP Changes to Achieve Nitrification-Denitrification

- Modify rectangular aeration basin with baffles to provide anoxic and aerobic zones
- Modify oxidation ditch to provide anoxic and aerobic zones
- Modify oxidation ditch operation with on/off aeration cycles to achieve denitrification
- Modify SBR system to include anoxic and aerobic cycles
- Modify step-feed system to include alternating anoxic and aerobic zones

Conventional Activated Sludge



Add an Anoxic Zone using Baffle, Mixed Liquor Return, and Mixing



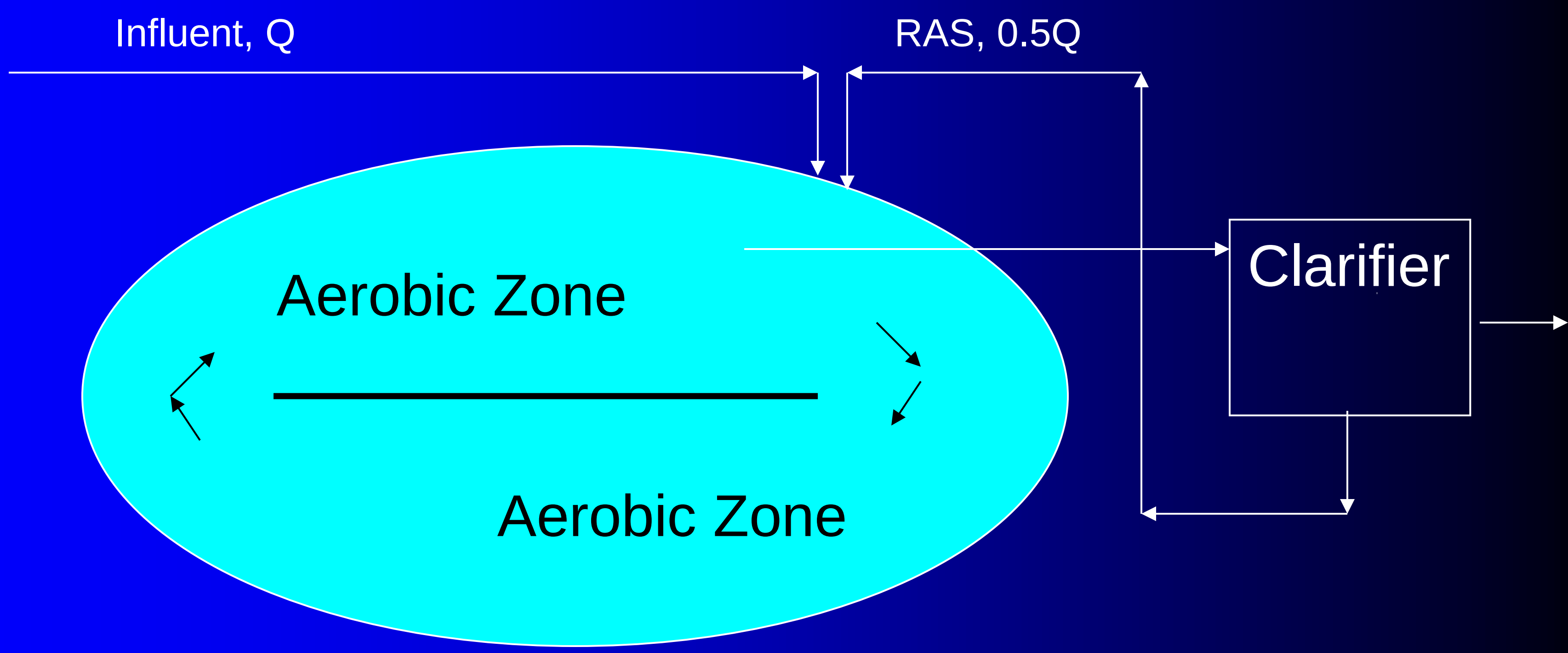
Before and After Effluent Quality

Effluent Quality:

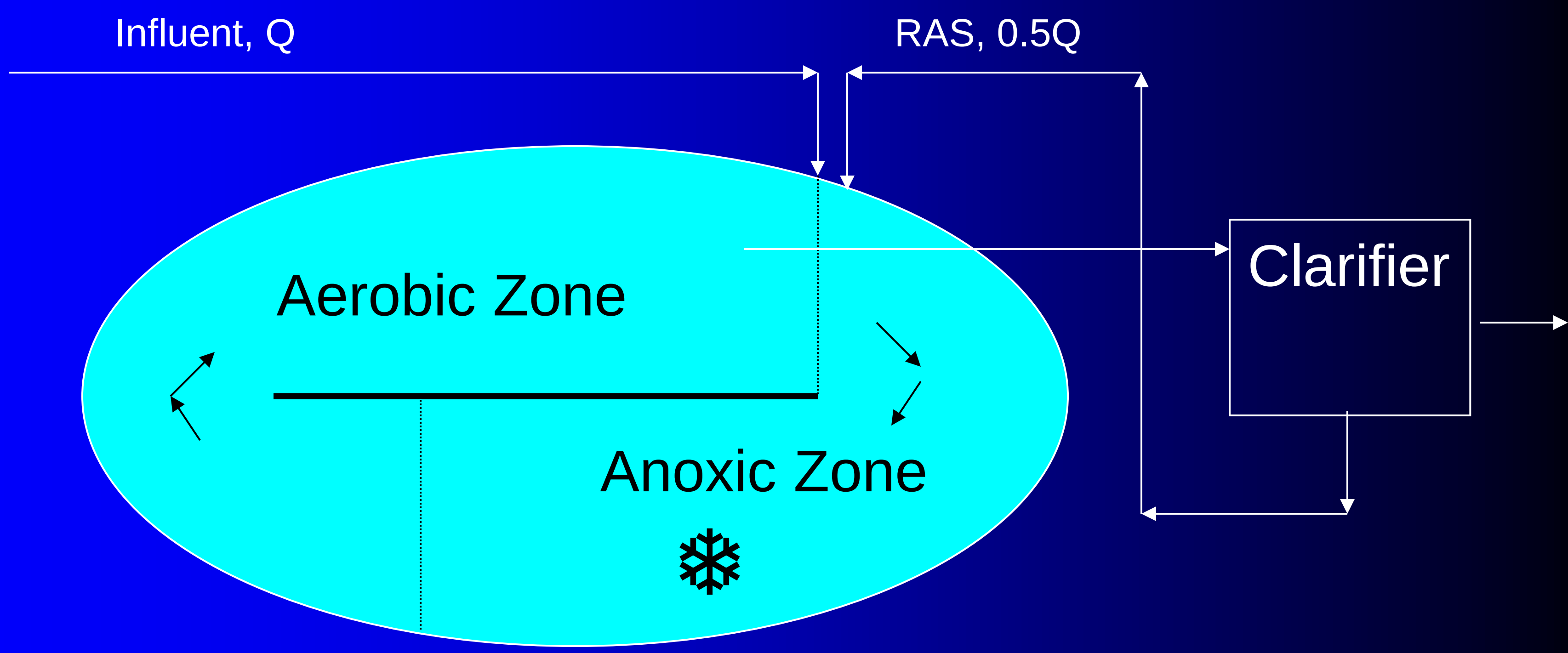
	Before	After
BOD_5	5 - 25 mg/l	5 - 15 mg/l
TSS	10 - 25 mg/l	10 - 20 mg/l
Ammonia-N	1 - 5 mg/l	1 - 2 mg/l
NO_x-N	8 - 15 mg/l	3 - 9 mg/l
Total N	10 - 20 mg/l	5 - 12 mg/l
*SVI	125 - 225	50 - 125

* impacts on mixed liquor at one facility

Oxidation Ditch Before Modification



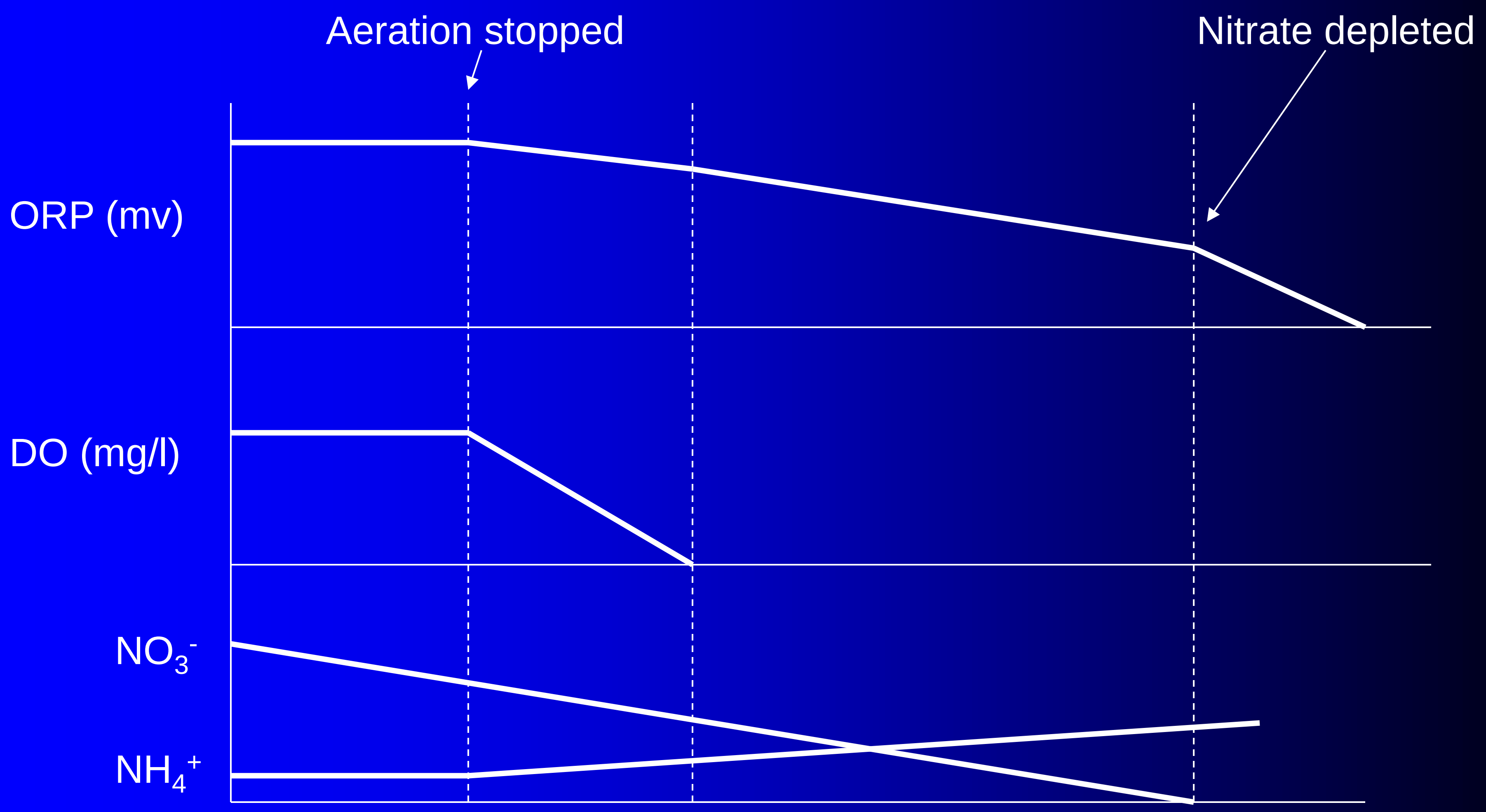
Oxidation Ditch After Modification



Intermittent Aeration for N Removal in Oxidation Ditch

- Cycle time for on/off operation of aerators may vary
- Process control with DO and ORP monitoring
- When aerator is off, must provide mixing
- During off period, oxidation ditch becomes anoxic reactor, and nitrate is consumed as bacteria degrade BOD
- ORP data are used to terminate off cycle and start aeration

Change in ORP and DO in On/Off Operation



Factors Affecting On/Off Operation

- Oxidation ditch HRT
- Influent flow rate
- TKN and BOD concentrations
- Number of on/off cycles per day
- Ditch MLSS concentration

Nitrogen Removal in SBRs

- Use anoxic and aerobic cycles to effectively remove nitrogen
- Cycles are:
  - Fill (anoxic)
  - React (aerobic/anoxic)
  - Settle
  - Decant

Nitrogen Removal in SBRs

Expected Effluent Quality:

BOD_5	5 - 15 mg/l
TSS	10 - 20 mg/l
Ammonia-N	< 1 mg/l
NO_x-N	3 - 10 mg/l
Total N	5 - 12 mg/l

N Removal in Step-Feed Process