Biological Nutrient Removal

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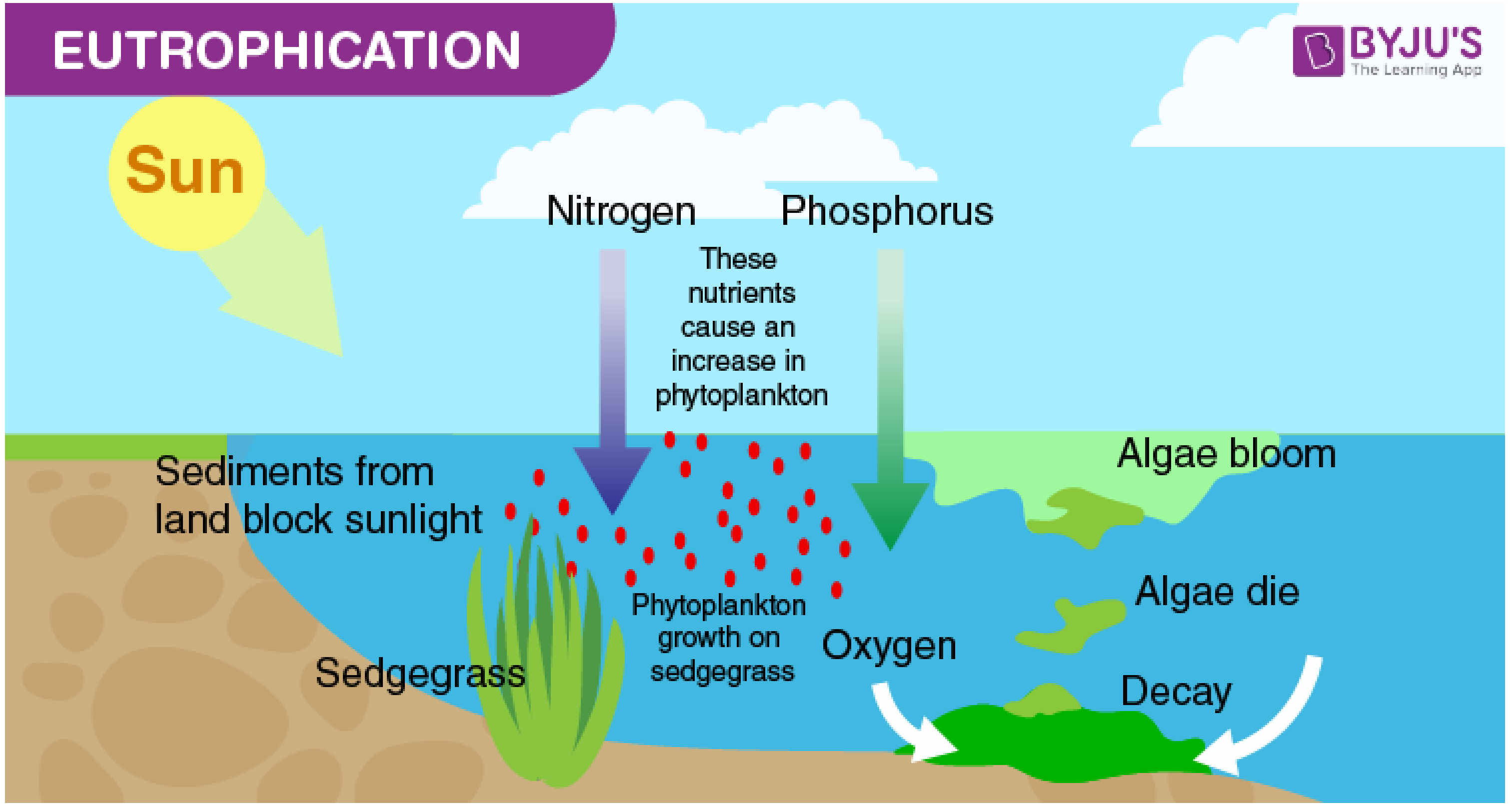
Introduction

What is BNR?

Why it matters

Nutrients in wastewater = major pollution risk

Changing limits necessitates proactive approach



The Problem with Nutrients

- Nitrogen & Phosphorus cause algal blooms
- Leads to oxygen depletion (fish kills)
- Stricter discharge permits (TMDLs)
- WWTPs are major point sources

Effects of Eutrophication

Carbonaceous Biochemical Oxygen Demand (CBOD5): 5 mg/L annual average.

Total Suspended Solids (TSS): 5 mg/L annual average.

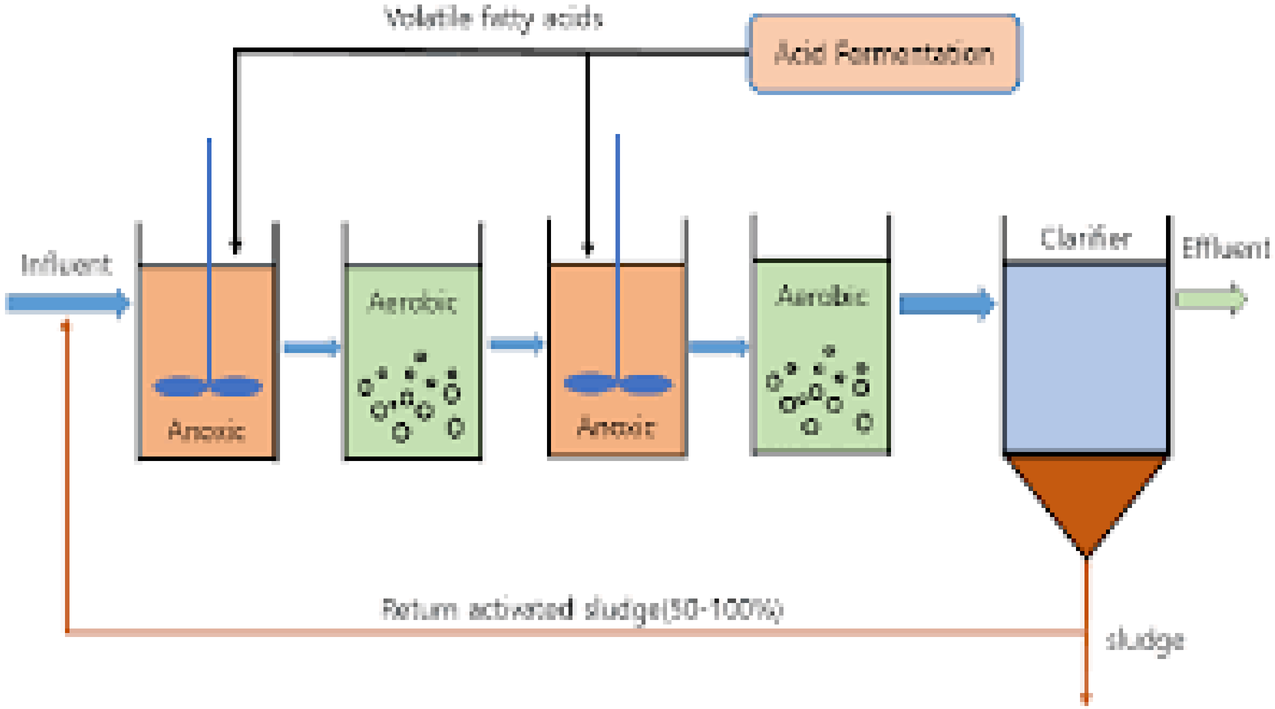
Total Nitrogen (as N): 3 mg/L annual average.

Total Phosphorus (as P): 1 mg/L annual average

Advanced Wastewater Treatment

5:5:3:1

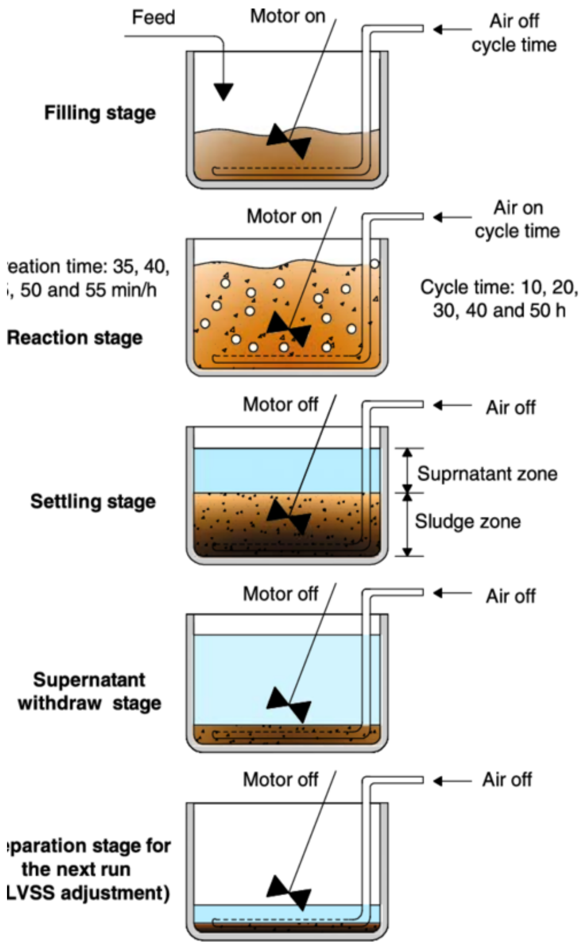
What is BNR?



- Using microbes to remove N and P
- Reduces chemical use
- Supports sustainability
- Requires controlled environments

Common BNR Configurations

- A/O: Anaerobic + Aerobic (P removal)
- A2/O: Anaerobic + Anoxic + Aerobic (N & P)
- MLE: Modified Ludzack-Ettinger (N)
- SBRs: Time-based BNR (N & P)
- Oxidation Ditch: Simple (N removal)

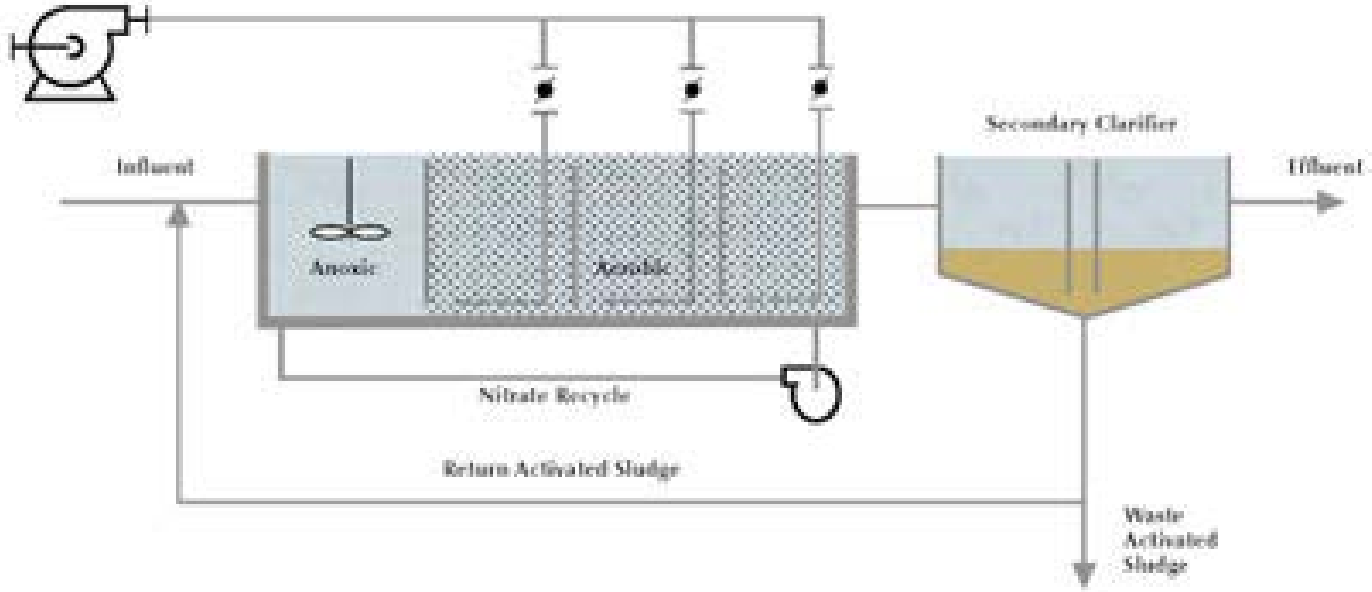


SBR Sequence

- Fill – Mix bacteria and wastewater (low oxygen).
- React – Biological nutrient removal (aerobic and anoxic processes).
- Settle – Solids sink to the bottom (no mixing or air).
- Decant – Clear water is drawn off the top.
- Idle – Optional waiting period or sludge wasting.

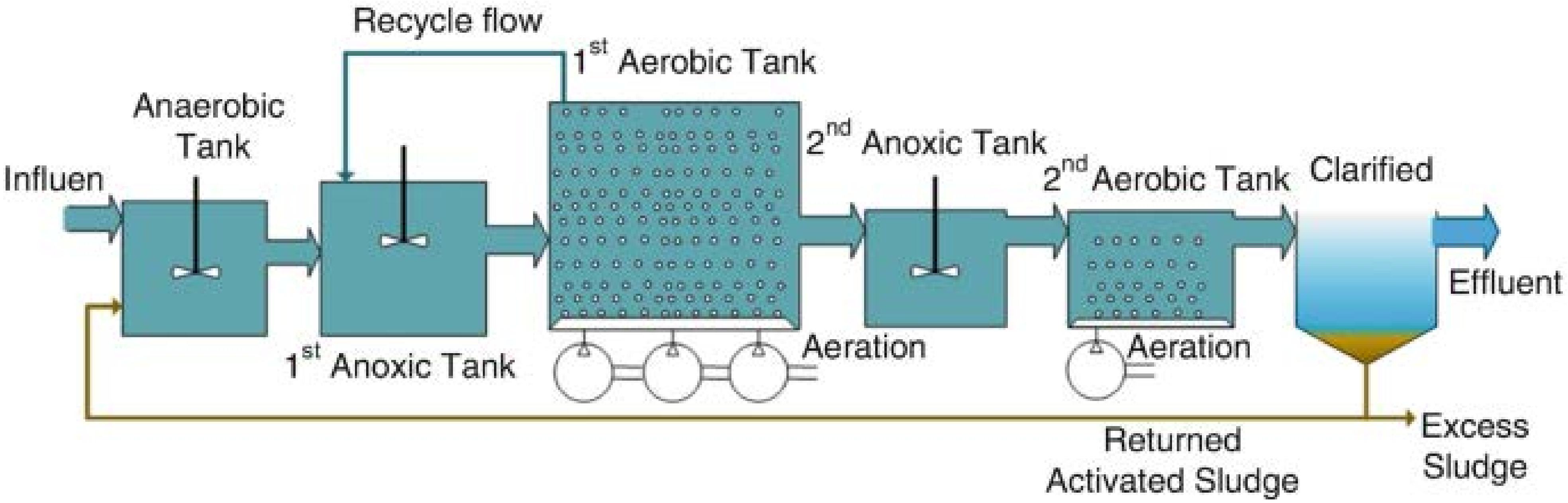
Modified Ludzack-Ettinger (MLE)

- Specifically for Nitrogen removal
- Simple, excellent denitrification
- Influent > Anoxic > Aerobic > Clarifier/Nitrate Recycle



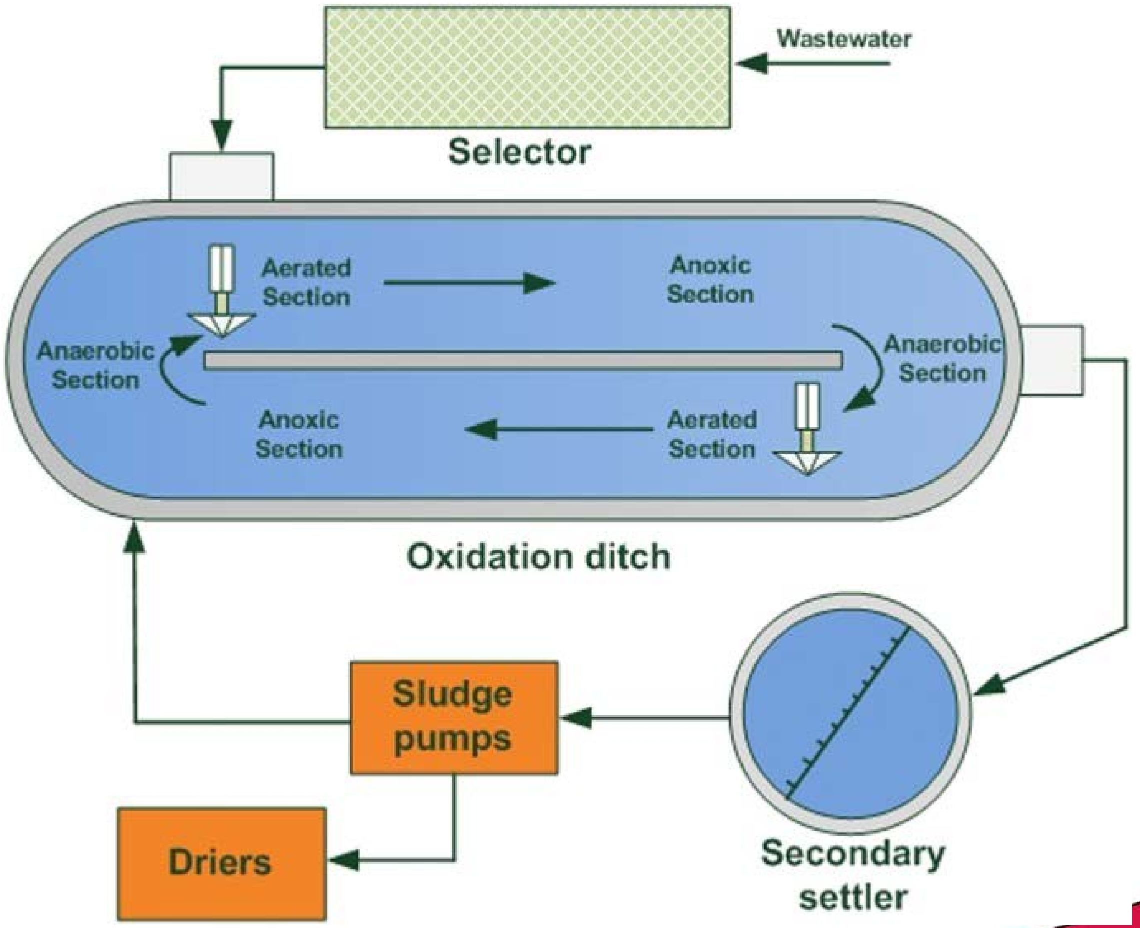
5-Stage Bardenpho

- Lower TN/TP goal (< 3mg/L TN, .5mg/L TP)
- Influent>Anaerobic>Anoxic>Aerobic>Post Anox>Re-air>Clarifier



Oxidation Ditch

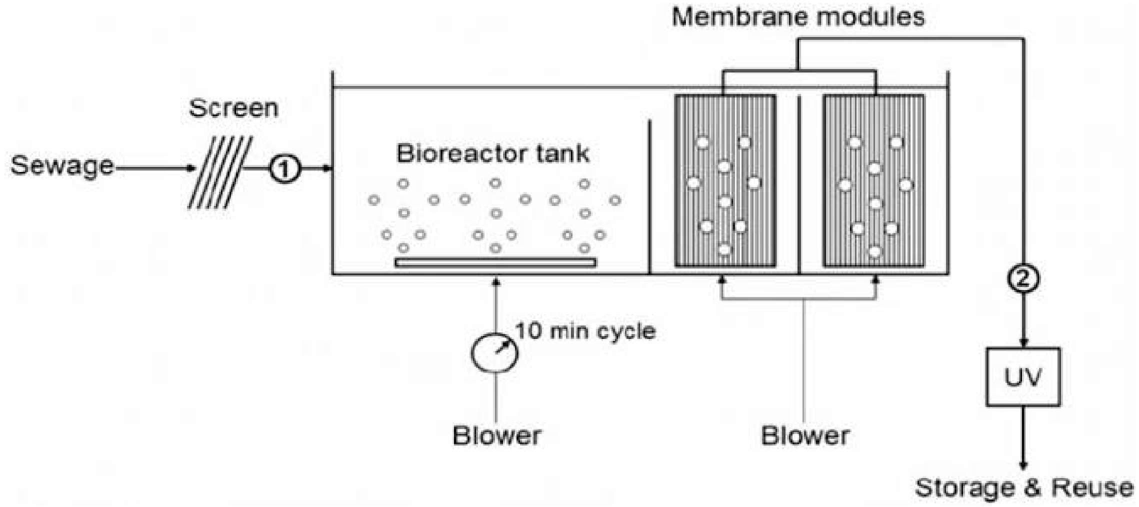
- Extended Air
- Long sludge age
- Stable Nitrifcation

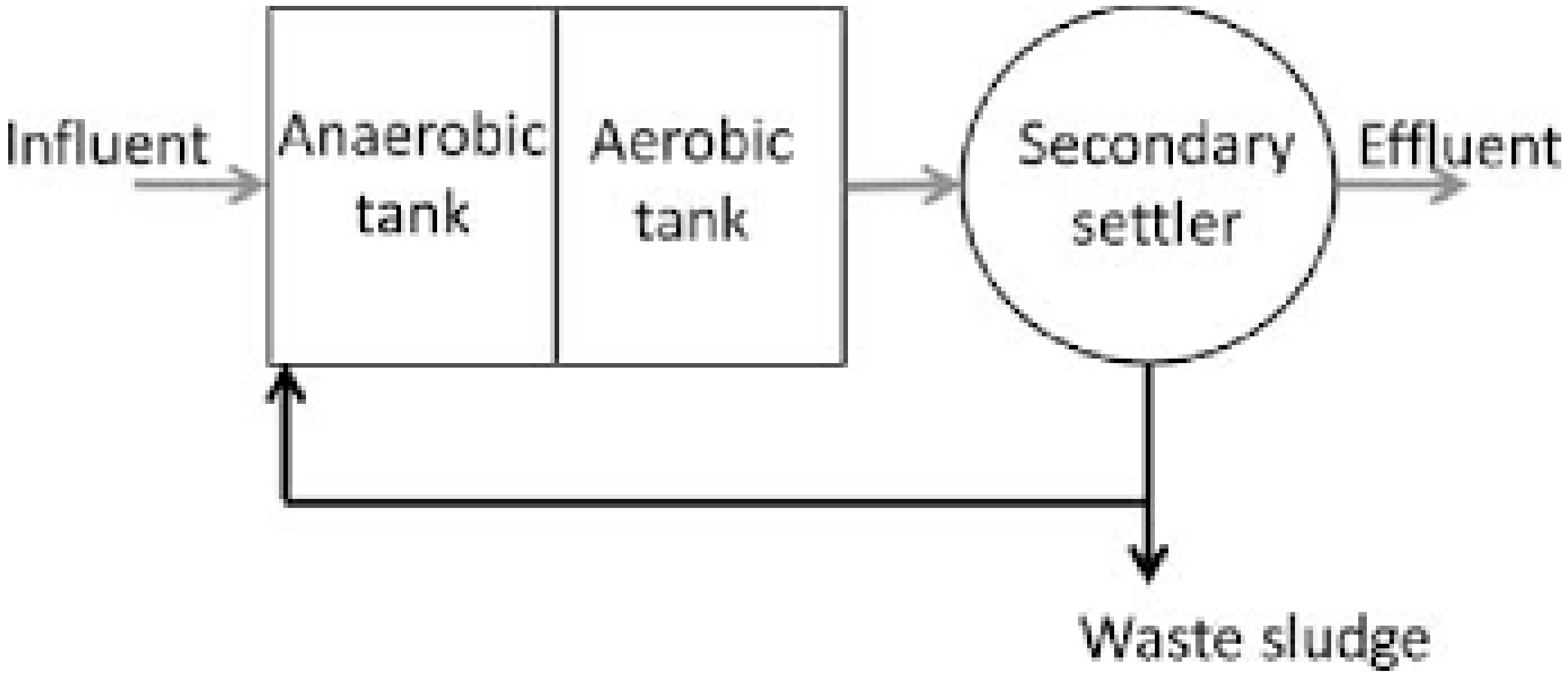


Membrane Bioreactor (MBR)

- Pros:
- Small footprint, can be combined with MLE/Bardenpho
- Excellent effluent quality (<1NTU)
- Ideal for reclaim

- Cons:
- Higher capital costs (Membranes/Construction)
- Higher energy demand (+20-60%)
- Routine cleaning required





Biological Phosphorus Removal (EBPR)

- Uses PAOs (polyphosphate accumulating organisms)
- Anaerobic zone: take up carbon, release P
- Aerobic zone: absorb more P than released
- Sludge wasted = P removal

Why Nitrate Harms EBPR

- PAOs need a true anaerobic environment to release phosphorus and store PHAs.
- If nitrate is present, denitrifiers outcompete PAOs for VFAs.
- This prevents PAOs from performing the EBPR cycle properly.
- Result: Less P release, less P uptake, poor phosphorus removal.

EBPR Key Conditions

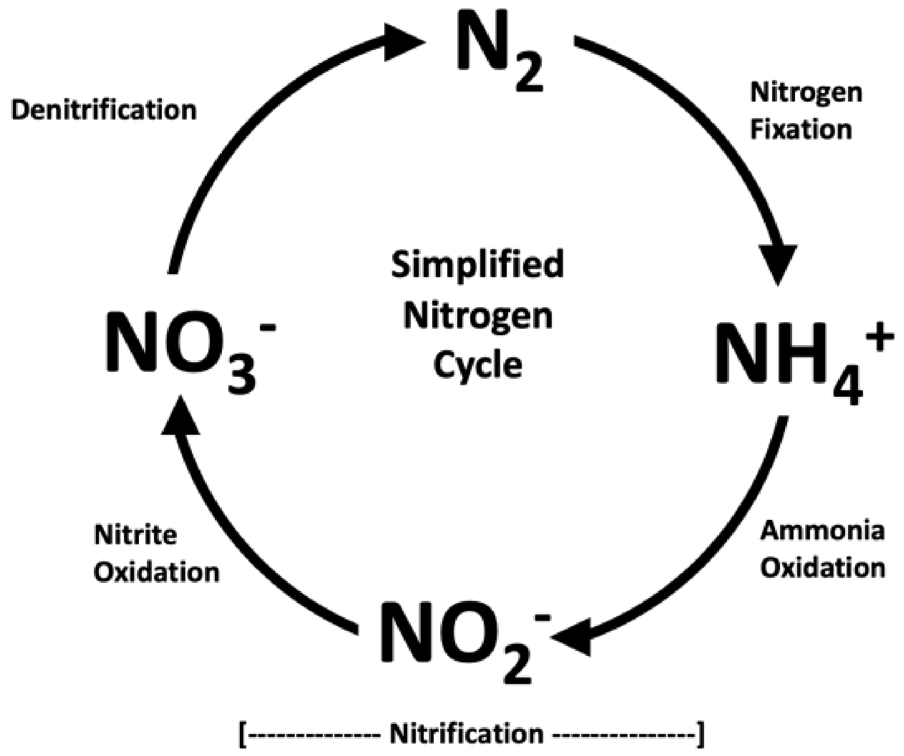
- Anaerobic zone must have no oxygen/nitrate
- VFAs (carbon) needed – fermenters help
- Enough retention time
- Watch for filament growth, low P uptake

Troubleshooting EBPR Failures

- Check for nitrate in the anaerobic zone – it blocks PAOs.
- Ensure enough VFAs or readily biodegradable COD (rbCOD).
- Maintain appropriate sludge age and avoid over-wasting.
- Avoid toxic shocks and ensure stable pH (6.8–7.5 ideal).

Nitrogen Removal Overview

- Nitrification: Ammonia → Nitrite → Nitrate
- Denitrification: Nitrate → Nitrite → N2 gas
- Needs two zones: aerobic and anoxic
- Carbon (microC) in anoxic zone to increase denitrification



Nitrification

AEROBIC PROCESS

NEEDS LONG SRT (SLOW-GROWING BUGS)

PH, DO, AND ALKALINITY ARE CRITICAL

WATCH FOR COLD TEMPS, TOXICITY

NITRIFIERS ARE DELICATE!

Denitrification

- Anoxic process (little-to-no oxygen)
- Needs nitrate + carbon source (Glycerin)
- Reduces nitrate to nitrogen gas

	Methanol	Ethanol	MicroCg™	MicroCglycerin™	56% Acetic Acid	30% Sodium Acetate
COD mg/L	1,200,000	1,650,000	670,000	1,016,000	577,000	222,480
Bulk Density lbs/gal.	6.6	6.6	10.2	9.92	9.09	9.8
Yield g COD/g COD	0.41	0.55	0.6	0.55	0.53	0.53
Total COD/N	4.82	6.36	6.45	6.36	6.09	6.09
Total dose gal substrate/ lb NO3N	0.48	0.46	1.15	0.77	1.19	3.09

Nitrifiers vs. Denitrifiers

- Nitrifiers are slow-growing, fragile, and need high DO.
- Denitrifiers are fast, tough, and can use oxygen or nitrate.
- Nitrifiers are easily knocked out by pH, toxins, or low oxygen.
- Protect nitrifiers with careful monitoring and control.

VFA & Carbon Sources

- VFAs (like acetate and propionate) are essential for EBPR.
- MicroC is not a true VFA source but can support denitrification.
- Sources of VFA: fermenters, primary sludge, high-strength waste.
- Carbon source matters: acetate > glycerol > methanol (for EBPR).

Operational Considerations

- Monitor DO, pH, alkalinity
- Maintain proper SRT
- Internal recycles and carbon dosing
- Regular sludge wasting critical

Biochemical Reactions and Corresponding ORP Values

Biochemical Reaction	ORP, mV
Nitrification	+100 to +350
cBOD degradation with free molecular oxygen	+50 to +250
Biological phosphorus removal	+25 to +250
Denitrification	+50 to -50
Sulfide (H_2S) formation	-50 to -250
Biological phosphorus release	-100 to -250
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

Troubleshooting BNR

- Low P removal: check anaerobic zone, VFAs
- High effluent ammonia: check DO, SRT
- Poor denitrification: check nitrate, carbon
- Sludge issues: filament growth, foaming

Chemical Precipitation

- Jar testing needed
- Aluminum-Based
- Iron-Based
- Rare Earth (CLC)

Chemical Precipitation

- Alum- Cheap, effective, significant pH depression, Lots of sludge. Pin floc
- Ferric – Stronger floc, better for cold temps, lots of sludge and pH depression
- PAC/ACH – Lower usage, Less pH depression/sludge
- Rare Earth – High efficiency, dense precipitate and minimal sludge/pH depression
- Blended Coagulants – Balance Floc size and metal use; more complex

Coagulant Comparison

pH impact : Ferric > Alum > ACH/PAC > RE

Sludge Volume : Ferric > Alum > ACH/PAC > RE

Jar test to determine ideal coagulant/dose

Jar Testing

- Why is it important?

Biological Phosphorus Removal (BioP)

- Manipulates system conditions to stimulate the growth of phosphorus accumulating organisms (PAOs).
  - 1st phase anaerobic zone to create volatile fatty acid production, PAOs accumulate VFAs and conditions them to accumulate phosphorus in the Aerobic Phase
  - Aerobic Phase PAO accumulate Phosphorus
  - As long as the system stays aerobic PAOs will hold Phosphorus

Enhanced Biological Phosphorus Removal

- Anaerobic Zone
  - o COD is converted to Volatile Fatty Acid (VFA) by facultative bacteria
    - The COD must be “readily biodegradable” soluble COD
  - o Phosphate Accumulating Organisms are conditioned
    - Take in VFAs as food and use stored polyphosphate as an energy source
    - PAOs become stressed if enough VFAs are present in the anaerobic zone

Phosphate Accumulating Organisms under anaerobic conditions

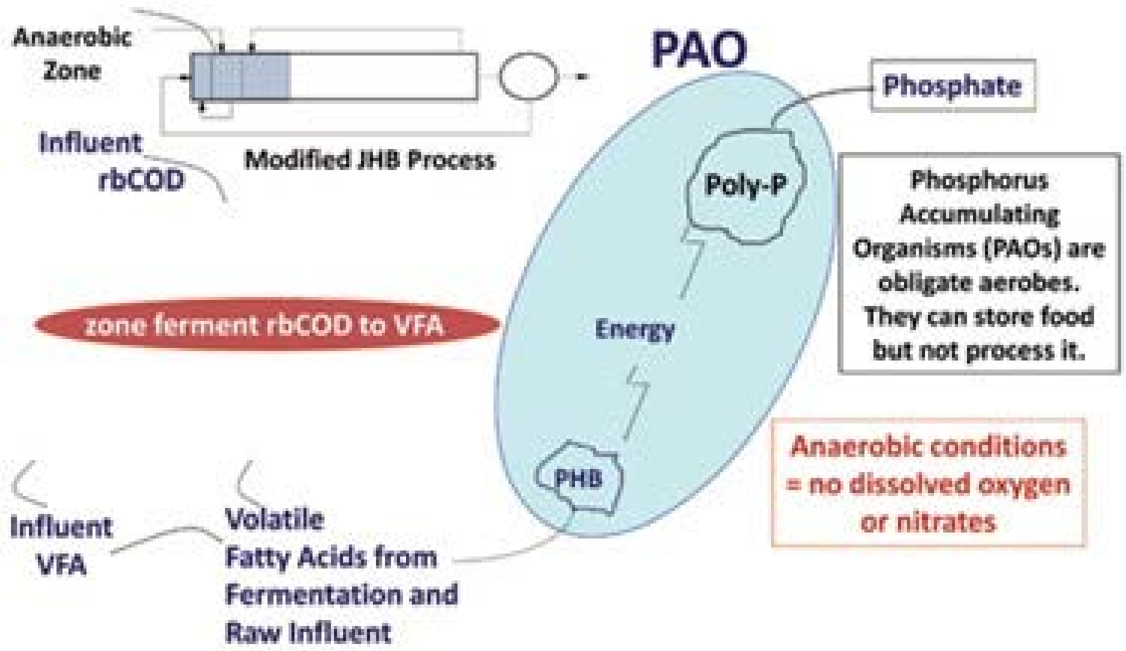
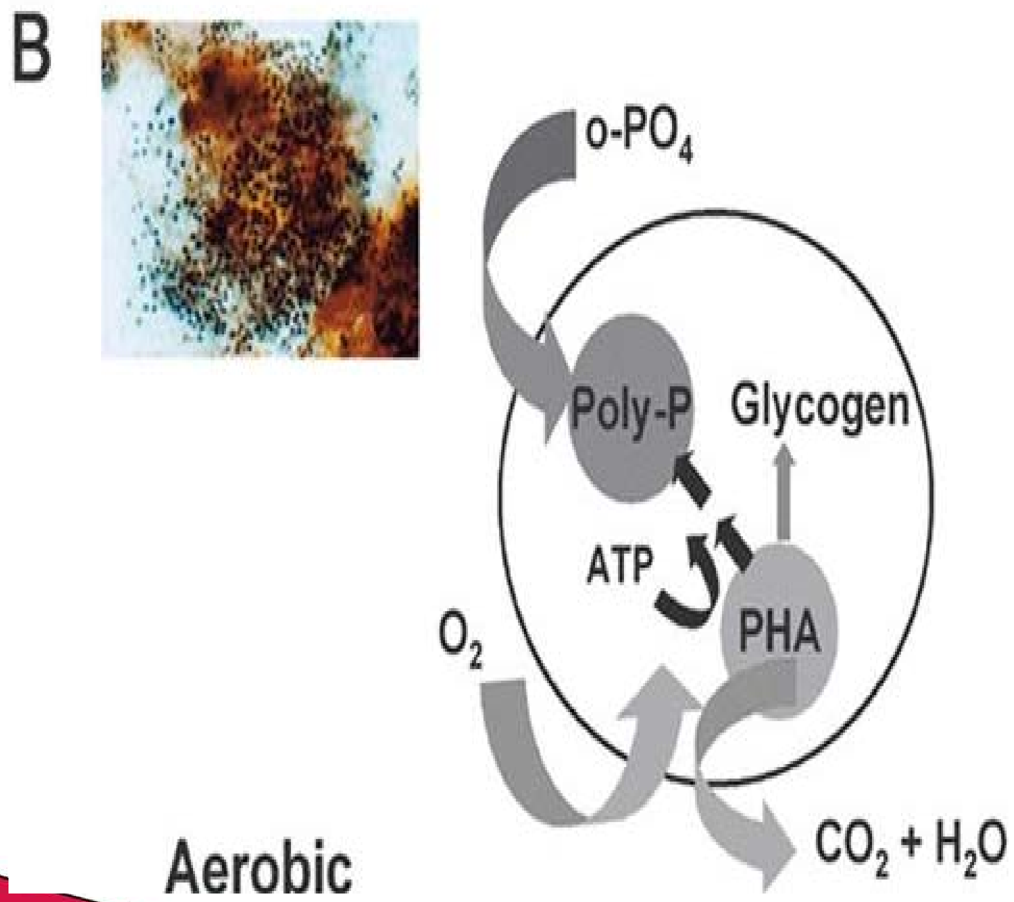


Figure 1. PAO Phosphorus Release in Anaerobic Zone

- Anaerobic
  - No oxygen
  - No nitrates
- Needs "readily biodegradable" COD (rbCOD)
- PAOs store VFAs as Polyhydroxybutyrate (PHB)
- Use polyphosphate as energy source for conversion of PHB

Aerobic Phase Enhanced Biological Phosphorus Removal



- PAOs are “stressed” and over react by over accumulating ortho-phosphate
- Convert ortho-phosphate to polyphosphate to be used as an internal energy source.
- DO should be maintained at 2.0 mg/L

Bio P continued

- Rules of thumb
  - o COD : P ratio minimum 40::1
    - Not all COD is the same it must be convertible to VFAs under anaerobic conditions
  - o VFA as COD::P >8 will result in Phosphorus removal of < 0.3 mg/L ortho P
- Some Bio-P plants still have to use chemical treatment.

Generating VFA

- Some plants may have to adjust conditions to generate enough VFAs
  - Increasing sludge holding time in primary clarifier
  - Adding a fermentation step for RAS, basically holding the sludge under anaerobic conditions to stimulate more VFA production

Typical Phosphate in Influent Wastewater

Phosphate Type	Level as “P” mg/L
Orthophosphate PO4-	3.0 – 4.0
Polyphosphate	2.0 – 3.0
Organic phosphate	0.7 – 1.0
Total Phosphorus “P”	5.7 – 8.0

Nitrogen Cycle – The Biology

- • Ammonia → Nitrite → Nitrate (nitrification)
- • Nitrate → Nitrogen gas (denitrification)
- • Requires aerobic + anoxic zones
- • Goal: convert reactive nitrogen to harmless N_2

Key Bacteria & Requirements

- Nitrifiers:
- Nitrosomonas: $NH_3 \rightarrow NO_2$
- Nitrospira/Nitrobacter: $NO_2 \rightarrow NO_3$
- Need: DO>2 mg/L, pH 7.2–8.2, alkalinity, long SRT

- Denitrifiers:
- Pseudomonas, Paracoccus, Bacillus
- Need: anoxic, nitrate, readily biodegradable carbon

How to Optimize BNR

- Maintain DO 2–3 mg/L in aerobic zones
- DO <0.3 mg/L in anoxic
- Maintain SRT for nitrifiers
- Maintain alkalinity (>70-100 mg/L)
- Optimize internal recycle
- Feed carbon where nitrate exists

Using TN, TKN & Nitrate for Troubleshooting

- TKN = Organic N + Ammonia
- TN = TKN + Nitrate + Nitrite
- High TKN, low nitrate: nitrification failure
- Low TKN, high nitrate: nitrification OK, denitrification lacking
- High TN with low ammonia: increase carbon/anoxic time
- Track influent vs effluent to identify limiting step

Common Causes of BNR Failure

- Low alkalinity/pH crash
- Toxicity (metals, disinfectants)
- Low SRT washing out nitrifiers
- Insufficient carbon
- High DO carryover into anoxic
- Nitrate carryover into anaerobic EBPR

BNR Troubleshooting Flowchart

- High ammonia → Check DO (>2 mg/L), SRT, pH, alkalinity
- High nitrate → Check carbon, anoxic DO, recycle
- High phosphorus → Check nitrate in anaerobic zone, VFAs, PAOs
- Rising solids → Check sludge age, filaments, wasting

Environmental Factors

- • pH: 7.0–8.0 ideal for nitrification
  • DO: Aerobic 2–3 mg/L; Anoxic <0.2 mg/L
  • Temperature: Nitrification slows below 15°C
  • ORP useful for process control

Carbon Source Comparison

- • Acetate: Best for EBPR
  • Glycerin (MicroC): Excellent for denitrification
  • Methanol: Low cost but specialized bugs required
  • Ethanol: Fast denitrification but higher cost

MHP Example

- Average influent TKN – 25-60mg/L
- Current influent TKN – 360 mg/L
- Significant Benzene
- pH increase to ~10


MHP Example

- Main Concern = pH – high pH favors free ammonia (toxic to nitrifiers)
- Benzene also toxic
- TKN of 360mg/L requires significant supplemental alkalinity
- Influent BOD unlikely to sustain denitrification required
- Biology dead/severely inhibited

TN vs TKN

- TKN = Organic nitrogen + ammonia/ammonium
- TN = Sum of all forms of nitrogen (TKN + Nitrite/Nitrate)

Using Plant Data

- NH_3 high + NO_3 low = Poor nitrification
- NH_3 low + NO_3 high = Poor denitrification
- TN≈TKN = Little nitrification
- TN much lower than TKN+nitrate influent = Good denitrification

Operator Cheat Sheet

- Nitrification uses 7.14 mg/L alkalinity per mg NH_3-N
- Protect nitrifiers—they recover slowly.
- Keep nitrate out of anaerobic EBPR.
- Trend data daily, not just permit samples.

Questions?

Thank you!