Tema 8b – BNR parte 2

CI7115 – Biotecnología Ambiental

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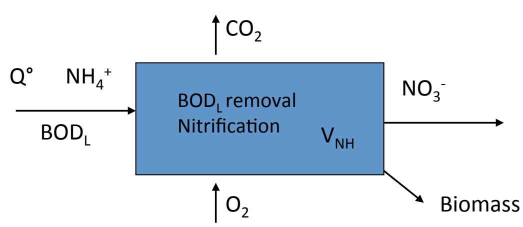
Configuraciones para nitrificación

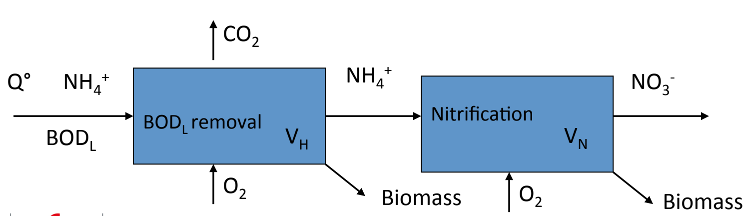
Single-Stage



$V_{NH} = f([\theta_x^{min}]_{lim}$ for nitrifiers, $X_i°, X_d°, X_v, S°, N°)$

Two-Stage

$V_{NH} > V_H + V_N$?



$V_H = f([\theta_x^{min}]_{lim}$ for heterotrophs, $X_i°, X_d°, X_v, S°)$

$V_N = f([\theta_x^{min}]_{lim}$ for nitrifiers, $N°')$

Nitrificación + denitrificación

Suppose we link nitrification to denitrification.

Let's see what happens when methanol is the electron donor for denitrification:

Nitrification: $NH_4^+ + 2O_2 = 2H^+ + NO_3^- + H_2O$

Denitrification: $\frac{5}{6}CH_3OH + NO_3^- = \frac{1}{2}N_2 + \frac{5}{6}CO_2 + \frac{7}{6}H_2O + OH^-$

Overall: $NH_4^+ + 2O_2 + \frac{5}{6}CH_3OH = \frac{1}{2}N_2 + H^+ + \frac{5}{6}CO_2 + \frac{19}{6}H_2O$

This is great!

1) We have removed both the ammonium and the methanol with the amount of oxygen required to remove ammonium by itself. The BOD_L of the methanol was oxidized without any additional O_2! Nitrification/denitrification saved O_2 and therefore energy.

2) We have removed the ammonium with half the acid production.

Looks like a good marriage!

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Nitrificación vs. denitrificación

	Process	
	Nitrification	Heterotrophic Denitrification
C source	CO_2 (Autotrophs)	Organic
Electron donor	NH_3	Organic
Electron acceptor	O_2	NO_3^-, NO_2^-, N_2O
$[\theta_x^{min}]_{lim}$	1-4 days	0.5-2 days
Environment	aerobic	anoxic
Y	0.33 g vss/g NH_4^+-N 0.083 g vss/g NO_2^--N	0.26 g vss/g BOD_L
$f_s°$	0.14 (ammonium oxidation) 0.10 (nitrite oxidation)	0.52
Effect on alkalinity (g as $CaCO_3$/g N)	Consumes ~7.1	Produces ~3.6

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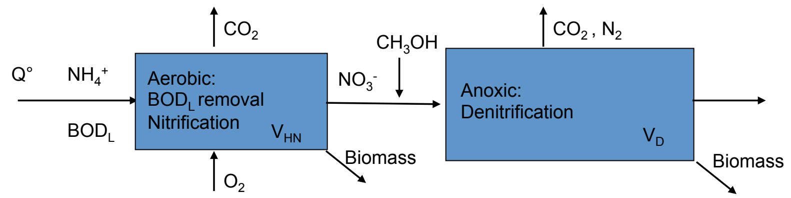
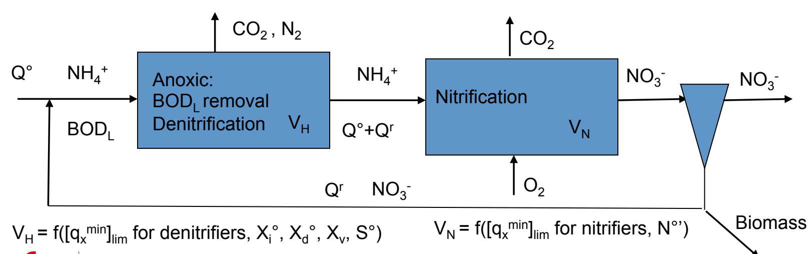
Configuraciones para Nitrificación / Denitrificación

Two-Stage (or 3-stage) - costly electron donor (methanol), but highly efficient



V_{NH} = f($[q_x^{min}]_{lim}$ for nitrifiers, $X_i°$, $X_d°$, X_v, S°, N°) V_D = f($[q_x^{min}]_{lim}$ for denitrifiers, N°')

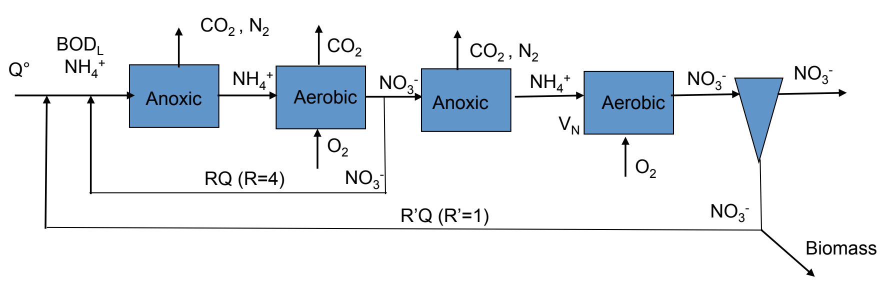
Two-Stage (Ludzack & Ettinger, 1962) - saves O_2, but has low efficiency



V_H = f($[q_x^{min}]_{lim}$ for denitrifiers, $X_i°$, $X_d°$, X_v, S°) V_N = f($[q_x^{min}]_{lim}$ for nitrifiers, N°')

N removal efficiency = f(Q^r/Q°, S°/N°)

El Proceso Bardenpho



Wow! 90-95% N removal without adding an external electron donor!

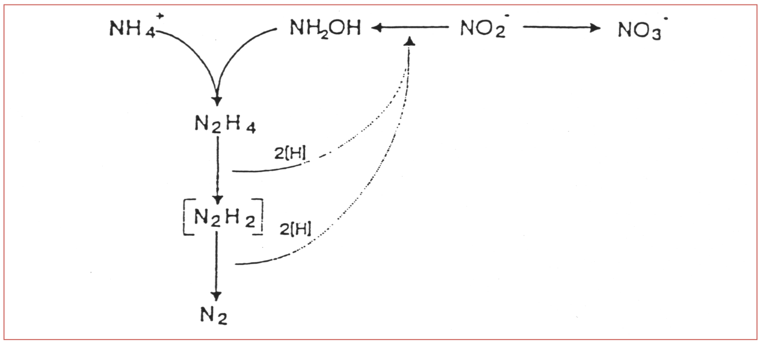
For Bernard (1976), an additional surprise was that the wasted biomass contained high levels of P. But how? Why?

Innovation: Nitrification - Denitrification without carbon
The ANAMMOX process (van de Graaf et al., 1996)

Planctomycetes

$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$

Note: this process requires a 1:1 ratio of ammonium to nitrate

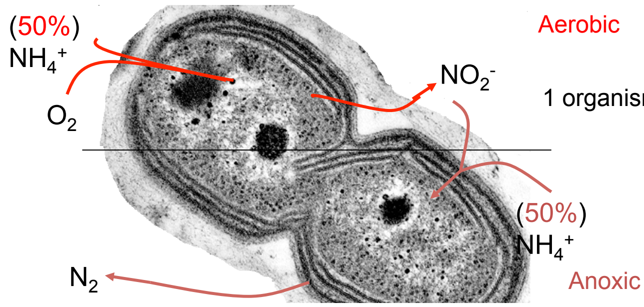


DO as low as 2 μM inhibits process!

Kinetic parameters for aerobic and anaerobic ammonia oxidation (Jetten et al., 2001)

Parameter	Nitrification	Annamox
ΔGr (kJ/mol)	-275	-357
Yield g vss/g N	0.33	0.12
Aerobic, g N/g vss-d	2-6	0
Anaerobic, g N/g vss-d	0.02 (microaerophilic)	0.6
μ_{max} (per day)	1	0.07
Doubling time (days)	0.7	11
K, NH_4^+ (μM)	5-2600	5
K. NO_2^- (μM)	N/A	<5
K, O_2 (μM)	10-50	N/A

Innovation: Nitrification - Denitrification at low oxygen
The OLAND process (Kuai and Verstraete, 1998)



1 organism: *Nitrosomonas*

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$$

Slide courtesy of W. Verstraete

El fósforo debe irse

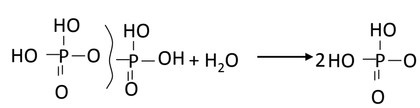
As little as 10 µg P/L can trigger an algal bloom. A typical standard is 1 mg P/L. Domestic wastewater contains 4-8 mg P/L.

Forms of phosphorus in wastewater:

Forms of phosphorus	Conc in medium strength municpal wastewater (mg P/L)
Dissolved	
Orthophosphate	2-4
Suspended & colloidal	
Condensed phosphates	1-3
Organic phosphates	1`
Total P	4-8

Condensed phosphates hydrolyze slowly in the environment:

- polyphosphates
- metaphosphates
- pyrophosphates



Estandares típicos de fósforo

USA	mg P/L
Great Lakes	1.0
Florida	1.0
Reno-Sparks	0.5
Lake Tahoe	1.0
Chesapeake Bay Basin	
- PA lower Sesquihanna	2.0
- MD	0.2, 1.0, 2.0
- VA Potomac	0.2- 1.0
- Washington DC	0.18
SWEDEN	1.0
SWITZERLAND	1.0 or 85%
EEC	2.0
SINGAPORE	
- watercourse	1.7
- controlled watercourse	0.7

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Cómo controlar el P: separarlo del agua en forma sólida

1. Precipitation by addition of metal salts

Iron or Aluminum salts are generally used

$FePO_4 \cdot 2H_2O \Leftrightarrow Fe^{+3} + PO_4^{-3} + 2H_2O$

$AlPO_4 \cdot H_2O \Leftrightarrow Al^{+3} + PO_4^{-3} + H_2O$

- Optimum pH for the two reactions are 5.3 and 6.3, respectively
- Additional sludge and chemical costs

2. Enhanced biological P removal.

There have been several recent breakthroughs in the understanding of enhanced biological phosphorus removal or “luxury uptake.” to understand this process, we first need to understand the various storage polymers inside cells.

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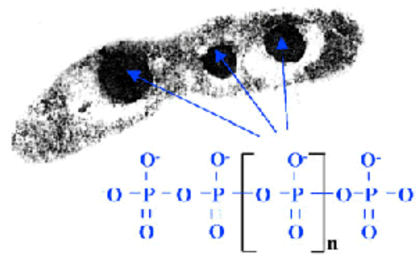
Remoción Biológica de P – Enhanced biological P removal (EBPR)

Enhanced biological P accumulation is due to polyphosphate (PolyP)



Polyphosphate kinase

Poly P_n + ATP = Poly P_{n+1} + ADP

Polyphosphate transferase

Poly P_n + AMP = Poly P_{n-1} + ADP

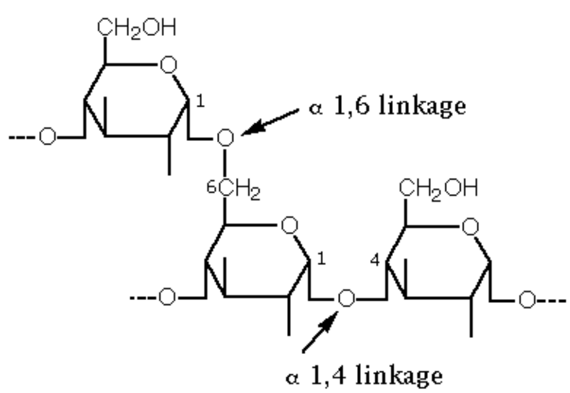
Adenylate kinase

2ADP = ATP + AMP

Since Poly P is stored as $K_{0.33}$ $Mg_{0.33}PO_3$, sufficient K and Mg must be present.

Almacenamiento de polímeros: La clave para EBPR

Glycogen is a polymer of glucose. It is a good source of reducing power.



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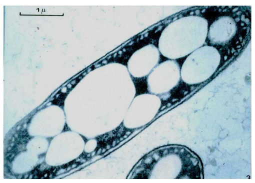
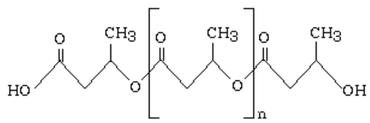
Almacenamiento de polímeros: La clave para EBPR

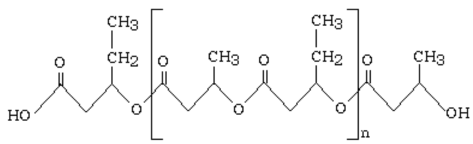


Polyhydroxyalkanoate (PHA) includes:
- polyhydroxybutyrate (PHB)
- polyhydroxyvalerate (PHV)

Poly-β-hydroxybutyrate (PHB)
(n ~ 60)



Poly-β-hydroxyvalerate (PHV)/poly-β-hydroxybutyrate (PHB) copolymer



Luxury P Uptake Organisms

The organisms responsible for luxury P uptake in wastewater treatment plants can accumulate 4-8% P.

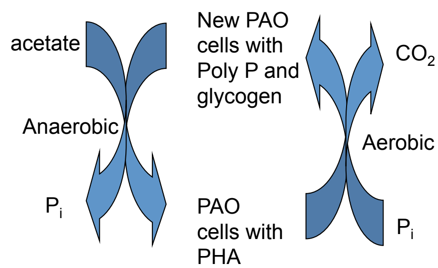
They are called:
- Bio-P bacteria or
- Phosphorus Accumulating Organisms (PAO) - *Rhodocyclus group*
  - (genus: *Candidatus,* species: *Accumulalibacter phosphatis)*

Other organisms implicated in P removal include:
- *Acinetobacter*
- *Nocardia*
- *Pseudomonas*
- *Arthrobacter*
- *Beyerinkia*
- *Ozotobacter*
- *Aeromonas*
- *Microlunatus*

Mecanismos para Enhanced P Uptake (4-10% P en biomasa)

Acetate comes from fermenters (acidogens)

Anaerobic uptake of acetate to form PHA is fueled by oxidation of glycogen AND hydrolysis of PolyP.

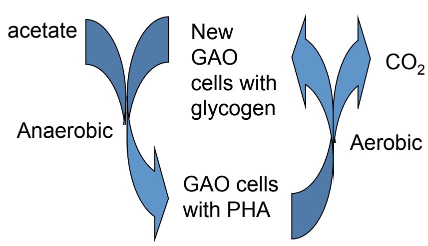


Cell division, PolyP formation, and glycogen formation are all fueled by aerobic oxidation of PHA.

Mecanismos para Enhanced P Uptake (4-10% P en biomasa)

PAOs compete with the G-bacteria, which are also called the Glycogen Accumulating Organisms (GAOs). These organisms <u>do not</u> accumulate Poly P.

Anaerobic uptake of acetate to form PHA is fueled by oxidation of glycogen, which is most favorable energetically at low pH

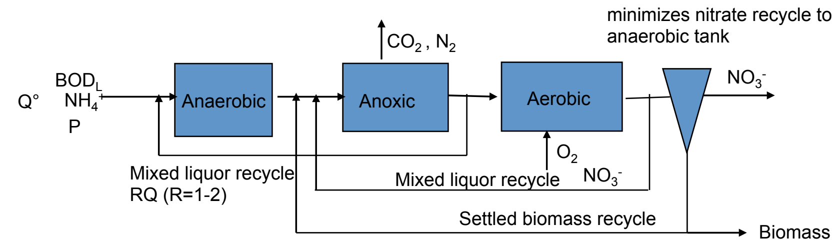


Competition between PAOs and GAOs is <u>pH sensitive</u> (Filipe et al., 2001):

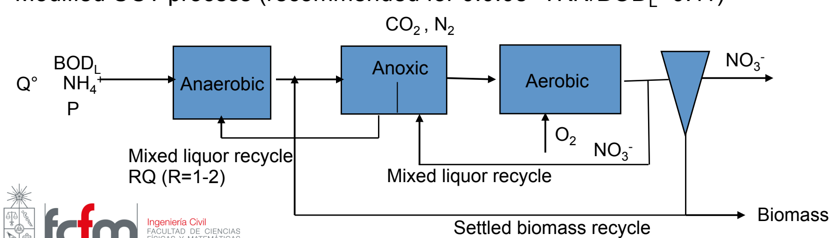
PAOs are favored if pH in anaerobic zone pH >7.2;
GAOs are favored at lower pH.

Configuraciones para remoción de P - University of Cape Town (UCT)

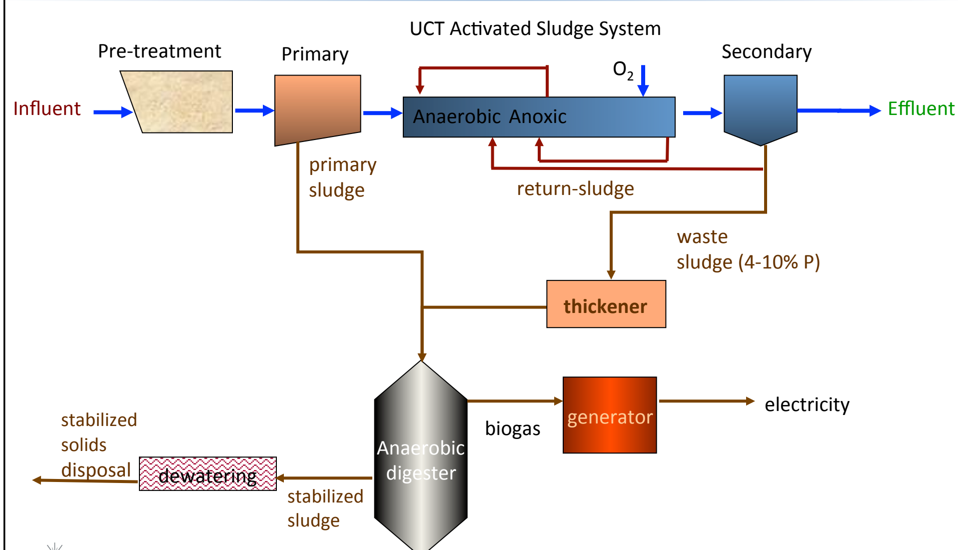
UCT process (recommended when $0.11<TKN/BOD_L<0.14$)



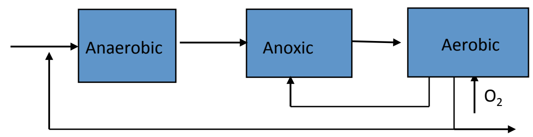
Modified UCT process (recommended for 0.0.08<TKN/BOD_L<0.11)



Remoción convencional de N y P (Proceso UCT)



- Three stage Phoredox (A^2/O) process (recommended for $TKN/BOD_L < 0.08$)



- The five stage version adds another anoxic and aerobic reactor in the series

- The Phostrip process does not rely on wasting of biomass with high P; instead the P is anaerobically stripped and precipitated chemically. See Fig 11.5 in the text for a process flow stream.

- Sequencing batch reactors are also effective.

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