The EU funded SWIM-SM: developing capacity for Sustainable and Integrated Wastewater Treatment and Reuse

Online Course on Natural Treatment Systems: Nitrification

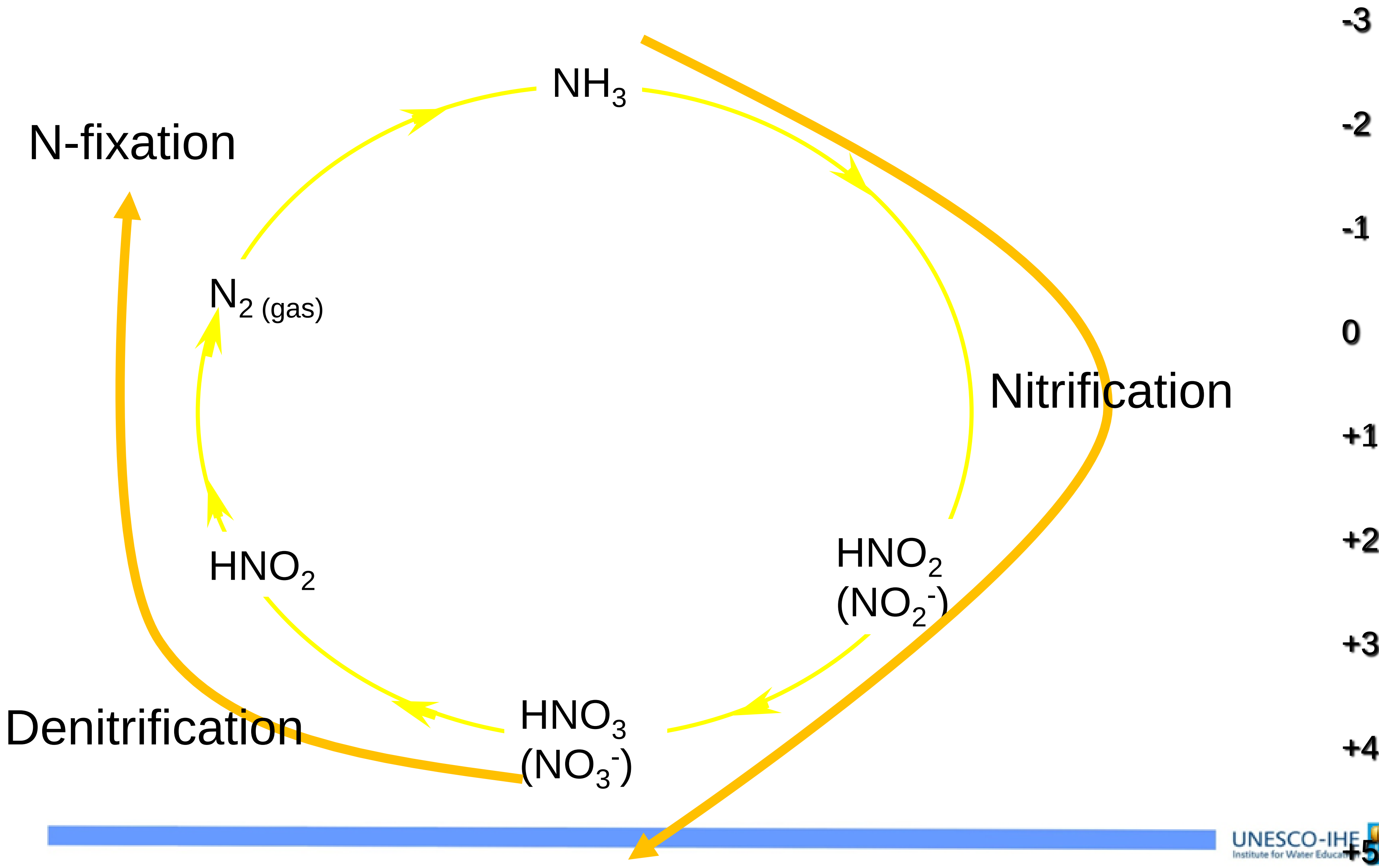
Nitrification

SWIM OLC

on

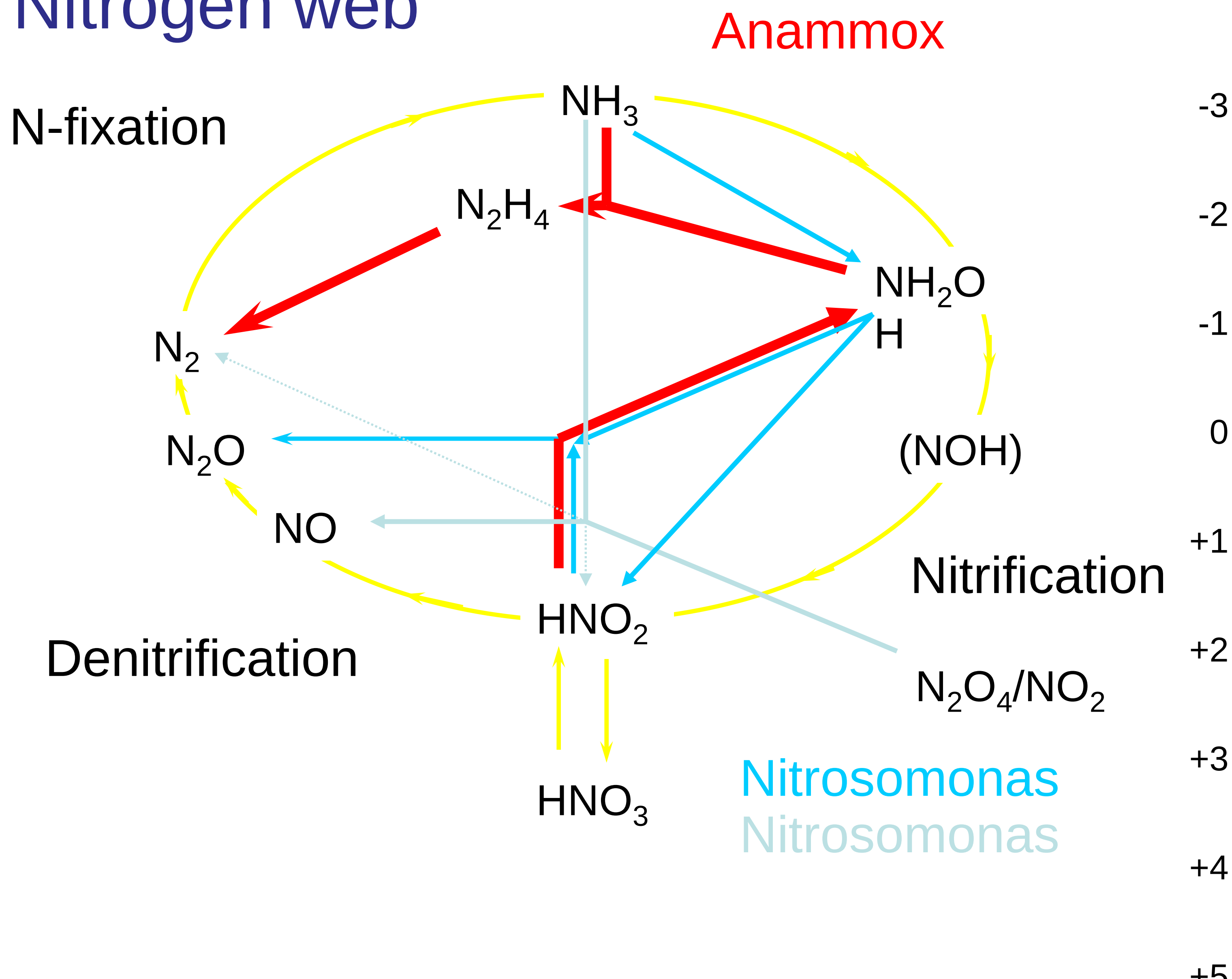
Natural Treatment Systems

N-Cycle



N-fixation
NH_3
$N_{2\ (gas)}$
HNO_2
HNO_2
(NO_2^-)
HNO_3
(NO_3^-)
Nitrification
Denitrification
-3
-2
-1
0
+1
+2
+3
+4
+5

Nitrogen web



Why removal ammonia?

- A nutrient, so can promote algae growth
- Can exert oxygen demand in receiver
- Free or un-ionized fraction is toxic to aquatic life

N-removal in natural systems

- Ammonia stripping! (does not deplete the ozone layer and does not contribute to global warming)
- **Nitrification-denitrification**
- Methane and nitrous oxide emissions!
- Ammonia and nitrate assimilation by algae (exit with effluent)
- Assimilation by plants
- Sedimentation of particulate organic N

Nitrification

The biological oxidation of free and saline (NH_3 and NH_4^+) ammonia by two groups of obligate aerobic autotrophic organisms.

Catabolism (energy):

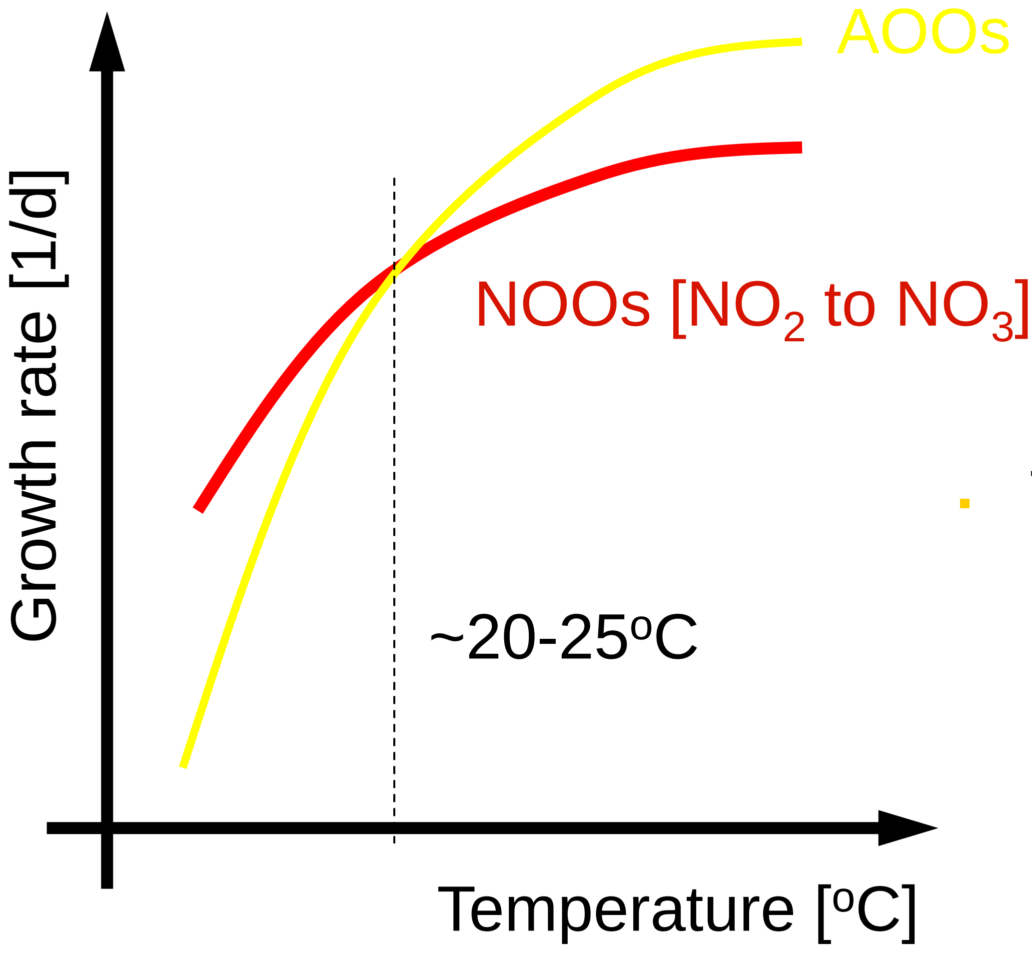
Ammonia oxidizing organisms (AOO, AOB)

$$NH_4^+ + {}^{3}/_{2}O_2 \rightarrow NO_2^- + H_2O + 2H^+ + \text{Energy}$$

Nitrite oxidizing organisms (NOO, NOB)

$$NO_2^- + {}^{1}/_{2}O_2 \rightarrow NO_3^- + \text{Energy}$$

Competition



- T_{sewage} < ~20-25^oC:
  - AOO grow slower
  - NH_4 oxidation is limiting step

Nitrification

Anabolism:

$$\text{Energy} + NH_4^+ + CO_2 + H_2O \rightarrow \text{Biomass}$$

- Biomass Yield of autotrophs is very low: Y_A~0.10 mgVSS/mgNH4-N nitrified
- Since normally NOO's faster than AOO's, then: no NO_2^- built up, and nitrification can be described as a single step.

Nitrification

Overall process stoichiometry by autotrophic nitrifying bacteria (ANB):

$$NH_4^+ + 2HCO_3^- + 2O_2 \rightarrow NO_3^- + 2CO_2 + 3H_2o$$

Therefore, per mg NH_4-N nitrified:

- 4.57 mg O_2 utilized (64 mgO_2/14 mgN)
- 7.14 mg/l as $CaCO_3$ consumed (2x50 g$CaCO_3$)/14
- 1 mg NO_3^--N generated.

Nitrification kinetics: stoichiometry and growth

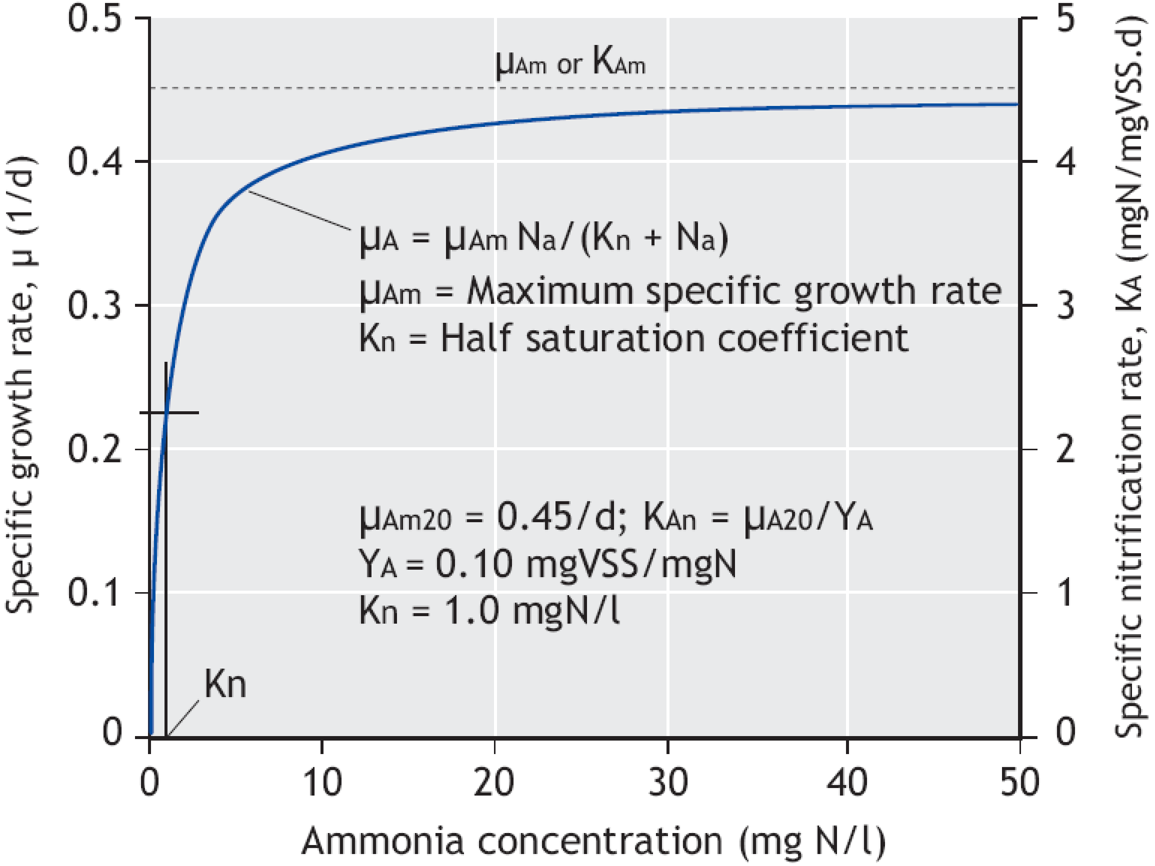
(1) ANB biomass (X_{BA}) generated is a fixed fraction (Y_A) of NH_4 (N_a) nitrified:

$$\frac{dX_{BA}}{dt} = Y_A\left[-\frac{dNa}{dt}\right]$$

(2) Specific growth rate (μ_{AT}) related to bulk liquid NH_4 concentration (N_a) - Monod

$$\frac{dX_{BA}}{dt} = \mu_{AT}X_{BA} = \frac{\mu_{AmT}N_a}{K_{nT}+N_a}X_{BA}$$

Nitrification kinetics: growth



μ_{Am} = 0.45/d

K_n =1 mgN/l

Y_A = 0.10 mgVSS/ mg NH_4-N

If N_a>4mg/L, ANB nitrify at maximum rate (μ_A), but it's difficult to get low N_a<1.0 mgN/l

Nitrification kinetics: growth

NH_4 (N_a) utilization rate, NO_3^- (N_n) generation rate and nitrification oxygen utilization (O_n) rate are linked to ANO biomass (X_{BA}) growth rate:

$$\frac{dN_n}{dt} = -\frac{dN_a}{dt} = \frac{1}{Y_a}\frac{\mu_{AmT} N_a}{K_{nT} + N_a} X_{BA}$$

$$\frac{dO_n}{dt} = 4.57\frac{dN_a}{dt} = 4.57\frac{dN_n}{dt}$$

Nitrification kinetics: endogenous respiration

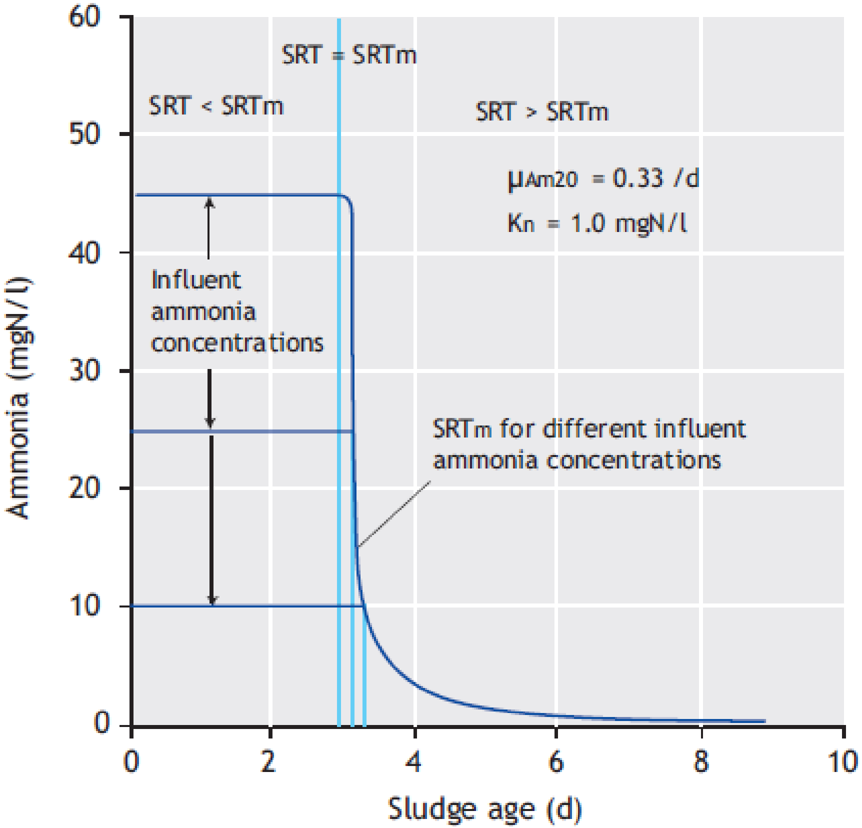
modelled in the same way in both steady state and simulation models as endogenous respiration for OHOs in steady state model, viz:

$$\frac{dX_{BA}}{dt} = -b_{AT}X_{BA}$$

b_{AT} = specific endogenous mass loss rate at T [^{o}C]

= 0.04 /d at 20^{o}C

Minimum sludge age



(1) Above certain R_s, NH_{4e} is very low.

(2) As R_s decreases, NH_{4e} increases.

(3) When $NH_{4e} = NH_{4i}$, $R_s \approx R_{sm}$.

R_{sm} = minimum sludge age for nitrification.

Sludge age (R_s) is the **most** important design parameter for systems required to nitrify!

Nitrifier μ_{Am}

Depends on many factors:

- Inhibitors in wastewater (amines, metals, salts).
- Wastewater temperature (T↓, μ_{Am}↓).
- Wastewater pH (pH↓, μ_{Am}↓).
- Reactor DO concentration (DO↓, μ_{Am}↓).
- AOB and NOB populations selection.

Factor affecting nitrification

- wastewater – magnitude of μ_{Am20},
- temperature,
- aerobic reactor DO concentration,
- pH.

Wastewater source

- Already mentioned - μ_{Am20} varies between different wastewaters then it is considered a wastewater characteristic rather than a kinetic constant.
- μ_{Am20} values range between 0.3 - 0.75 /d.
- b_{A20} is accepted to stay constant (0.04/d).

Temperature

Nitrifier kinetic constants μ_{Am20}, b_{A20} and K_{n20} all dependent on temperature:

- $\mu_{AmT} = \mu_{Am20}(\Theta_n)^{(T-20)}$; $\Theta_n=1.123$
- $K_{nT} = K_{n20}(\Theta_n)^{(T-20)}$; $\Theta_n=1.123$
- $b_{nT} = b_{n20}(\Theta_b)^{(T-20)}$; $\Theta_b=1.029$.

$\Theta_n=1.123$ is equivalent to a 50% reduction every 6^{o}C – if 0.45/d at 20^{o}C, then is 0.23 at 14^{o}C.

DO concentration

- Effect of DO on μ_{Am} is formulated as -

$$\mu_{AO} = \mu_{AmO}\frac{O_2}{K_O + O_2}$$

O = DO conc in mixed liquor

K_O = Monod half saturation conc for DO

= 0.3 to 2 mgO/L (depends on floc size, mixing).

- If reactor DO < K_O, nitrification rate is less than half the maximum.

pH and alkalinity

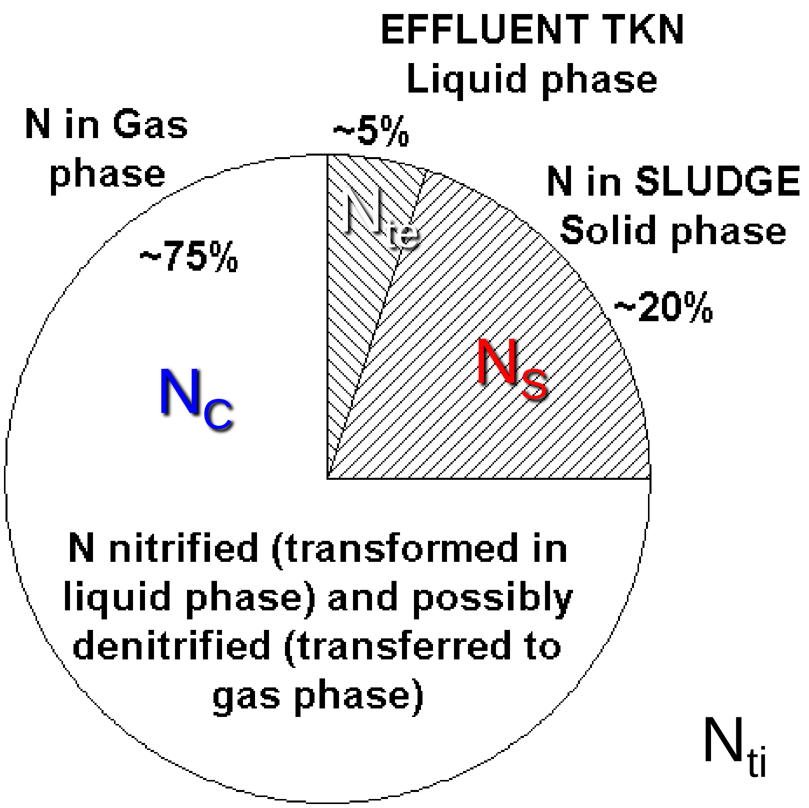
- Nitrification consumes 7.14 mg/l Alk as $CaCO_3$ per mgN/l NH_4 nitrified.
- If mixed liquor alkalinity decreases below 40 mg/l as $CaCO_3$, mixed liquor pH decreases below 7
- Nitrification is very sensitive to pH.
- Optimum pH range is 7-8.
- In low alkalinity WW, nitrification can inhibit itself due to H^+ release, which reduces mixed liquor pH below 7, which reduces μ_{Am}.

pH and alkalinity

- If influent Alkalinity = 200 and 24 mgN/l NH_4 is nitrified, then effluent Alkalinity = 200 – 7.14x24=29 mg/l.
- Less than 40!!! so mixed liquor pH will decrease below 7!
- In this event, either
  - Introduce anoxic zones to denitrify nitrate and recover half Alk lost, or
  - Dose lime to keep pH > 7.0.

N requirements for sludge growth

- About 15-20% of influent TKN is required for AS sludge growth (N$_s$).
- N$_s$ decreases with R$_s$ and settled WW.
- Influent biodeg OrgN adds to NH_4 pool in reactor and nitrified.



Nitrification: influence on AS system

(1) Sludge age: Nitrification requires $R_s > R_{sm}$, so has major influence on selection of R_s.

(2) Reactor volume and sludge production: For the same sludge age, no influence. Nitrifiers < 4% of VSS mass in reactor (TKN load << COD load and $Y_A << Y_H$). However, nitrification usually needs longer R_s so reactor volume larger and sludge production lower.

Nitrification: influence on AS system

(3) Oxygen demand (OD): Increases significantly with nitrification – by about 40-60% of COD removal OD depending on influent TKN/COD conc ratio.

Also, if nitrification requires longer sludge age, COD removal OD increases.

(4) In low DO conditions, COD removal OD takes preference and nitrification will be partial – DO should be >2 mgO/l.

Nitrification: influence on AS system

(5) Effluent quality: No difference in COD, low NH_4, high nitrate, reduced alkalinity, lower pH – possibly aggressive to concrete surfaces.

(6) When nitrification can take place, by design or accident, include denitrification and hydraulic control of sludge age, especially for warm WW, to reduce nitrate and oxygen demand, recover alkalinity, raise pH and minimize rising sludge in SST.