SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

SWIM-H2020 SM Regional Activities 14

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SWIM and Horizon 2020 SM REG-14: Refugee Emergency: Fast track project Design of wastewater

26 March 2018, Beirut, Lebanon

This Project is funded by the European Union

ACTIVATED SLUDGE PROCESSES

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7. Anoxic Bioreactor sizing.
8. Nitrogen mass balance

BIOLOGICAL TREATMENT PROCESSES

Suspended Growth Processes

Bacteria grow in suspension within a tank of liquid.

Examples – Conventional ASP, SBR, Oxidation ditch, extended aeration plants, Various BNR configurations.

Attached Growth(Fixed Film) Processes:

Bacteria and other organisms grow on the surface of a fixed media

Examples –Plastic media trickling filter, SAF, RBC

Integrated(Two Stage) Biological Processes

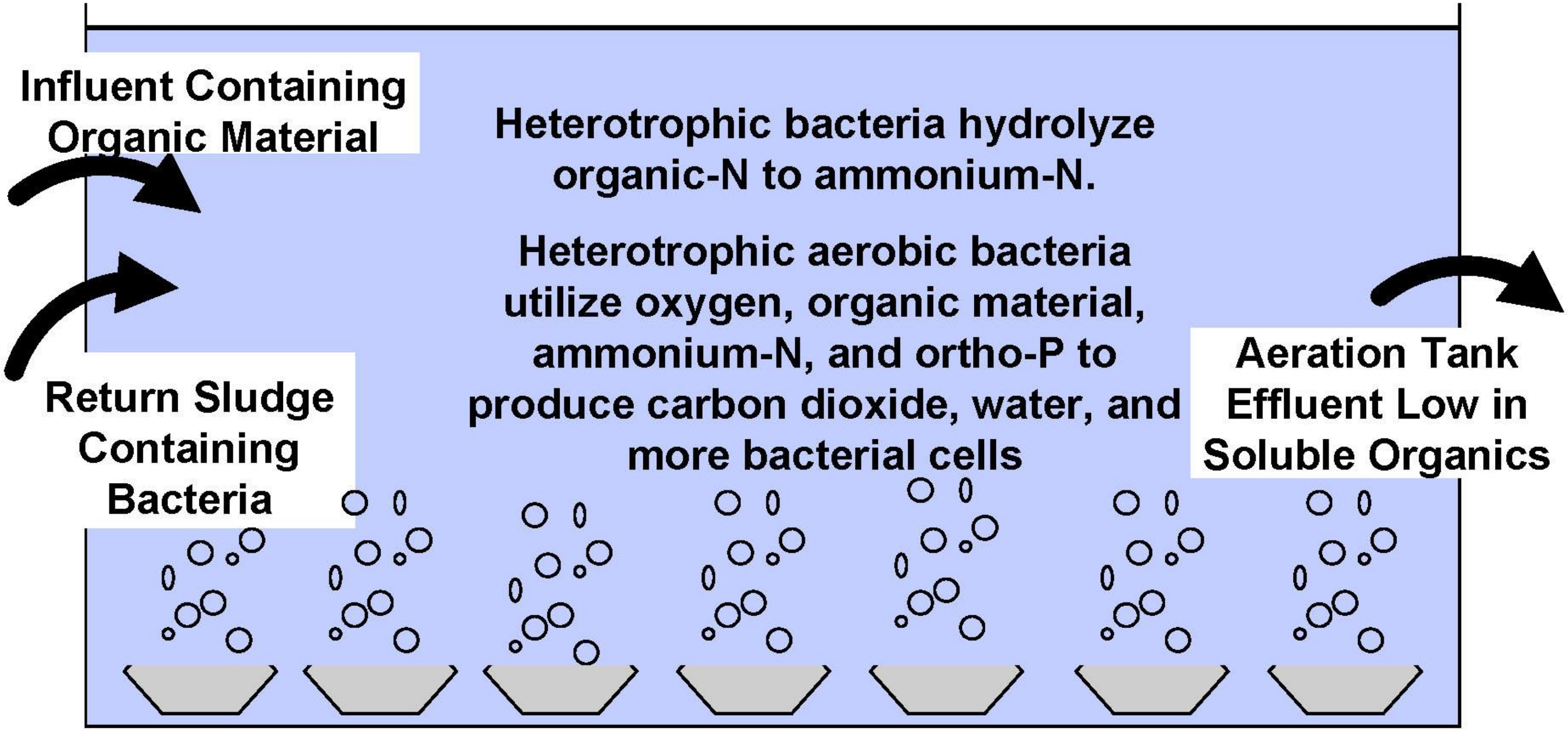
Integrated fixed-film activated sludge(IFAS)

Trickling filters/activated sludge

- **Lagoons**
- **Membranes**

NITRIFICATION

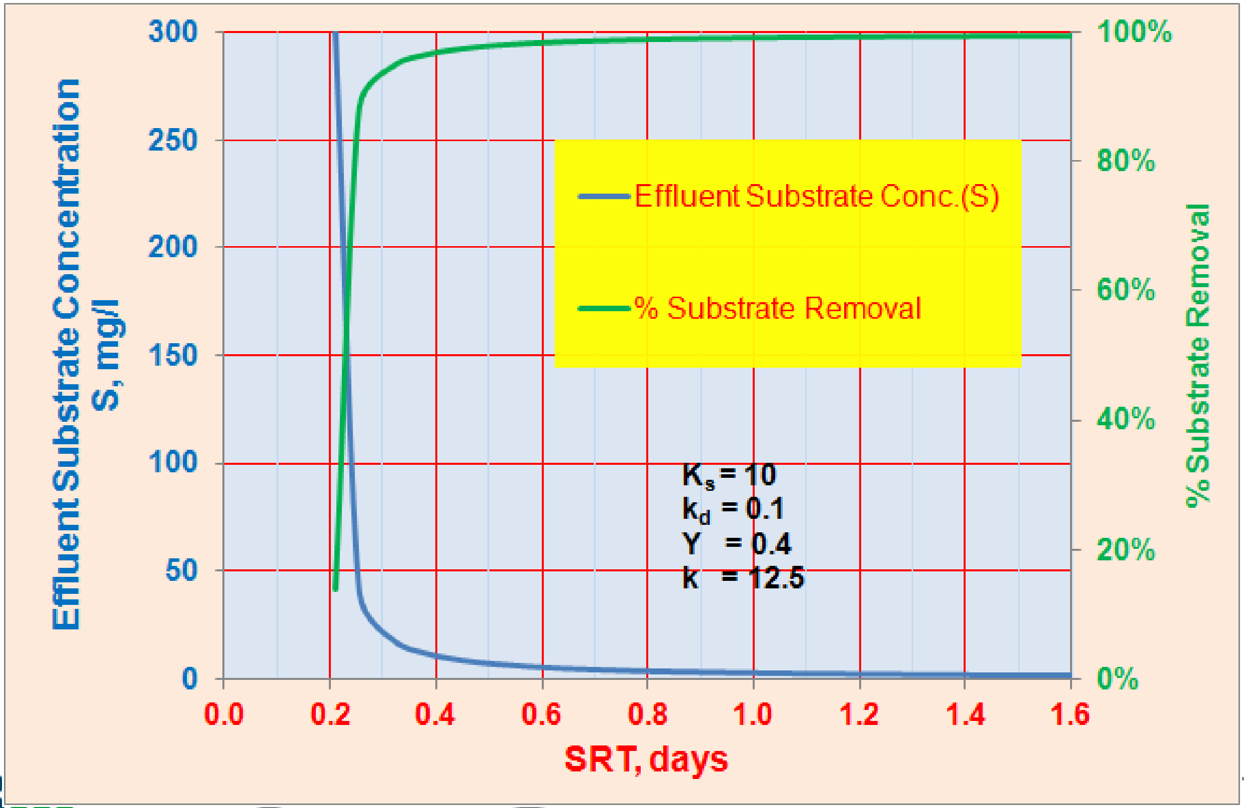
BOD REMOVAL IN THE ACTIVATED SLUDGE PROCESS



MINIMUM CONDITIONS NECESSARY TO MAINTAIN CARBONACEOUS BOD REMOVAL IN THE ACTIVATED SLUDGE PROCESS

- SRT=0.5 to 1 day
- pH=5 to 9
- Temperature – above freezing
- Dissolved Oxygen – above 0.5 mg/l

$$S = \frac{K_S\left[1 + k_d SRT\right]}{SRT(\mu_m - k_d) - 1}$$



Effluent Calculator

WHAT'S DIFFERENT FOR NITRIFICATION

- Need longer SRT
- Need more oxygen
- Need more alkalinity
- Need to be careful about inhibitory compounds
- Temperature has a greater impact

B IOLOGICAL NITRIFICATION

Aerobic autotrophic bacteria are responsible for nitrification

Nitrosomonas-bacteria

$$2NH_4^+ + 3O_2 + \rightarrow 2\,NO_2^- + 4H^+ + 2H_2O$$

Nitrobacter-bacteria

$$2NO_2^- + O_2 = 2NO_3^-$$

Total oxidation reaction

$$NH_4^+ + 2O_2 + \rightarrow NO_3^- + 2H^+ + H_2O$$

Nitrogen Cycle

Nitrification

Considering synthesis, for each g of ammonia nitrogen converted:

- 4.25 g are utilized.
- 0.16 g of new cells are formed.
- 7.07 g of alkalinity as CaCO3 are removed.
- 0.08 g of inorganic carbon are utilized in the formation of new cells.

Theoretically(without considering synthesis) the oxygen required for complete oxidation of ammonia is 4.57 g O_2/g N oxidized with 3.43 g O_2 g used for nitrite production and 1.14 g O_2/g NO_2 oxidized.

NITRIFICATION EFFECT ON HYDROGEN-ION CONCENTRATION (pH)

- Nitrification is pH sensitive and rates decline significantly at pH values below 6.8.
- Optimal nitrification rates occur at pH values in the range of 7.5 to 8.
- Alkalinity is added at WWTPs to maintain acceptable pH values for wastewater with low alkalinity.
- Alkalinity is added in the form of lime, soda ash, and sodium bicarbonate.

Alkalinity to maintain pH~7=Influent alkalinity - alkalinity used for nitrification + alkalinity added from denitrification

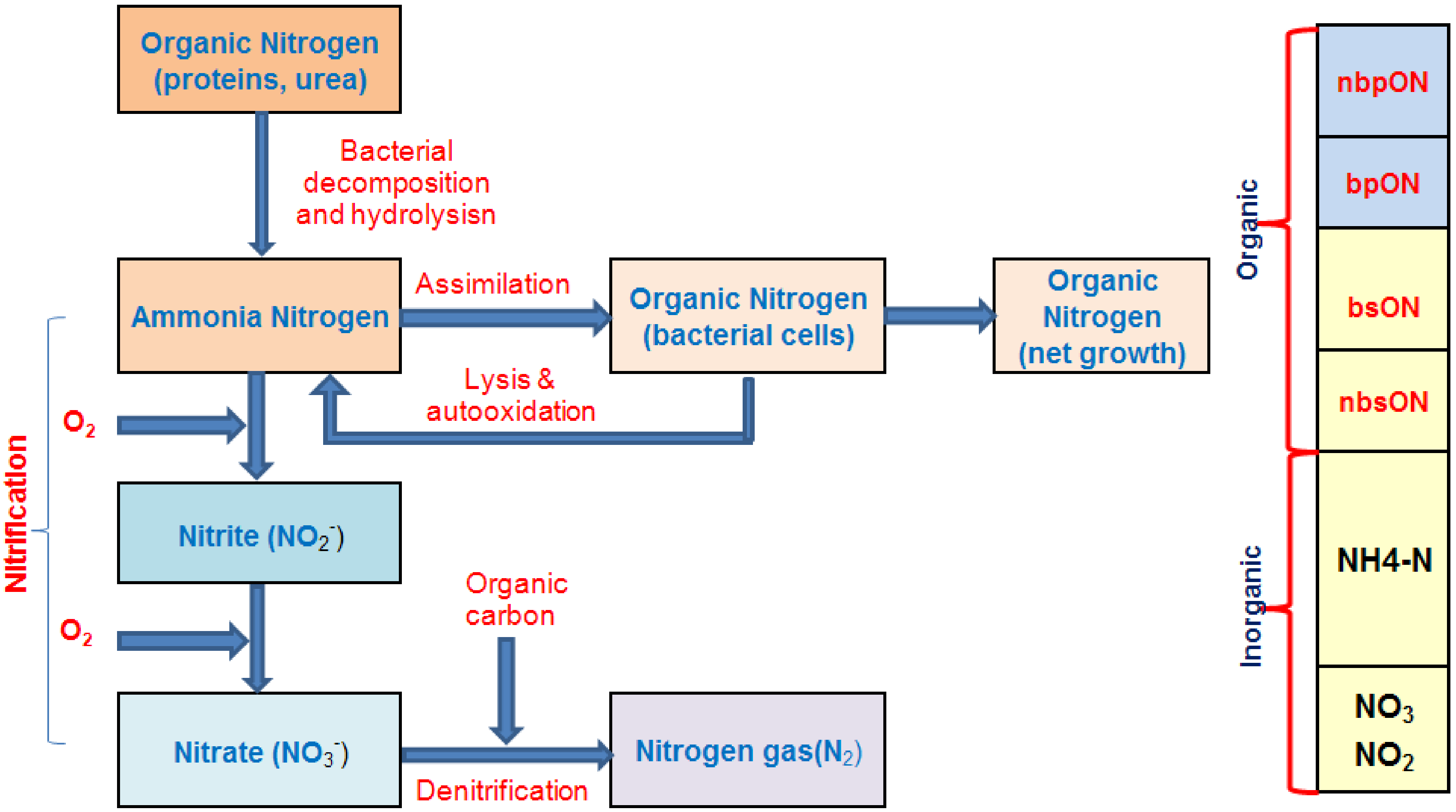
7.14 $gCaCO_3/g\ NH_4\text{-}N$ used for nitrification

OPERATING STRATEGIES FOR NITRIFICATION

What do we need to do to get my plant to nitrify?

Establish sufficient SRT

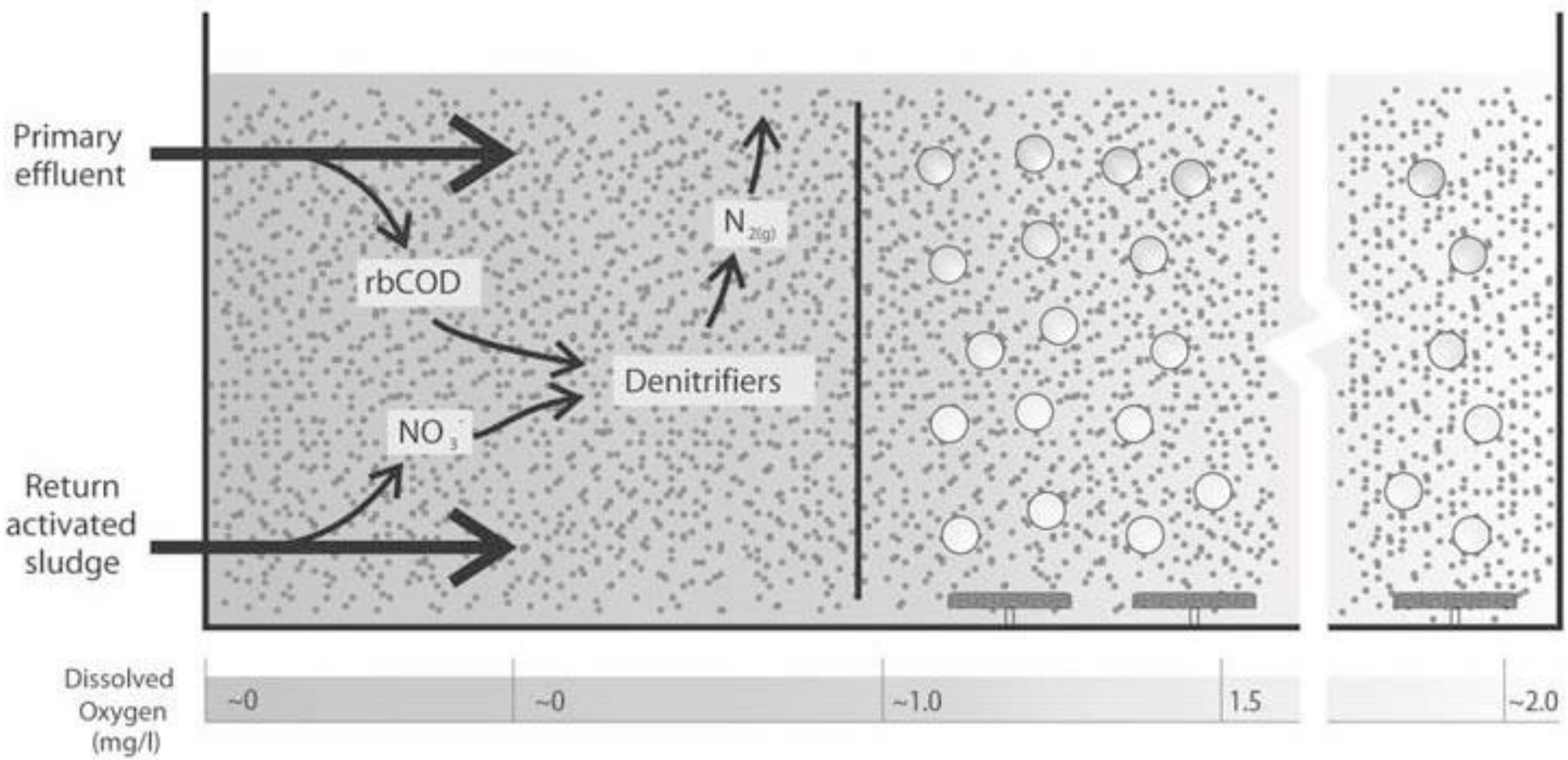
NITROGEN TRANSFORMATIONS IN BIOLOGICAL TREATMENT PROCESSES



Organic nitrogen is converted to ammonia during carbonaceous oxidation making the organic nitrogen available for oxidation to nitrate.

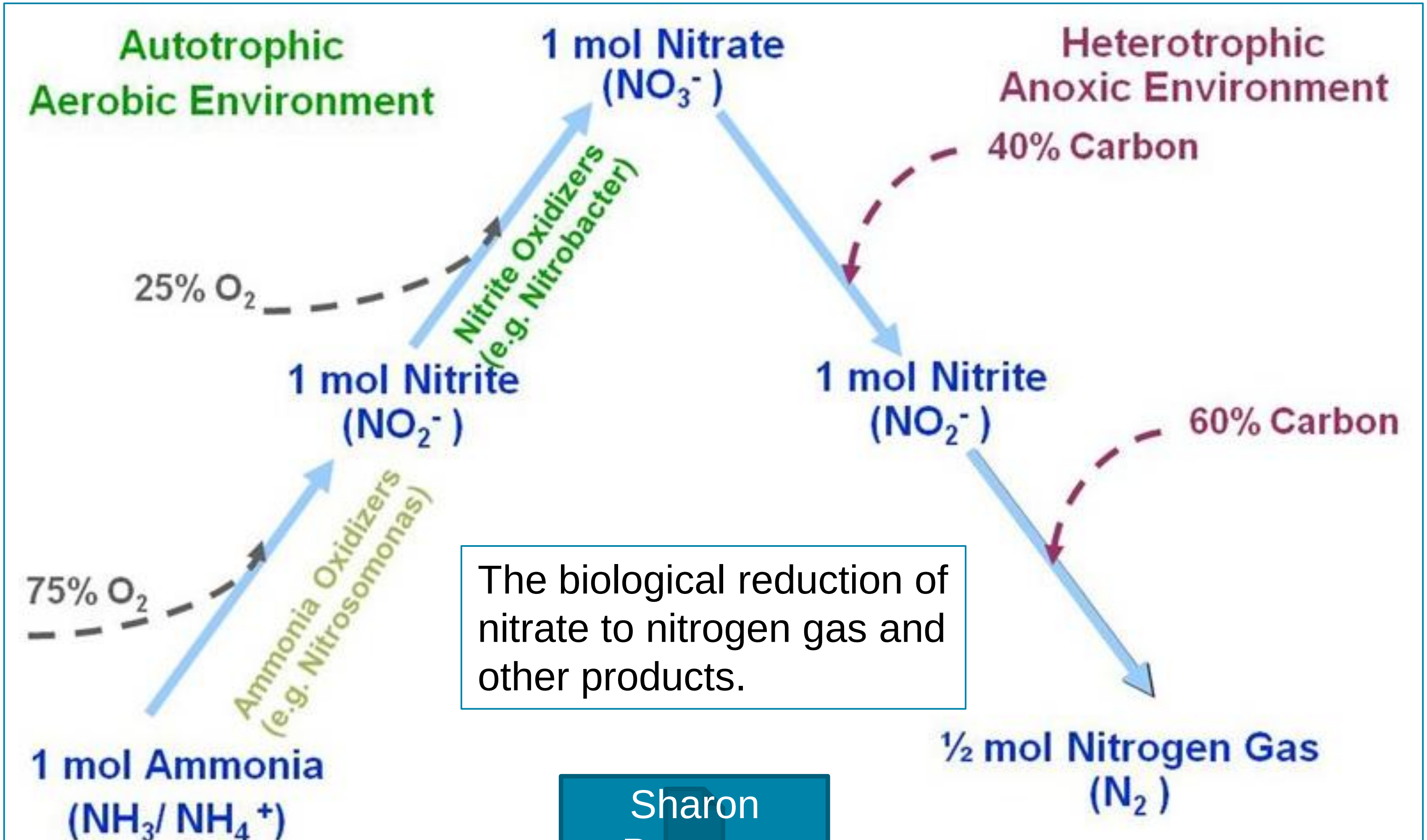
Ammonia is used as a source for nitrogen for cell synthesis. At low ammonia concentrations assimilative ammonia production from either nitrate or nitrite will occur to satisfy synthesis demand.

DENITRIFICATION



Denitrification

NITROGEN REMOVAL(DENITRIFICATION)

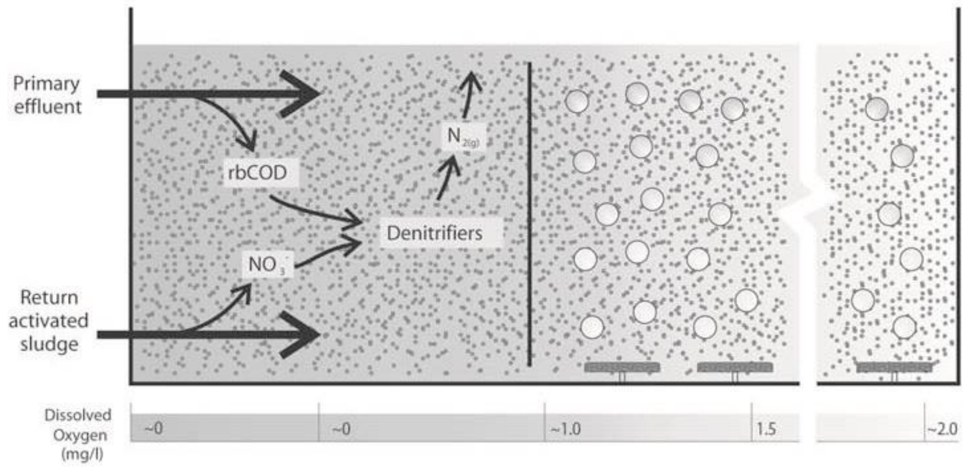


The biological reduction of nitrate to nitrogen gas and other products.

Sharon Process

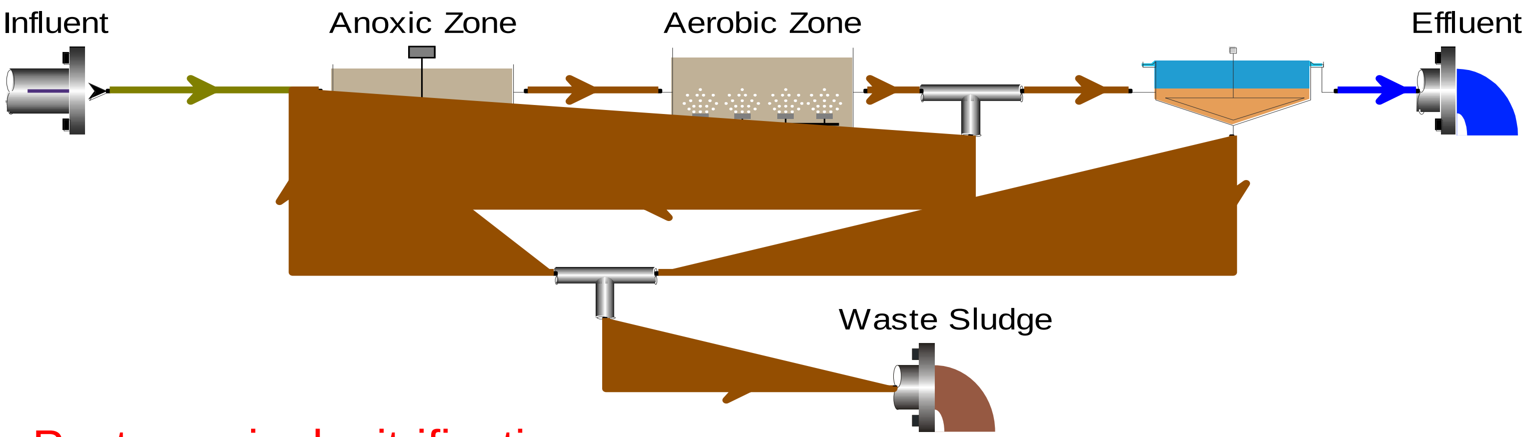
REQUIREMENTS FOR DENITRIFICATION

- Presence of nitrate.
- Absence(low) of DO(When DO=0, 100% denitrification)(Hetretrophic bacteria are more efficient when using oxygen than nitrate)
- Facultative bacteria mass.
- Carbon material(energy source)

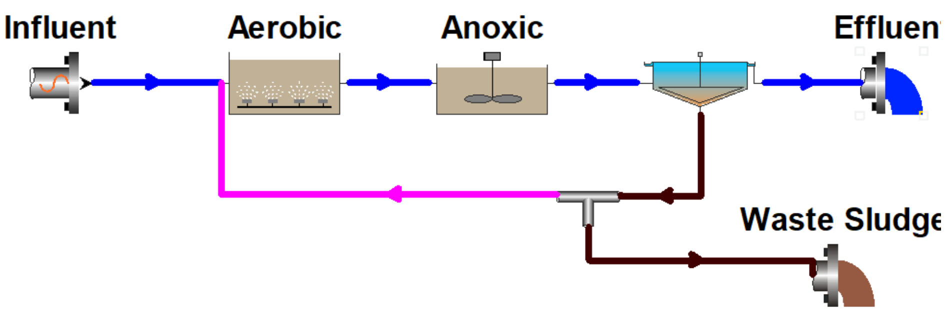


TYPES OF DENITRIFICATION PROCESSES

1- Pre-anoxic denitrification



2- Post-anoxic denitrification



3- Intermittenet

4- Simultaneous Nitrification-denitrification

DENITRIFICATION MICROBIOLOGY

- Bacteria capable of denitrification are both heterotrophic and autotrophic.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Nitric oxide   Nitrous oxide

- Sources for electron donor:
  - bsCOD in influent.
  - bsCOD produced during endogenous respiration.
  - Exogenous source(methanole ,acetate).

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

Biodegradable organic matter

Oxygen equivalent for of nitrate equals 2.86 g O2/g NO3-N.
Oxygen equivalent for of nitrite equals 1.71 g O2/g NO2-N.

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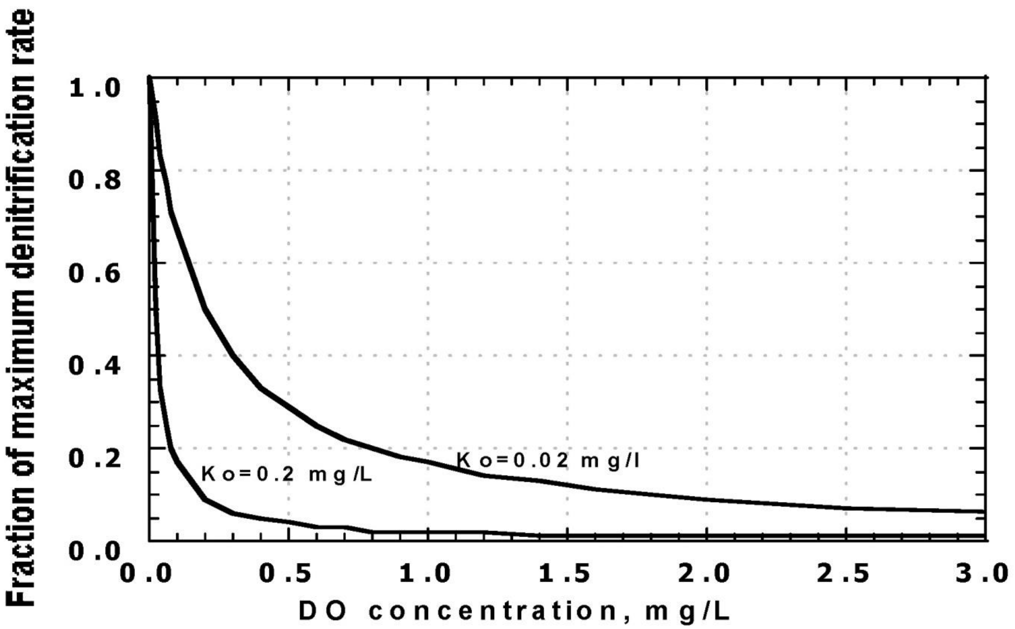
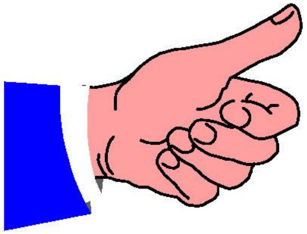
EFFECT OF DISSOLVED OXYGEN ON DENITRIFICATION

- Dissolved oxygen inhibits denitrification.
- As DO increases, denitrification rate decreases.





Rule of Thumb:

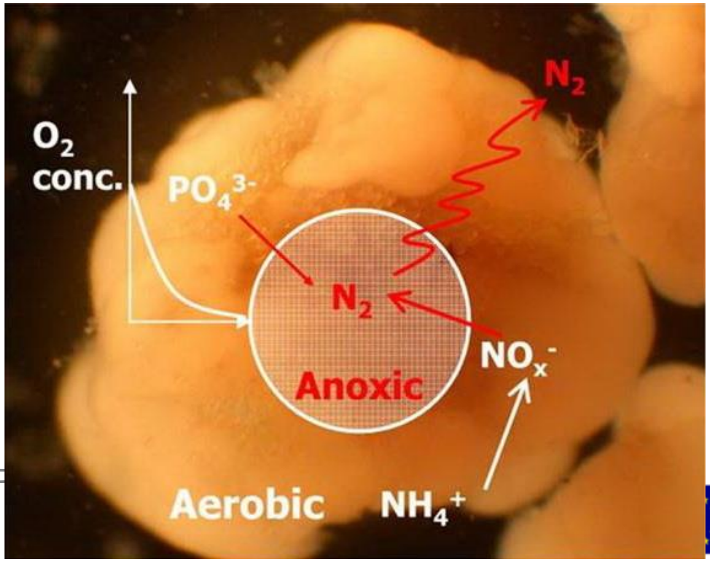
Maintain DO below 0.3 mg/l in anoxic zone to achieve denitrification.

EFFECTS OF AVAILABLE CARBON SOURCE ON DENITRIFICATION

- Denitrification rate vary greatly depending upon the source of available carbon.
  - Highest rates are achieved with addition of an easily-assimilated carbon source as methanol.
  - Lower denitrification rate is achieved with raw wastewater or primary effluent as the carbon source.
  - Lowest denitrification rate is observed with endogenous decay as the source of carbon.

SIMULTANEOUS NITRIFICATION/DENITRIFICATION(SNDN)

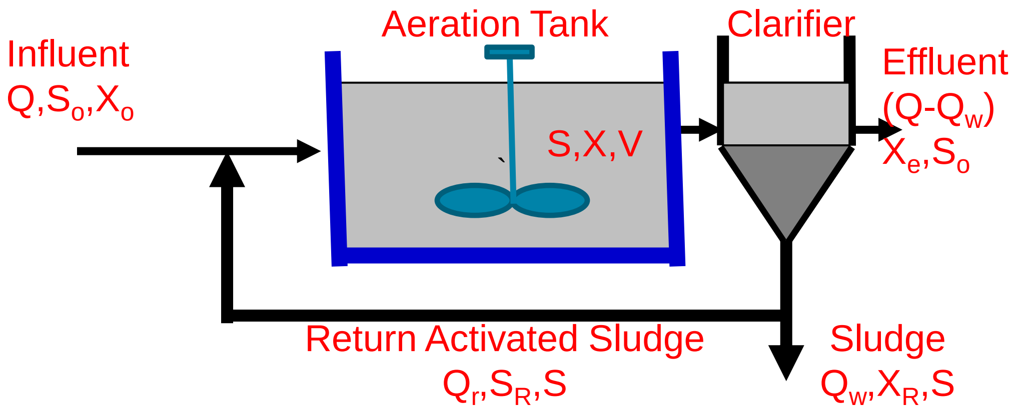
- Biological process where nitrification and denitrification occur concurrently in the same aerobic reactor(or in the same floc).
- 80 to 96% N removal can be realized.
- COD:N ratio of at least 5 is required to maximize denitrification.
- Optimum bulk DO conc. From 0.2 mg/l to 0.7 mg/l.



Denitrification Tanks

AEROBIC BIOREACTOR SIZING

PARAMETERS REQUIRED FOR AEROBIC BIOREACTOR DESIGN



Bioreactor Design Requires:

- Observed Sludge yield estimation(Y_{obs}).
- Selection of the key operating parameters:
  - Design aerobic sludge age(SRT).
  - Design MLSS concentration.
  - DO.
  - Return sludge rate.

DESIGN PROCEDURE FOR AEROBIC BIOREACTORS

a) **Select observed yield** (Y_{obs})
b) **Select SRT based on effluent requirements and process objectives.**
c) **Select Design MLSS(secondary clarifier design)**
d) **Select other operating parameters(DO,pH, recycle rate, etc)**
e) **Calculate aerobic reactor volume based on above.**

AEROBIC REACTOR SIZING

$$Mass\_of\_solids\_in\_Reactor = Bioreactor\_volume \times MLSS$$

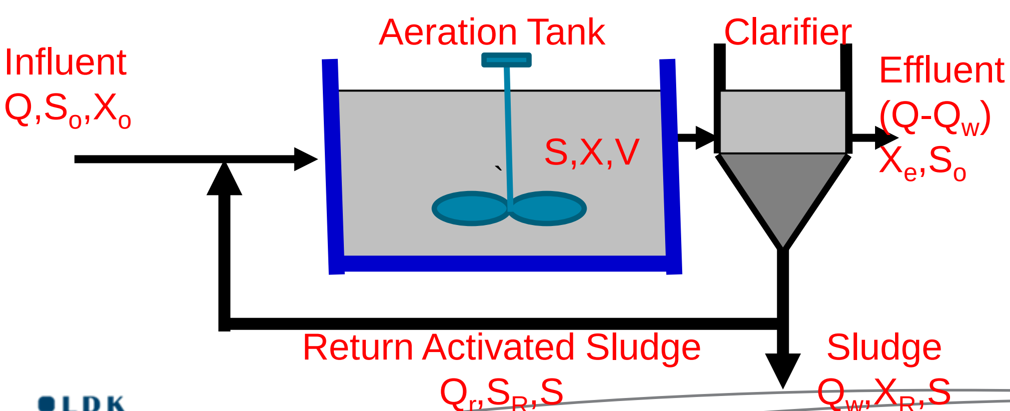
$$Bioreactor\_volume = \frac{Mass\_of\_solids\_in\_Reactor}{MLSS}$$

$$Mass\_of\_solids\_in\_Reactor = Waste\_sludge\_production \times SRT$$

$$Waste\_sludge\_production = BOD\_removed \times Y_{obs}$$

$$V = \frac{Q \times Y_{obs} \times S_o \times SRT}{MLSS}$$

$$V = \frac{Q \times Y_{obs} \times (S_o - Se) \times SRT}{MLSS}$$



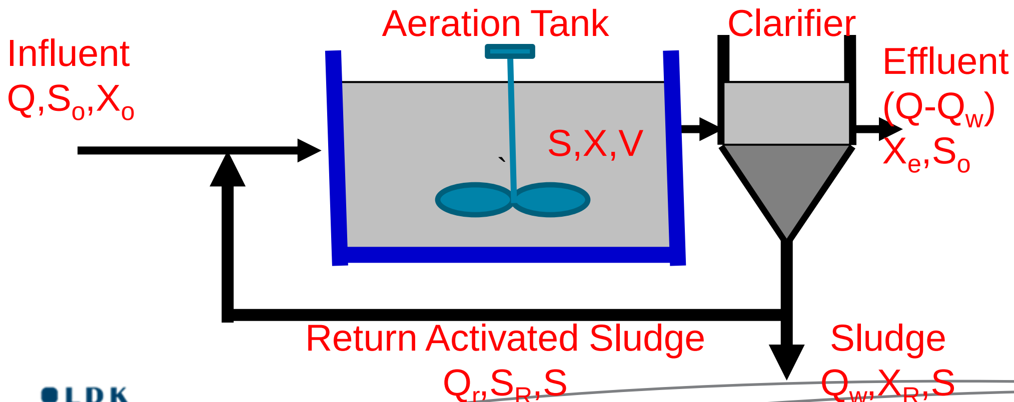
Where
- V = Aerobic bioreactor volume.
- Y_{obs} = observed yield.
- S_o = influent substrate concentration.
- S_e = effluent substrate concentration.
- SRT = Sludge age
- MLSS = Mixed liquor suspended solids concentration

CAPACITY ASSESSMENT FOR AEROBIC REACTOR WITH KNOWN VOLUME

$$V = \frac{Q \times Y_{obs} \times S_o \times SRT}{MLSS}$$

$$V = \frac{Q \times Y_{obs} \times (S_o - Se) \times SRT}{MLSS}$$

$$BOD\_Load = \frac{V \times MLSS}{Y_{obs} \times SRT}$$



Where
V = Aerobic bioreactor volume.
Y_{obs} = observed yield.
S_o = influent substrate concentration.
S_e = effluent substrate concentration.
SRT = Sludge age
MLSS = Mixed liquor suspended solids concentration

HRT AND VOLUMETRIC LOADING FOR BIOREACTORS

- Hydraulic retention time (HRT).

$$\tau = \frac{V}{Q}$$

Where:
τ = hydraulic retention time in reactor.
V = reactor volume.
Q = Influent flow.

- Volumetric Loading

$$B_v = \frac{Q \cdot S_0}{V} = \frac{S_0}{\tau}$$

Where:
B_v = Volumetric loading
V = reactor volume
S_o = influent substrate concentration.
Q = Influent flow.

Neither of the above approaches should be used for Bioreactor Sizing

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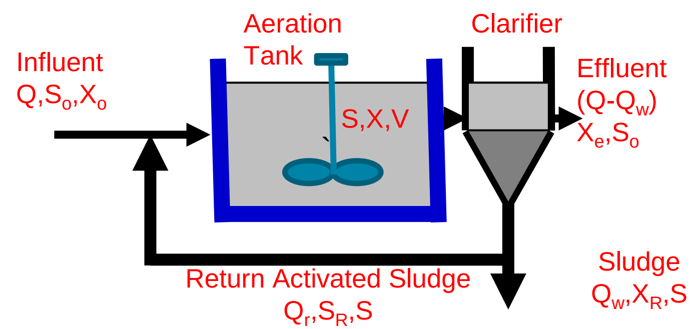
F/M RATIO FOR BIOREACTORS SIZING

$$\left[\frac{F}{M}\right] = \frac{Total\_applied\_substrate\_rate}{Total\_microbial\_biomass} = \frac{QS_o}{VX} = \frac{S_o}{\tau X}$$

$$\tau = \frac{V}{Q}$$

- The F/M ratio is not recommended for direct sizing of bioreactors.
- The F/M ratio forms the basis of some empirical relationships and sizing techniques for selectors.
- SRT and F/M ratio are inversely propositional and are both indicators of biological growth rate.



Where:

F/M : food to biomass ratio, g BOD or bsCOD/g VSS.d

Q : influent wastewater flowrate, m3/d

S_o :Influent BOD or bCOD concentration, g/m3.

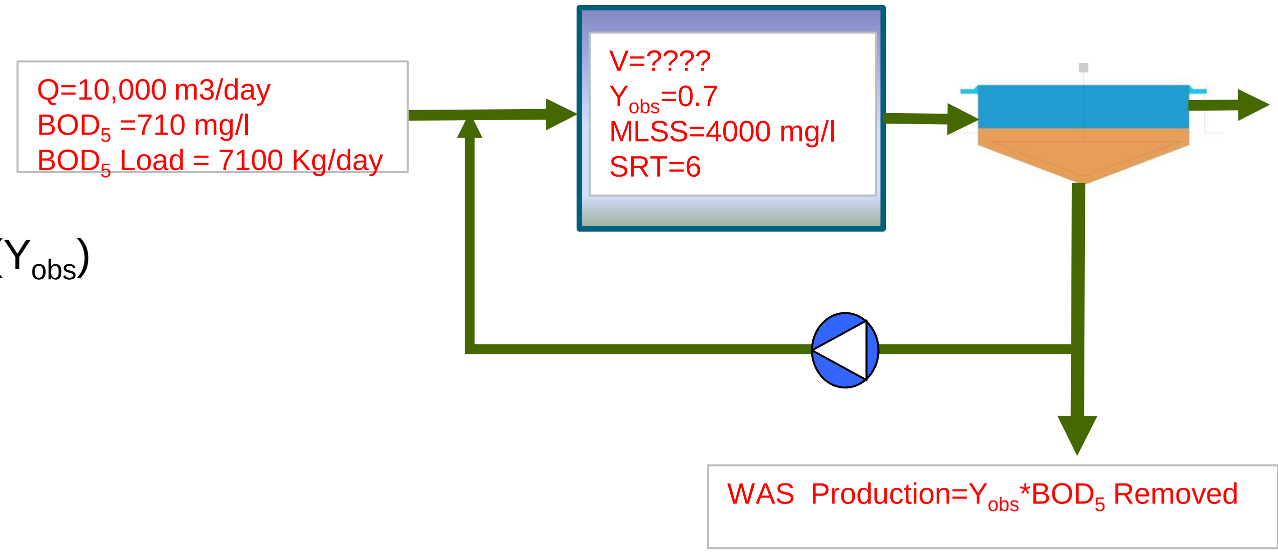
V : aeration tank volume, m3.

X : mixed liquor biomass concentration in the aeration tank, g/m3.

τ : hydraulic retention tie of aeration tank, V/Q,d.

EXAMPLE FOR BIOREACTOR SIZING

- Given
  - Influent Flow(Q)
  - Influent BOD_5 Load
  - Solids observed Yield(Y_{obs})
  - SRT
  - MLSS



Waste Sludge production = BOD removed* Y_{obs}
Mass of Sludge in Basin = Waste Sludge Production x SRT

$$Basin\ Volume = \frac{Mass\ of\ Sludge\ in\ Basin}{MLSS}$$

$$V = \frac{Q \times S_o \times Y_{obs} \times SRT}{MLSS}$$

$$Basin\ Volume = \frac{7100 \times 0.7 * 6}{4} = 7455\ m3$$

SRT

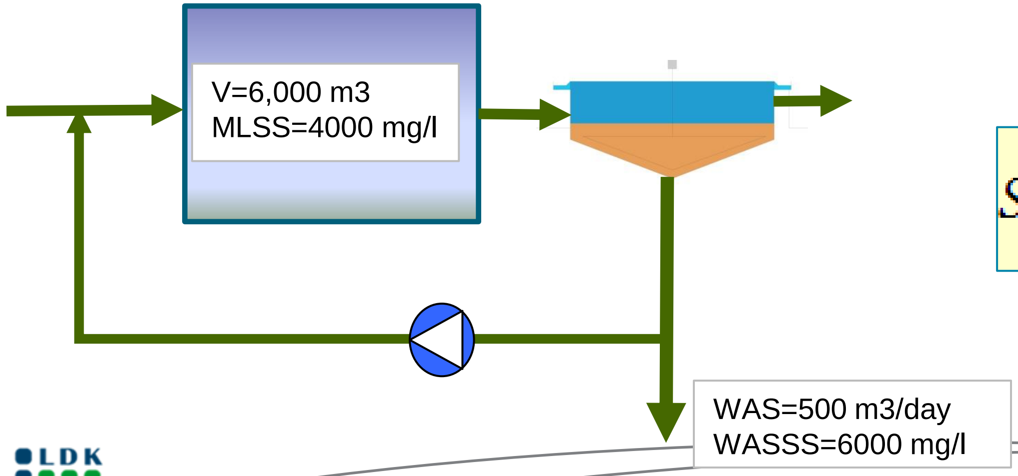
SLUDGE AGE – SOLIDS RETENTION TIME (SRT)

Sludge Age(SRT) : Average residence time of the activated sludge particle in the bioreactor.

$$SRT = \frac{Mass\_of\_Solids\_in\_Bioreactor}{Mass\_of\_solids\_wasted\_per\_day}$$

$$SRT = \frac{V \times MLSS}{Q_W \times RASSS}$$

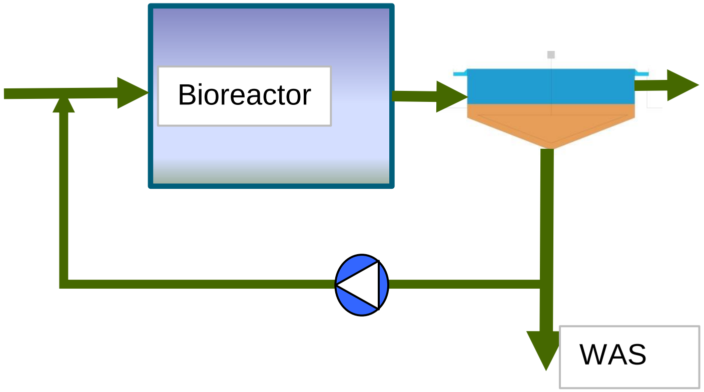
- SRT may be further defined as total, aerobic, anoxic, and anaerobic based on the specific reactor volume and biomass used in the numerator of the SRT equation.
- Sludge age is maintained by ‘wasting’ a proportion of the sludge each day
  - E.g. if 5% of the sludge in a system is wasted each day, you would have a sludge age of 20 days.



$$SRT = \frac{6000 \times 4}{500 \times 6} = 8\ days$$

SLUDGE AGE(SRT) Vs %WASTE SLUDGE

Percent of Waste Sludge From Sludge in the System	Sludge Age SRT (days)
4%	25.0
5%	20.0
10%	10.0
15%	6.7
20%	5.0
25%	4.0
30%	3.3
31%	3.2
32%	3.1
33%	3.0



RELATIONSHIP BETWEEN SRT & F/M RATIO

SRT is inversely proportional to the F/M ratio.

$$\left[\frac{F}{M}\right] = \frac{Total\_applied\_substrate\_rate}{Total\_microbial\_biomass} = \frac{Q \times S_o}{V \times MLSS} = \frac{S_o}{\tau X}$$

$$V = \frac{Q \times Y_{obs} \times S_o \times SRT}{MLSS}$$

$$\frac{1}{SRT} = \frac{Q \times S_o}{V \times MLSS} \times Y_{obs}$$

$$\frac{1}{SRT} = \left[\frac{F}{M}\right] \times Y_{obs}$$

$$SRT = \frac{1}{\left[\frac{F}{M}\right] \times Y_{obs}}$$

S_o = Influent substrate concentration assuming effluent substrate concentration is negligible

VARYING APPROACHES TO CALCULATING SRT

- Include biomass in aeration tank only(aerobic SRT)
- Include biomass in aeration tanks and clarifiers.
- Include biomass in anoxic reactors(anoxic SRT).