



# Biological Wastewater Treatment Training Series Presentation #8: Biological Nitrification-Denitrification

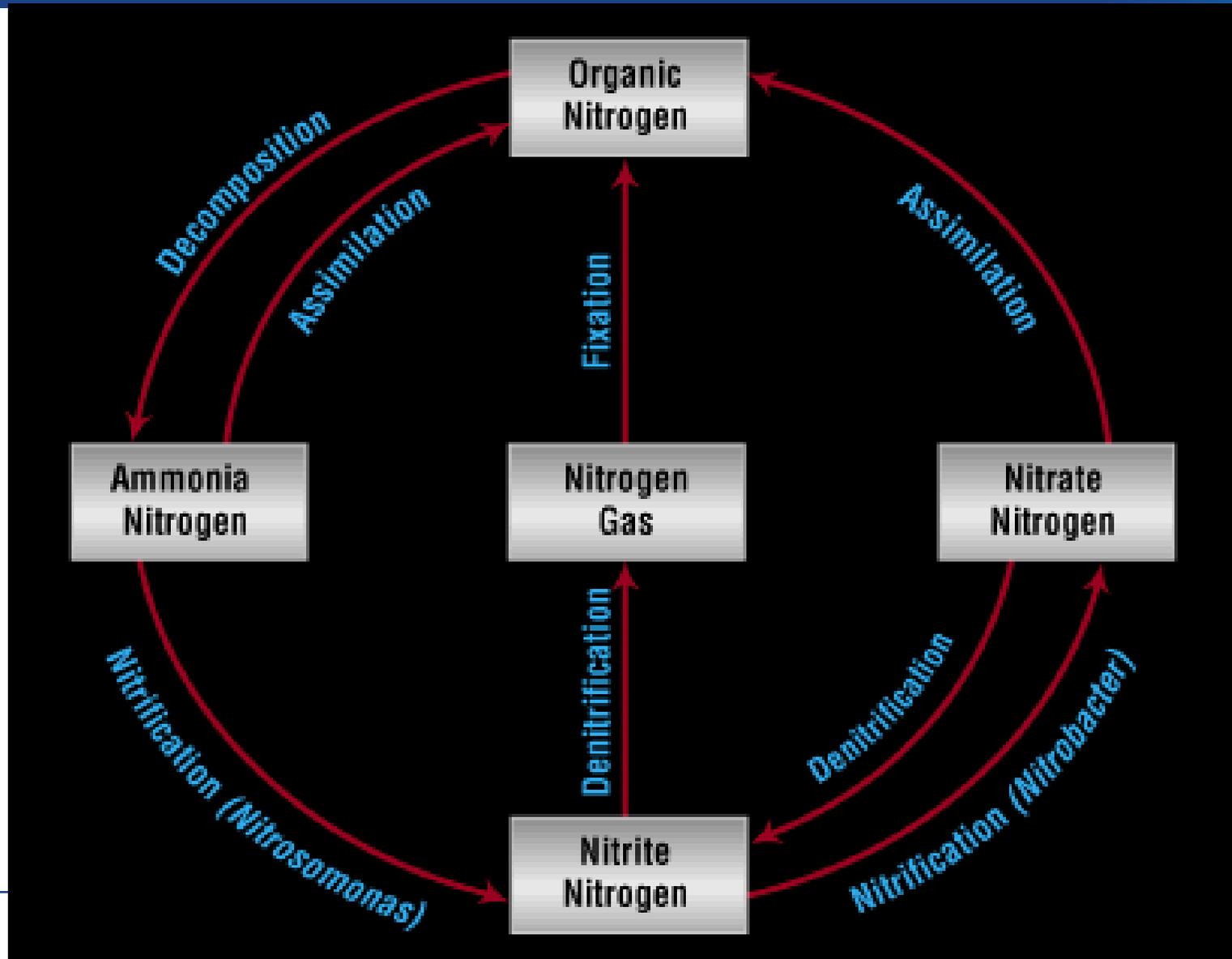
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# Introduction to Biological Nitrification-Denitrification

References: Metcalf & Eddy, 4<sup>th</sup> edition  
Water Environment Federation: Activated Sludge Process Control

# Nitrogen Cycle



# Algae Growth in Activated Sludge Final Clarifier

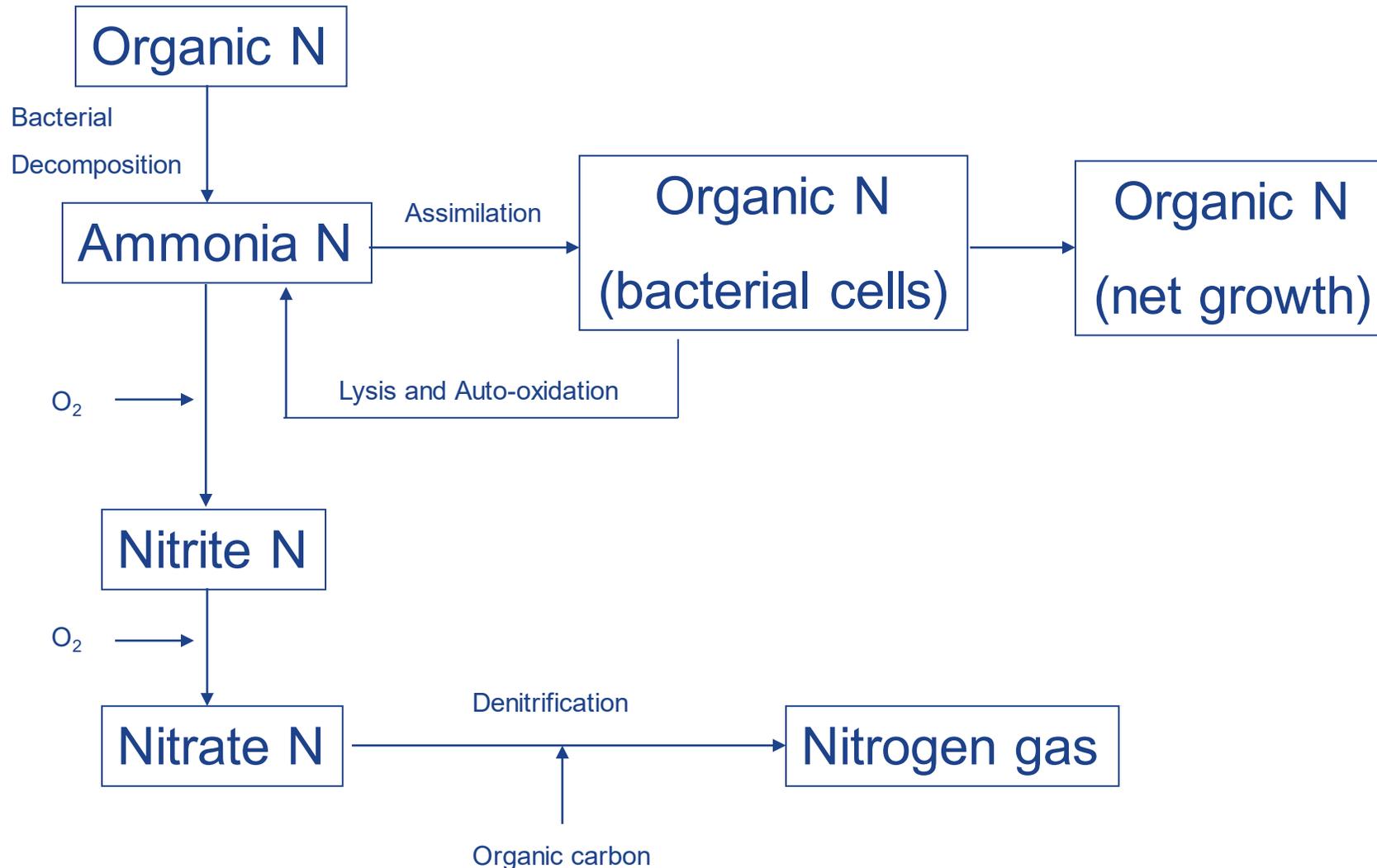


Algal blooms can be caused by excess nutrient levels.

# Definition of Nitrification

Nitrification: A bacterial process that converts ammonia nitrogen to nitrate and consumes alkalinity.

# Biochemical Reactions Involving Nitrogen Species



# Nitrification: Biomass Yield

- In most wastewaters, CBOD  $\gg$  N
- Heterotrophic organism yield  $\gg$  autotrophic organism yield
- Therefore, autotrophic population is usually a small fraction of total biomass
- All biokinetic relationships for the design of nitrification systems are based on the growth kinetics of *Nitrosomonas* (ammonia oxidizing bacteria ... AOB)!
- Note: other bacteria can nitrify (*Nitrosococcus*, *Nitrospirra*, *Nitrosocystis*, & *Nitrosoglea*)

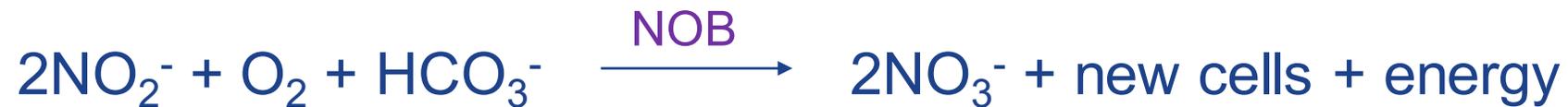
# Nitrogen Removal by Assimilation

- N is essential component of microbial cells ( $C_5H_7O_2N$ )
- Any net growth of biomass that is removed from the waste stream results in N removal
- Amount of N removed by assimilation is limited by amount of net growth - depends on:
  - CBOD content of wastewater
  - System operating conditions
- N removed by assimilation = 0.08 to 0.12 x biomass production

# Nitrogen Removal by Assimilation

- N removed by assimilation is ~ 2% to 5% of the raw wastewater BOD
- N removal in treating domestic wastewater usually ranges from 8% to 20%
- For wastewater high in BOD, N removal may be very significant
- However, when a large portion of assimilated N returns to influent from sludge handling processes (anaerobic digestion and heat treatment), overall N removal will be less

# Nitrification: Biochemical Reactions



The overall reaction is:



AOB – *Ammonia Oxidizing Bacteria*; NOB – *Nitrite Oxidizing Bacteria*

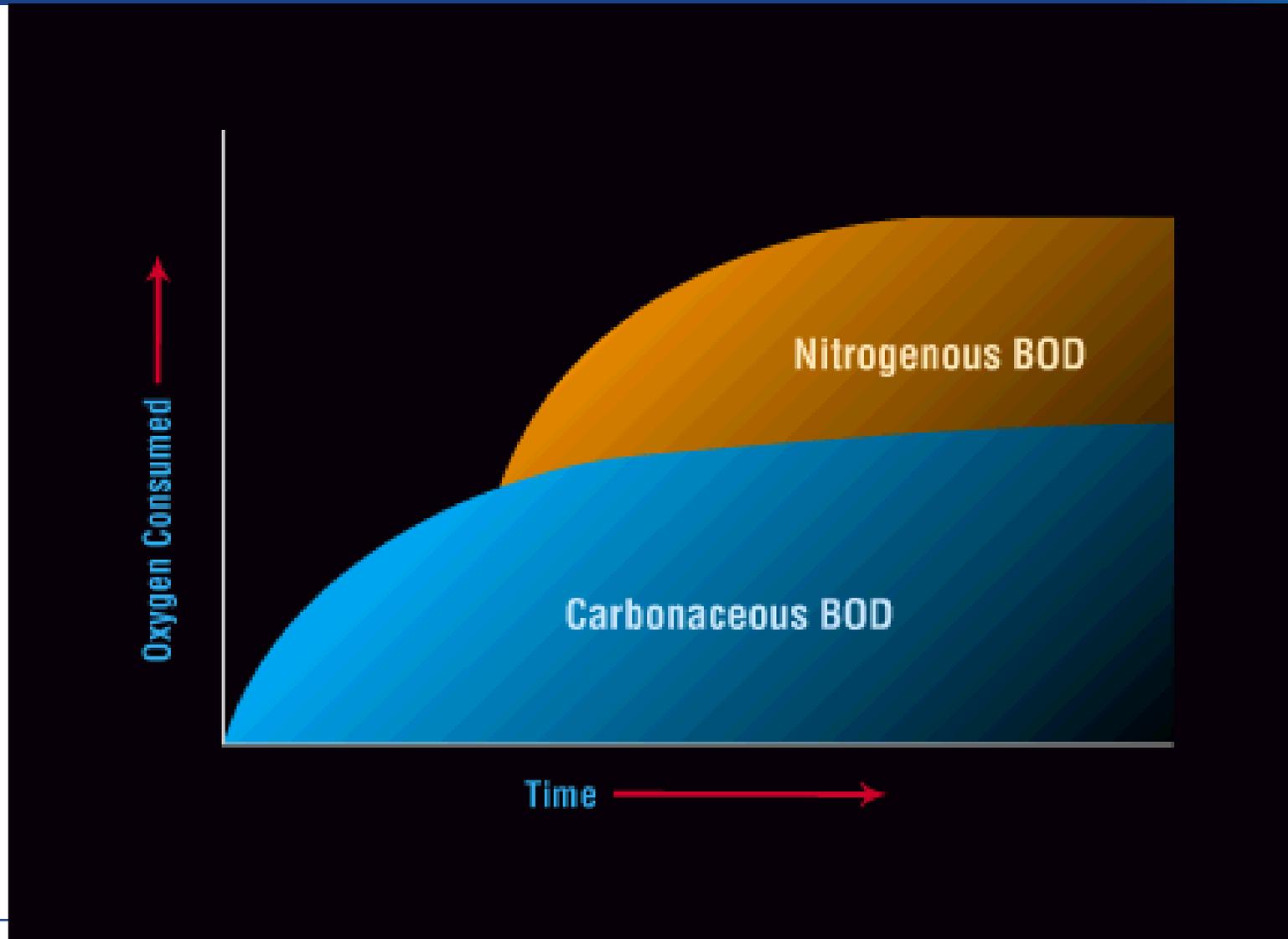
# Nitrification Requirements

O <sub>2</sub> requirement	4.33 g O <sub>2</sub> / g NH <sub>4</sub> -N
Alkalinity destroyed	7.14 parts/ part NH <sub>4</sub> -N
New cells formed	0.15 part/ part NH <sub>4</sub> -N
Inorganic carbon consumed	0.08 part/ part NH <sub>4</sub> -N

# Nitrification Oxygen Demand

Nitrification coupled with CBOD removal typically requires 25% to 45% more oxygen than conventional activated sludge processes designed just for CBOD removal.

# Oxygen Consumed by the Activated Sludge Process



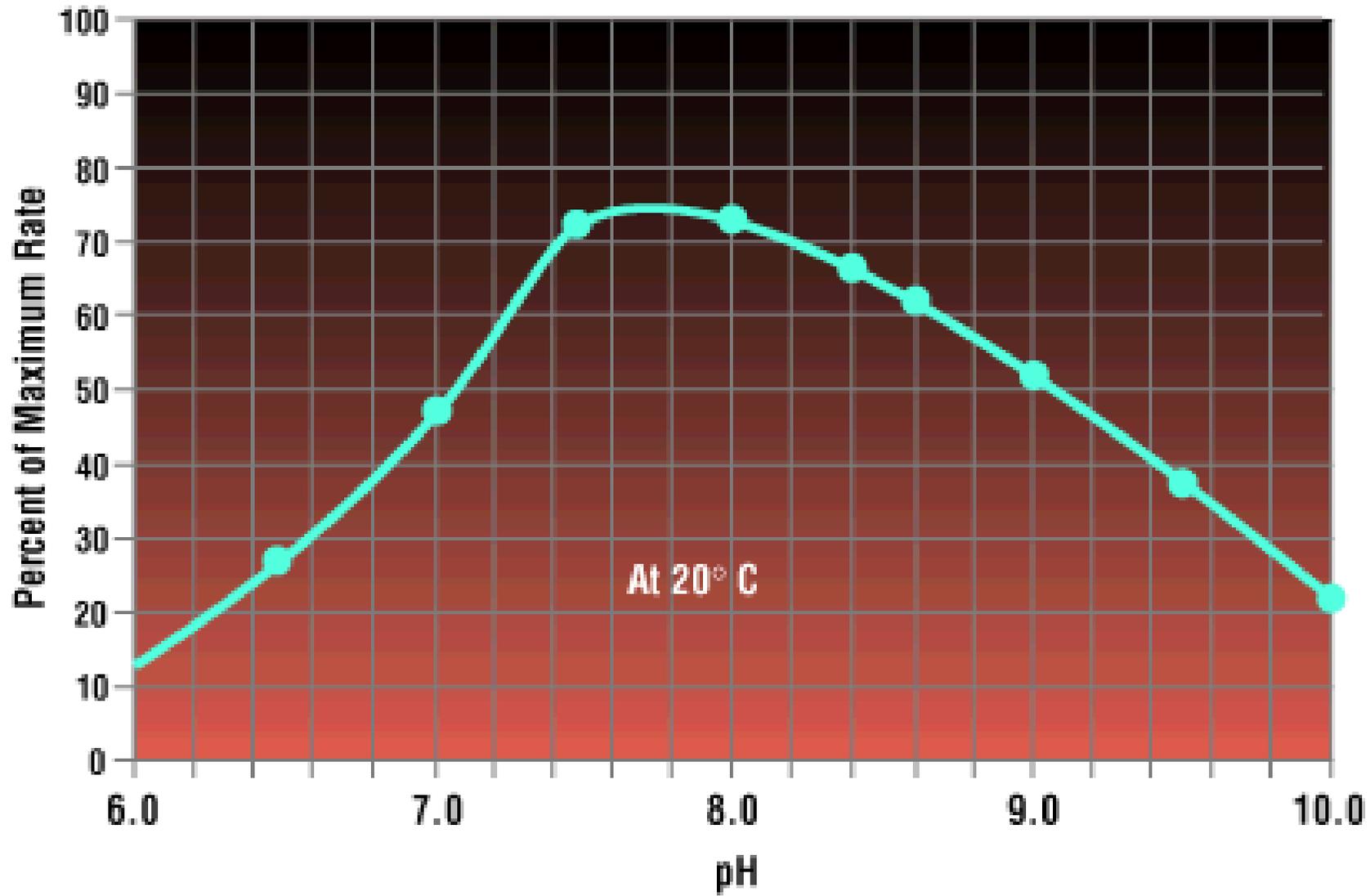
# Nitrification: Alkalinity & pH

- Wastewater with low alkalinity and/or high ammonia-N content may need supplemental alkalinity to maintain optimum pH (7.0 to 8.0)
- For wastewater with TKN = 50 mg/L, you need about 400 mg/L alkalinity to have a residual alkalinity of 40 mg/L
- Drop in pH is mediated by CO<sub>2</sub> stripping during aeration

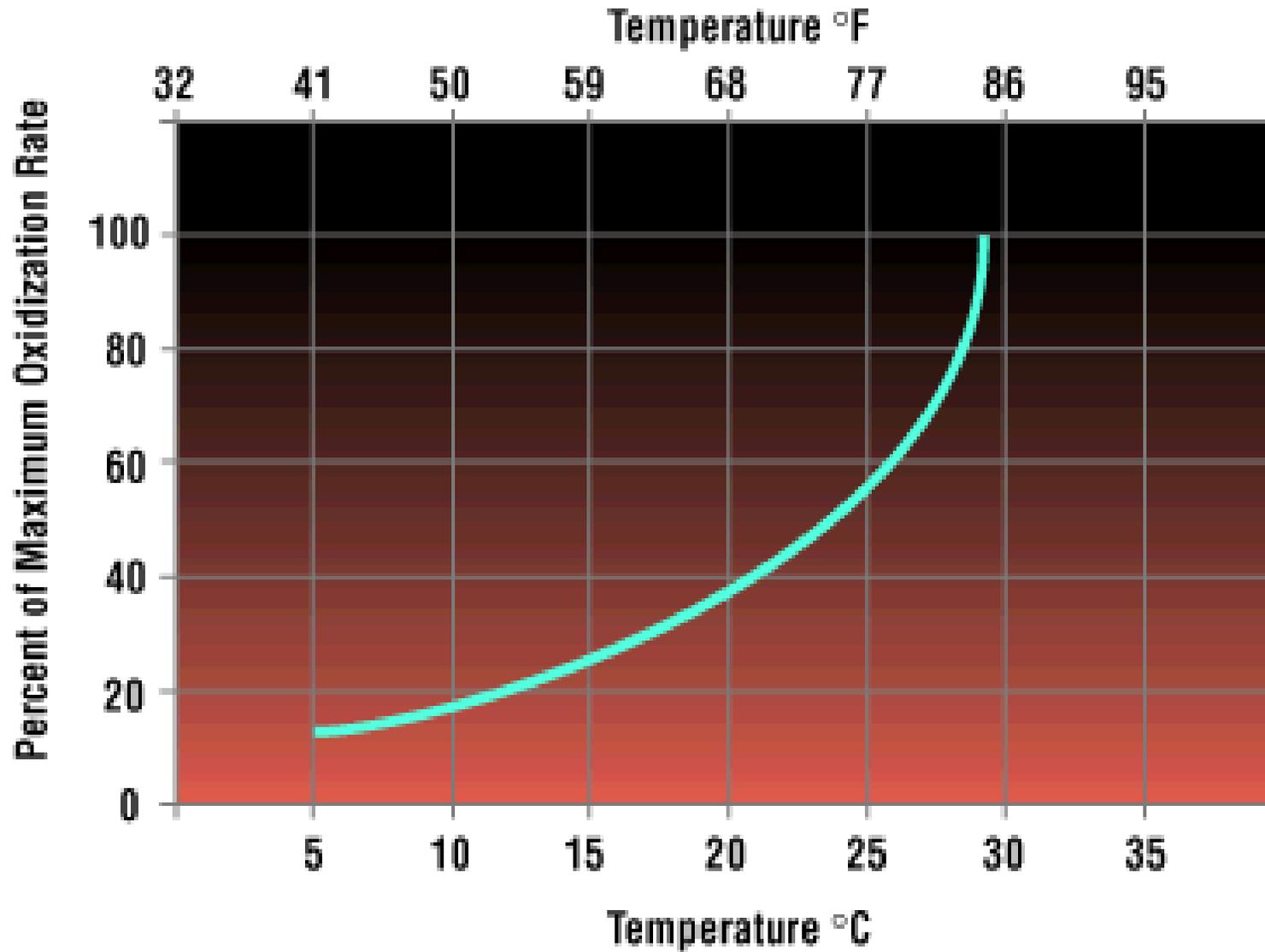
# Nitrification: Biokinetic Relationships

- The actual growth rate of nitrifiers depends on  $\text{NH}_4\text{-N}$  concentration, DO concentration, pH, sludge age, temperature, and inhibition
- To maintain a population of nitrifiers in activated sludge, the sludge age or solids retention time (SRT) must exceed the reciprocal of the nitrifiers' net specific growth rate
- The minimum SRT or sludge age required for significant nitrification is about 5 days at  $23^\circ\text{C}$

# Percent of maximum rate of nitrification at constant temperature versus pH



# Effect of temperature on oxidization of ammonium by Nitrosomonas in Activated Sludge



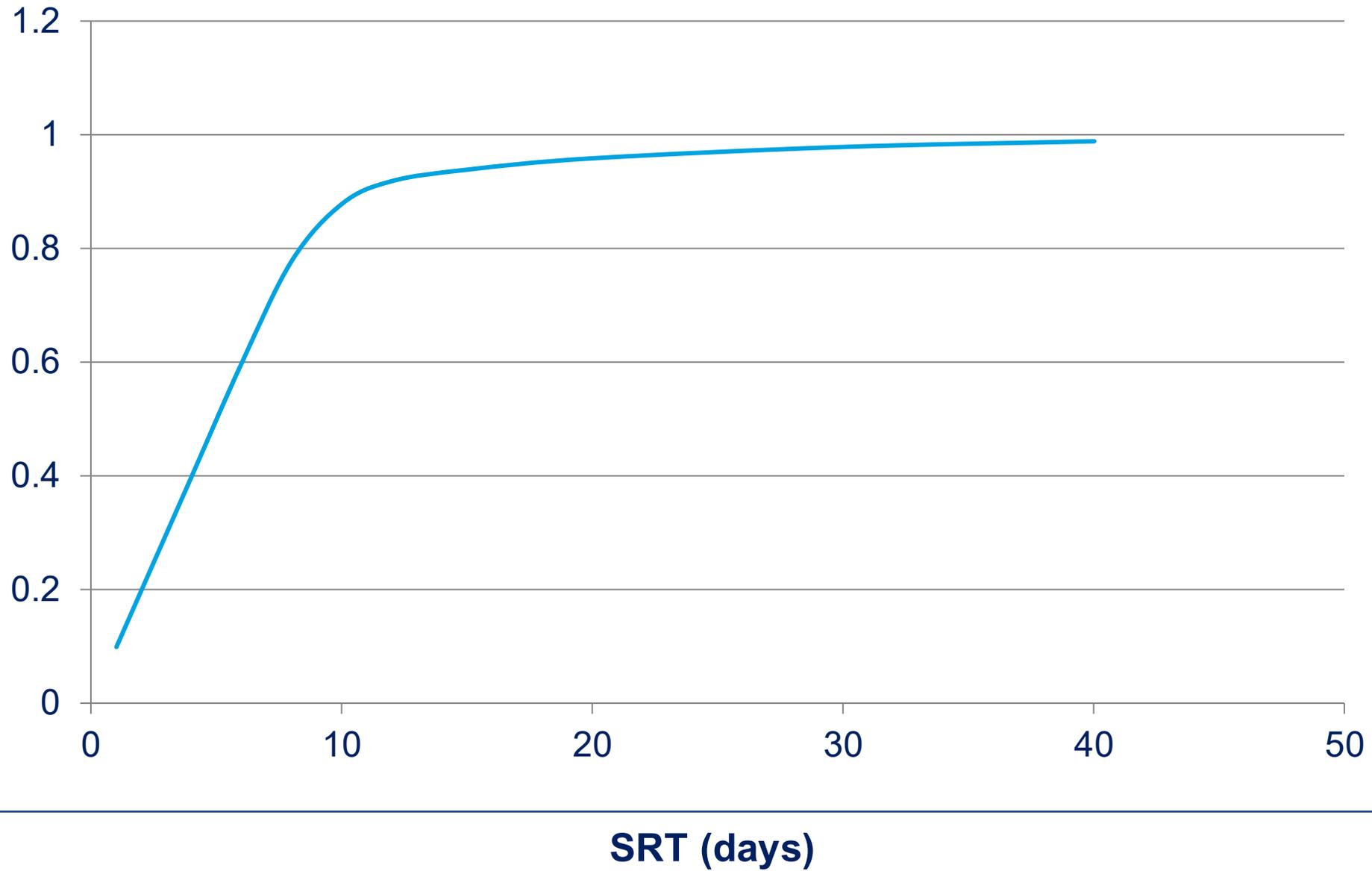
# Effect of DO on Nitrification Rates

<u>DO, mg/L</u>	<u>% of Maximum Rate</u>
0.1	16
0.5	50
1.0	67
2.0	80
3.0	86

# Minimum MCRT for Good Nitrification Efficiency

Most processes will require an MCRT of 8 days or more to achieve >75% nitrification efficiency.

# Fraction $N_{ox}$ Oxidized at 20°C



# Inhibition of Nitrification

Nitrifying organisms are subject to inhibition by:

- Free ammonia and nitrous acid
- Heavy metals
- Organic compounds

If inhibitory compounds are present in wastewater, the performance of separate stage or combined systems will likely be different

# Inhibition of Nitrification

- ***Separate stage system*** - inhibitory substance will probably be degraded in first stage and second stage kinetics will proceed normally
- ***Combined system*** - performance may be poorer because of reduced degradation of the inhibitory substance

# Inhibition of Nitrification

- Higher SRT should improve nitrification
- Plug flow system will be more susceptible to toxicity at front end of aeration tank
- For industrial wastewaters or municipal wastewaters with high industrial input, the nitrification rate may be sharply reduced
- Where inhibition is present, consider adding powdered activated carbon (PAC)

# Inhibition of Nitrification

Nickel	0.25 mg/L
Chromium	0.25 mg/L
Copper	0.1 - 0.5 mg/L
Zinc	0.1 - 3.0 mg/L

Wide range of organic compounds

# Denitrification

Denitrification is the biological conversion of  $\text{NO}_3\text{-N}$  to more reduced forms:

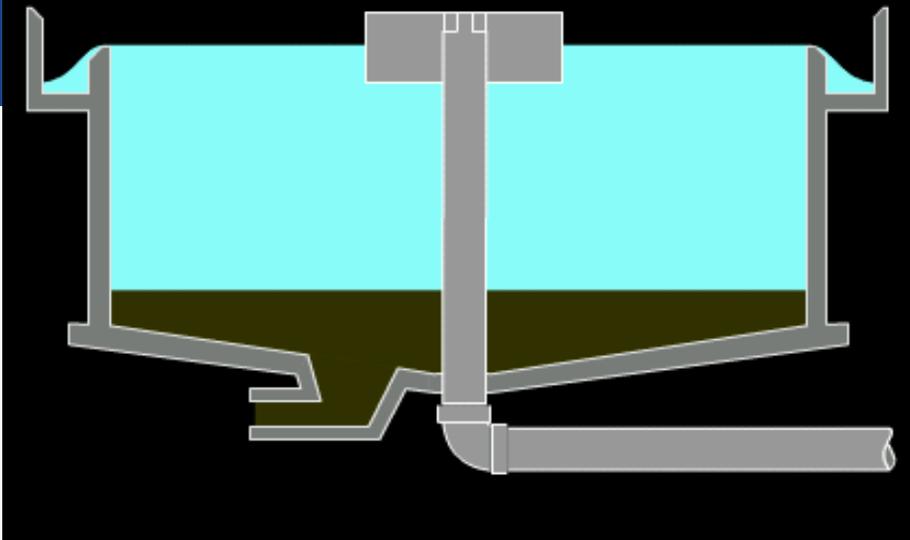


Denitrification generally occurs under anoxic conditions and is achieved by facultative heterotrophs

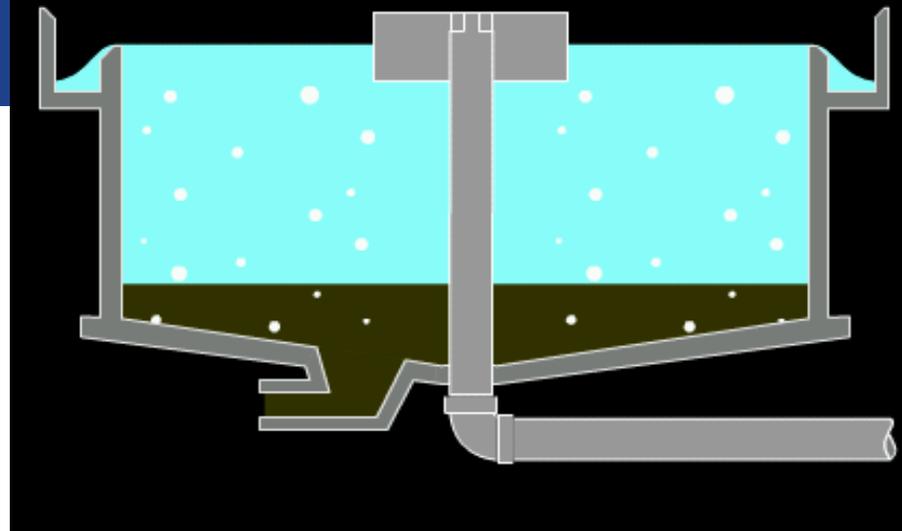
# Denitrification May Cause Operational Problems

Denitrification can occur unintentionally causing operational difficulties.

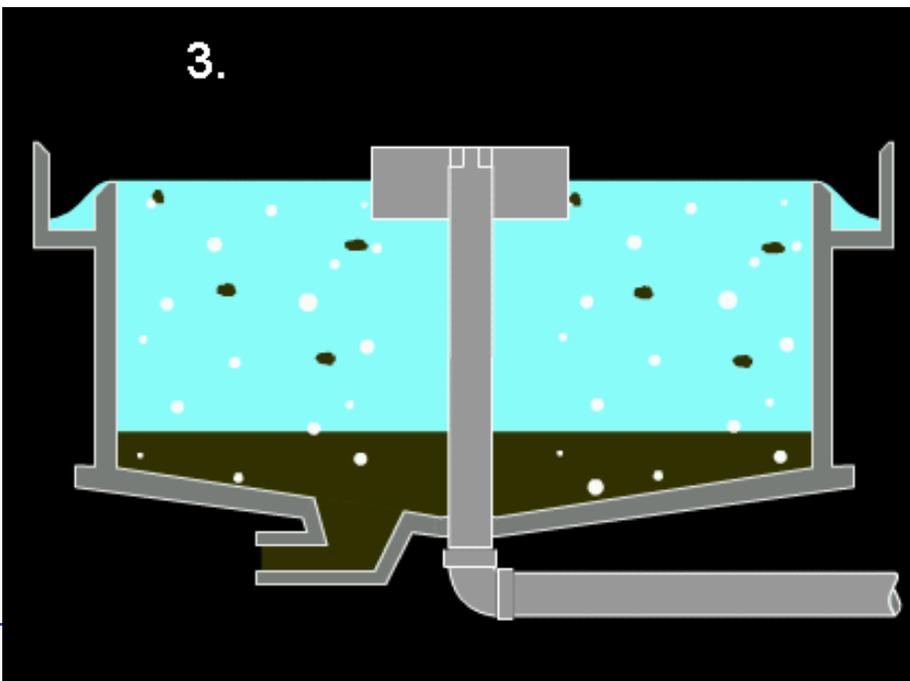
1.



2.



3.



Denitrification can cause rising sludge problems in the secondary clarifier.

# Advantages of Denitrification

- Use of nitrate returns some of the extra oxygen needed.
- A portion of the alkalinity removed by nitrification is returned.
- Total Nitrogen discharged to the receiving stream may be substantially reduced.

# Biological Metabolism

Biological activity in aerobic, anaerobic, and anoxic zones is differentiated by ...

- Sources of energy
- Means of respiration

# Thank you!

For Questions or Comments please reach out to the following:

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