Nitrification and Denitrification

Prepared by
Michigan Department of Environmental Quality
Operator Training and Certification Unit

Nitrogen

Environmental
And
Public Health
Concerns

N

Forms of Nitrogen in Wastewater

Ammonia – NH_3

Toxic

Oxygen Demand

Nitrite – NO_2^-

Chlorine Demand

Nitrate – NO_3^-

Health Concern

All Are Nutrients (fertilizer)

Forms of Nitrogen in Wastewater

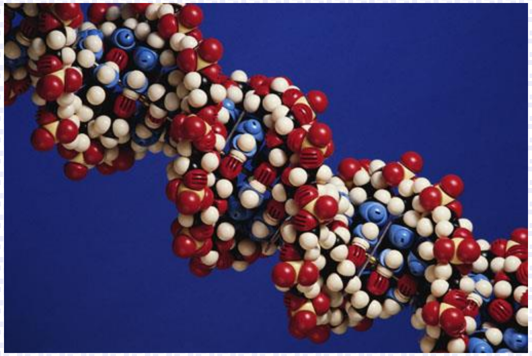
Organic Nitrogen

Complex Compounds

Protein (plant & animal)

Amino Acids

etc.



Oxygen Demand

Nutrient Source

N Forms of Nitrogen in Wastewater

Total Kjeldahl Nitrogen - "TKN"

Sum of

Organic N + Ammonia

Total Inorganic Nitrogen - "TIN"

Sum of

Ammonia + Nitrite + Nitrate

N

Forms of Nitrogen in Wastewater

Ammonia – NH_3

Nitrite – NO_2^-

Nitrate – NO_3^-

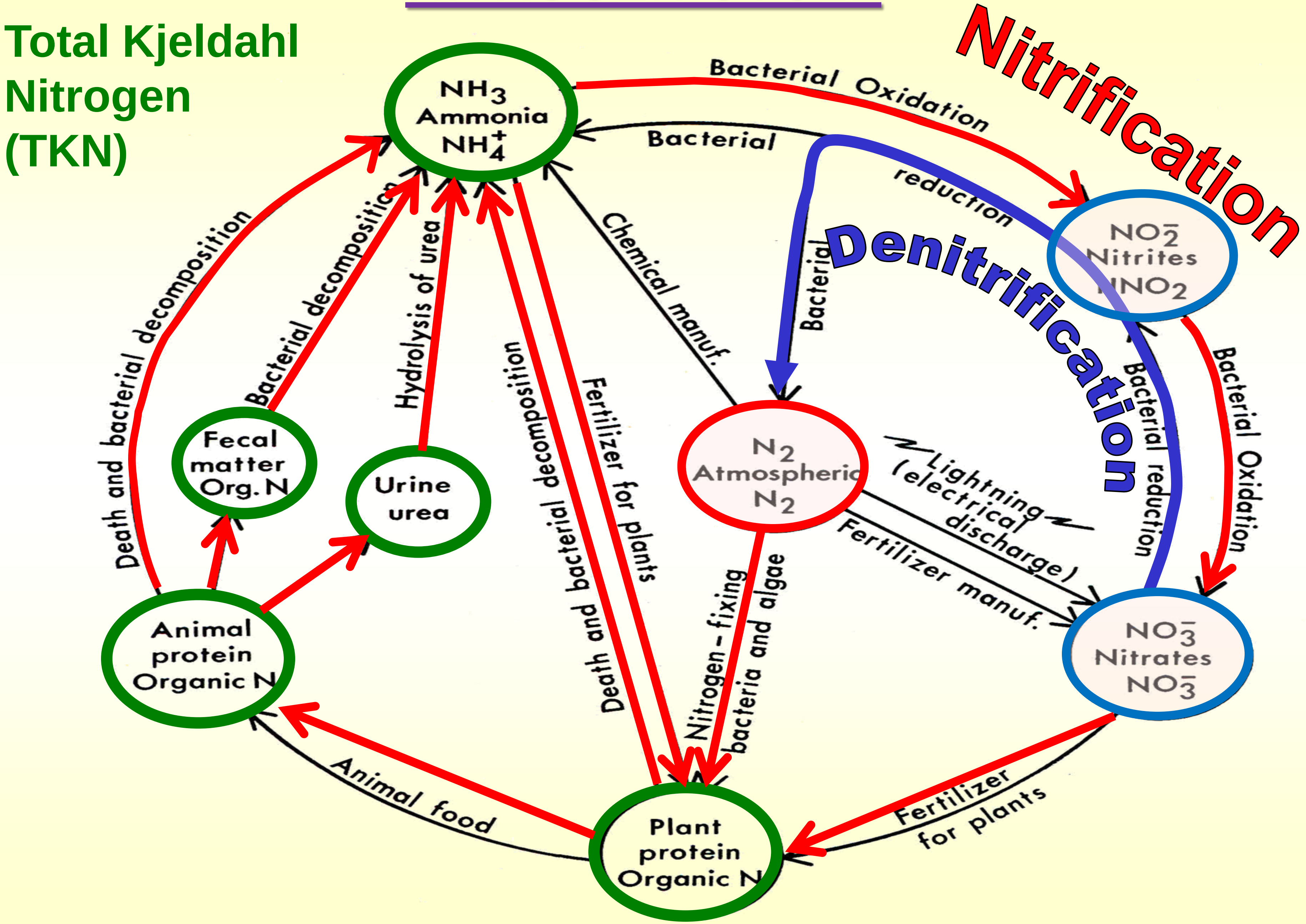
Organic

“Transform”
In
Environment
And
Treatment Plants

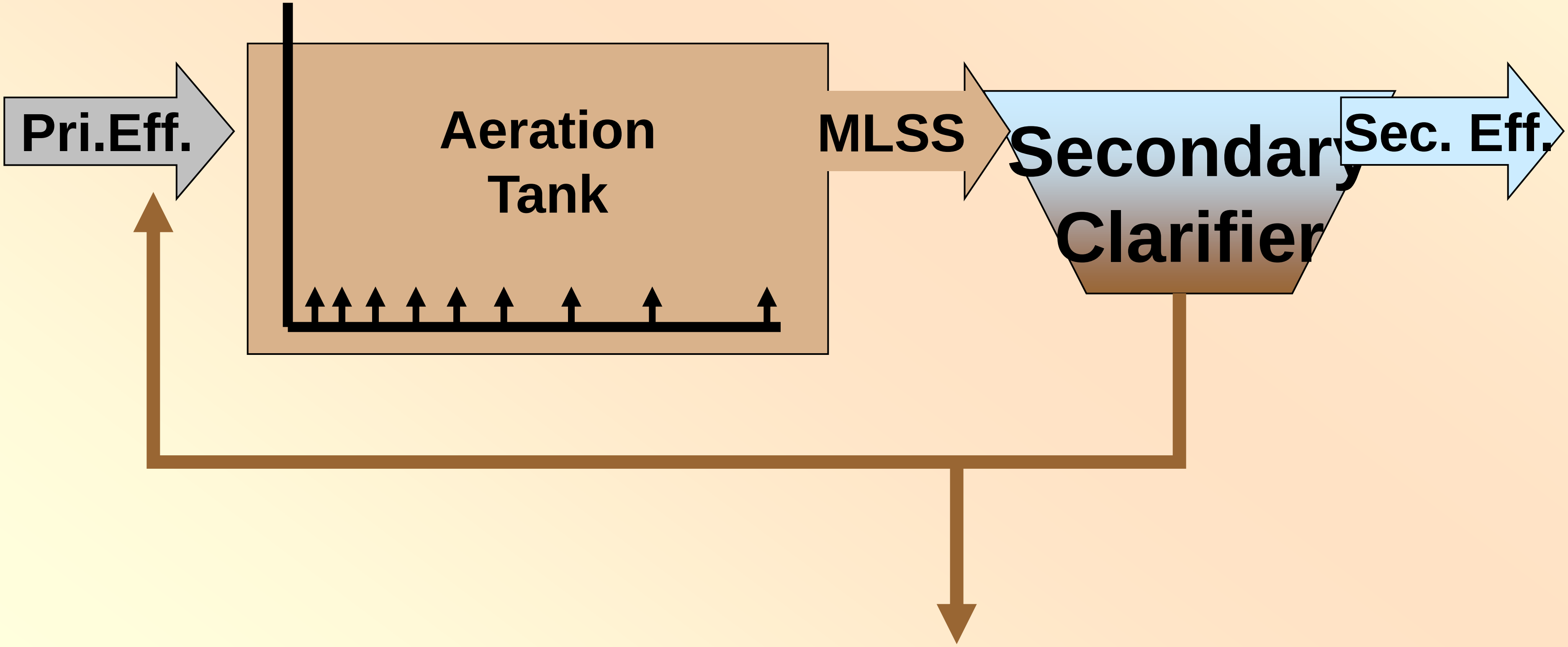
TKN

TIN

NITROGEN CYCLE



WASTEWATER "TREATMENT"
Of
Nitrogen



N

WASTEWATER “TREATMENT”
Of
Nitrogen

“Raw” Sewage

Organic Nitrogen & Ammonia

No Nitrite or Nitrate

N

WASTEWATER “TREATMENT” Of Nitrogen

Primary Clarification

Some Organic Nitrogen Removed (settled solids)

No Ammonia Removed

May Increase

(Solids Handling)

WASTEWATER "TREATMENT" Of Nitrogen

N

Primary Effluent
(Secondary Influent)

Organic Nitrogen (Less)

Ammonia

WASTEWATER "TREATMENT"
Of
Nitrogen

Secondary "Treatment"
(Biological)

N

Some Nitrogen Will be Removed By the Biomass (assimilation)

Heterotrophic Bacteria Breakdown Organics (Proteins, etc.)

To Ammonia

Bacteria Also Take Up Ammonia

100 : 5 : 1

C : N : P

N

Some Nitrogen Will be Removed By the Biomass
(assimilation)

To Meet an Ammonia Limit or a Total Inorganic Nitrogen (TIN) Limit the Process Must be Capable of Nitrification

Biological Oxidation of Ammonia to Nitrite to Nitrate

$$NH_3 \longrightarrow NO_2 \longrightarrow NO_3$$

Nitrification

*Heterotrophic Bacteria Break Down Organics
Generate NH_3, CO_2, and H_2O

*Autotrophic Bacteria Utilize Inorganic Compounds
(and CO_2 as a Carbon Source)

Nitrification

Nitrification of Ammonia Occurs in Two Steps

***Autotrophic Bacteria Utilize Inorganic Compounds**
(and CO_2 as a Carbon Source)

NH_3-N → **NO_2-N**
Ammonia N → **Nitrite N**

Nitrosomonas

NO_2-N → **NO_3-N**
Nitrite N → **Nitrate N**

Nitrobacter

Operational Controls for Nitrification

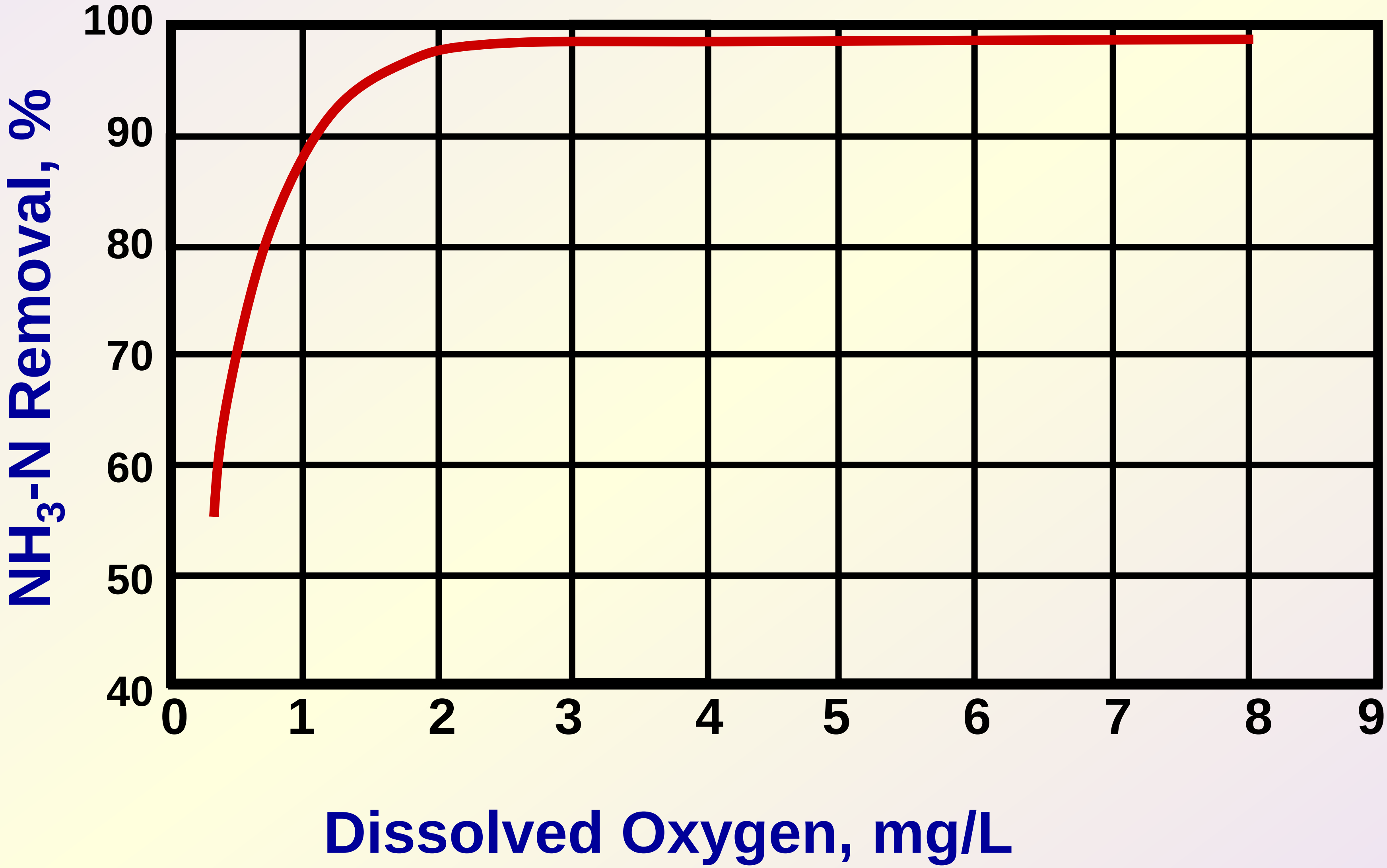
Air Requirements

1.5 lbs O_2 / lb BOD

4.6 lbs O_2 / lb TKN

Increase D.O. in Aeration Tank to 3 - 5 mg/L

Nitrification VS D.O.



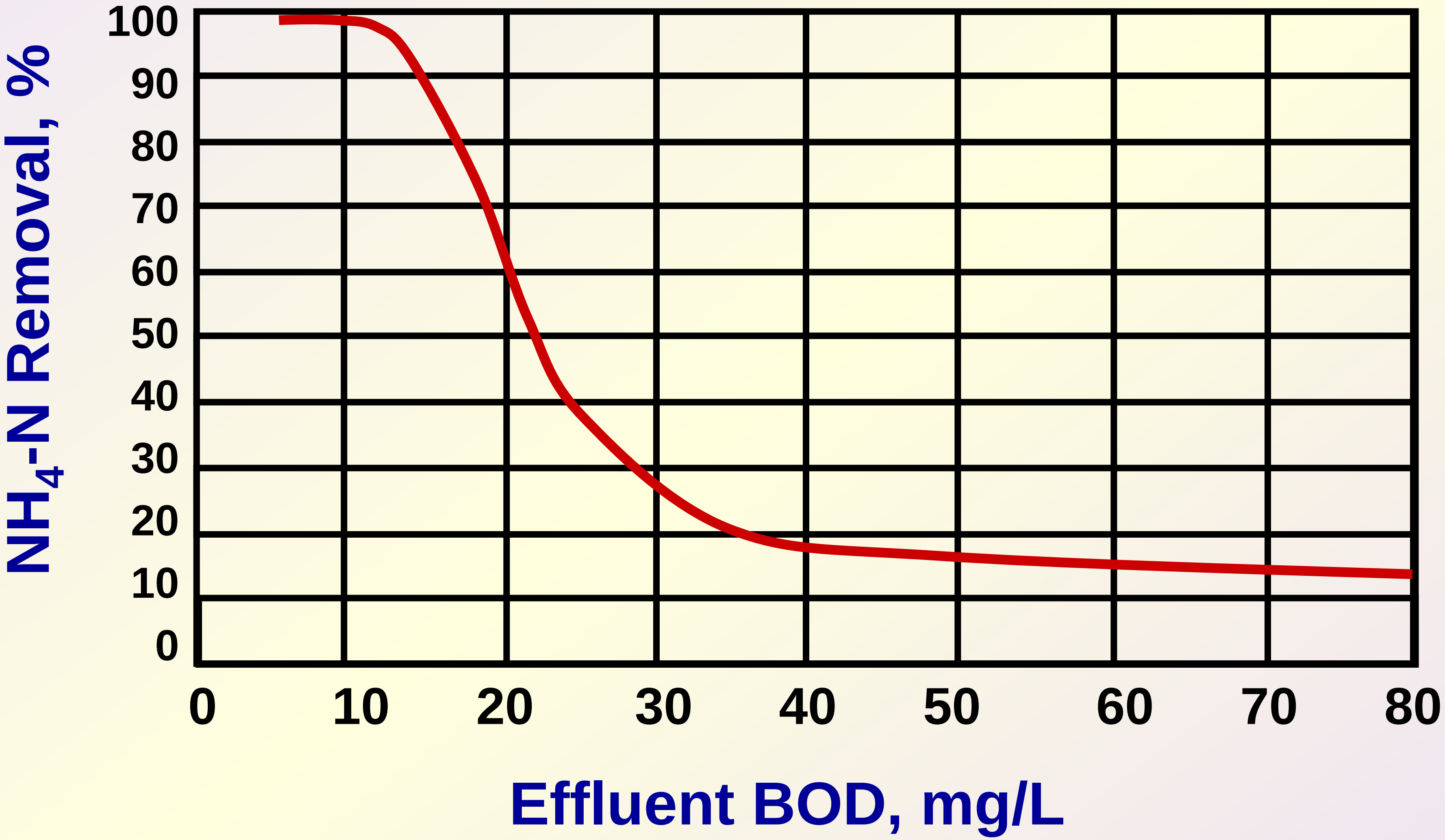
Operational Controls for Nitrification

Aerobic React Time Must Be Long Enough
(> 5 hrs.)

(BOD Removal Must Occur First)

F:M Ratio Must Be Low Enough
(< 0.25)

Effluent BOD Vs % NH_3-N Removal



Operational Controls for Nitrification

Control Solids Handling

In-plant Return Flows

High in BOD and Ammonia

Inhibit Nitrification

Exceed Nitrification Capability

Return Slowly

Low Quantities

At Low Loading Times

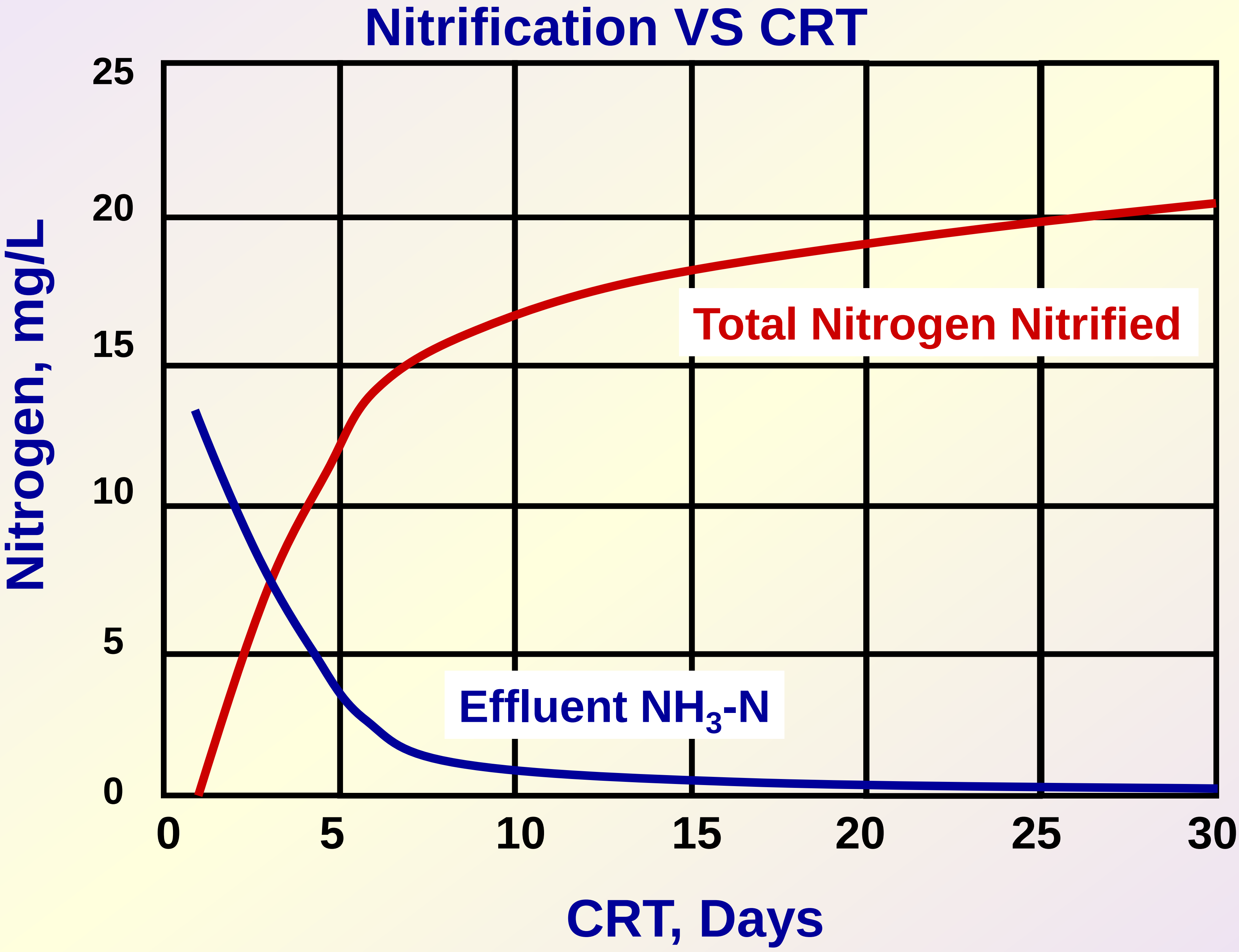
Operational Controls for Nitrification

Nitrifiers Grow Slowly

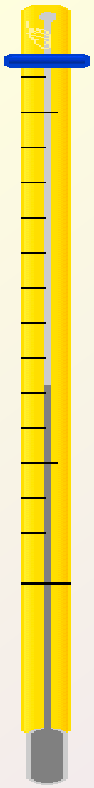
CRT Must Be Long Enough

> 5 Days (minimum)

Best > 8 Days

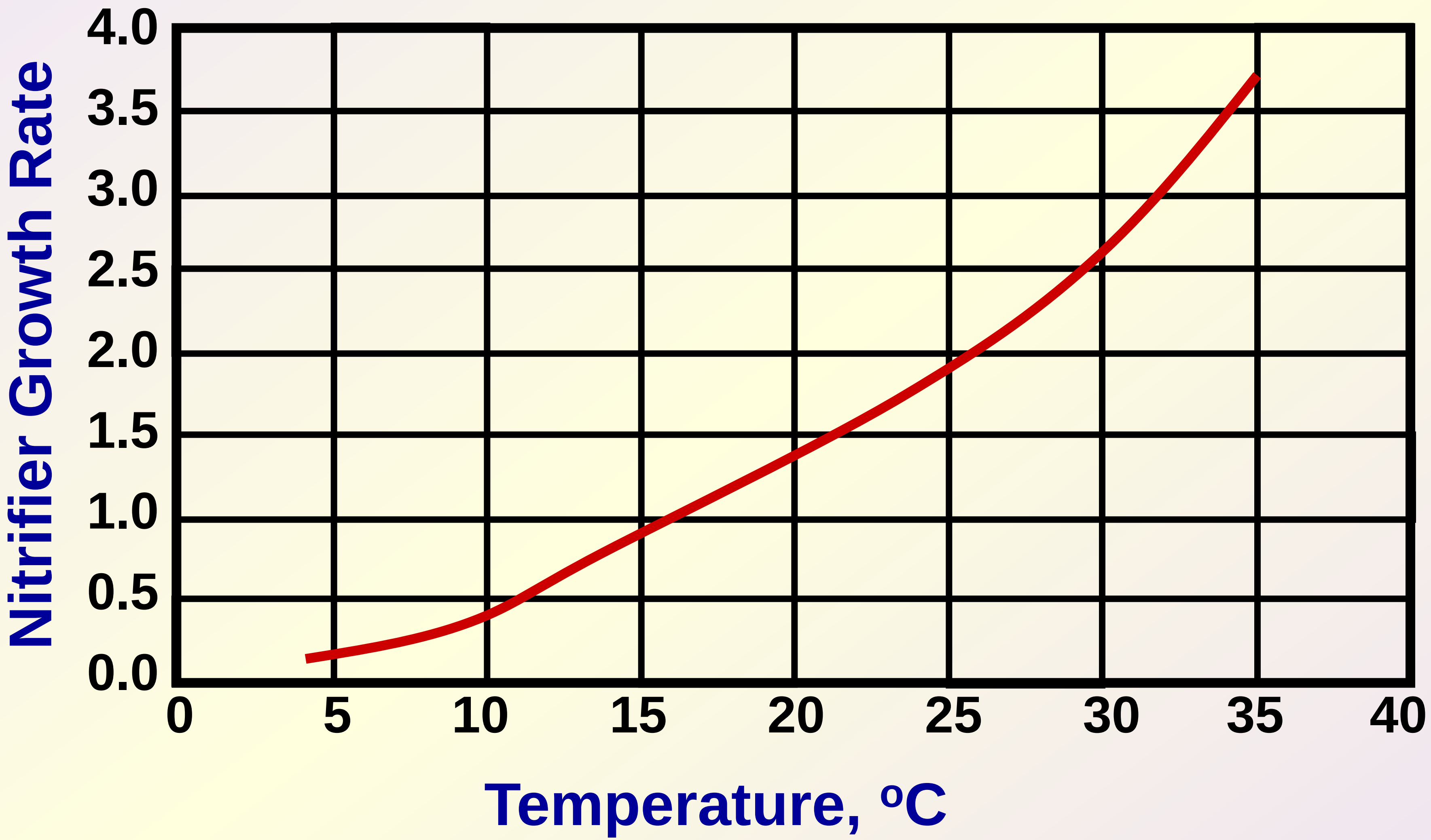

Nitrification VS CRT
Nitrogen, mg/L
0
5
10
15
20
25
Total Nitrogen Nitrified
Effluent NH_3-N
0
5
10
15
20
25
30
CRT, Days

Effect of Temperature on Nitrification



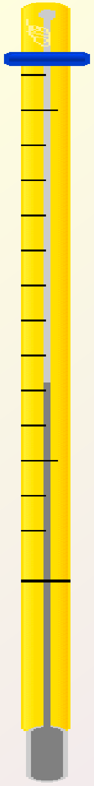
Lower Temperatures Cause Slower Nitrifier Growth Rate

Effect of Temperature on Nitrification



Effect of Temperature on Nitrification

Lower Temperatures Cause Slower Nitrifier Growth Rate



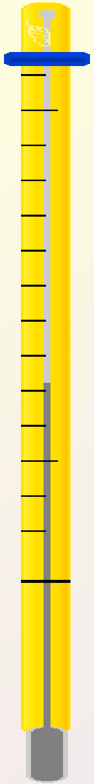
Minimum of 59 Degrees F. (15 ^{o}C)

for 90 % Nitrification

Below 50 Degrees F. (10 ^{o}C)

Expect Maximum of 50 % Nitrification

Effect of Temperature on Nitrification



Lower Temperatures Cause Slower Nitrifier Growth Rate

Higher MLSS Concentration May Compensate for Lower Temperature

Limited By:

- Oxygen Transfer
- Maximum MLSS Controllable
- High CRT Problems

Importance of Alkalinity in Nitrification

$$NH_4HCO_3 + O_2 \longrightarrow HNO_3 + H_2O + CO_2$$

7 mg Alkalinity Destroyed Per mg NH_3-N Oxidized

Chemicals Added For Phosphorus Removal Also Destroy Alkalinity

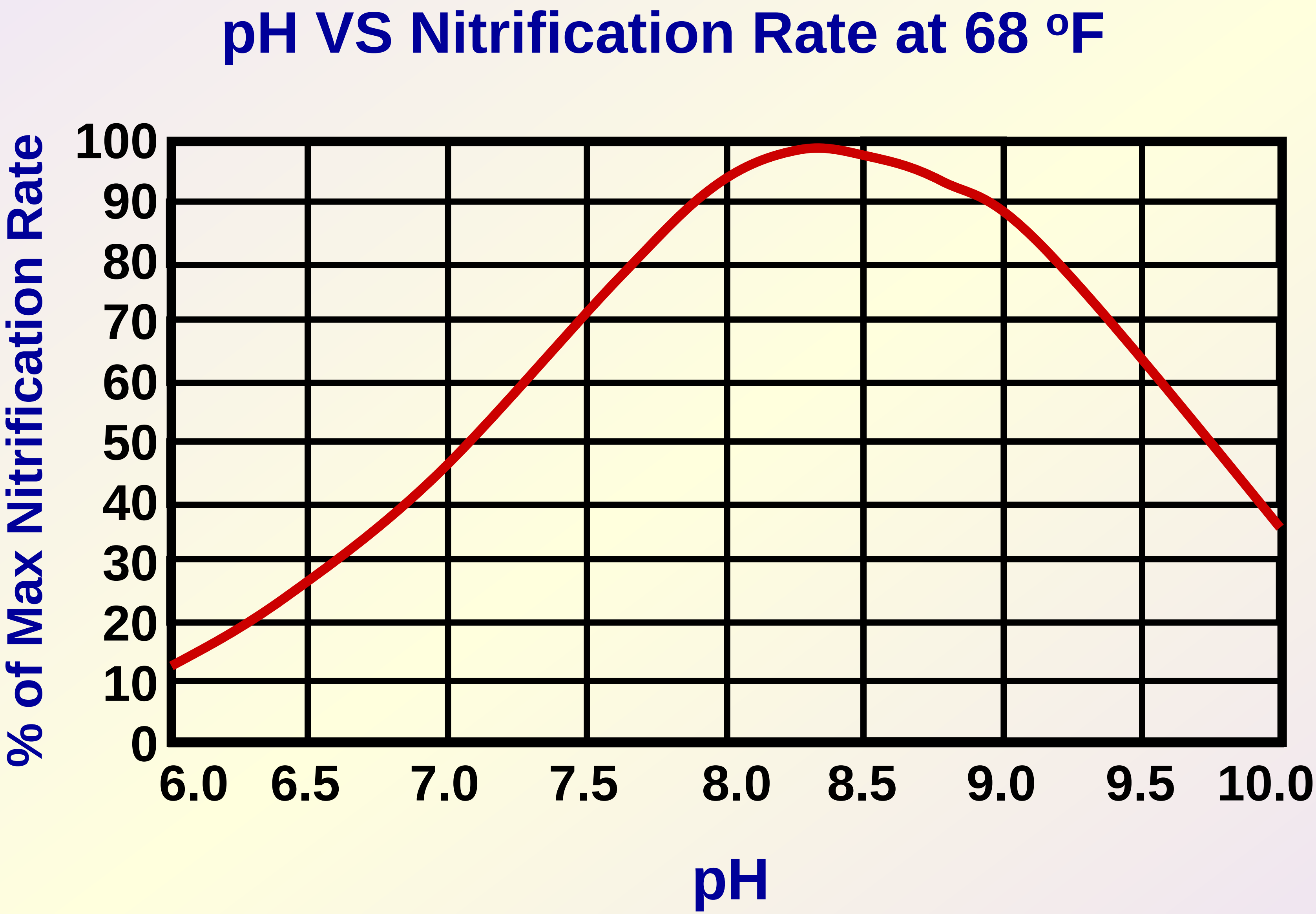
5.3 - 13.5 lbs Alkalinity per lb Fe Added

6.0 - 9.0 lbs Alkalinity per lb Al Added

pH May Become Depressed If Not Enough Alkalinity is Present

Nitrifiers are pH Sensitive

Most Efficient at pH 8.0 - 8.5


pH VS Nitrification Rate at 68 oF
% of Max Nitrification Rate
100
90
80
70
60
50
40
30
20
10
0
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
pH

Importance of Alkalinity in Nitrification

$$NH_4HCO_3 + O_2 \longrightarrow HNO_3 + H_2O + CO_2$$

7 mg Alkalinity Destroyed Per mg NH_3-N Oxidized

Assure Adequate Alkalinity

Effluent Above 50 mg/L

Influent Above 150 mg/L

Importance of Alkalinity in Nitrification

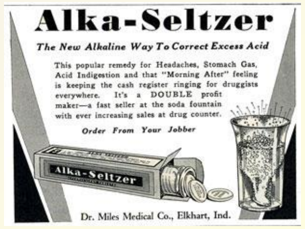
$$NH_4HCO_3 + O_2 \longrightarrow HNO_3 + H_2O + CO_2$$

7 mg Alkalinity Destroyed Per mg NH_3-N Oxidized

Assure Adequate Alkalinity

Effluent Above 50 mg/L

Influent Above 150 mg/L

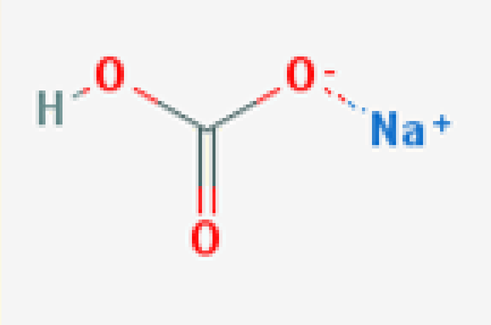


Importance of Alkalinity in Nitrification

$$NH_4HCO_3 + O_2 \longrightarrow HNO_3 + H_2O + CO_2$$

7 mg Alkalinity Destroyed Per mg NH_3-N Oxidized

Assure Adequate Alkalinity
Effluent Above 50 mg/L
Influent Above 150 mg/L



Sodium Bicarbonate

Nitrification Problems

$NH_3 \longrightarrow NO_2 \longrightarrow NO_3$

Dissolved Oxygen

CRT, F/M

Temperature

Alkalinity

Return Flows From Solids Handling

pH Swings

***Toxics in Influent**

DENITRIFICATION

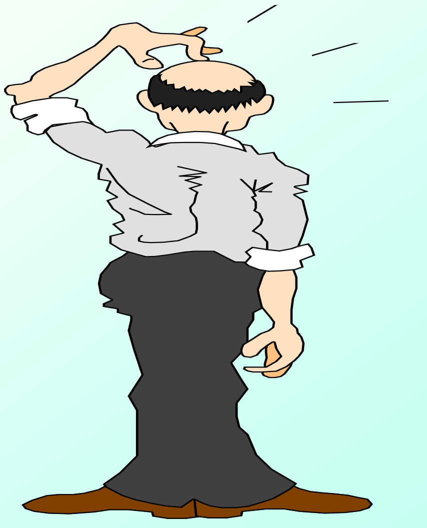
$$NO_3 \longrightarrow NO_2 \longrightarrow N_2\uparrow$$

Why Denitrify ???

Groundwater Discharge Permits Limit Total Inorganic Nitrogen

(5 mg/L NO_3-N + NO_2-N + NH_3-N)

Biological Phosphorus Removal Depends on Removal of Nitrate



Definitions

Aerobic – Dissolved (Free) Oxygen Present – O_2

Oxic – Dissolved (Free) Oxygen Present – O_2

Anoxic – No Free Oxygen

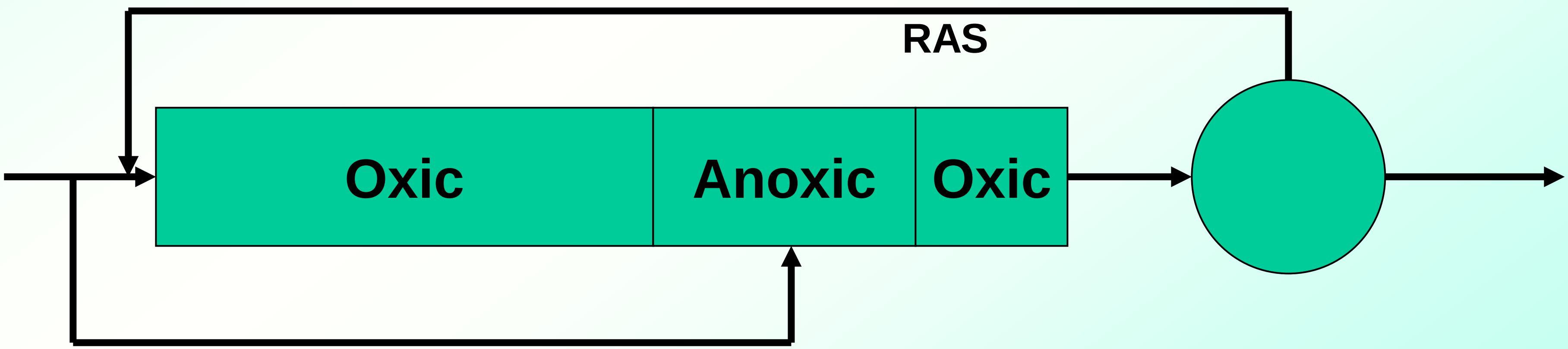
(Combined Oxygen –Nitrates NO_2 and Nitrites NO_3)

Anaerobic – Oxygen Absent

DENITRIFICATION

$$NO_3 \xrightarrow[\text{Anoxic environment}]{\text{heterotrophic bacteria + BOD}} N_2 \uparrow$$

In an anoxic environment, heterotrophic bacteria will use the oxygen from nitrates as they assimilate BOD, producing nitrogen gas.



DENITRIFICATION

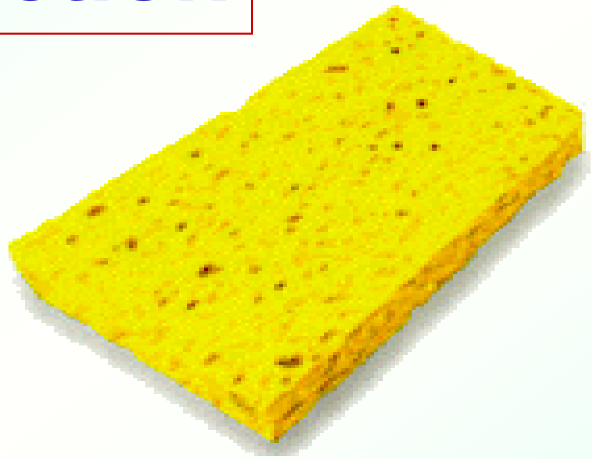
Added Benefits

- Minimizes Rising Sludge
- Helps Recover Oxygen
- May Help Control Filamentous Bacteria
- Recovers Alkalinity

$$NO_3 + ORG \xrightarrow[\text{anoxic}]{\text{het. bact.}} N_2\uparrow,\ CO_2\uparrow,\ H_2O,\ OH^-$$

3.57 mg Alkalinity per mg NO_3 Reduced

Nitrite and Disinfection



Nitrite is a Chlorine "Sponge"

Chlorine reacts with Nitrite Instead of Disinfecting

Can't Meet Fecal Coliform Limits Even With Increased Chlorine Dosage

Nitrite and Disinfection

$$Cl_2 + H_20 \longrightarrow HCl + HOCl$$

$$HOCl \longrightarrow H^+ + OCl^-$$

$$OCl^- + NO_2^- \longrightarrow NO_3^- + Cl^-$$

Amount of Cl_2 Consumed:

5 mg Cl / mg NO_2

Nitrite and Disinfection

Nitrification

Above 63 ^oF (17 ^oC)

First step is slowest

$$NH_3 \xrightarrow[\text{Slow}]{} NO_2 \xrightarrow[\text{Fast}]{} NO_3$$

(results in < 1 – 2 mg/L NO_2)

Nitrite and Disinfection

Nitrification

Cold Water NO_2 Problem

At 54 to 57 ^oF (12 to 14 ^oC)

Second step becomes slowest

$$NH_3 \xrightarrow[\text{Slow}]{} NO_2 \xrightarrow[\text{Really Slow}]{} NO_3$$

NO_2 can reach 15 mg/L

Disinfection with Chlorine Becomes Very Difficult

Nitrite and Disinfection

Warm Water NO_2 Problem

Denitrification

$$NO_3 \xrightarrow[\text{Fast}]{} NO_2 \xrightarrow[\text{Slow}]{} N_2$$

Second step is slower

Worst when carbon (BOD) is limited

Nitrite and Disinfection

Warm Water NO_2 Problem

Denitrification

$$NO_3 \xrightarrow[\text{Fast}]{} NO_2 \xrightarrow[\text{Slow}]{} N_2$$

Second step is slower

Denitrification Not Needed

Keep System Aerobic

Nitrite and Disinfection

Warm Water NO_2 Problem

Denitrification

$$NO_3 \xrightarrow[\text{Fast}]{} NO_2 \xrightarrow[\text{Slow}]{} N_2$$

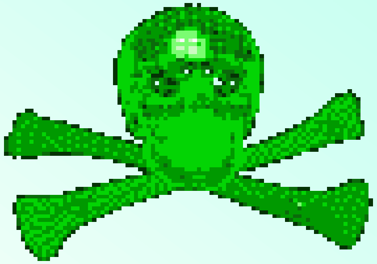
Second step is slower

To Intentionally Denitrify

Make Sure BOD is Available During Denitrification

Nitrite and Disinfection

Toxicity



Nitrifiers are more affected than other bacteria

Some toxins affect the Nitrobacter more than the Nitrosomonas

Results in a build-up of NO_2

Nitrite and Disinfection

Effect of Ammonia

$\boxed{NH_3 \quad NO_2 \quad NO_3}$ + Cl = Disinfection Problems

If ammonia is not present,
Free Cl reacts quickly with NO_2

If enough NH_3 is present,
Cl reacts to form Chloramines.

$NH_3 + Cl \longrightarrow$ Chloramines

Chloramines disinfect,
but don't react quickly with NO_2

ORP

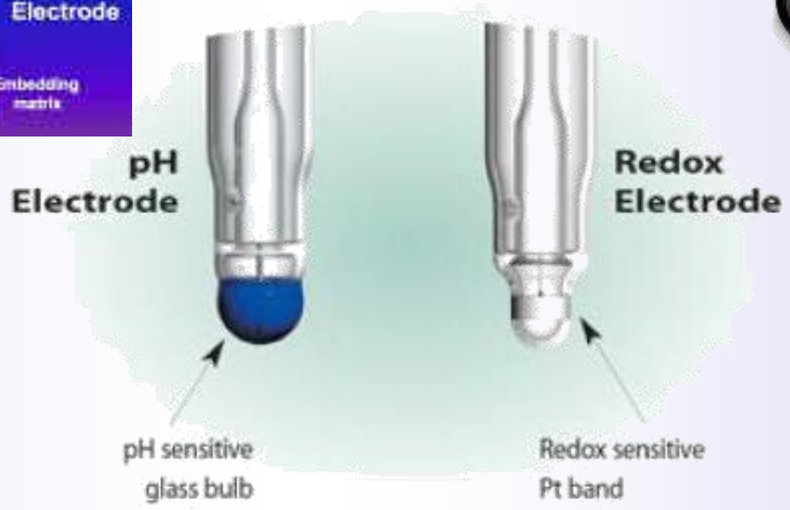
Oxidation-Reduction Potential

The electrical potential (mv) required to transfer electrons from one compound to another.

Used as a qualitative measure of the state of oxidation.

ORP

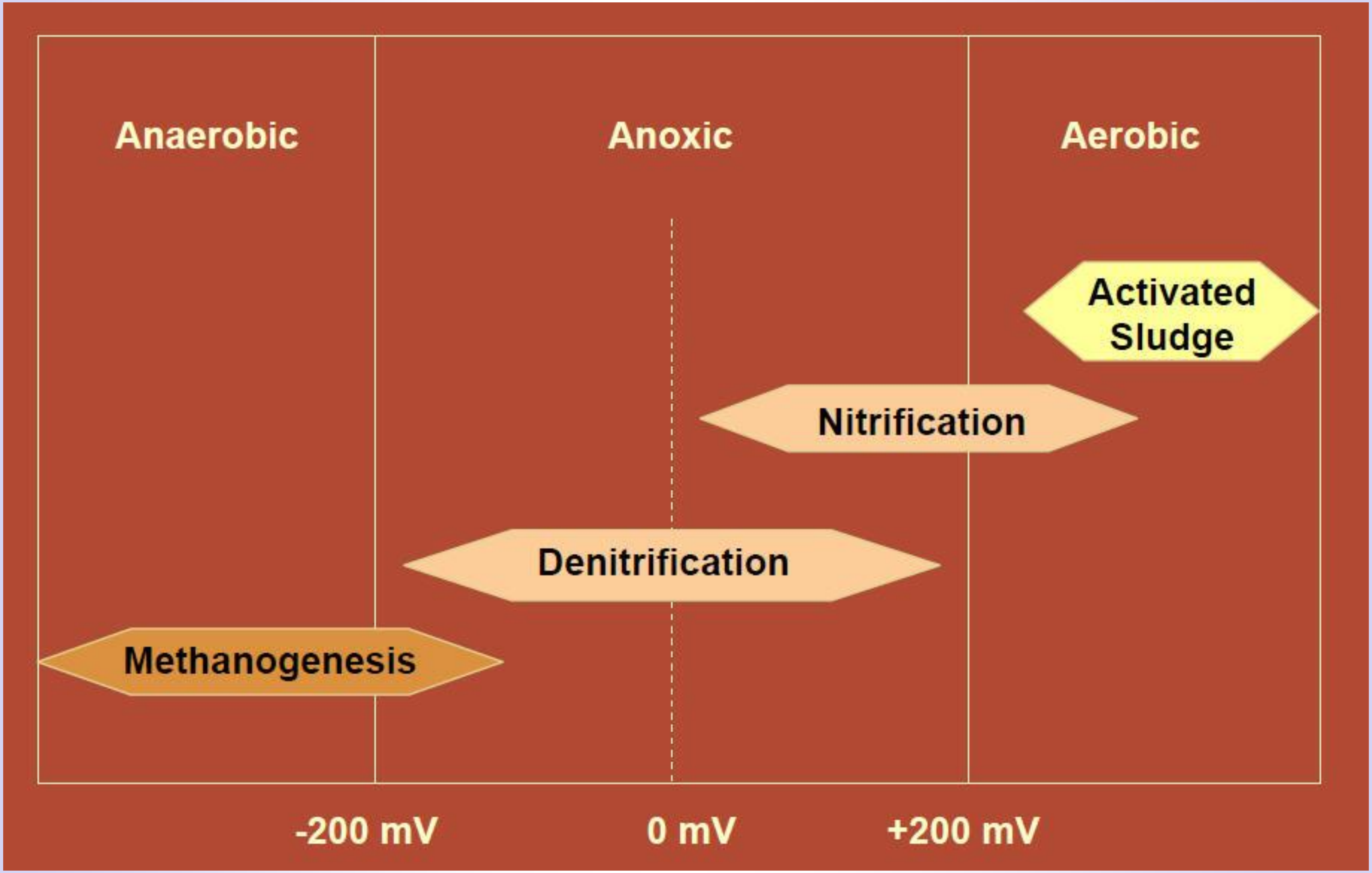
Oxidation-Reduction Potential



ORP

Raw (influent)	~ -200 mV (dependent on strength of ww)
Primary effluent	~ -150 mV (change due to loss of settleable solids)
Secondary effluent	~ +100 mV (dependent on strength of ww)
Final effluent	~ +150 mV (dependent on strength of ww)

ORP


Anaerobic
Anoxic
Aerobic
Activated Sludge
Nitrification
Denitrification
Methanogenesis
-200 mV
0 mV
+200 mV

Nitrification and Denitrification

Prepared by
Michigan Department of Environmental Quality
Operator Training and Certification Unit