Understanding and Operating BNR Facilities

BNR Fundamentals
An Operator's Perspective

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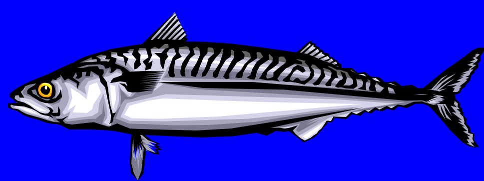
Why do we Remove Nutrients?

- In the 1970s, scientific research focused on three areas of environmental degradation:
  - Nutrient over-enrichment
  - Dwindling underwater grasses
  - Toxic pollution

Why do we Remove Nutrients?

- Harmful to the receiving waters
- Nutrient source for aquatic plant growth
- Causes oxygen depletion
- Harmful to fish



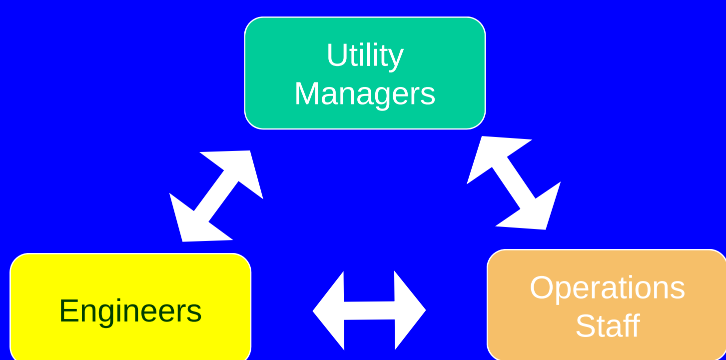
Current Nutrient Limits

- **For most facilities in Maryland, effluent limit for TN is 4.0 mg/L.**
- **For most facilities in Maryland, effluent limit for TP is 0.3 mg/L (lower for facilities which discharge into sensitive waterways)**

Role of the Operator

- More stringent TN and TP limits require **more efficient** operation than was previously required.
- **Optimization** of process performance is necessary to meet the new requirements which are set at the "**limit of technology**"

Communication



Importance of Communication

- **Operators should convey to management what their needs are for ease of operation.**
- **Input from Operators during the design-phase of a project will lead to a better designed facility.**
- **Operators will have more knowledge how to run the facility if they actively participate during the design.**

Definitions

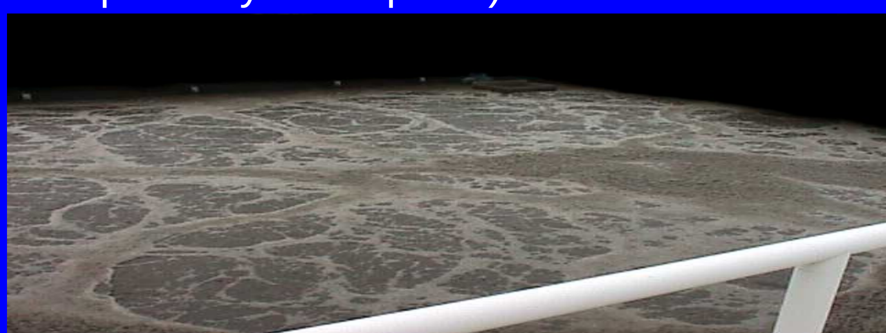
- Anaerobic zones - Areas within a reactor that contain no oxidized nitrogen and no dissolved oxygen. (This is where biological phosphorous removal begins)

Definitions

Anoxic zones - Areas within a reactor that contain Oxidized Nitrogen and no dissolved oxygen. (This is where denitrification primarily takes place)

Definitions

Aerobic zones - Areas within a reactor that contain the presence of dissolved oxygen. (This is where nitrification primarily takes place)



Understanding and Operating BNR Facilities

Nitrogen Removal

What is Nitrogen and its different forms in Wastewater?

N_2 - Nitrogen Gas

NH_3 - Ammonia

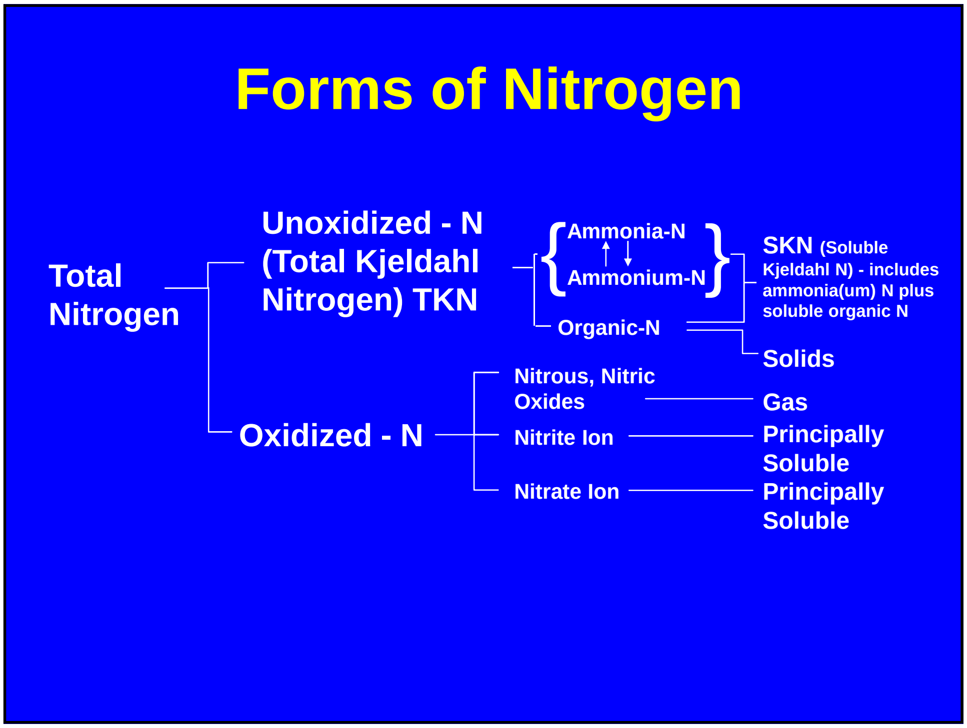
NH_4 - Ammonium

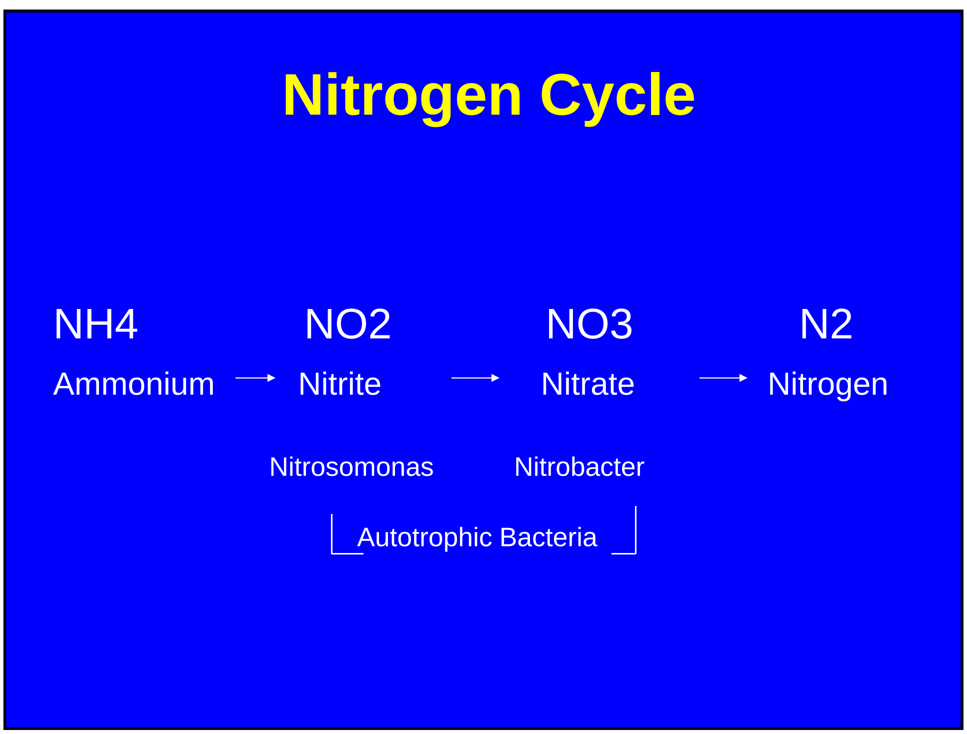
NO_2 - Nitrite

NO_3 - Nitrate

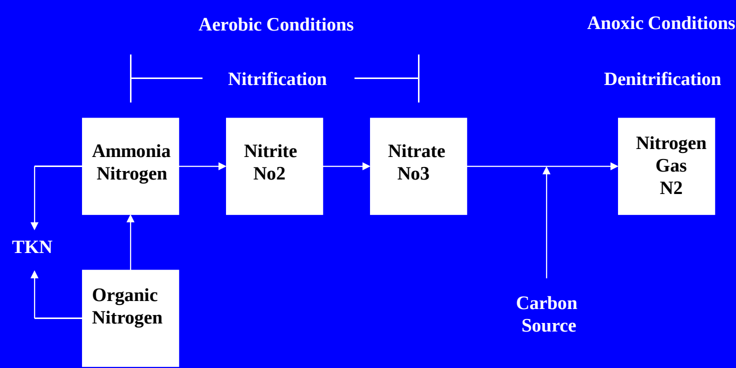
TKN - Ammonia + Organic Nitrogen

Total Nitrogen - TKN + NO_x


Forms of Nitrogen
Total Nitrogen
Unoxidized - N (Total Kjeldahl Nitrogen) TKN
Ammonia-N
Ammonium-N
Organic-N
SKN (Soluble Kjeldahl N) - includes ammonia(um) N plus soluble organic N
Solids
Oxidized - N
Nitrous, Nitric Oxides
Gas
Nitrite Ion
Principally Soluble
Nitrate Ion
Principally Soluble


Nitrogen Cycle
NH4
Ammonium
NO2
Nitrite
NO3
Nitrate
N2
Nitrogen
Nitrosomonas
Nitrobacter
Autotrophic Bacteria

The Nitrogen Removal Blueprint



What's Required for Nitrification?

- Longer MCRT
- More oxygen
- Adequate alkalinity
- Temperature has a greater impact
- pH has an impact

Conditions Necessary to Achieve Nitrification in Activated Sludge

- **Aerobic Mean Cell Residence Time - 4 to 15 days**
- **pH - 6.5 to 8 optimal**
- **Temperature - 25° C for optimal nitrification**
- **Dissolved Oxygen - >2.0 mg/l for optimal nitrification**

Nitrifying Bacteria

- Nitrifying bacteria fall into the species classification of autotrophic bacteria.
- Strict aerobes.
- Very slow growers.
- Autotrophic bacteria derive their carbon source from inorganic carbon compounds.
- The most commonly known nitrifying bacteria that we deal with are :

  Nitrosomonas: Ammonia Oxidizers

  Nitrobacter: Nitrite Oxidizers

Nitrification

Nitroso-bacteria

$NH_4^+ + O_2 + HCO_3^- \longrightarrow NO_2^- + H^+ + C_5H_7O_2N$

Inorganic Carbon source

Acid produced consumes alkalinity

New bacteria Growth (typ.)

Nitro-bacteria

$NO_2^- + O_2 + HCO_3^- \longrightarrow NO_3^- + C_5H_7O_2N$

For both reactions together:

Total Oxygen Requirement = 4.25 lbs / lb N oxidized

Total Alkalinity Requirement = 7.14 lbs as $CaCO_3$ / lb N oxidized

Factors Affecting Nitrification

What is the Key Factor
for Achieving Nitrification?

MEAN CELL RESIDENCE TIME
(MCRT)

Effect of Temperature on Nitrification

As temperature increases, nitrifier growth rate increases (within the range of 4^o C to 35^o C).

T ↑ μ ↑

As nitrifier growth rate increases, required MCRT decreases.

μ ↑ MCRT ↓

<u>Rule of Thumb</u>:
For every 10^oC increase in temperature, nitrifier growth rate doubles, required MCRT is cut in half and required MLSS concentration is also reduced.

Effect of Dissolved Oxygen Concentration on Nitrification

As dissolved oxygen increases, nitrifier growth rate increases up to DO levels of about 5 mg/L.

DO ↑ μ ↑

<u>Rule of Thumb</u>:
Maintain dissolved oxygen concentration at
2.0 mg/l or higher for optimum nitrification.

Effect of pH and Alkalinity on Nitrification

Nitrification consumes alkalinity and lowers pH in the activated sludge mixed liquor.

pH below 6.5 or above 8.0 can significantly inhibit nitrification.

Rules of Thumb:
Maintain pH in the range 6.5 - 8.0 for optimum nitrification.

Overall alkalinity consumption is generally less than the theoretical 7.14 lbs as $CaCO_3$ per lb of ammonia-N nitrified.

BNR and Alkalinity

- Alkalinity measures the capacity of the wastewater to neutralize acids
- Alkalinity = $[HCO_3^-] + 2[CO_3^{-2}] + [OH^-] – [H^+]$
- Common Sources of Alkalinity include:
  - Lime $Ca(OH)_2$
  - Caustic Soda $NaOH$
  - Soda Ash Na_2HCO_3

Where Does Nitrogen End Up In A Nitrifying Plant ?

- In the Sludge
- In the Effluent
- In the Atmosphere

Operating for Denitrification

Now that my plant is nitrifying, what do I need to do to make it denitrify

?

Establish anoxic conditions in the activated sludge process

Biological Denitrification

Denitrification:

- The process takes place utilizing the proper MCRT, organic carbon source and detention time.
- Takes place in anoxic conditions.
- The process is performed by Heterotrophic bacteria.

How Denitrification Works

- Under anoxic conditions, Heterotrophic bacteria utilize organic carbon for food. While metabolizing carbon they require oxygen for respiration. The oxygen is derived from the nitrate produced during nitrification.
- After using the oxygen component of the nitrate (NO3) the remaining product is a form of nitrogen gas, which is then released to the atmosphere.

Denitrification

Nitrate + Organic carbon → Carbon Dioxide + Nitrogen Gas + Alkalinity

$NO_3^- + CH_3OH$ (methanol) → CO_2(gas) + N_2(gas) + OH^- (alkalinity)

Organic carbon: BOD5/TKN of 4 to 5:1 required or
Methanol dose required = 2.5 to 3.0 lbs methanol per lb nitrate-N denitrified)

Alkalinity produced = 3.57 lbs as $CaCO_3$ per lb nitrate-N denitrified

$$2NO_3^- + 2H^+ \longrightarrow N_2\overset{\text{Gas}}{\uparrow} + H_2O + 2.5O_2$$

Oxygen equivalent = 2.86 lbs per lb nitrate-N denitrified

Conditions in the Anoxic Zone

- DO less than 0.3 mg/l
  - No aeration
  - Low aeration
  - Cyclical Aeration
- Carbon source
  - Primary Effluent
  - Endogenous
  - Methanol
  - Micro C
- Mixing
  - Pulsed or cycled air
  - Submersible mixers
  - Vertical mixers

Seasonal High D.O. in the Anoxic Zones

- **High DO in anoxic zones may be more of a problem during the winter because more DO is absorbed by colder water and biological kinetics are reduced.**

Effect of pH on Denitrification Rate

- **Denitrifiers are generally less sensitive to pH than nitrifiers.**

Rule of Thumb:

- **If pH is within the recommended range of 6.5 - 8.0 for nitrification, there will be no pH effects on denitrification.**

Effect of Available Carbon Source on Denitrification

- **Denitrification rate varies greatly depending upon the source of available carbon.**
  - **Highest rates are achieved with addition of an easily-assimilated carbon source such 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.**

Items of concern

Alkalinity & pH:

- During the nitrification process alkalinity within the reactor is lowered or consumed.
- This results in the possibility of pH fluctuations.
- Can also will inhibit the performance of the process if the level is too low.
- If the alkalinity is too low, the addition of caustic soda (NaOH) could be necessary.

Items of Concern

Chlorine demand:

- During the nitrogen conversion, if the oxidation to NO3 is not fully achieved, or is stopped at the nitrite stage. A high chlorine demand will be experienced.

Ammonia $\longrightarrow$ Nitrite = Trouble

Items of Concern

Reactor Detention Time:

- As in all biological process, the amount of time that the bio-mass has to perform the conversion is critical.
- If time is restricted, this can be compensated by increasing the amount of nitrifiers in the system.

Items of Concern

Reactor water temperature:

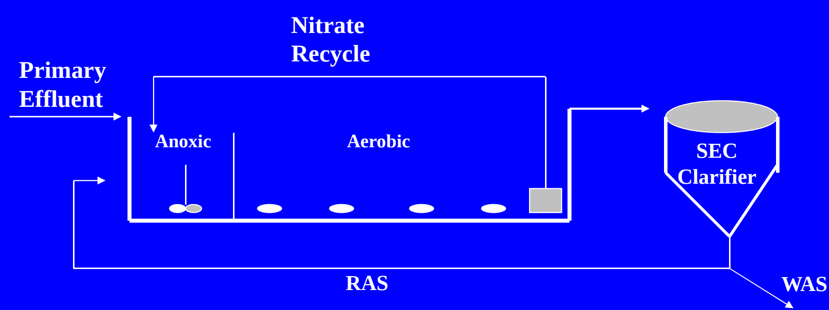
- Another criteria that plays an effect is the MLSS temperature.
- As the temperature increases, biological activity increases.
- Temperature also plays a factor in the nitrogen cycle conversion rate.
- Thus temperature can play a factor in the system's proper MCRT.

Items of Concern

Carbon Source:

- As the "fuel" for denitrification, an organic carbon source is necessary.
- Examples of carbon source in the industry are:
  - Primary Effluent or Raw Influent
  - Methanol
  - Micro C

Conventional Nitrogen Removing Reactor Configuration



Understanding and Operating BNR Facilities

Phosphorus Removal

Methods of Phosphorus Removal

- **Phosphorus can be removed:**
  - **Chemically**
  - **Biologically**
  - **Or Both**

Chemical Phosphorous Removal

Most commonly used chemicals:

- Common Chemical Additives for P Removal
  - Alum ($Al_2(SO_4)_3$
  - Ferric Chloride ($FeCl_3$)
  - Ferrous Sulfate ($FeSO_4$
    - Must first oxidize to ferric iron to be effective
    - Additional benefit for odor control
  - Waste pickle liquor
    - Impurities may cause problems, also may contain heavy metals

Chemical Phosphorus Removal

- Advantages of Chemical Phosphorus Removal
  - Easy to control process
  - High level of reliability
  - May improve settling

Chemical Phosphorus Removal

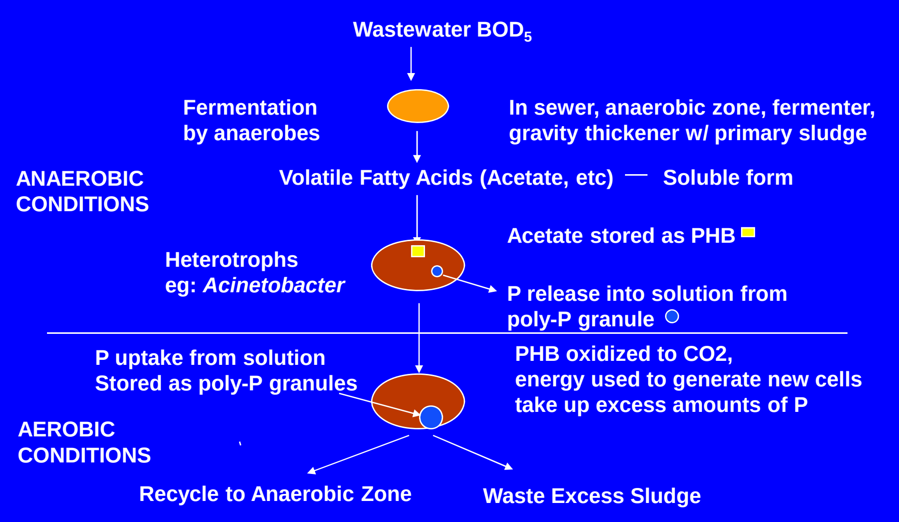
- Disadvantages of Chemical Phosphorus Removal
  - Adds cost for chemicals and for sludge disposal
  - Safety issues with chemical storage and handling
  - May lower pH
  - May inhibit UV disinfection performance
  - Overfeeding chemical before reactor may cause system to be P limited

Biological Phosphorus Removal

Key factors for successful removal:

- Anaerobic Conditions
  - **NO** Dissolved Oxygen or Nitrates
- Fermentation – VFAs
- Detention time

Mechanism of BEPR



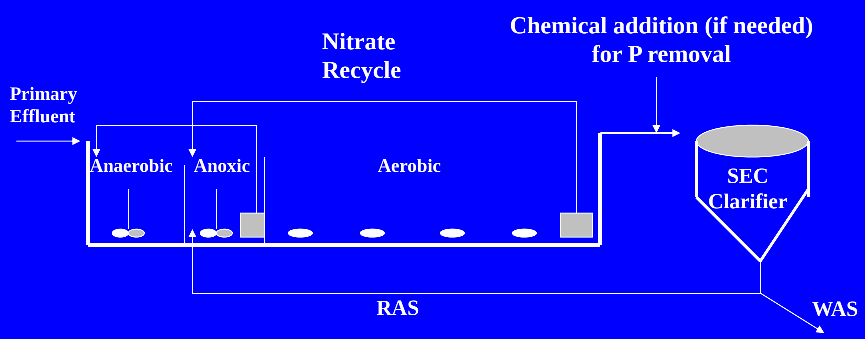
Biological Phosphorus Removal

- Advantages of Biological Phosphorus Removal
  - Low operating cost

Biological Phosphorus Removal

- Disadvantages of Biological Phosphorus Removal
  - Requires dedicated volume in Aeration Tanks
  - Process upsets are difficult to anticipate or mitigate
  - Most facilities still store chemicals on-site to use for "trim" or for process upsets

Conventional Nitrogen and Phosphorous Removing Reactor Configuration



What differs this plant from a nitrogen removing plant ?

Understanding and Operating BNR Facilities

Process Control Methods

Process Control Methods

- Process Control Parameters for BNR
  - MCRT
  - D.O.
  - Recycle Rates
  - Sludge Settleability

Process Control Methods

- Controlling MCRT:
  - Data Collection
  - MCRT Calculation Methods
  - Seasonal Adjustment
  - Sludge Wasting Methods

Process Control Methods

- Controlling DO:
  - – D.O. Monitoring Methods
  - – Manual Aeration Adjustments
  - – Automatic D.O. Control

Process Control Methods

- Controlling Recycle Rates:
  - – Return Sludge
  - – Nitrate Recycle

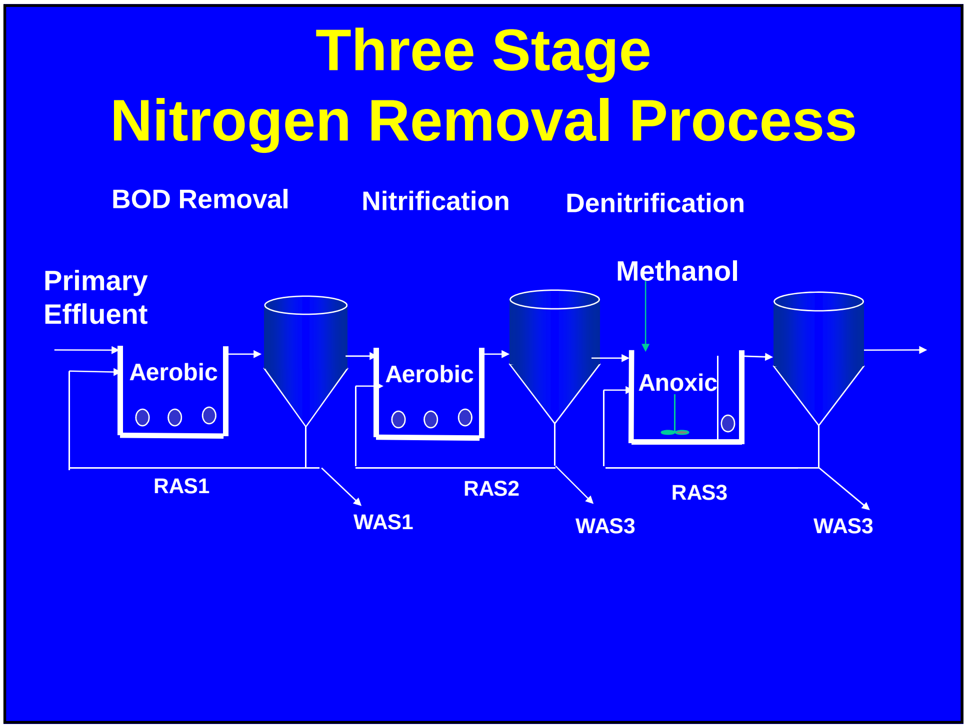
Understanding and Operating BNR Facilities

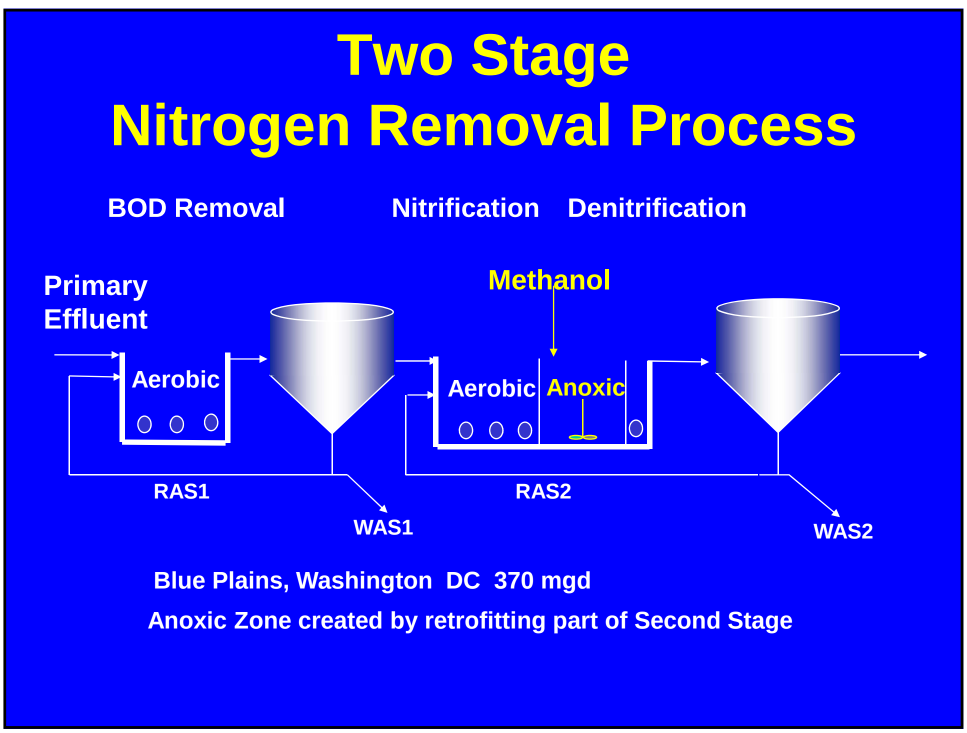
Common Nitrogen Removal Processes

Post-Denitrification

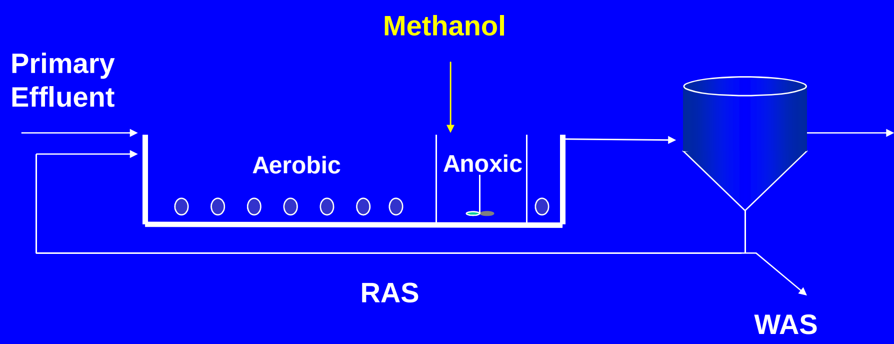
Post-denitrification uses an anoxic zone at the end of the activated sludge tanks.

An example is the **Three Stage Nitrogen Removal** Process


Three Stage
Nitrogen Removal Process
BOD Removal
Nitrification
Denitrification
Primary
Effluent
Methanol
Aerobic
Aerobic
Anoxic
RAS1
RAS2
RAS3
WAS1
WAS3
WAS3


Two Stage
Nitrogen Removal Process
BOD Removal
Nitrification
Denitrification
Primary
Effluent
Methanol
Aerobic
Aerobic
Anoxic
RAS1
RAS2
WAS1
WAS2
Blue Plains, Washington DC 370 mgd
Anoxic Zone created by retrofitting part of Second Stage

Single Stage Nitrogen Removal Process



Wuhrmann Process with Methanol feed for Denitrification

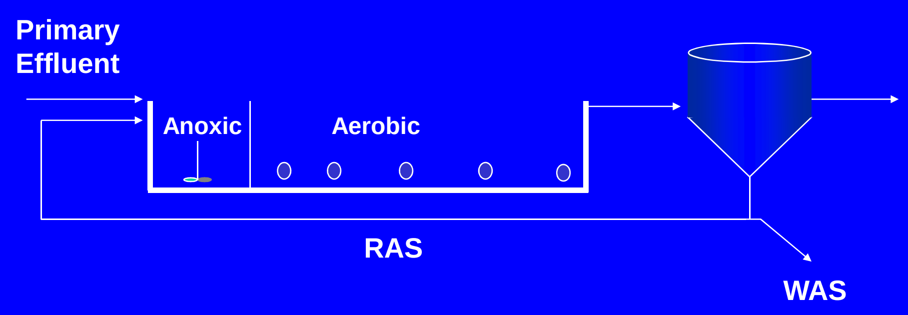
Pre-Denitrification

Pre-denitrification uses an anoxic zone at the beginning of the activated sludge tanks.

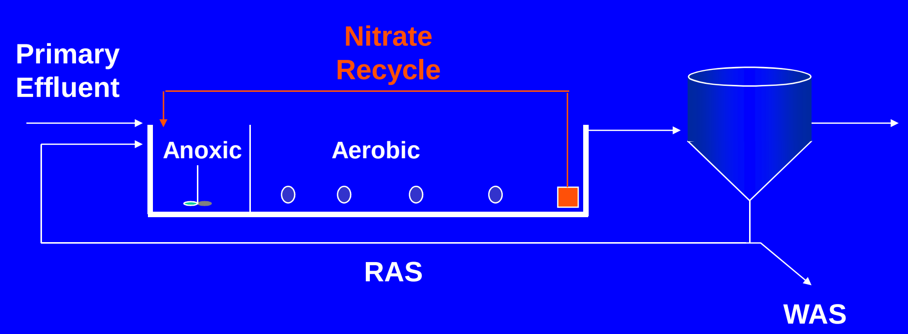
An example is the Ludzack-Ettinger (LE) process.

Typical Effluent TN levels are 6 to 12 mg/L

Ludzack-Ettinger (LE) Process



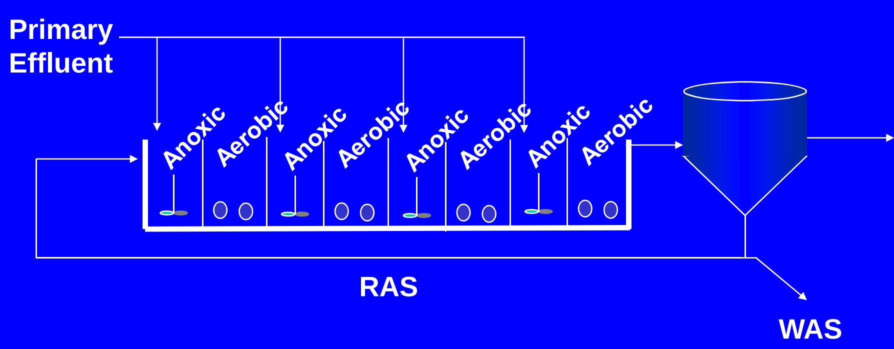
Modified Ludzack-Ettinger (MLE) Process



Step-Feed Denitrification

Primary effluent is fed at multiple points along the tank to provide a carbon source for denitrification.

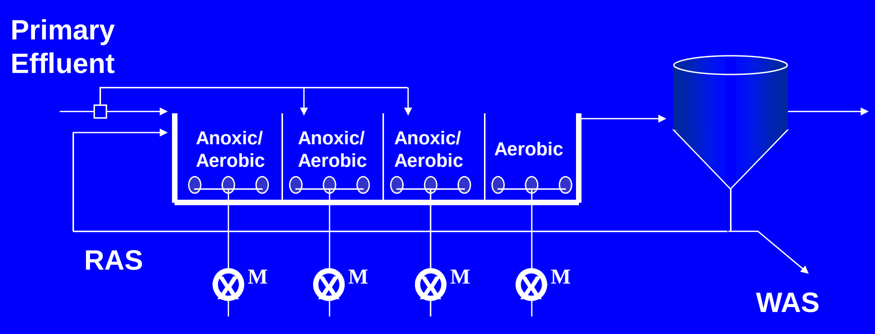
Step-Feed Denitrification

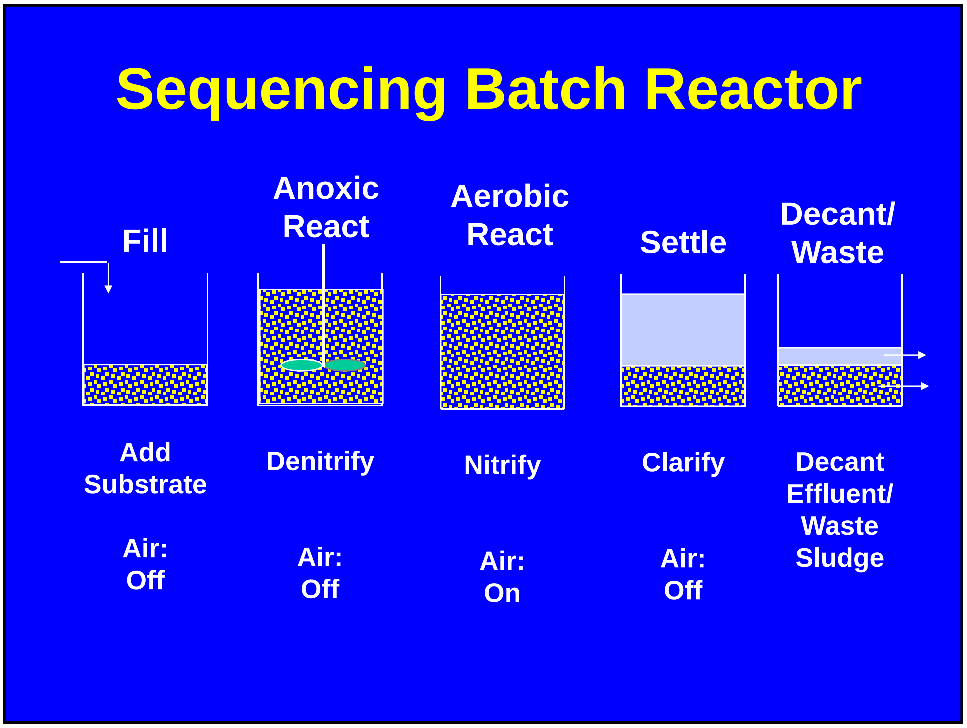


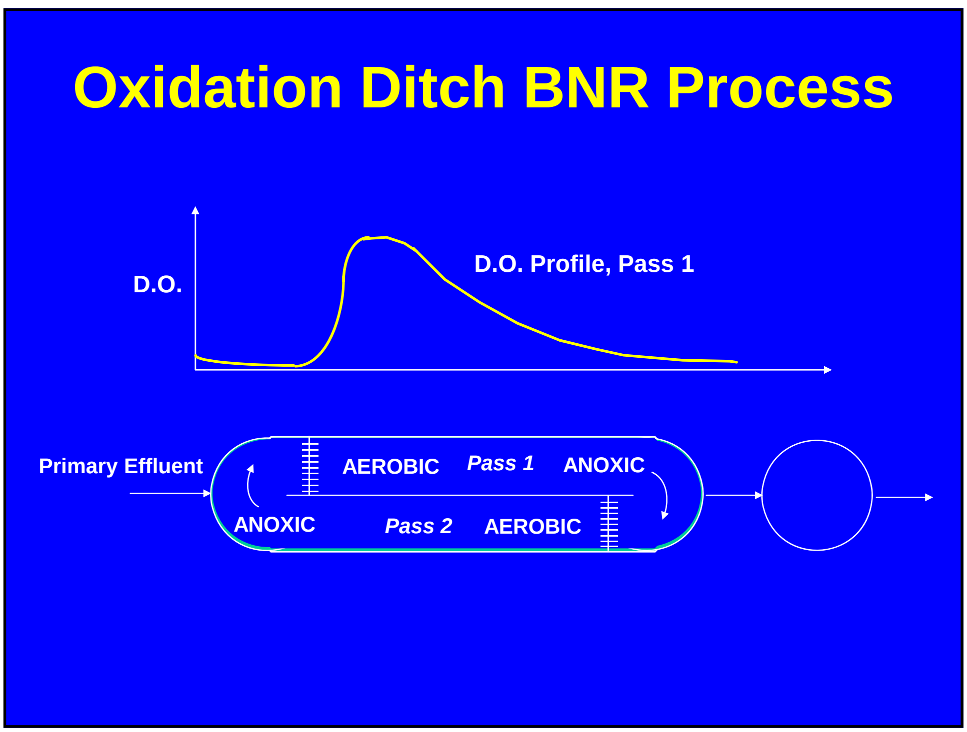
Cyclical Nitrogen Removal

- Cyclical Nitrogen Removal process uses alternating periods of aerobic and anoxic conditions. Anoxic and Aerobic conditions are established at different times in the same tank
- Examples
  - **Cyclically aerated and mixed tank**
  - **Sequencing Batch Reactors (SBRs)**
  - **Schreiber Process Reactor**

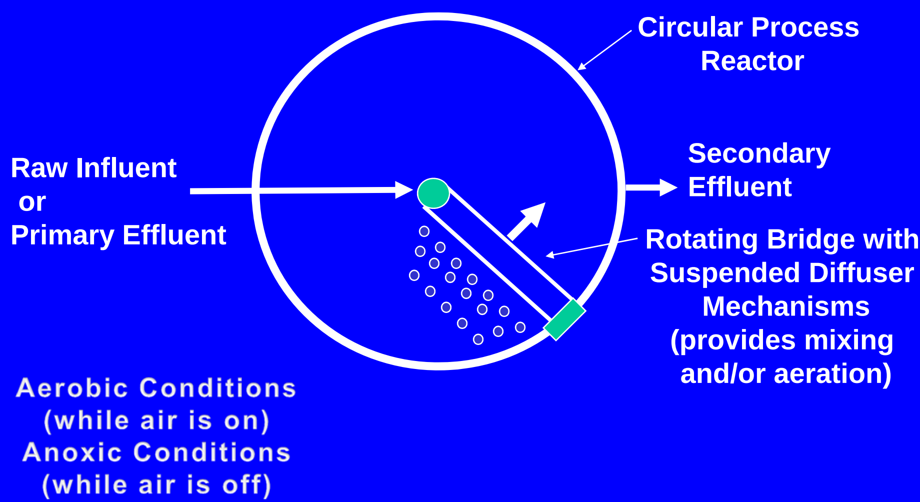
Step Feed Denitrification With Cyclical Aeration




Sequencing Batch Reactor
Fill
Anoxic React
Aerobic React
Settle
Decant/ Waste
Add Substrate
Denitrify
Nitrify
Clarify
Decant Effluent/ Waste Sludge
Air: Off
Air: Off
Air: On
Air: Off

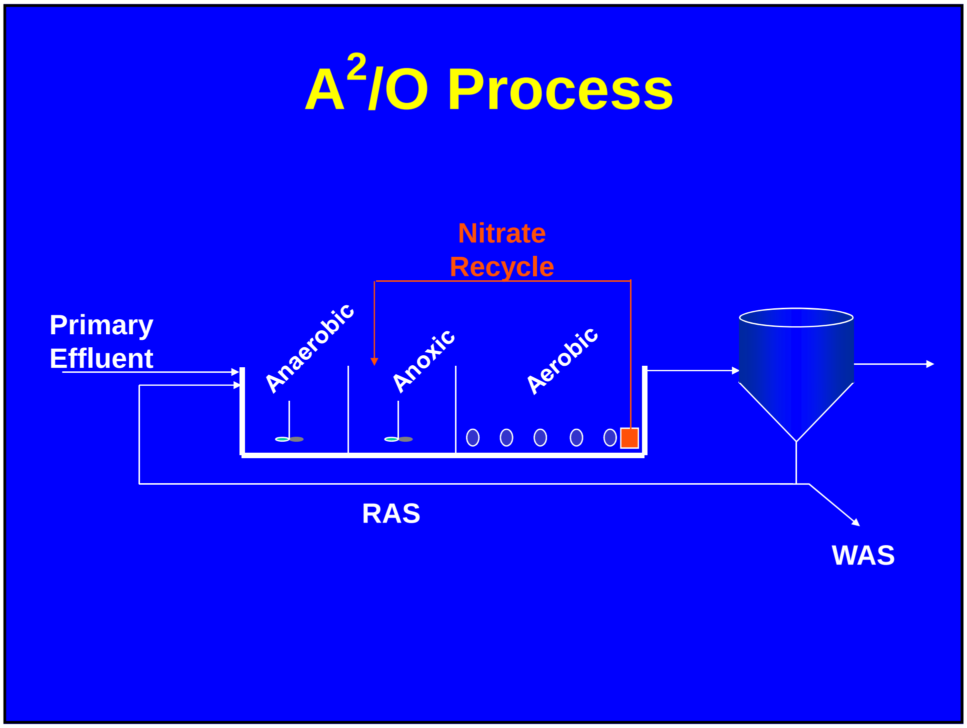

Oxidation Ditch BNR Process
D.O.
D.O. Profile, Pass 1
Primary Effluent
AEROBIC
Pass 1
ANOXIC
ANOXIC
Pass 2
AEROBIC

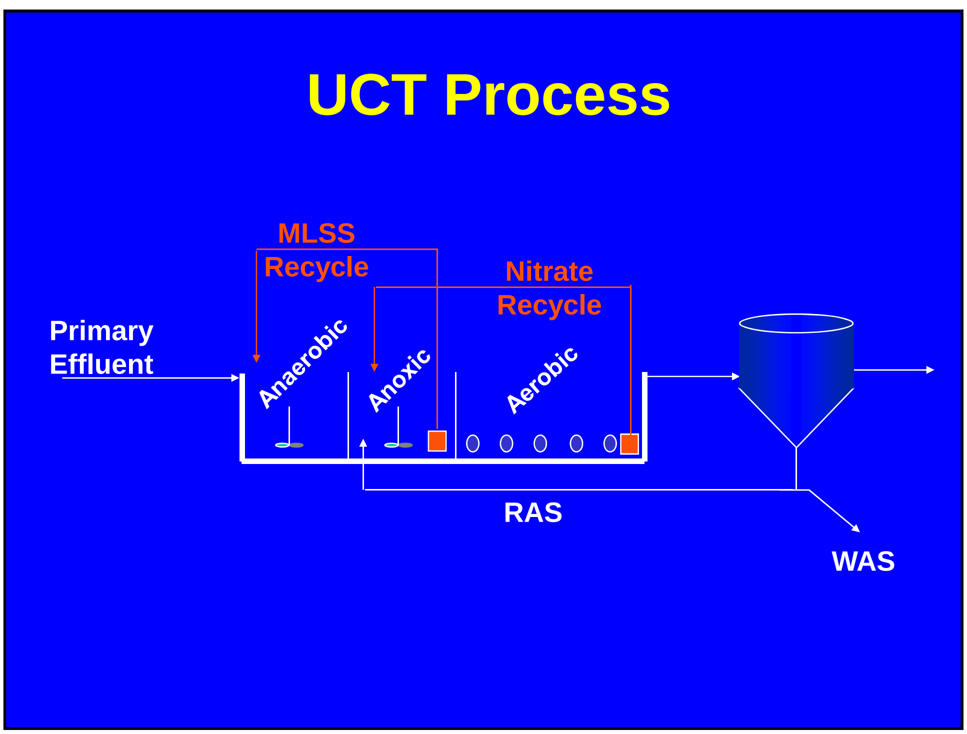
Schreiber Process

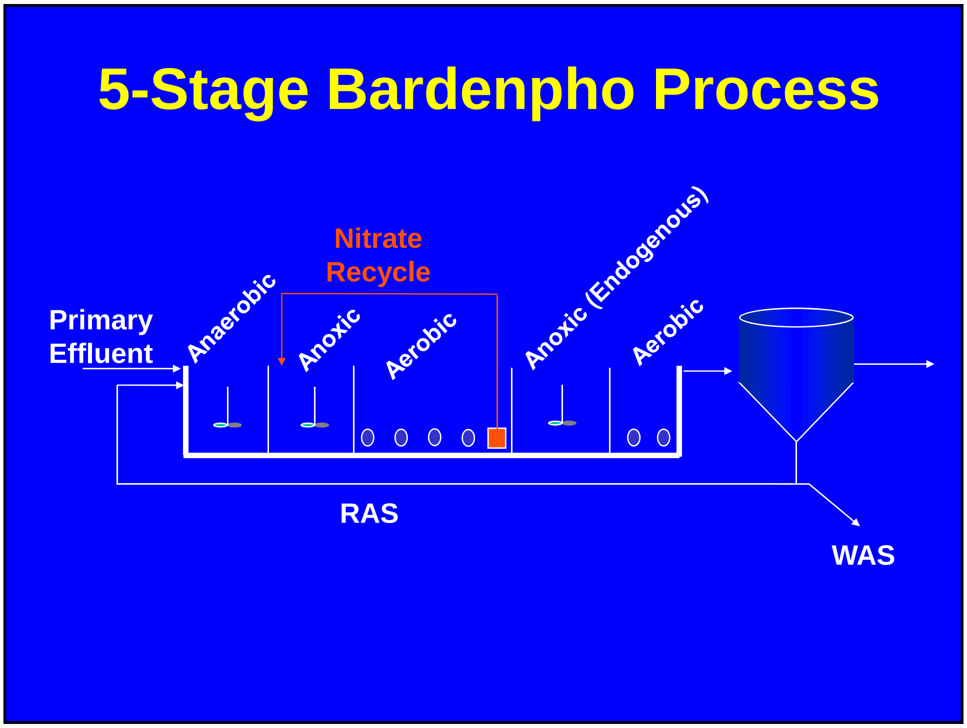


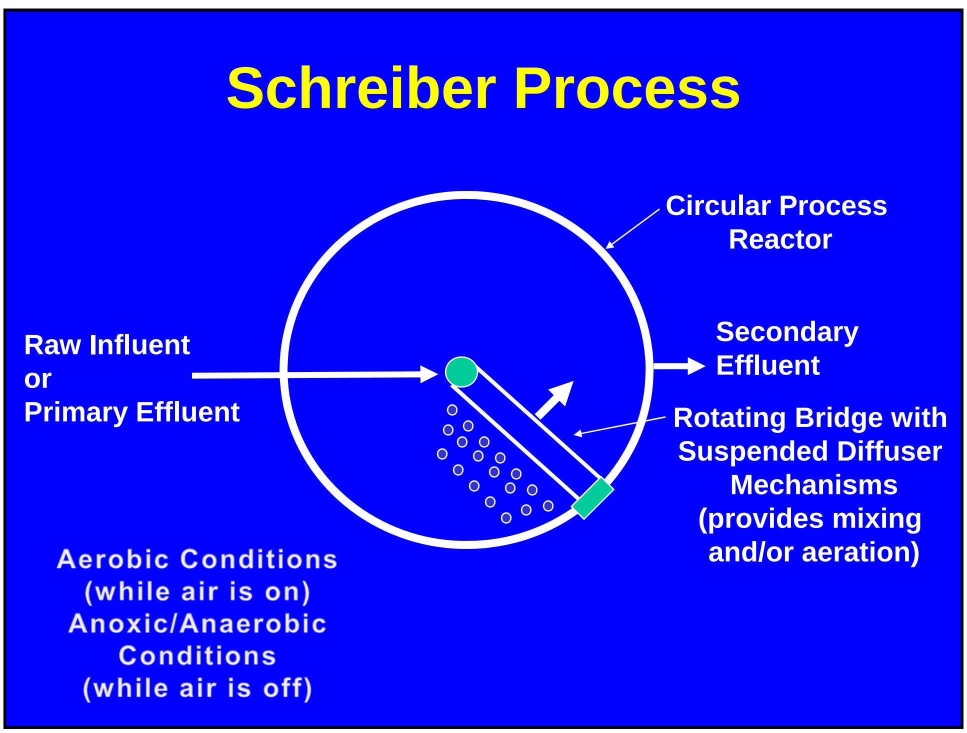
Understanding and Operating BNR Facilities

Nitrogen and Phosphorus Removal Processes


A²/O Process
Nitrate
Recycle
Primary
Effluent
Anaerobic
Anoxic
Aerobic
RAS
WAS


UCT Process
MLSS
Recycle
Nitrate
Recycle
Primary
Effluent
Anaerobic
Anoxic
Aerobic
RAS
WAS


5-Stage Bardenpho Process
Nitrate
Recycle
Primary
Effluent
Anaerobic
Anoxic
Aerobic
Anoxic (Endogenous)
Aerobic
RAS
WAS


Schreiber Process
Circular Process
Reactor
Raw Influent
or
Primary Effluent
Secondary
Effluent
Rotating Bridge with
Suspended Diffuser
Mechanisms
(provides mixing
and/or aeration)
Aerobic Conditions
(while air is on)
Anoxic/Anaerobic
Conditions
(while air is off)

Operating BNR Facilities

Thank You

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