Aeration University – Advanced Concepts in Energy Efficiency

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Aeration and Energy

- Wastewater Treatment Plants (WWTPs) are Large Energy Users
- Aeration Consumes >50% of WWTP Energy
- Energy Efficient Aeration is a Good Investment for WWTPs

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Aeration and Energy

- Fine Bubble Aeration – Mainstream Beginning in 1980s and 1990s
  - Ceramic Domes
  - Membrane Disks
  - Reduced Aeration Requirements by 30% to 50%.

Aeration and Energy

- Dissolved Oxygen Control Systems
  - Mainstream in Last 10 Years
  - Better DO Sensors and VFDs Allow Reliable Operation
  - Reduced Aeration Requirements by 10% to 20%.

Aeration and Energy

- What is Next?
  - Process Improvements
  - Operation Improvements
  - Further Equipment Enhancements

Understanding Aeration Systems

- Terminology
  - SOR – Standard Oxygen Requirement
  - SOTE – Standard Oxygen Transfer Efficiency
  - Standard Conditions
    - 20° C
    - 1.0 Atmosphere Pressure
    - 0.0 mg/l Dissolved Oxygen
    - Clean Water (Potable)

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Understanding Aeration Systems

- Terminology
  - AOR – Actual Oxygen Requirement (Oxygen Required under Field Conditions)
  - AOTE – Actual Oxygen Transfer Efficiency
  - Typical Fine Bubble AOR:SOR = 0.33

Understanding Aeration Systems

- AOR is the Sum of:
  - CBOD (Carbonaceous Biochemical Oxygen Demand)
  - NOD (Nitrogenous Oxygen Demand)
  - Denitrification (Oxygen Credit from Nitrate Reduction)

Determining Oxygen Demand

- CBOD
  - Substrate Oxidation – 0.7 lbs O_2 per lb BOD Removed
  - Endogenous Decay - 0.5 lbs O_2 per lb BOD Removed
- Total CBOD = 1.2 lbs O_2 per lb BOD Removed

Determining Oxygen Demand

- NOD
  - Substrate Oxidation – 4.6 lbs O_2 per lb Ammonia-N Removed
- Denitrification Credit = 2.86 lbs O_2 per lb Nitrate-N Reduced

Calculating AOR and SOR

- $AOR = SOR(\propto)\left[\left(\left(\beta\left(\frac{P_f}{P_m}\right)Csat_t\right) - C\right)/Csat_{20}\right]\theta^{T-20}$

  - ∝ – Ratio of mass transfer coefficient of wastewater to clean water (0.4 - 0.9)
  - β – Saturation Factor (typically 0.95)
  - P_f/P_m – Ratio of field barometric pressure to mean sea level pressure

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Calculating AOR and SOR

- $AOR = SOR(\propto)\left[\left(\left(\beta\left(\frac{P_f}{P_m}\right)Csat_t\right) - C\right)/Csat_{20}\right]\theta^{T-20}$
  - $Csat_t$ – DO saturation at design temperature
  - $Csat_{20}$ – DO saturation at 20° C
  - C – DO concentration under operating conditions
  - θ^{T-20} – temperature correction factor – 1.024

Key Variables

- C – DO Concentration in Aeration Tank
  - Make as Small as Possible
  - Need Adequate DO for Good Treatment
  - Too Much DO Wastes Energy
  - Too Much DO can Negatively Impact Nutrient Removal

Impact of DO Concentration

- DO Transfer Like Pumping Up a Tire
  - Easy When No Air in Tire
  - Difficulty Increases With More Air in Tire
  - Oxygen Transfer More Difficult with Higher DO Concentration
- Approximately 14% More Energy Required at 3 mg/l DO vs 2 mg/l DO

Impact of DO Concentration

- How Does DO Concentration in Aeration Basins Impact Oxygen Transfer?

Dissolved Oxygen – mg/l	Energy Requirement Ratio – DOX/DO0
0	1.0
1	1.11
2	1.24
3	1.42
4	1.65
5	1.96
6	2.43
7	3.19
8	4.64

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Design for Variable DO Concentration

- Complete Mix Reactors = Uniform Substrate and DO Concentration
- Need 2.0 mg/l DO for Good Effluent
- Avoid Complete Mix Reactors
  - Single Tanks
  - Parallel Tanks
  - Oxidation Ditch (Single or Parallel)

Design for Variable DO Concentration

- Use Plug Flow Reactors
  - Single Tank With Large Length to Width Ratio and Tapered Aeration
  - Multiple Tanks in Series
- Initial Tanks Operate at 0 mg/l DO
- Final Tank Operate at 2.0 mg/l DO

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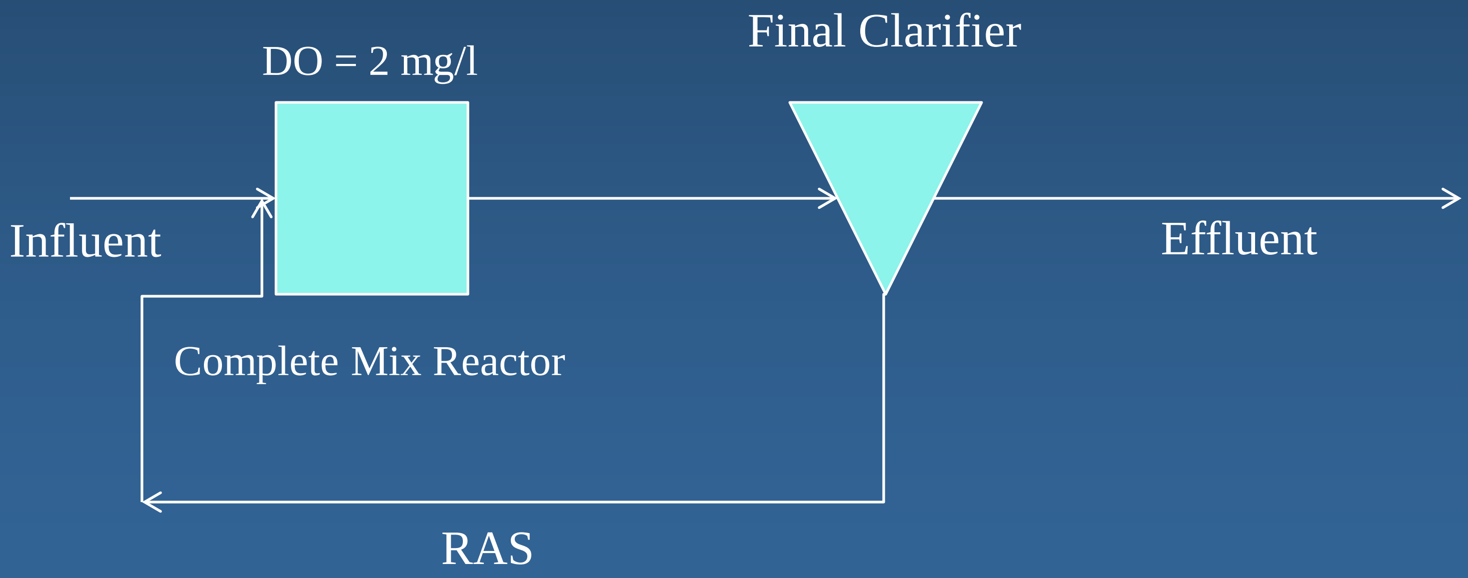
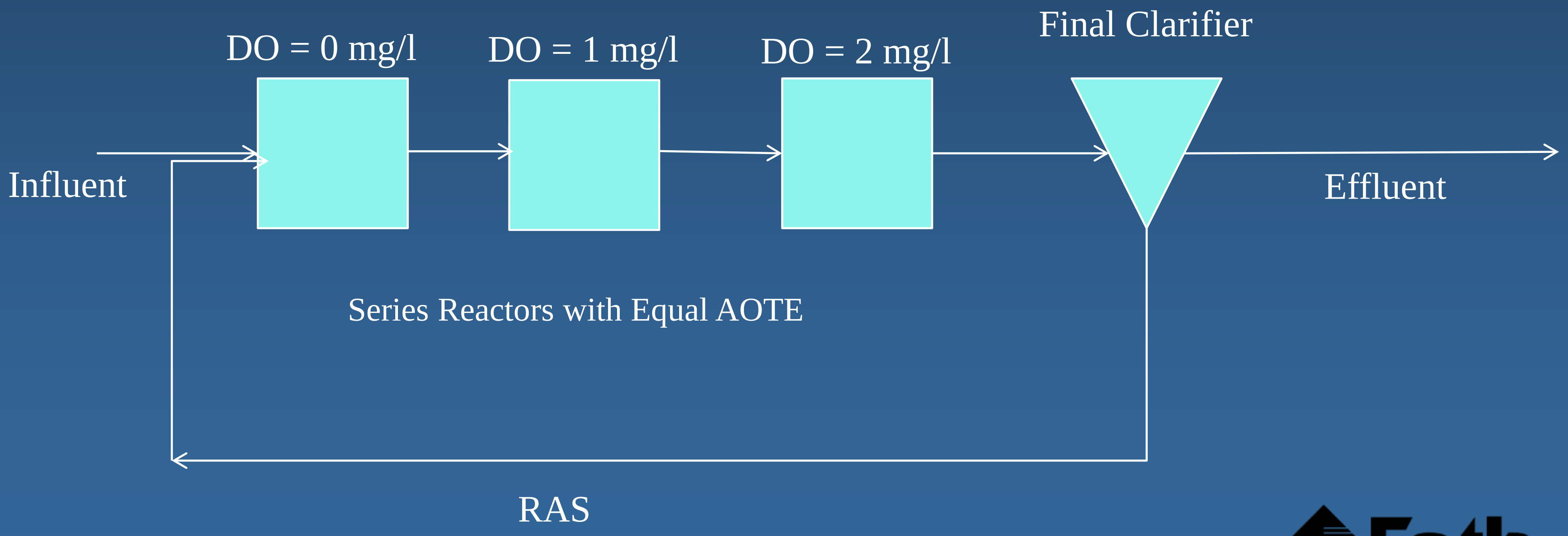
Design for Variable DO Concentration

- Example 1 – Complete Mix Reactor - No Ability to Run at Low DO



Design for Variable DO Concentration

- Example 2 – Plug Flow Reactor - Variable DO Operation



Example of Variable DO

- C is Only Variable
- 130 lbs/hr AOR and 4 lbs O_2/HP-Hr (S)
- Example 1 - Complete Mix = **282 HP**
- Example 2 – Plug Flow = **230 HP**
- 19% Reduction in Energy by Using Example 2

Key Variables - ∝

- ∝ – Ratio of mass transfer coefficient of wastewater to clean water
- Highly Variable Depending On
  - Type of Aeration Device
  - Surfactants (Including Low Molecular Weight Organics)
  - Sludge Age - Proportional

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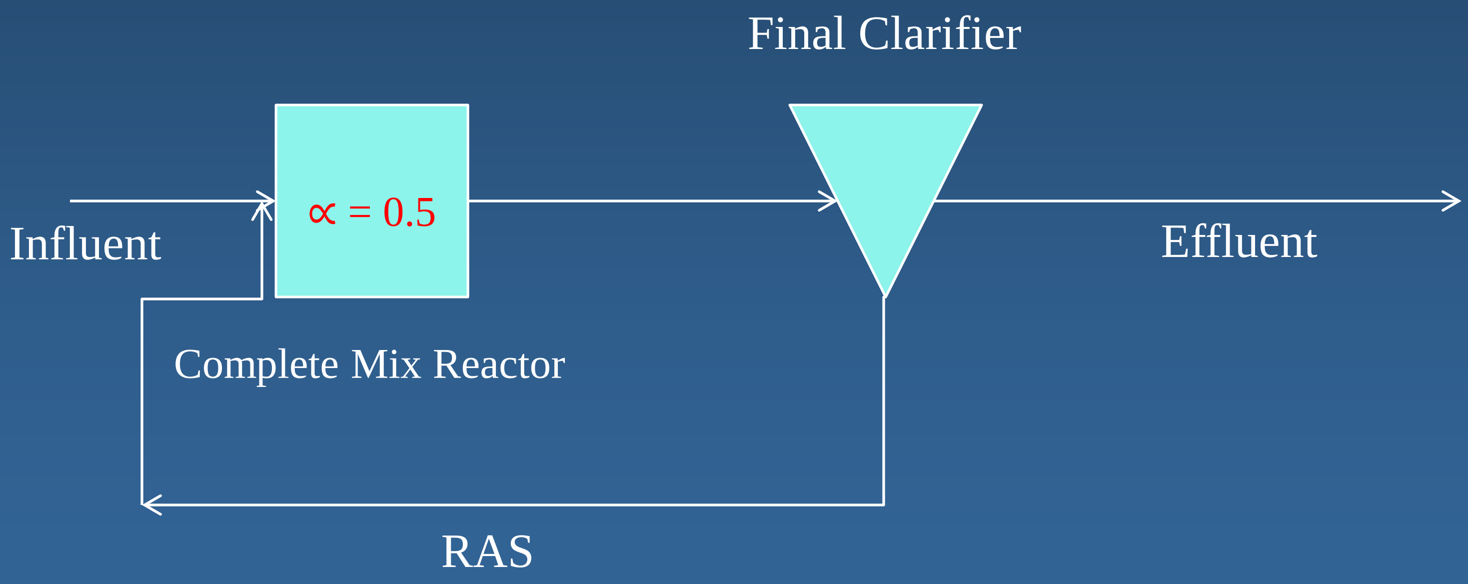
Key Variables - $\propto$

- How To Improve $\propto$
  - Operate at High Sludge Age – Better Uptake of Dissolved Substrate = Cleaner Water
  - Un-Aerated Selectors – Remove Surfactants Without Aeration
  - Use Plug Flow Reactors With Increased $\propto$ at Effluent End

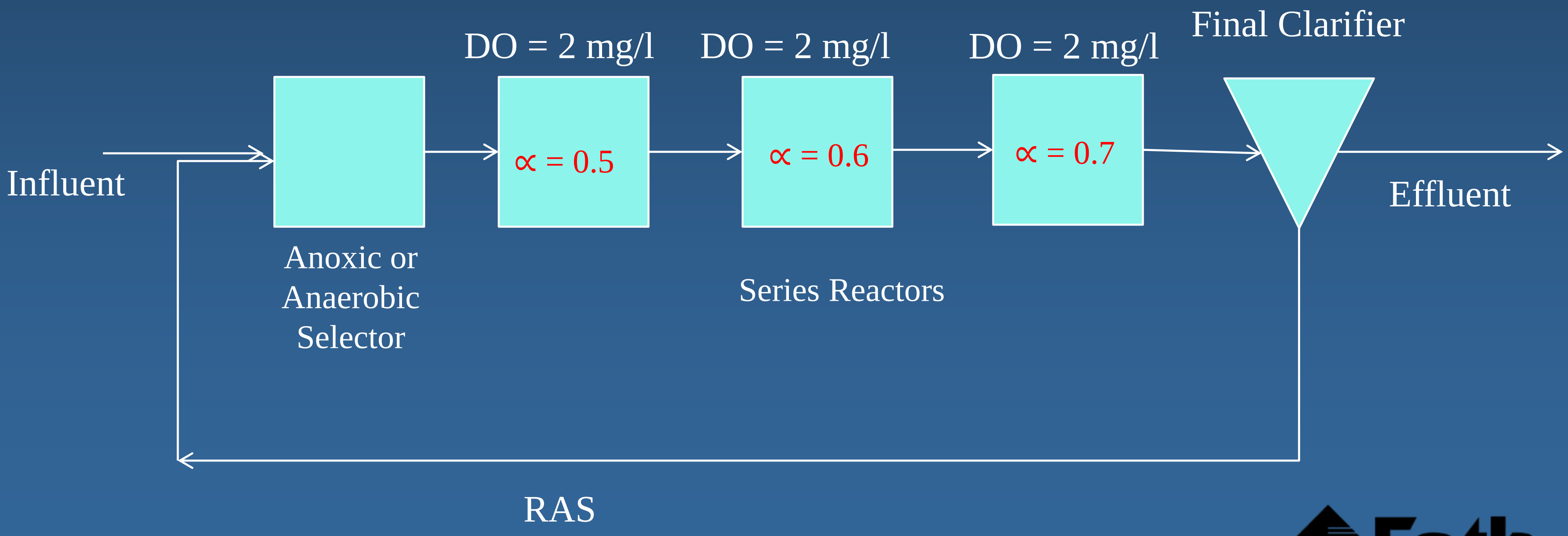
Design for Variable α Concentration

- Example 1 – Complete Mix Reactor – Constant ∝



Design for Variable α

- Example 2 – Plug Flow Reactor - Variable ∝ Operation



Example of Variable ∝

- ∝ is Only Variable
- 130 lbs/hr OTR and 4 lbs O_2/HP-Hr
- Example 1 - Complete Mix = **282 HP**
- Example 2 – Plug Flow = **207 HP**
- 27% Reduction in Energy by Using Plug Flow With Selector

Impact of Denitrification

- Fate of Ammonia and Organic Nitrogen
  - A Portion of N Goes to Cell Growth (~ 25%)
  - Remainder is Oxidized to Nitrate (NO_3)
- Denitrification ($NO_3 \rightarrow N_2$ gas)
  - 2.86 mg/l O_2 Per mg NO_3 Reduced

Example of Denitrification

- 40 mg/l N in Influent
- 12 mg/l to Biological Cell Growth
- 28 mg/l for Nitrification
- 28 x 4.6 = 129 mg/l O_2
- Denitrification Leaves 5 mg/l NO_3
- 23 x 2.86 = 66 mg/l O_2 Recovered
- 51% O_2 Recovered

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Optimum Design for Oxygen Transfer

- Anoxic Selector – Aerated Anoxic – Aerobic
- Advantages
  - Oxygen Credit from Denitrification
  - Improved Alpha Value
  - Phased DO Concentration Improves Transfer

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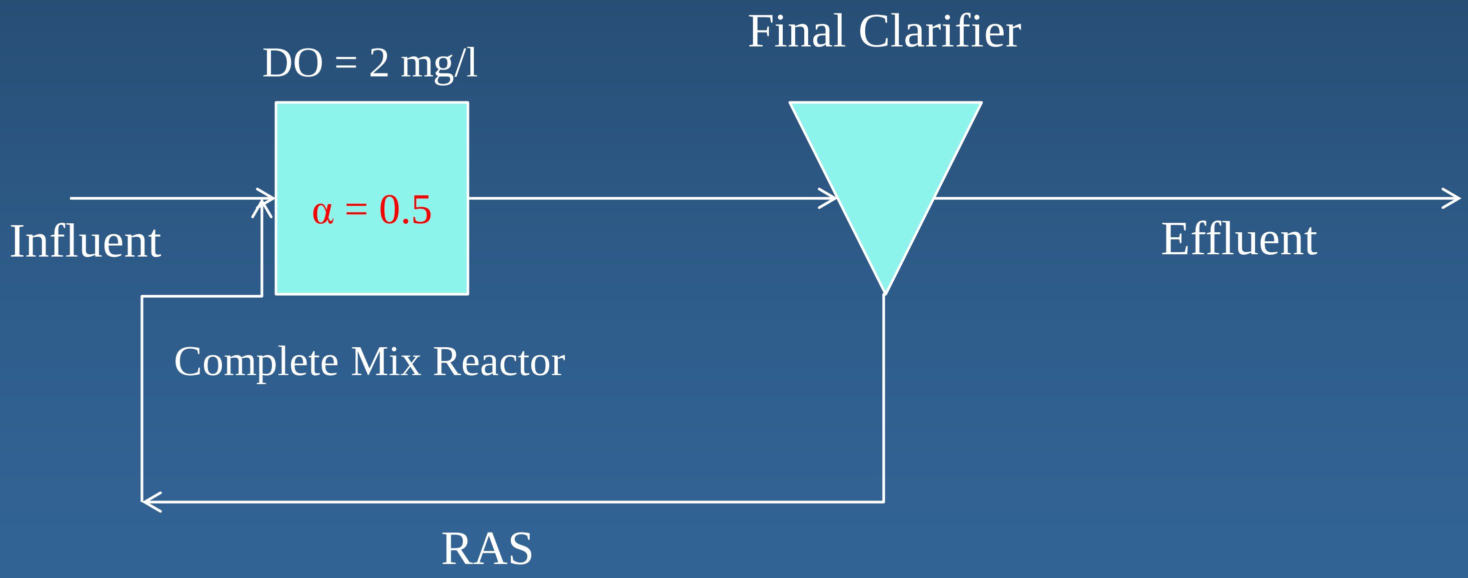
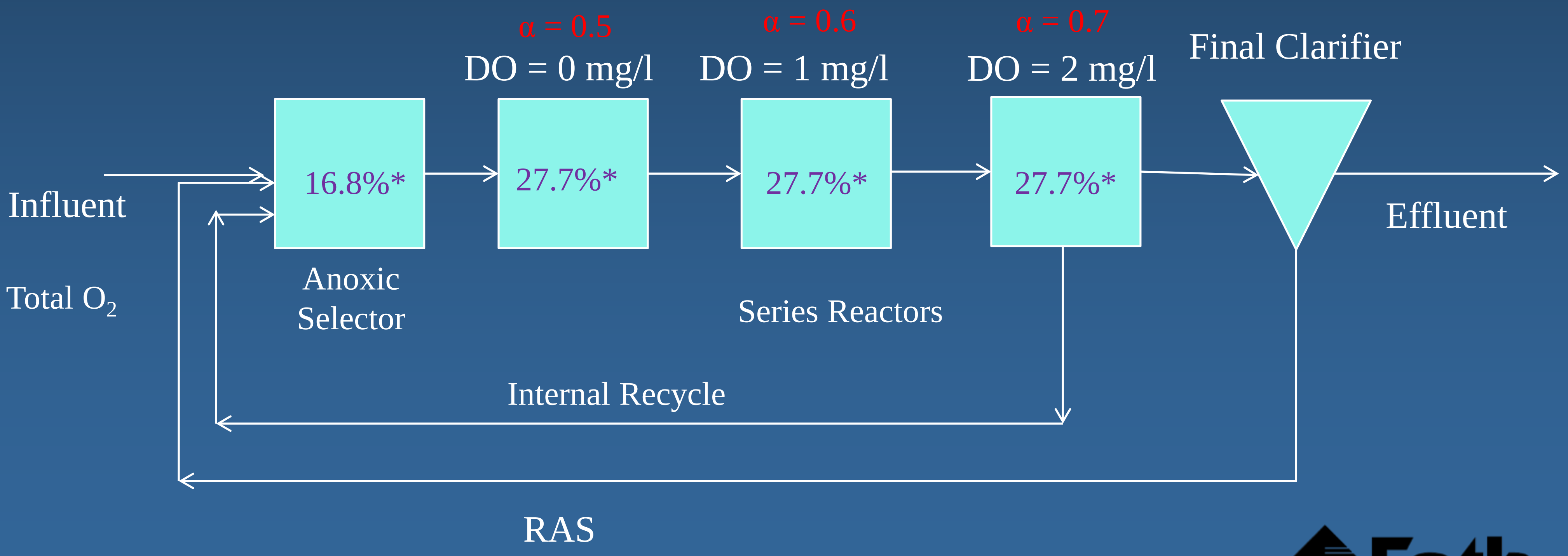
Optimum Design for Oxygen Transfer

- Example 1 – Complete Mix Reactor



Optimum Design for Oxygen Transfer

- Example 2 – Selector and Plug Flow Reactor



α = 0.5
DO = 0 mg/l
α = 0.6
DO = 1 mg/l
α = 0.7
DO = 2 mg/l
Final Clarifier

Influent
16.8%*
27.7%*
27.7%*
27.7%*
Effluent

Anoxic Selector

Series Reactors

Internal Recycle

RAS

* = % of Total O_2 Demand

Example of Optimum Design

- 130 lbs/hr OTR and 4 lbs O_2/HP-Hr
- Example 1 - Complete Mix = **282 HP**
- Example 2 – Selector and Plug Flow Reactor = **143 HP**
- 49% Reduction in Energy by Using Plug Flow With Selector

Enhanced Nitrification/Denitrification with Aerated Anoxic Reactors

- Siemens Developed Aerated Anoxic Reactors
- Promotes Aerobic Treatment Under Anoxic Conditions
  - Reduced Energy
  - Nitrification and Denitrification in Same Tank

Standard Process

- “Text Book” Nitrification
  - $NH_3 \rightarrow NO_2 \rightarrow NO_3$
  - Nitrosomonas – Ammonia Oxidizer
  - Nitrobacter – Nitrite Oxidizer
  - Need DO > 2.0 mg/l
- “Text Book” Denitrification
  - $NO_3 \rightarrow NO_2 \rightarrow N_2\uparrow$
  - Need DO at 0 mg/l

Aerated Anoxic Reactors

- Unconventional Nitrification/Denitrification
  - $NH_3 \rightarrow NO_2 \rightarrow N_2\uparrow$
  - Nitrospirea – Ammonia Oxidizer
- Nitrospirea
  - Out competes Nitrosomonas in Aerated Anoxic Reactors
  - Can Go Dormant

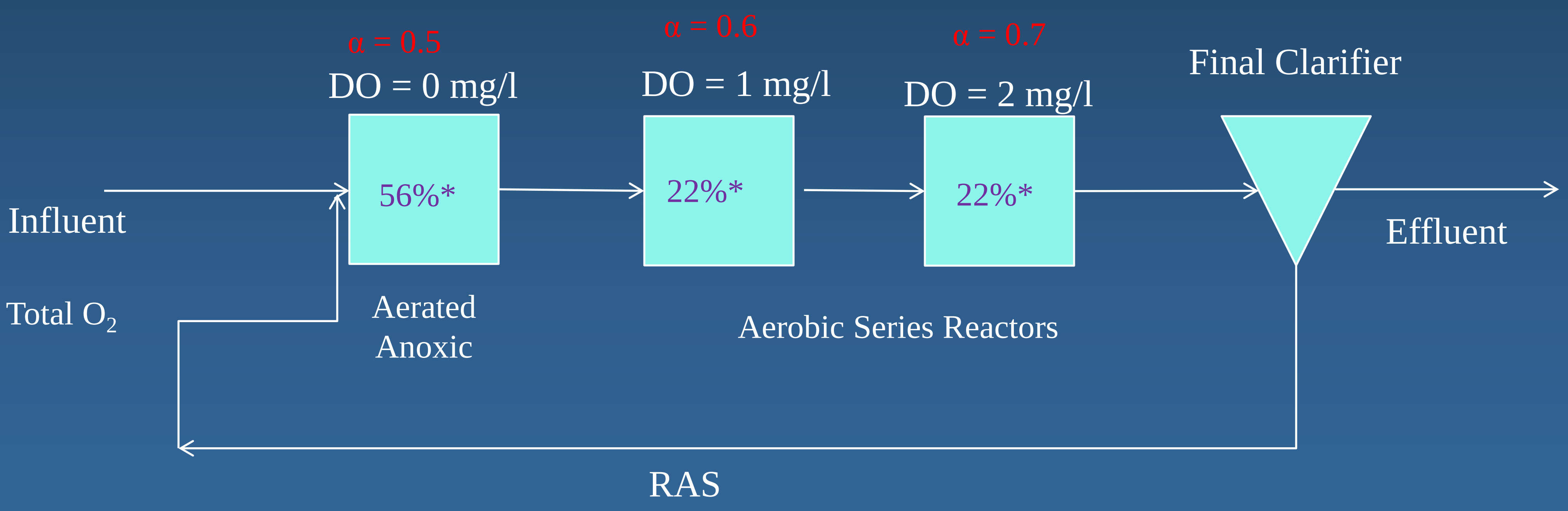
Aerated Anoxic Reactors

- Design for Simultaneous Nitrification and Denitrification
- Larger Aerated Anoxic Zone
- Zero DO Concentration - Maximize Aeration
  - ?
  - This is Key to Process

Aerated Anoxic Reactors

- Benefits
  - Transfers Bulk of Oxygen at Zero DO
  - Skips $NO_2 \rightarrow NO_3$ Step – Less Oxygen Required
  - Less Carbon Required for Denitrification
    - Benefit in Low Carbon Application
    - Carbon Available for Bio-P

Aerated Anoxic



* = % of Total O_2 Demand

Example of Aerated Anoxic Design

- 130 lbs/hr OTR and 4 lbs O_2/HP-Hr
- Example 1 - Complete Mix = **282 HP**
- Example 2 – Aerated Anoxic + Plug Flow Reactor = **130 HP**
- 54% Reduction in Energy by Aerated Anoxic

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Other Optimization Options

- Tank Depth Has Minor Impact on Oxygen Transfer
- Use Dedicated Mixers in Mixing Limited Reactors

Impact of Tank Depth

- Fine Bubble Aeration – 2% O_2 Transfer/Ft.
- Blower HP = CFM x PSI x .006

Diffuser Depth – Ft.	Pressure - PSI	Blower HP
10	6.0	100%
12	6.9	95%
14	7.7	92%
16	8.6	89%
18	9.5	87.5%

Mixing Limited Reactors

- Problem - Oxygen Demand is Low and the Air Supplied for Oxygen is Not Adequate to Mix Tank
- Solutions
  - Provide Excess Air and Waste Energy
  - Provide Separate Mechanical Mixers and Limit Air – Saves Energy

Reduce Oxygen Demand

- Add Primary Clarifiers or Primary Treatment
- Improve BOD Removal in Primary Clarifiers
    - Improve Hydraulics
    - Add Chemical (Alum or Ferric)

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Salsnes Screen for BOD Removal

Primary Clarifier Improvements – Mid Tank Baffles

Primary Clarifier Improvements – Parallel Effluent Troughs

Primary Clarifier Improvements – Parallel Effluent Troughs

Enhanced Primary Clarification and Overall Energy Balance

- With Anaerobic Digestion, Enhanced Primary BOD Removal Improves Energy Balance
  - Less BOD for High Energy Aeration
  - More BOD for Low Energy Anaerobic Digestion
  - More Biogas for Fuel

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Equipment Improvements

- Modern Diffusers Offer Enhanced Performance
  - Higher Density
  - Improved Oxygen Transfer

Equipment Improvements

- Modern Blowers Offer Higher Efficiency
  - Turbo Systems with Air or Magnetic Bearings Reduce Friction and Maintenance
  - High Speed Motors (25,000 rpm) Offer Improved Efficiency - Eliminate Gear Reducers

Turbo Blowers

Turbo Blowers

Summary

- Large Aeration Energy Savings Available
- Designers and Operators Can Influence Alpha and DO Concentration
  - Anoxic and Aerated Anoxic Reactors
  - Plug Flow Reactors

Summary

- Evaluate BOD Reduction for Overall Energy Improvement
- Evaluate Newer Technology for Aeration Equipment that is More Energy Efficient

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