Long Island Sound Nitrogen Removal Training Program

Module 4
Fixed Film Operational Strategies

SUNY Farmingdale
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New York State
Department of Environmental Conservation

Stearns & Wheler, LLC
ENVIRONMENTAL ENGINEERS & SCIENTISTS

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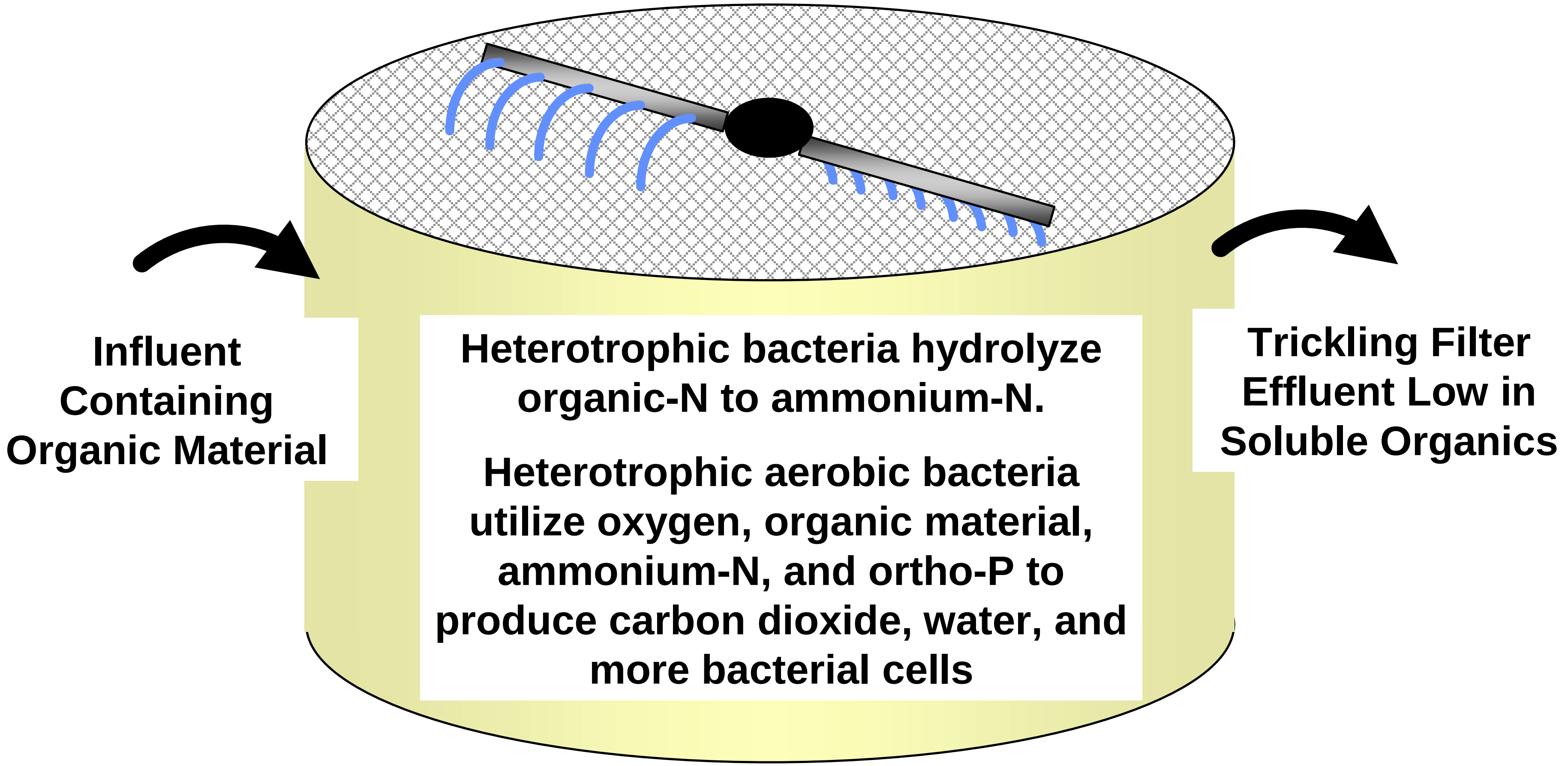
BOD Removal in Fixed Film Processes



Nitrification

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+$$

Oxygen Required = 3.43 lb / lb N oxidized

Alkalinity Required = 7.14 lb as $CaCO_3$/ lb N oxidized

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$$

Oxygen Required = 1.14 lb/ lb N oxidized

For both reactions together:

Total Oxygen Requirement = 4.57 lbs / lb N oxidized

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

What Factors Affect Nitrification in Fixed Film Processes

?

Factors Affecting Nitrification in Fixed Film Processes

- **BOD loading rate**
- **Ammonia loading rate**
  - **Per unit surface area**
  - **Per unit volume**
- **Dissolved oxygen**
- **Hydraulic loading rate**
- **Recirculation**
- **Temperature**
- **pH**
- **Alkalinity**
- **Inhibitory compounds**
- **Predator growth**

BOD Loading Rates for Carbonaceous BOD Removal in the Trickling Filter or RBC Process

- **Trickling Filter Loading Rate**
  - **25 lbs BOD_5 / day / 1000 cu ft (rock media)**
  - **1.7 lbs BOD_5 / day / 1000 sq. ft.**
- **RBC Loading Rate**
  - **1.0 to 2.0 lbs / day / 1000 sq. ft.**

BOD Loading Rates for Nitrification in the Trickling Filter or RBC Process

- **Trickling Filter Loading Rate**
  - **5 lbs BOD_5 / day / 1000 cu ft (rock media)**
  - **0.3 lbs BOD_5 / day / 1000 sq. ft.**
- **RBC Loading Rate**
  - **0.8 lbs BOD_5 / day / 1000 sq. ft.**

Definitions

Heterotroph - Organism which uses organic matter for energy and growth. The BOD-removers and denitrifiers in BNR systems are heterotrophic organisms

Autotroph - Organism which uses inorganic matter for energy and growth. The nitrifiers in BNR systems (nitrosomonas and nitrobacter) are autotrophic organisms

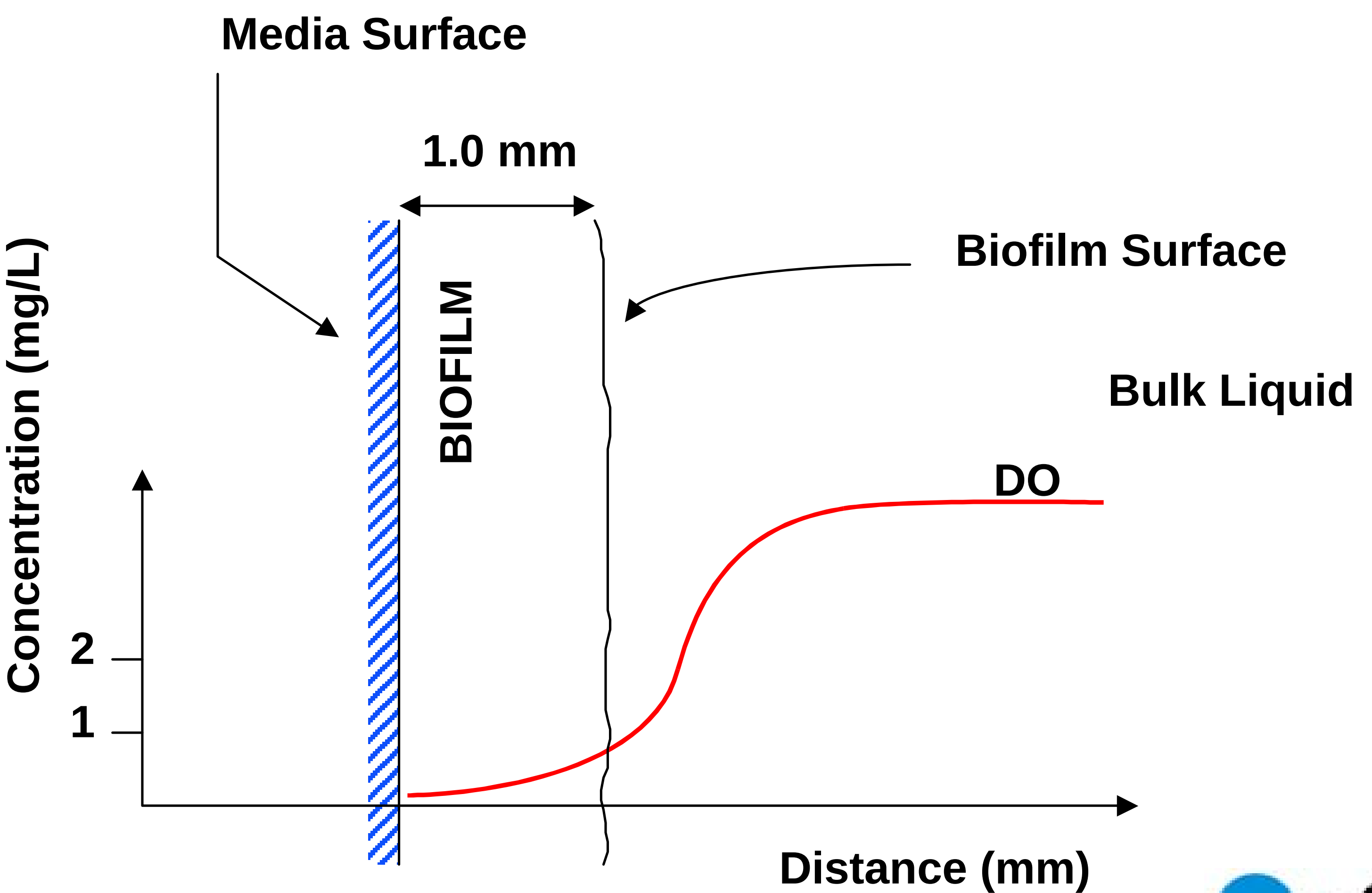
Competition Between Heterotrophs and Autotrophs

- **Heterotrophs (BOD-removers) have competitive advantage over autotrophs (nitrifiers)**
- **Heterotrophs grow at head end of TF or RBC, autotrophs grow at tail end**
- **Soluble BOD_5 must drop below about 15 mg/L to allow nitrifiers to grow**

Dissolved Oxygen

- **As dissolved oxygen increases, nitrifier growth rate increases**
- **Oxygen available to nitrifiers is affected by turbulence and diffusion into biofilm**
- **DO concentration often masks pH and temperature effects**
- **At temperatures above 15°C dissolved oxygen is often the rate limiting parameter**
- **Forced ventilation for TFs or aerated RBCs can increase nitrification rate**

DO Depletion in Biofilm



Hydraulic Loading Rate - Trickling Filters

- **Typical 25 - 200 gpd per sq. ft. of trickling filter plan area**
- **Past studies indicated importance of recirculation rate in Trickling Filters**
- **More recent studies have indicated no significant benefit from recirculation as long as sufficient wetting is provided**
- **Use 1:1 recirculation directly around trickling filter**
- **Some studies have shown benefits from slowing down distributor, other studies have shown no benefit to slowing distributor**

SK Approach

$$SK = \frac{(Q+R)(1.337 \times 10^5 \text{ cu. ft./mil.gal.})(304.8 \text{ mm/ft})}{(A)(a)(n)(1440 \text{ min/d})}$$

SK = flushing intensity, mm/pass of an arm
Q+R = average flow to trickling filters, mgd
A = total trickling filter plan area, sq. ft.
a = number of arms
n = rpm

Adapted from WEF MOP 8, 1992, p. 695, Equation (3)

Suggested SK Values

BOD5 loading (lb/d/1000 cu.ft.)	Design SK mm/pass	Flushing SK mm/pass
16	10-100	>200
31	15-150	>200
62	30-200	>300
125	40-250	>400
187	60-300	>600
250	80-400	>800

Adapted from WEF MOP 8, 1992, p. 697, Table 12.4

Hydraulic Loading Rate - RBCs

- **Typical 1 - 3 gpd per sq. ft. of media surface area**
- **Recirculation is not normally necessary in RBC systems**
- **In aerated RBCs of SBCs, can provide a return sludge stream and develop some suspended growth in RBC basin**
- **Recirculation of RBC effluent in nitrifying systems may provide some denitrification**

Competing Effects of Increasing Temperature

Increases BOD Uptake Rate

- **Reduces BOD in Bulk Phase**
- ***Increases Nitrification Rate***

Increases Nitrifier Growth Rate

- ***Increases Nitrification Rate***

Decreases Solubility of Oxygen in Water

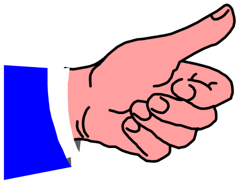
- **Reduces Oxygen Transfer into Biofilm for Same Air Flow**
- ***Decreases Nitrification Rate Unless Air Flow Rate Increased***

Result - Often no temperature effect is observed between 15°C and 20°C

Effect of pH and Alkalinity on Nitrification

Nitrification consumes alkalinity and lowers pH of the wastewater

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.

Simplified Calculation of Alkalinity Requirement for Nitrification

Given:

Plant Influent Flow	=	10 mgd
Primary Effluent TKN	=	31.5 mg/l

Alkalinity Consumed by Nitrification :

<u>In lbs/day</u>

(10) mgd Flow (mgd)	x	(31.5 mg/l) TKN conc. (mg/l)	x	(7.14) lbs. of alkalinity required per lb of ammonia-N nitrified	x	(8.34)	=	18,757 lbs alkalinity as $CaCO_3$ per day

<u>In mg/l</u>

(31.5 mg/l) x (7.14) = 225 mg/l alkalinity as $CaCO_3$ consumed

Sources of Alkalinity

Source	Form Delivered	lbs. Alkalinity as $CaCO_3$ per lb. or gallon of Product	Cost per lb. of Alkalinity as $CaCO_3$
Hydrated Lime	50 lb. Bags 20 Ton Truck	1.33 per lb.	\$0.074 (50 lb. Bag) \$0.05 (20 Ton Truck)
Sodium Bicarbonate	50 lb. Bags	1.19 per lb.	\$0.36
Sodium Hydroxide (Caustic Soda)	55 Gallon Drum ½ Truck (1,750 Gallons) Full Truck (3,500 Gallons)	7.87 per gallon	\$0.19 (55 Gallon Drum) \$0.125 (½ Truck) \$0.104 (Full Truck)

Compounds Which Inhibit Nitrification

Organic Compounds:

- Acetone
- Carbon Disulfide
- Chloroform
- Ethanol
- Monoethanolamine
- Phenol
- Ethylenediamine
- Hexamethylene Diamine
- Aniline

Metals and Inorganic Compounds:

- Zinc
- Free Cyanide
- Perchlorate
- Copper
- Mercury
- Chromium
- Nickel
- Silver
- Cobalt
- Thiocyanate
- Sodium Cyanide
- Sodium Azide
- Hydrazine
- Sodium Cyanate
- Potassium Chromate
- Cadmium
- Arsenic (trivalent)
- Fluoride
- Lead

Denitrification

Nitrate + Methanol → Carbon Dioxide + Nitrogen Gas + Water + Hydroxide

$$6NO_3^- + 5CH_3OH \longrightarrow 5CO_2 + 3N_2 \overset{\text{Gas}}{\uparrow} + 7H_2O + 6OH^-$$

Methanol Utilized = 1.9 lbs methanol per lb nitrate-N denitrified
This is equivalent to 2.86 lbs COD utilized 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 recovered = 2.86 lbs per lb nitrate-N denitrified

Simplified Calculation of Oxygen and Alkalinity Recovered by Denitrification

Given:

Plant Influent Flow = 10 mgd
Nitrate to be Denitrified

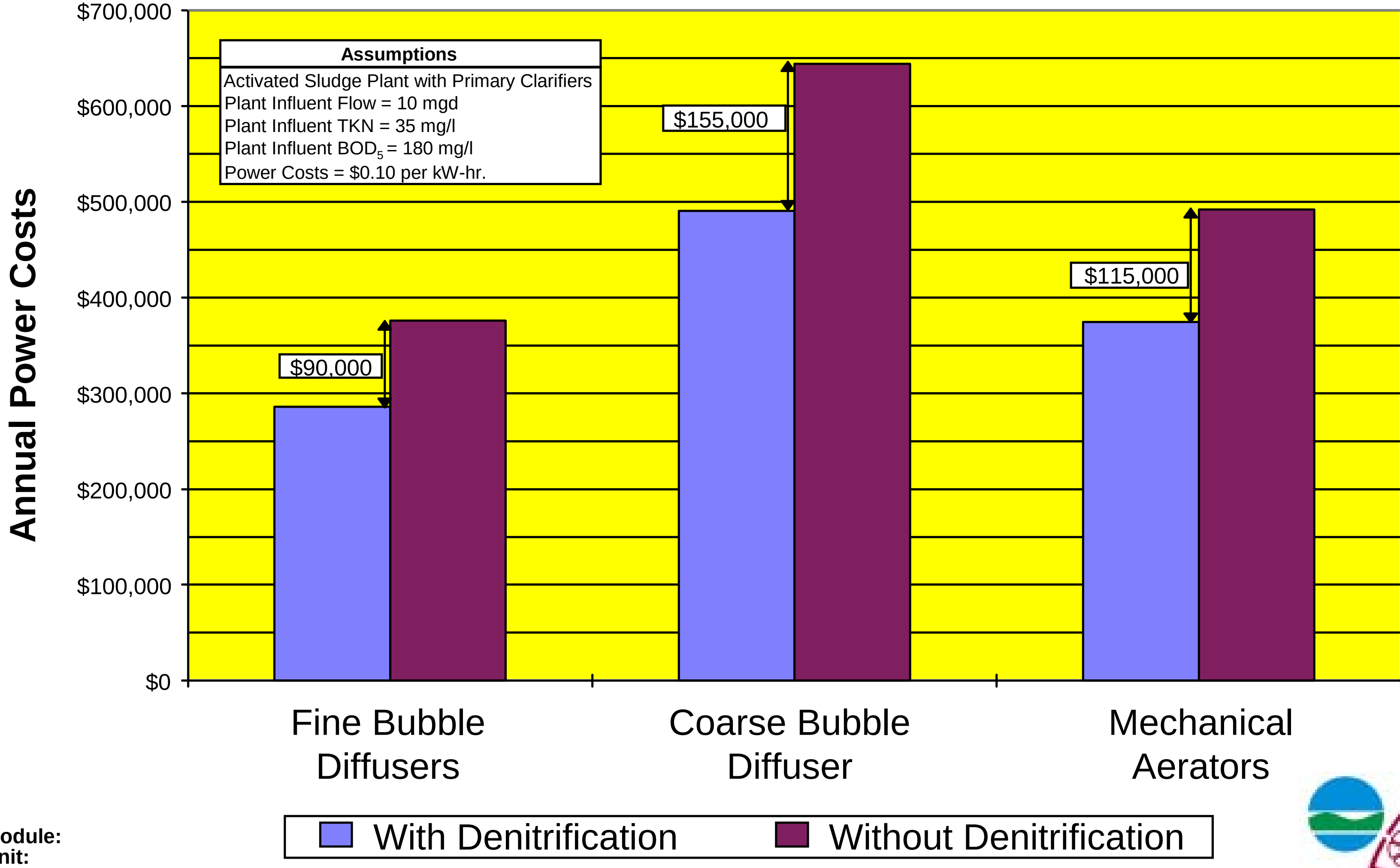
Oxygen Recovered

(10 mgd)	**x**	**(22 mg/l)**	**x**	**2.86**	**x**	**8.34**	**=**	**5,248 lbs O_2 recovered per day**
Flow (mgd)		Nitrate-N to be Denitrified		lbs O_2 recovered per lb nitrate denitrified				

Alkalinity Recovered

(10 mgd)	**x**	**(22 mg/l)**	**x**	**3.57**	**x**	**8.34**	**=**	**6,550 lbs alkalinity as $CaCO_3$ recovered per day**
Flow (mgd)		Nitrate-N Denitrified		lbs alkalinity per lb nitrate denitrified				

Potential Aeration Power Savings Due to Denitrification



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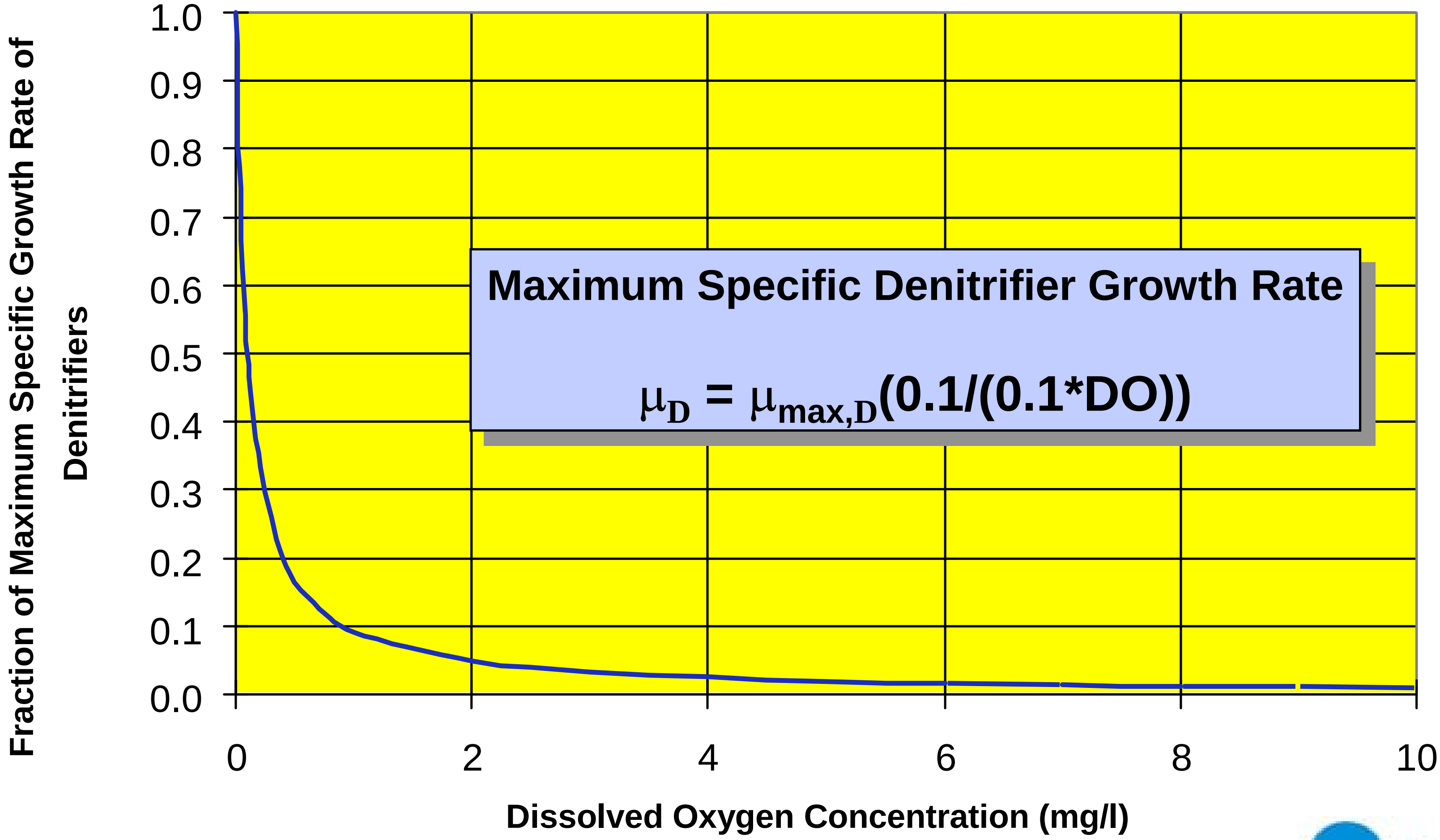
Effect of Dissolved Oxygen on Denitrification

- **Dissolved oxygen inhibits denitrification.**
- **As DO increases, denitrification rate decreases.**
- **To achieve denitrification, the nitrified wastewater must be subjected to anoxic conditions. This can happen to some extent within the biofilm.**

Effect of Dissolved O_2 on Denitrification Rate

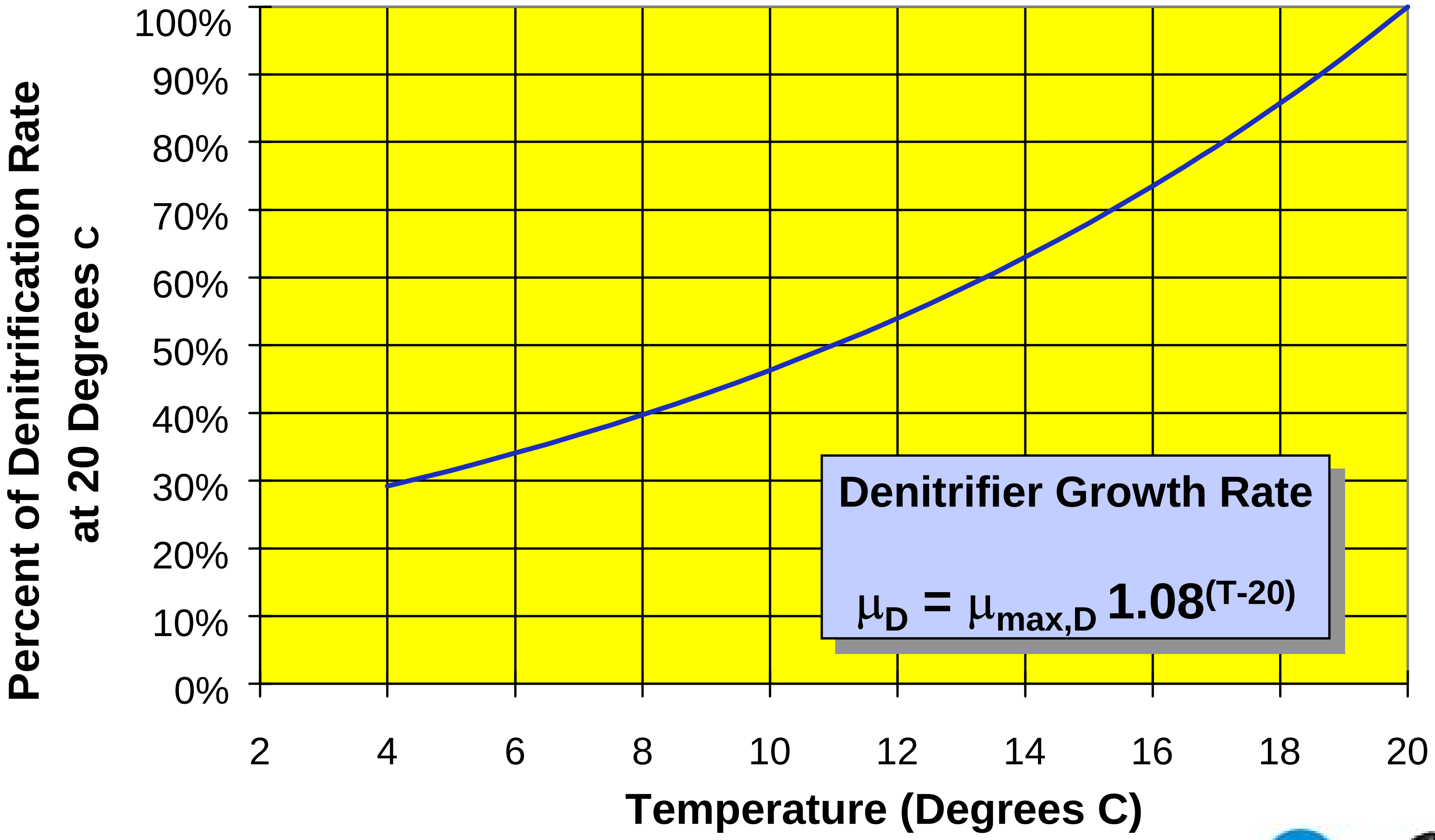


Effect of Temperature on Denitrification Rate

As temperature increases, denitrifier growth rate increases.

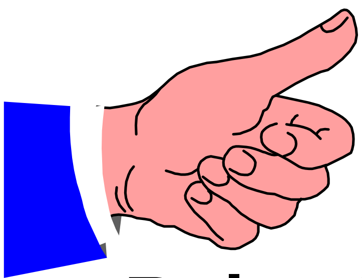
$$T \uparrow \qquad \mu_D \uparrow$$

Effect of Temperature on Denitrification Rate



Effect of pH on Denitrification Rate

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



<u>Rule of Thumb</u>:

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

Effects of Inhibitory Compounds on Denitrification

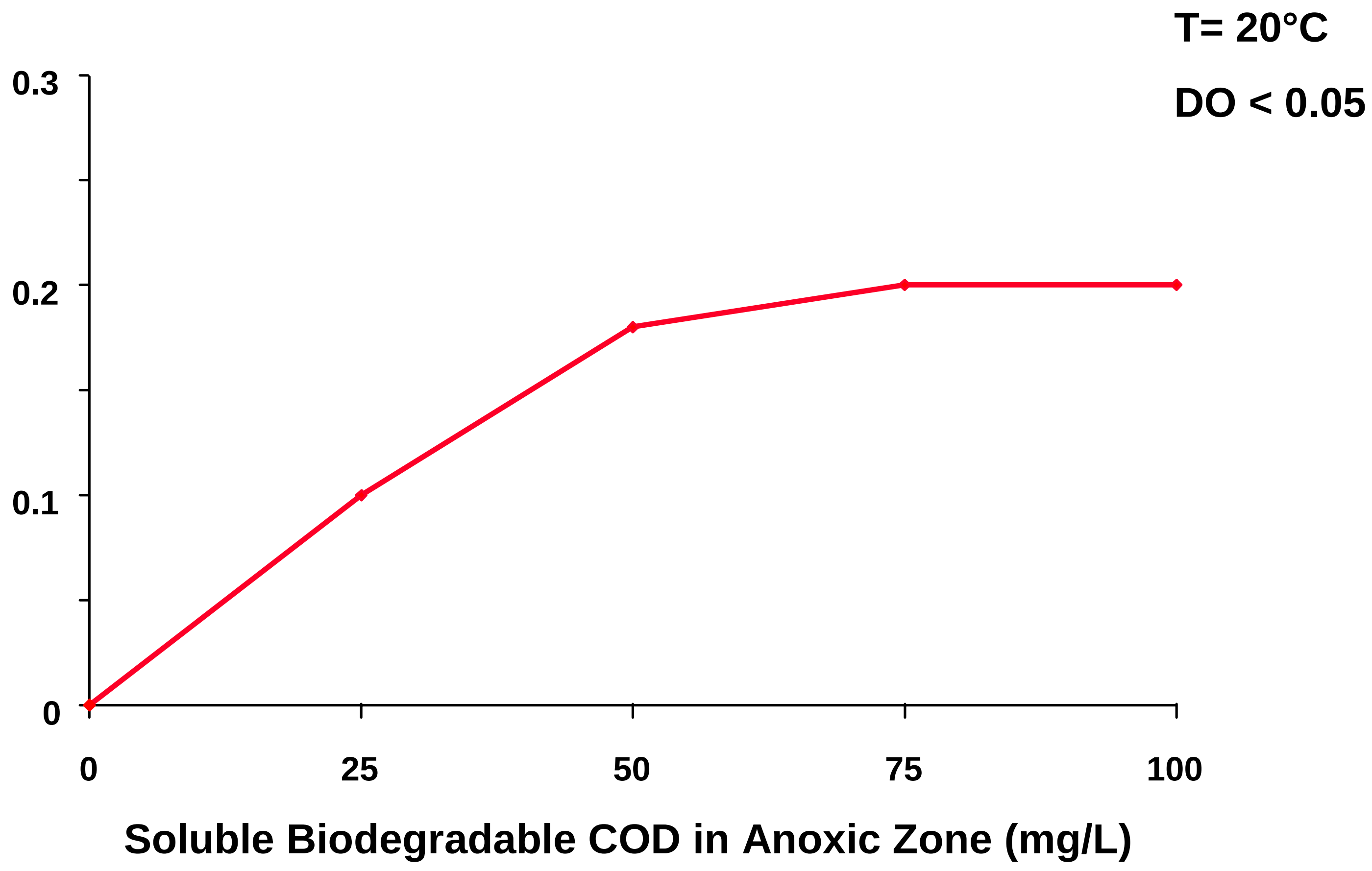
- **Denitrifiers are generally less sensitive to inhibitory compounds than nitrifiers.**

- **If there are no compounds present which inhibit nitrification, there will probably be no inhibition of denitrification.**

Effects 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.**

Effect of Biodegradable SCOD in Anoxic Zone on Specific Denitrification Rate



Range of Variation of Ks

Ks = 20-50 mg/L SCOD at 12°C

So, what do we need to do to get my plant to nitrify

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So, what do we need to do to get my plant to nitrify

?

Create a fixed film loading rate conducive to nitrification, and provide sufficient oxygen for nitrification

Methods to Decrease Loading Rate

- **Activate trickling filter or RBC by adding a return sludge line**

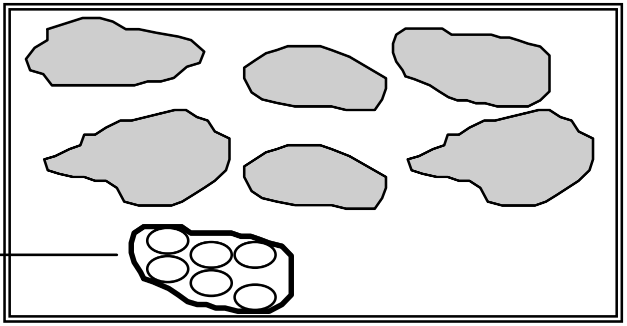
- **Increase surface area of media in existing unit**
  - **Replace rock TF media with plastic media**
  - **Increase RBC media density**

- **Add a new biological treatment unit**
  - **Tertiary trickling filter**
  - **Additional RBC**
  - **Nitrification filter**

Methods to Increase Surface Area

- **Change Size of Media**

Reduce Size of Media Increases Surface Area

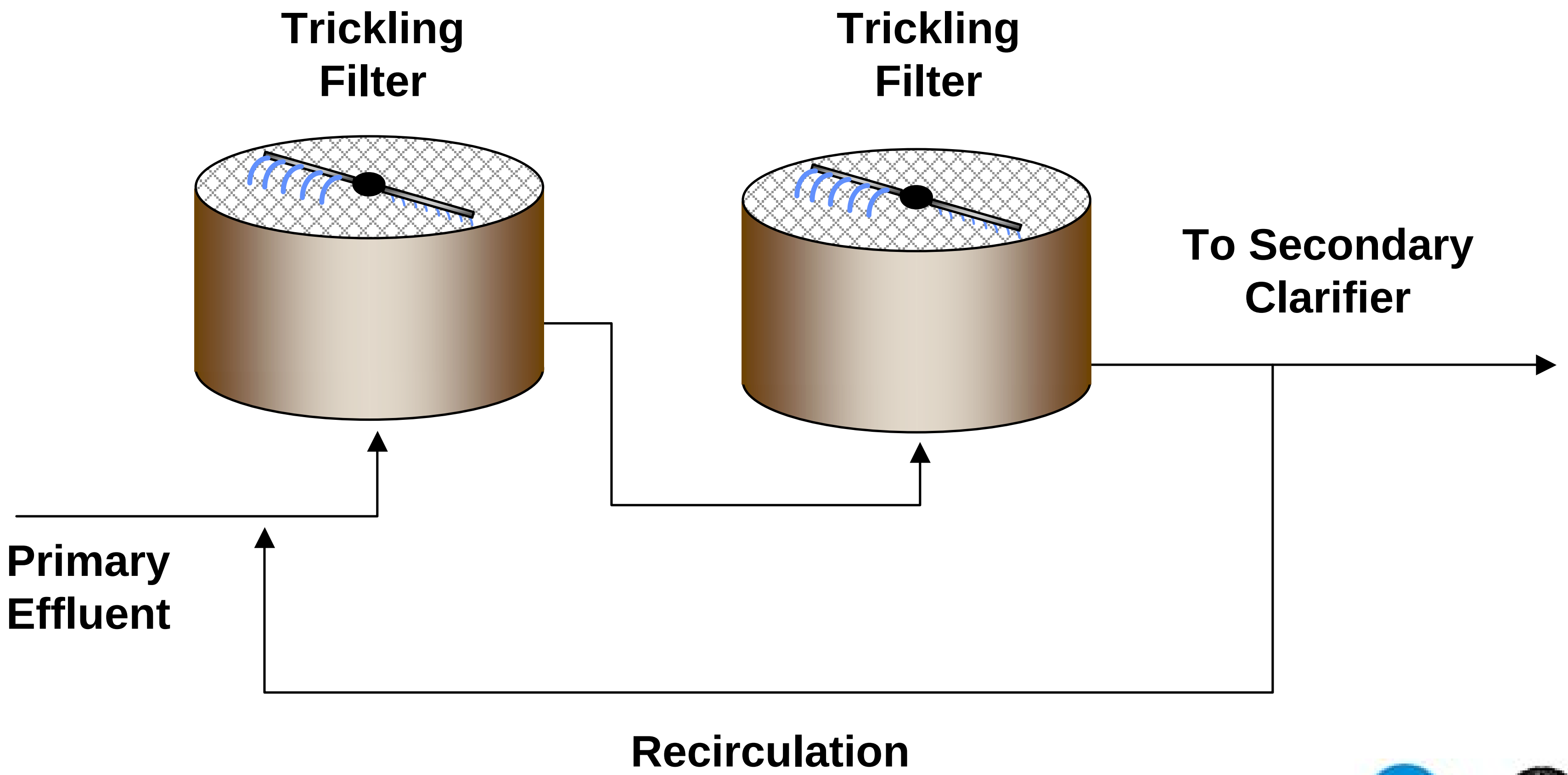


$$\text{Surface Area}\left(\frac{m^2}{m^3}\right) = \frac{\pi}{\text{DIAMETER (in m)}}$$

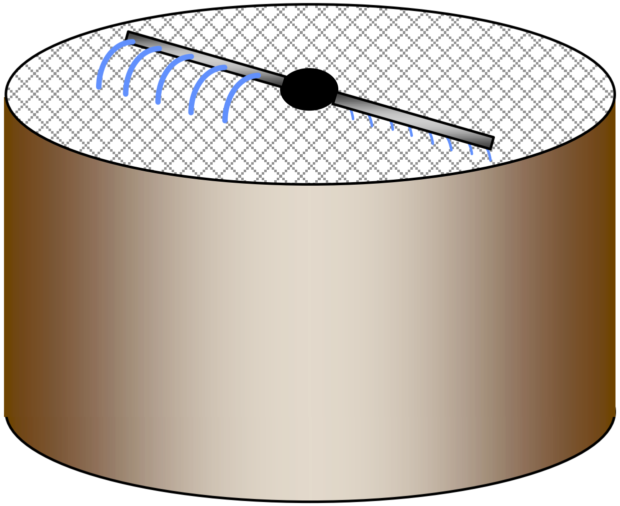
$$\text{Surface Area}\left(\frac{ft^2}{ft^3}\right) = \frac{\pi}{\text{DIAMETER (in feet)}}$$

PROBLEM: Calculate surface area per unit volume of a filter with rock media with a diameter of 150 mm (~ 6 inches) and shale with a diameter of 5 mm.

Convert Rock Media Trickling Filters to Plastic Media



Effects of Conversion to Plastic TF Media



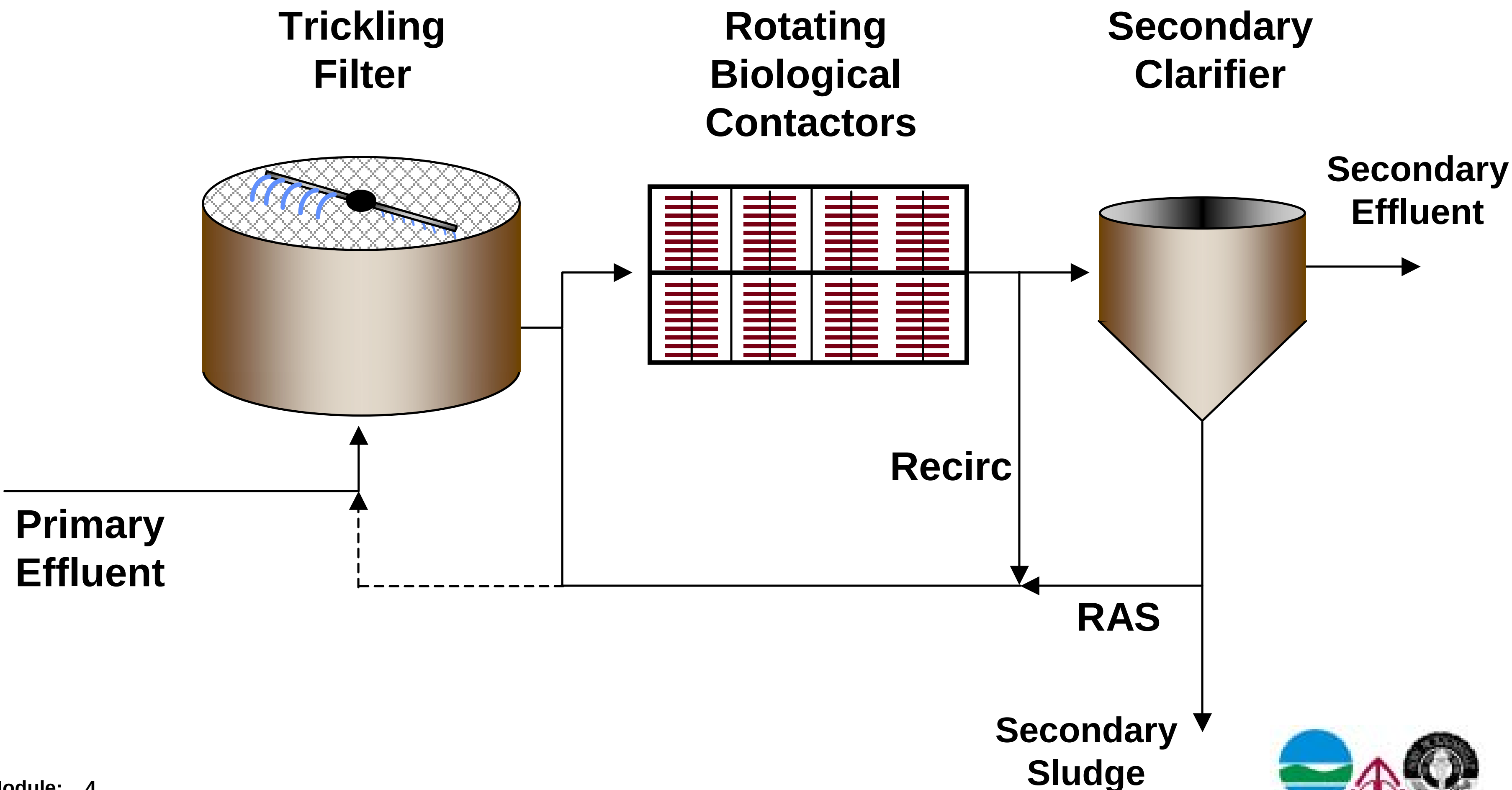
- Higher Surface Area Per Unit Volume
- More Void Space - Better Oxygen Transfer
- Higher Volume for a Footprint -Taller Filters, Lighter Media

Should First Stage Filters for BOD Removal Also Use Plastic Media?

How Thick Should the Biofilm Be?

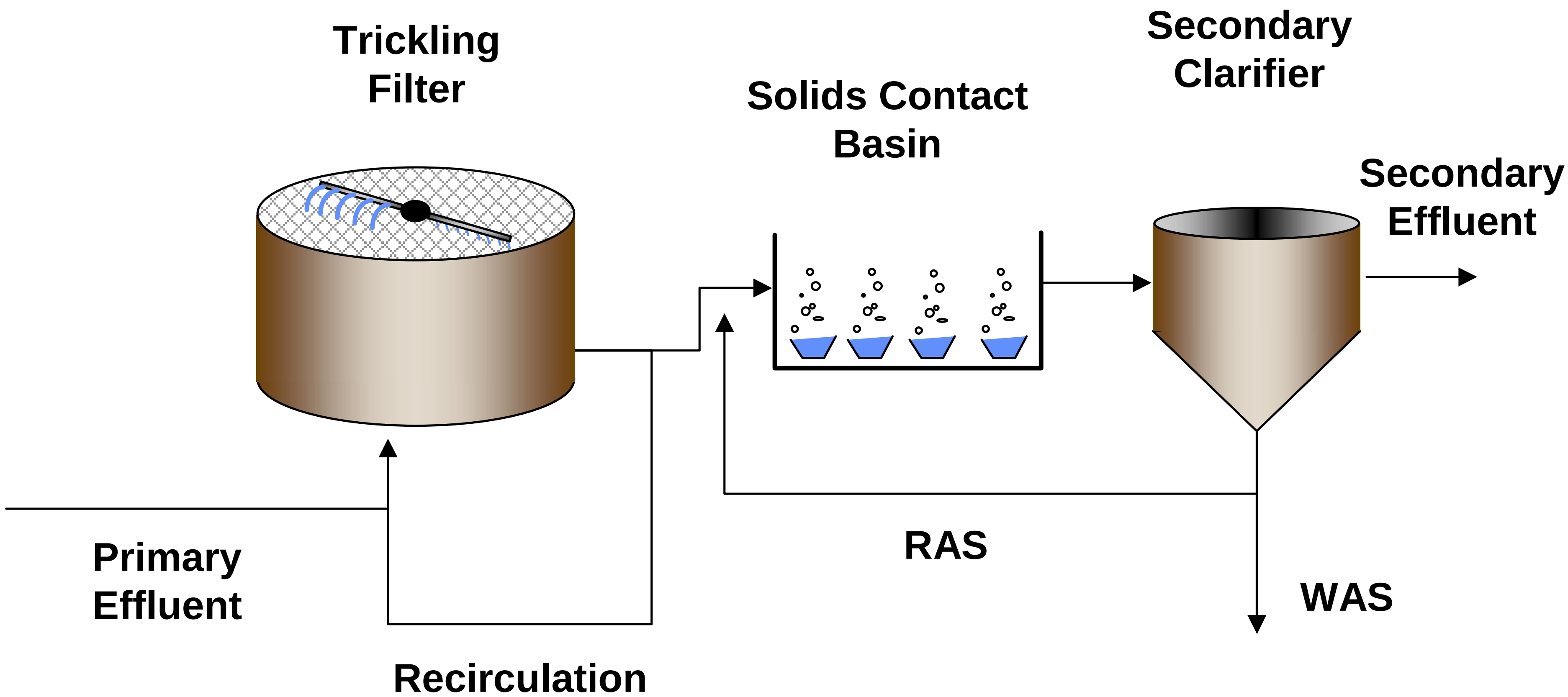
How Do We Control Thickness?

Trickling Filter Followed by RBCs

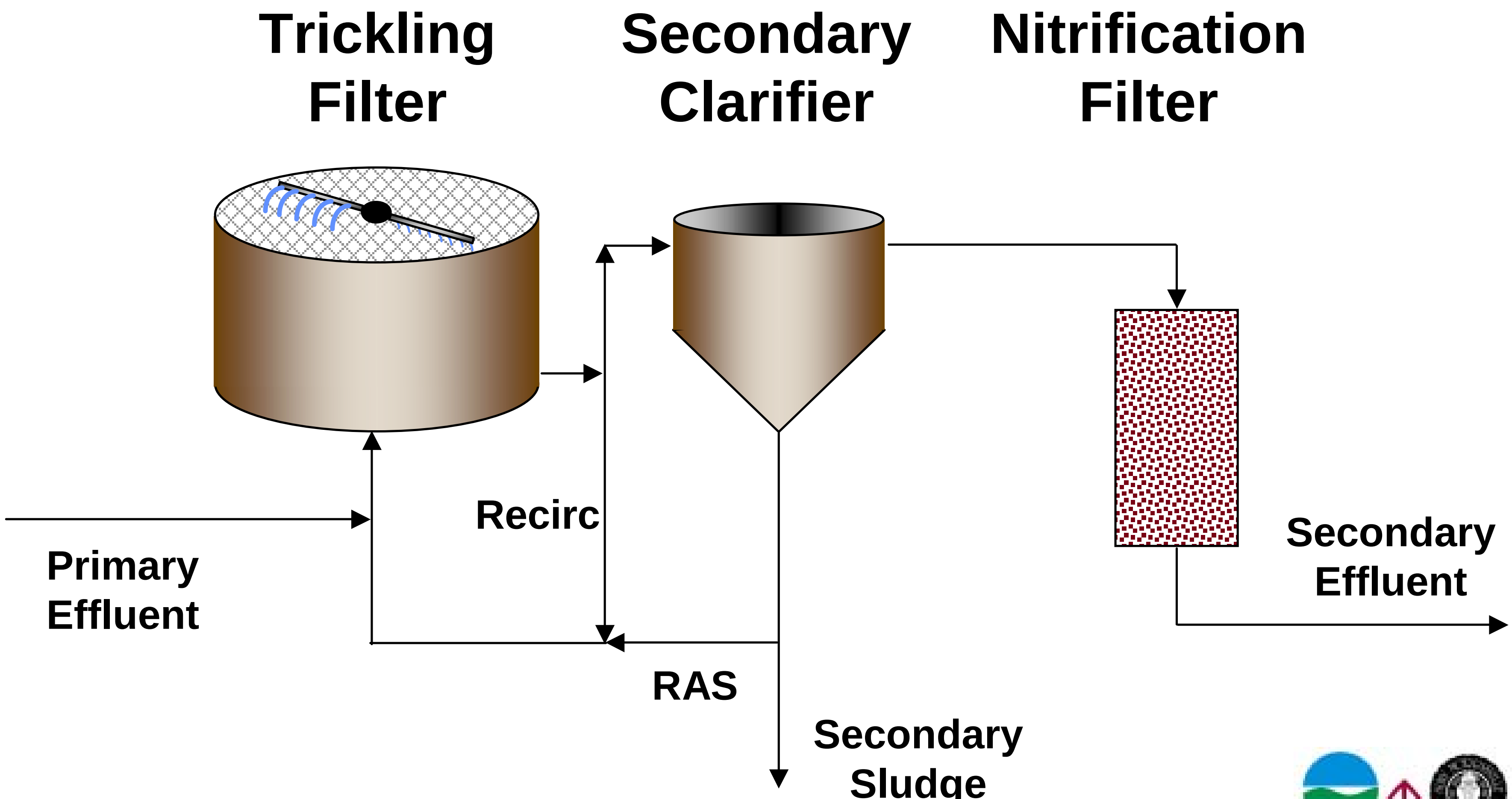


Module: 4
Unit: 2
Transparency: 2-6

Trickling Filter Solids Contact Process



Trickling Filter Followed by Nitrifying Filter



Evaluation of TF or RBC Loading Rate

- Determine specific surface area of media
- Determine total surface area of media
- Determine BOD_5 loading rate
- Compare loading rate to standard rates

Determine Specific Surface Area

• Rock media (1” - 3”)	19 ft^2/ft^3
• Rock media (2” - 4”)	14 ft^2/ft^3
• Surfpac X-Flo 30	30 ft^2/ft^3
• Surfpac X-Flo 42	42 ft^2/ft^3
• Brentwood Accu-Pac CF-3000	31 ft^2/ft^3
• Brentwood Accu-Pac CF-1900	48 ft^2/ft^3
• Brentwood Accu-Pac CF-1200	69 ft^2/ft^3

- See manufacturer’s data sheet for other manufactured media

Determine Total Media Surface Area

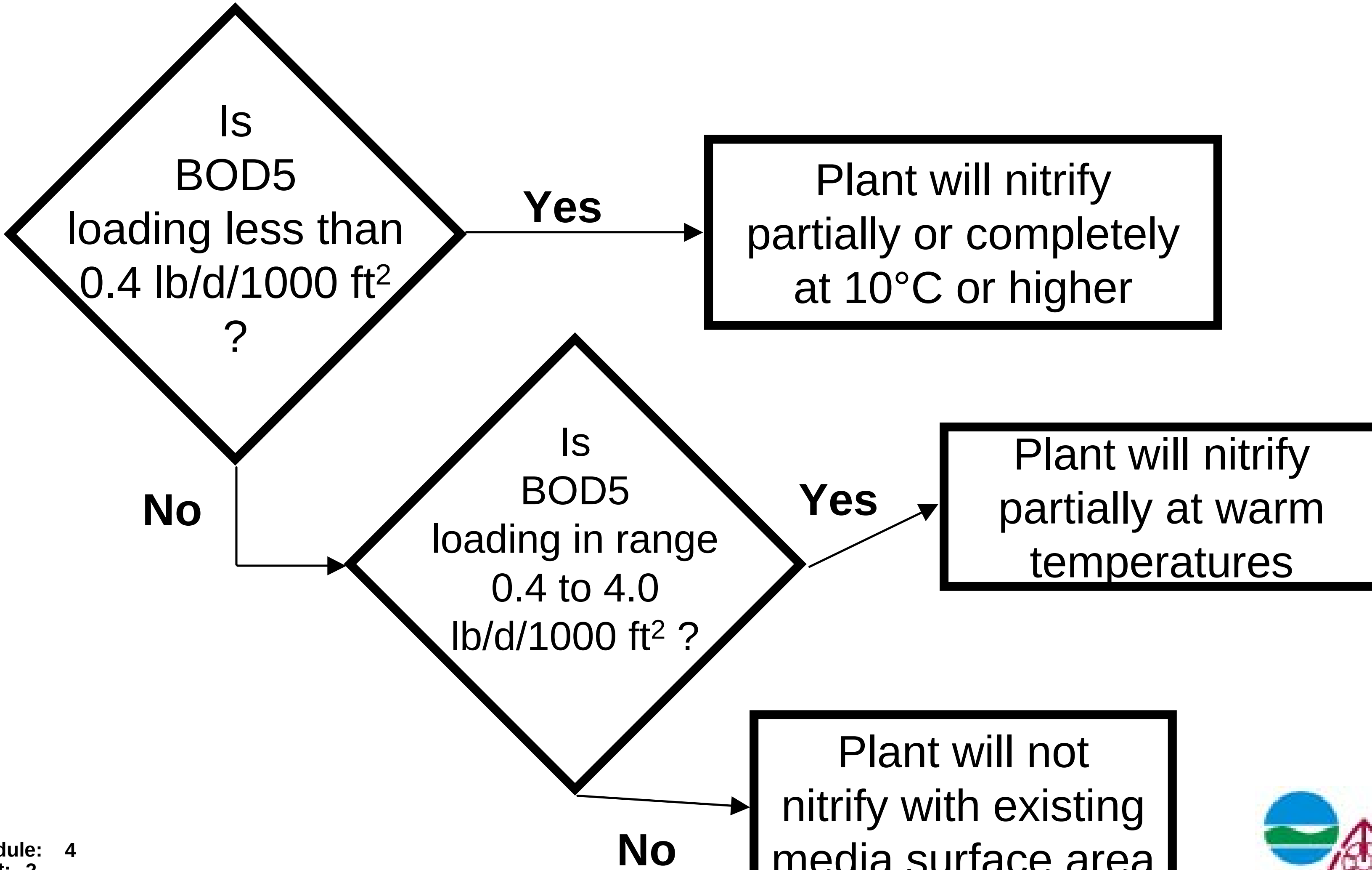
Total Media Area (ft^2) =

Specific Surface Area (ft^2/ft^3) X Total Media Volume (ft^3)

Determine BOD_5 Loading Rate

$$\text{BOD}_5 \text{ Loading Rate (lbs/1000 ft}^2\text{/day)} = \frac{\text{TF or RBC Influent BOD}_5 \text{ (lbs/d)}}{\text{Total Media Surface Area (1000 ft}^2\text{)}}$$

Evaluate Loading Rate



Trickling Filter Media Replacement

See worksheet

Methods to Increase Dissolved Oxygen

- **Provide forced ventilation for trickling filters**
- **Increase hydraulic loading rate in trickling filters**
- **Replace trickling filter media with media with a greater void ratio**
- **Add diffused air in RBCs**

Biological Aerated Filters

- **Can be used as an add-on nitrifying filter when existing process cannot be made to nitrify**
- **Upflow or downflow configuration**
- **Various media including sand, shale, polystyrene**

Operating for Denitrification

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

?

Operating for Denitrification

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

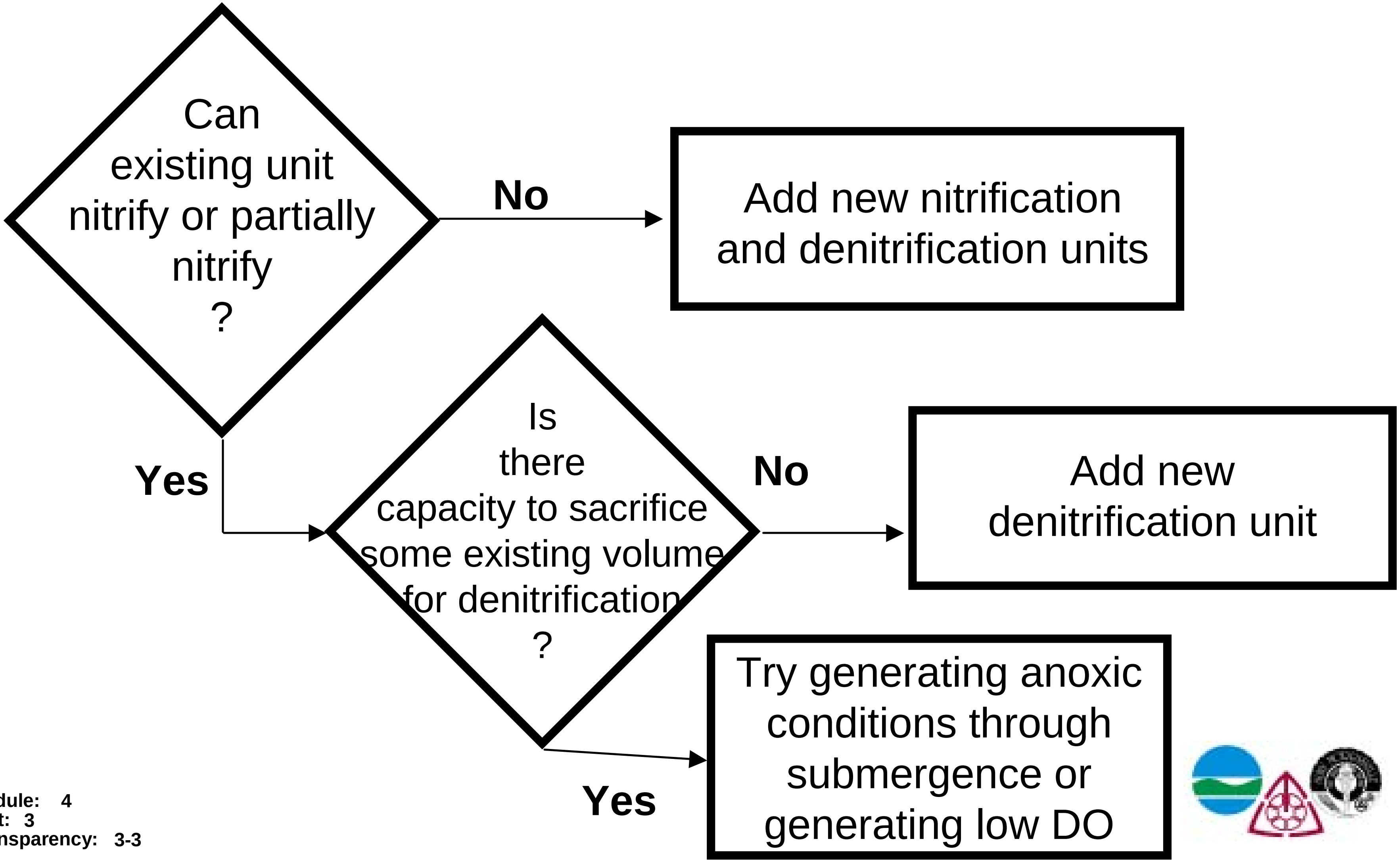
?

Establish anoxic conditions somewhere in the biological process.

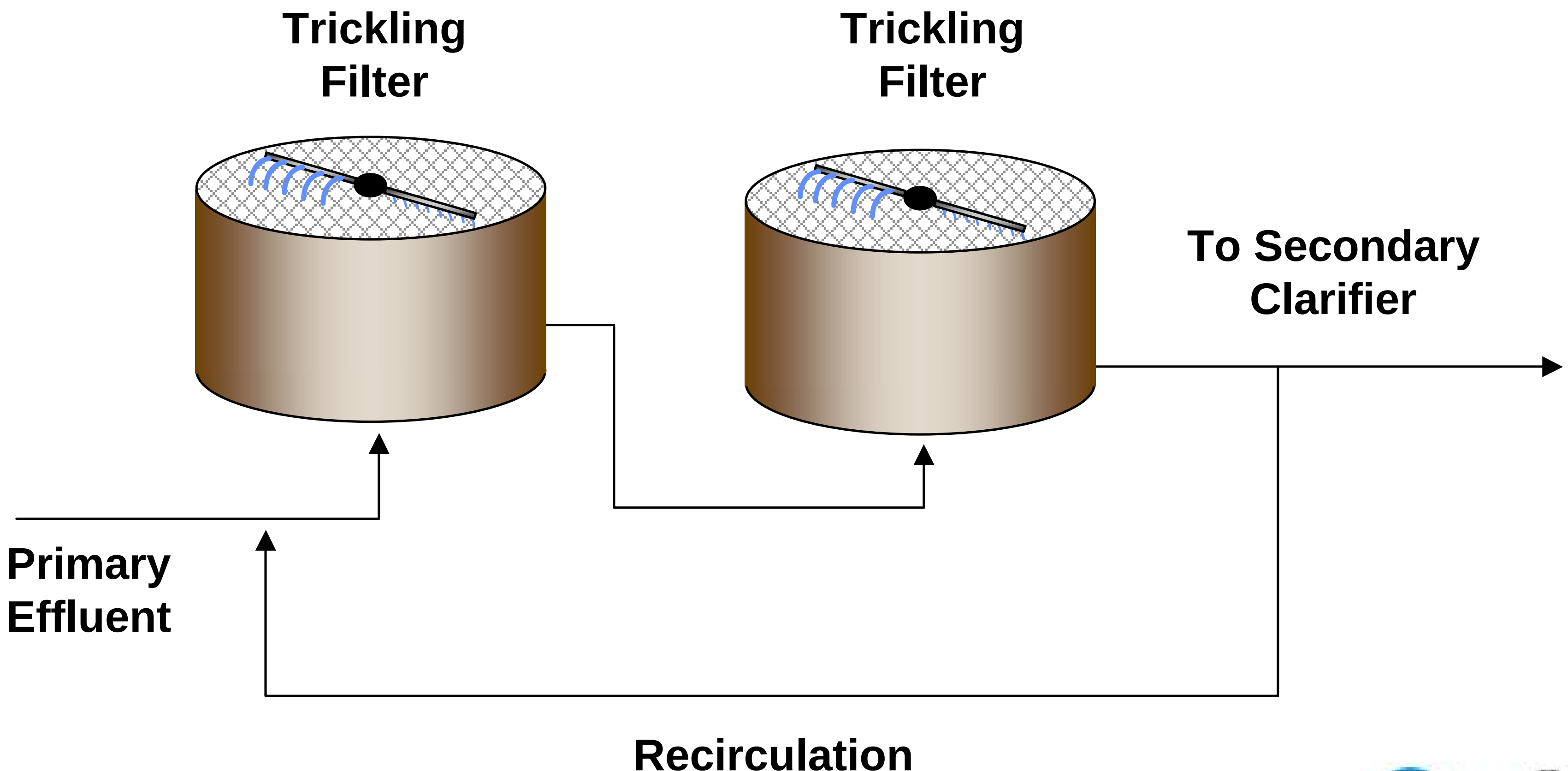
Methods to Achieve Denitrification

- **Incidental denitrification in trickling filter or RBC with recycle**
- **Convert a portion of existing unit to anoxic zone**
- **Add a new denitrification filter downstream of the nitrifying process**

Preliminary Evaluation of Denitrification Alternatives



Incidental Denitrification



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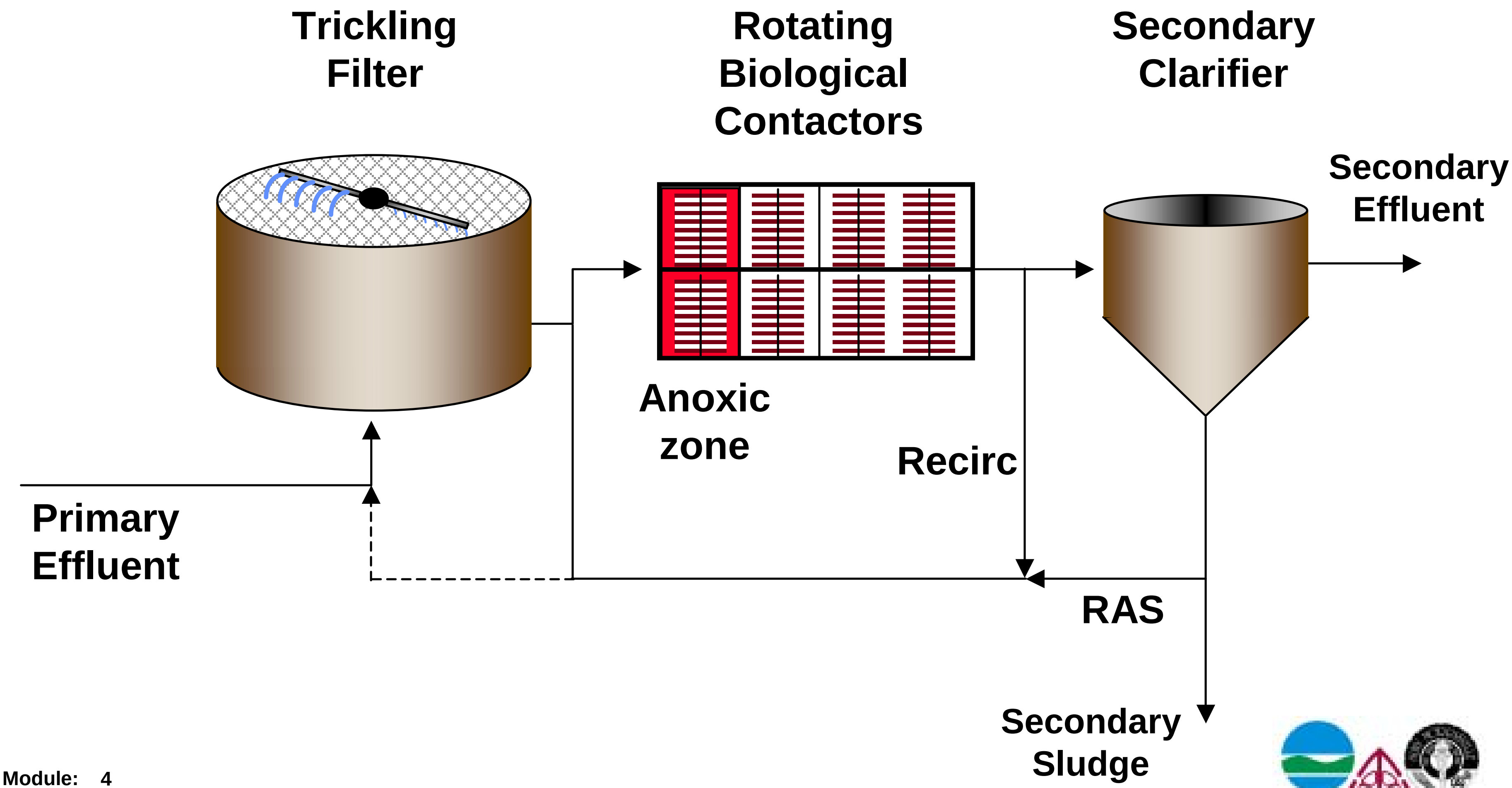
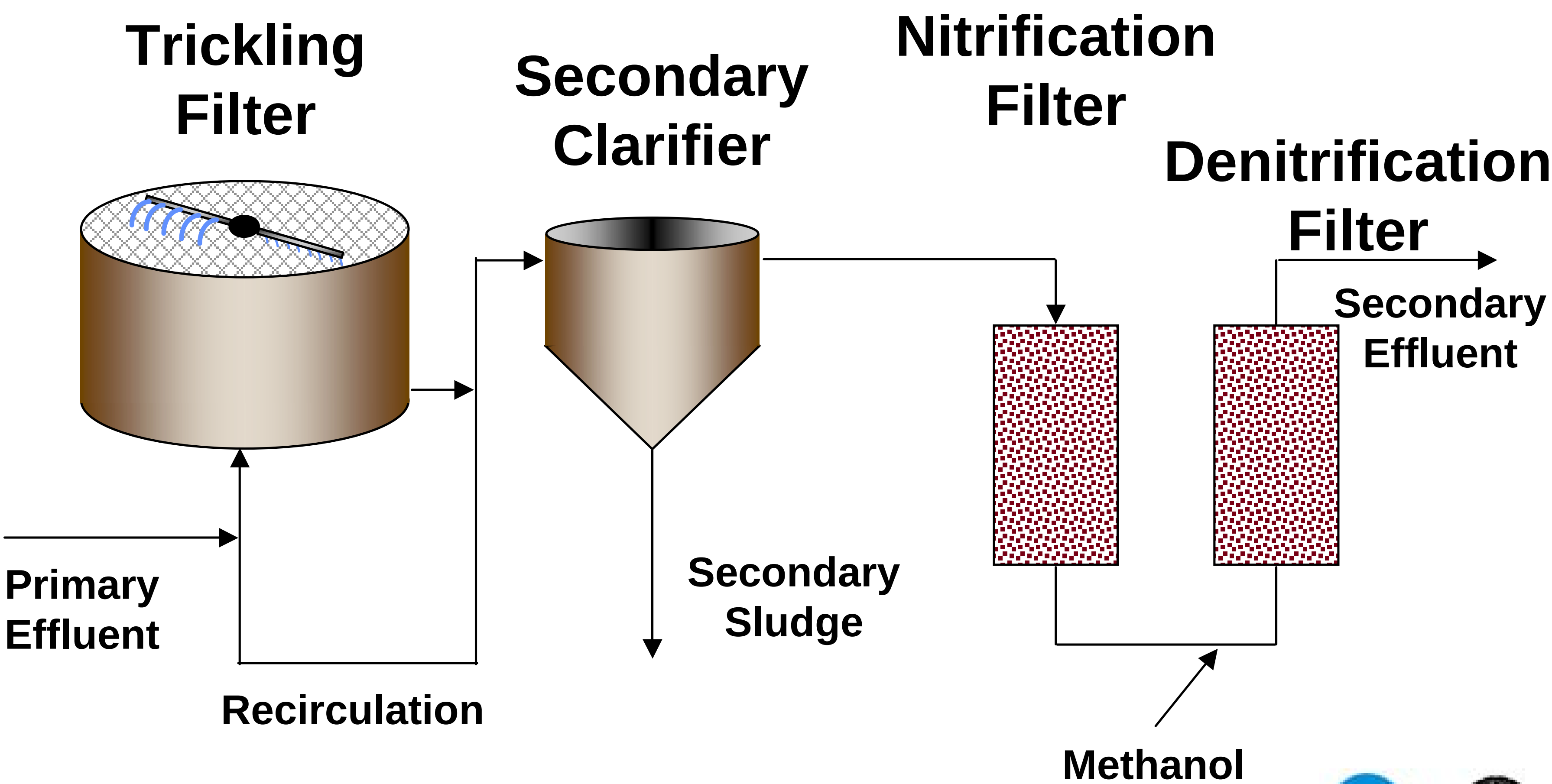
Unit: 3
Transparency: 3-4

Establishing an Anoxic Zone



Trickling Filter Followed by Nitrifying and Denitrifying Filters



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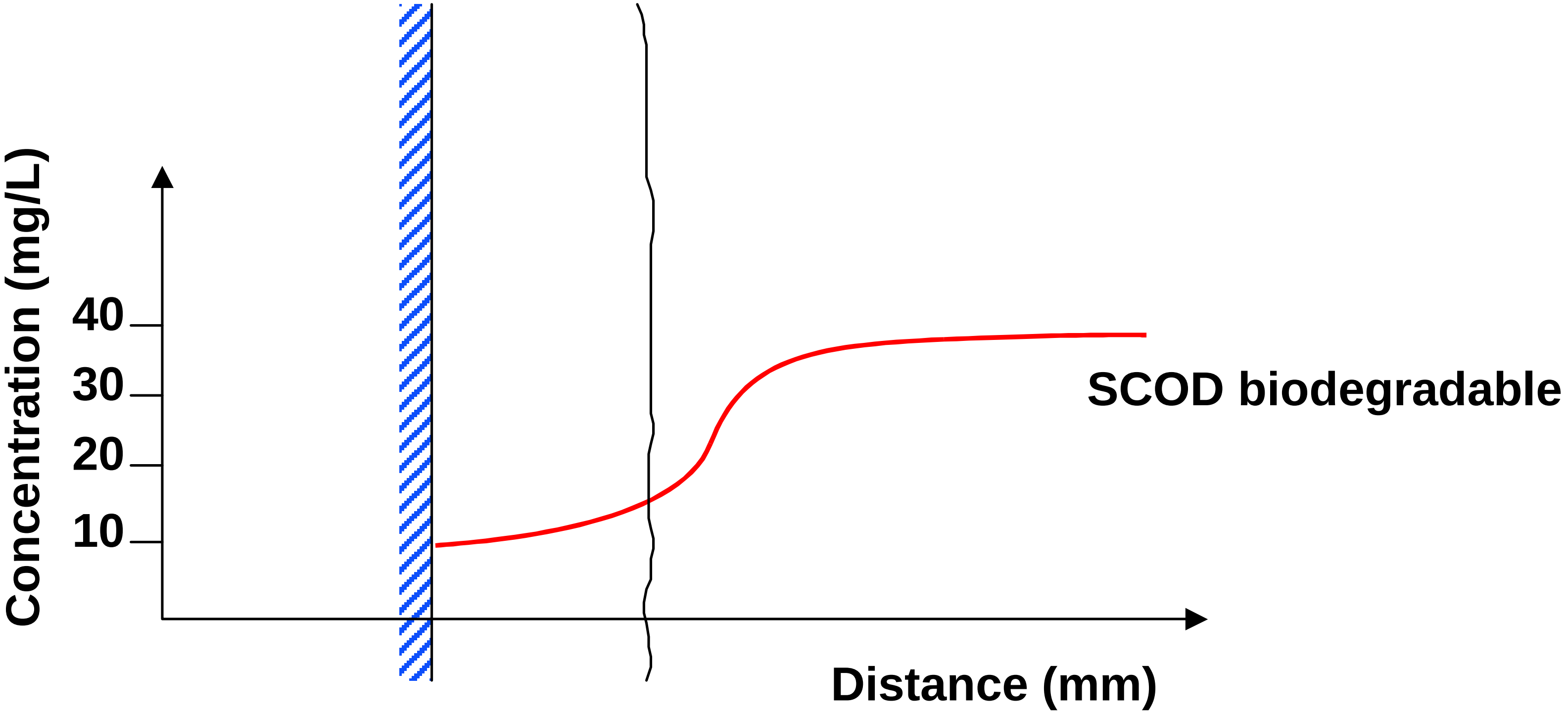
Unit: 3
Transparency: 3-6

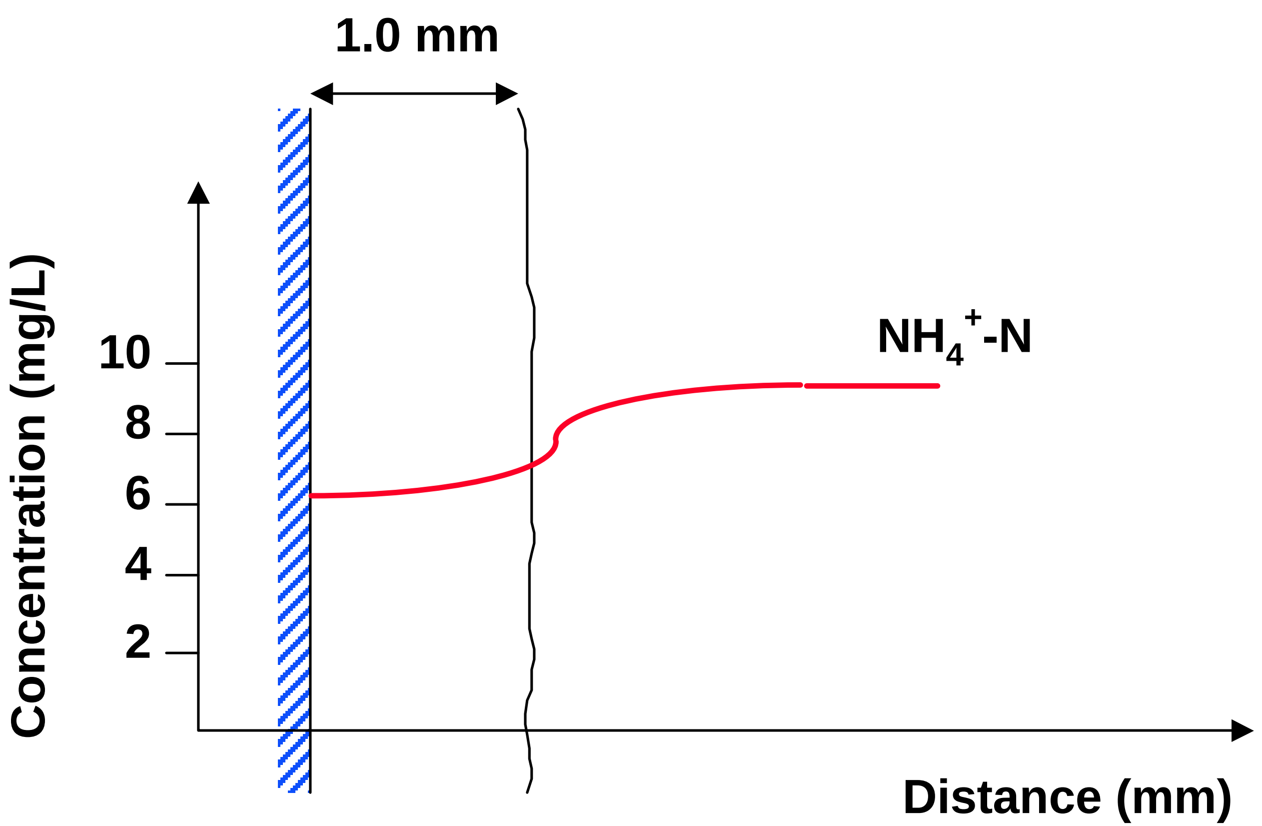
Denitrification Filters

- **Can be used as an add-on denitrifying filter when existing process cannot be made to denitrify**
- **Upflow or downflow configuration**
- **Various media including sand, shale, polystyrene**
- **Methanol addition for carbon source**

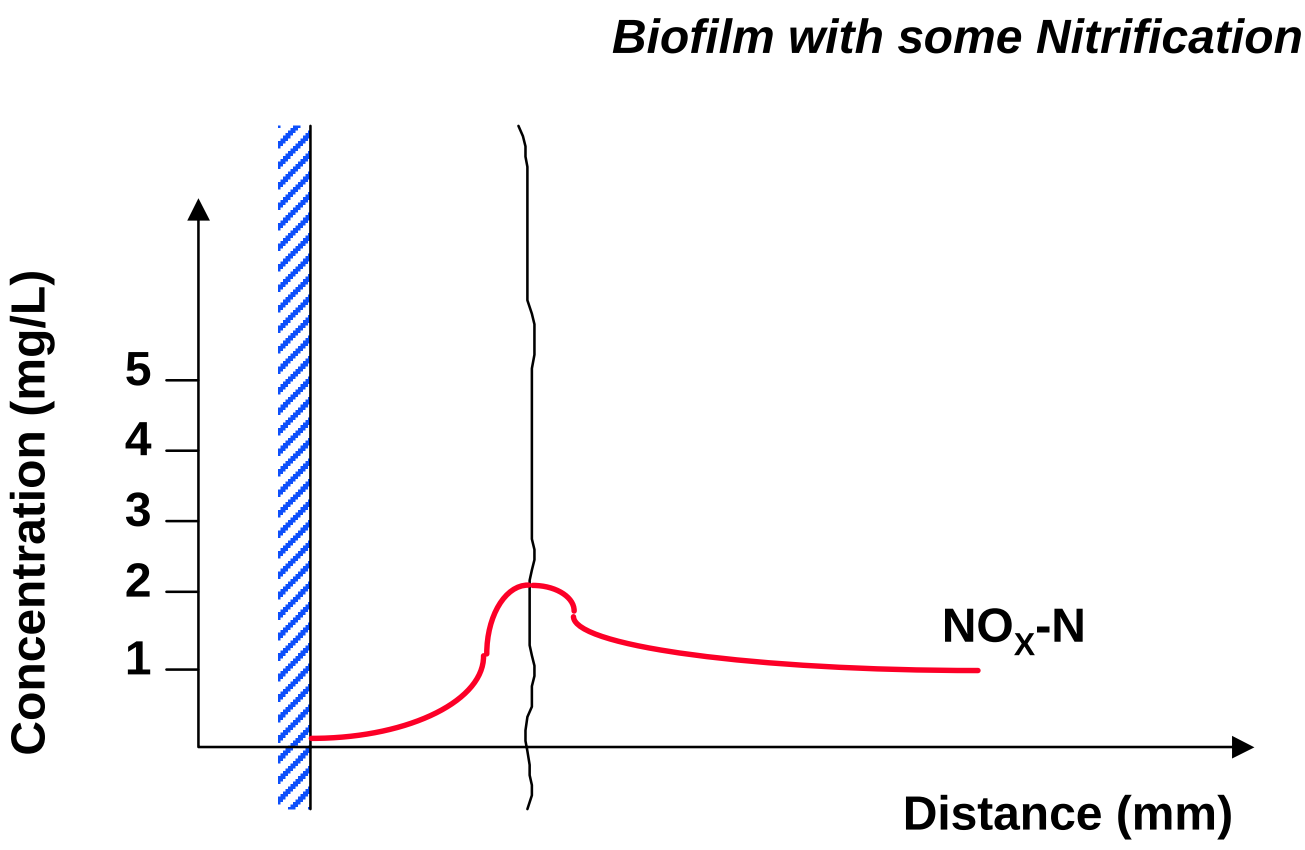
COD Depletion in Biofilm



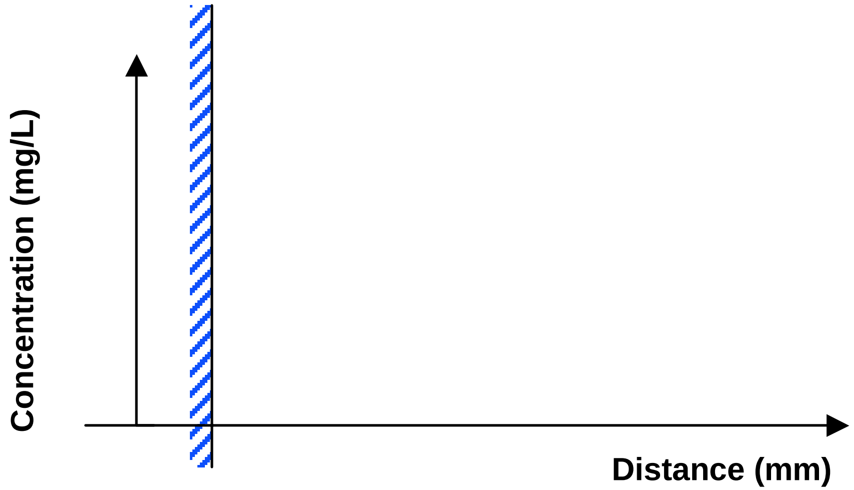
Ammonia Depletion in Biofilm

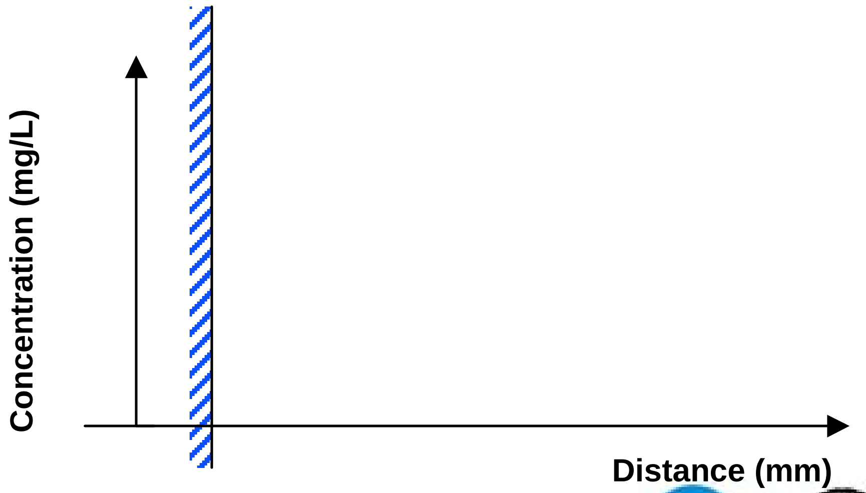


Nitrate Profile in Biofilm



Biofilm Profiles





Fixed Film Discussion

- Contact Between Biofilm Surface and Liquid Flowing Through the Filter.
  - How Good Is the Contact?
  - Is It One Form?
  - How Do We Improve It?
- Thickness of Stagnant Liquid Layer
  - Should We Reduce Thickness?
  - How Is Biofilm Sloughing Affected?
- Thickness of Biofilm
  - A. Submerged Filters Vs. “Exposed to Air Filters”
  - B. Upflow Vs. Downflow