Module 3
Optimization of Activated Sludge Performance for Nitrogen Removal

- **Case Studies**
- **Overall Plant Evaluation Procedure**
- **Operating and Troubleshooting Biological Nitrogen Removal Facilities**

Overall Plant Evaluation Procedure

Optimization of Plant Performance for Nitrogen Removal

Goals and Objectives:

1. **Increase MCRT to provide conditions necessary for the growth of biological microorganisms responsible for nitrogen removal.**

2. **Avoid potential adverse impacts on plant effluent quality which may result from changes in sludge settling characteristics.**

3. **Assess impacts of nitrogen removal on plant capacity for future growth.**

Optimization of Plant Performance for Nitrogen Removal

General Procedure:

1. **Identify limitations of system components:**

   - **Is secondary clarifier surface area adequate to handle expected peak hourly flows?**
   - **Is return sludge pumping capacity adequate for nitrogen removal?**
   - **Is aeration system capacity adequate to support nitrogen removal?**
   - **Is there sufficient alkalinity?**

2. **Calculate target MCRT, Target MLSS and maximum MLSS concentration based on suggested peak secondary clarifier solids loading rates.**

3. **Gradually increase MCRT by decreasing sludge wasting.**

Optimization of Plant Performance for Nitrogen Removal

4. **Monitor changes to MLSS concentration, aeration tank dissolved oxygen concentrations and sludge settling characteristics.**
5. **Make adjustments to return sludge pumping rates and aeration rate.**
6. **If capacity for ammonia removal is demonstrated, evaluate process modifications for creation of anoxic zones required for denitrification.**
7. **Create Anoxic zone**

Impact on Clarifier Hydraulic Capacity

Maximum Clarifier Overflow Rates (peak hourly flow conditions)

- **BOD Removal Only = 1,200 gal/sq ft/day**
- **Nitrification/Denitrification = 1,000 gal/sq ft/day**

Example Calculations

- **Consider 6 clarifiers (width = 40 ft., length = 125 ft.)**
- **Clarifier Surface Area = 6 (40 ft.) (125 ft.) = 30,000 sq. ft.**
- **Peak Hourly Flow Capacity:**

BOD Removal Only

$$= \frac{(30{,}000 \text{ sq. ft.})(1{,}200 \text{ gal/sq. ft./day})}{10^6 \text{ gal/Mgal}} = 36 \text{ mgd}$$

Nitrification/Denitrification

$$= \frac{(30{,}000 \text{ sq. ft.})(1{,}000 \text{ gal/sq. ft./day})}{10^6 \text{ gal/Mgal}} = 30 \text{ mgd}$$

Operation for nitrification/denitrification reduces peak hourly flow capacity of secondary clarifiers by approximately 17 percent.

Return Sludge Pumping Capacity Requirements

Return Sludge Rates

- **BOD Removal Only** =25% to 100% of design average daily flow
- **Nitrification/Denitrification** =50% to 150% of design average daily flow

Example

- **Consider average daily flow = 10 mgd**
- **Use mid-point of typical RAS flow ranges (60% for BOD removal, 100% for nitrification/denitrification)**
- **Return Sludge Pumping Capacity Required**

  BOD_5 Removal Only = 0.6 (10 mgd) = 6 mgd

  Nitrification/Denitrification = 1.0 (10 mgd) = 10 mgd

Operation for nitrogen removal may require a significant increase in return sludge pumping capacity.

Typical Design/Operating Values

	BOD Removal Only	Nitrification	Nitrification-Denitrification
Clarifier Overflow Rate	1,200	1,000	800
Peak Solids Loading Rate *	50	35	35
Clarifier Weir Loading Rate			
Less than or equal to 1 MGD	20,000	20,000	20,000
Greater than 1 MGD	30,000	30,000	30,000
Return Sludge Rate	25-100%	50-150%	50-150%

* Calculated based on design maximum day flow plus maximum return.

Calculate Oxygen Required

Oxygen Requirements:

For BOD_5 Removal only = 1.1 (BOD_5)

For Nitrification = 1.5 (BOD_5) + 4.6 (NH_4^+ -N oxidized)

With Pre-Denitrification = 1.5 (BOD_5) + 4.6 (NH_4^+ -N oxidized) - 2.9 (NO_x -N Reduced)

Oxygen Transfer Capacity (Mechanical Aeration Including Brush Rotor Aerators)

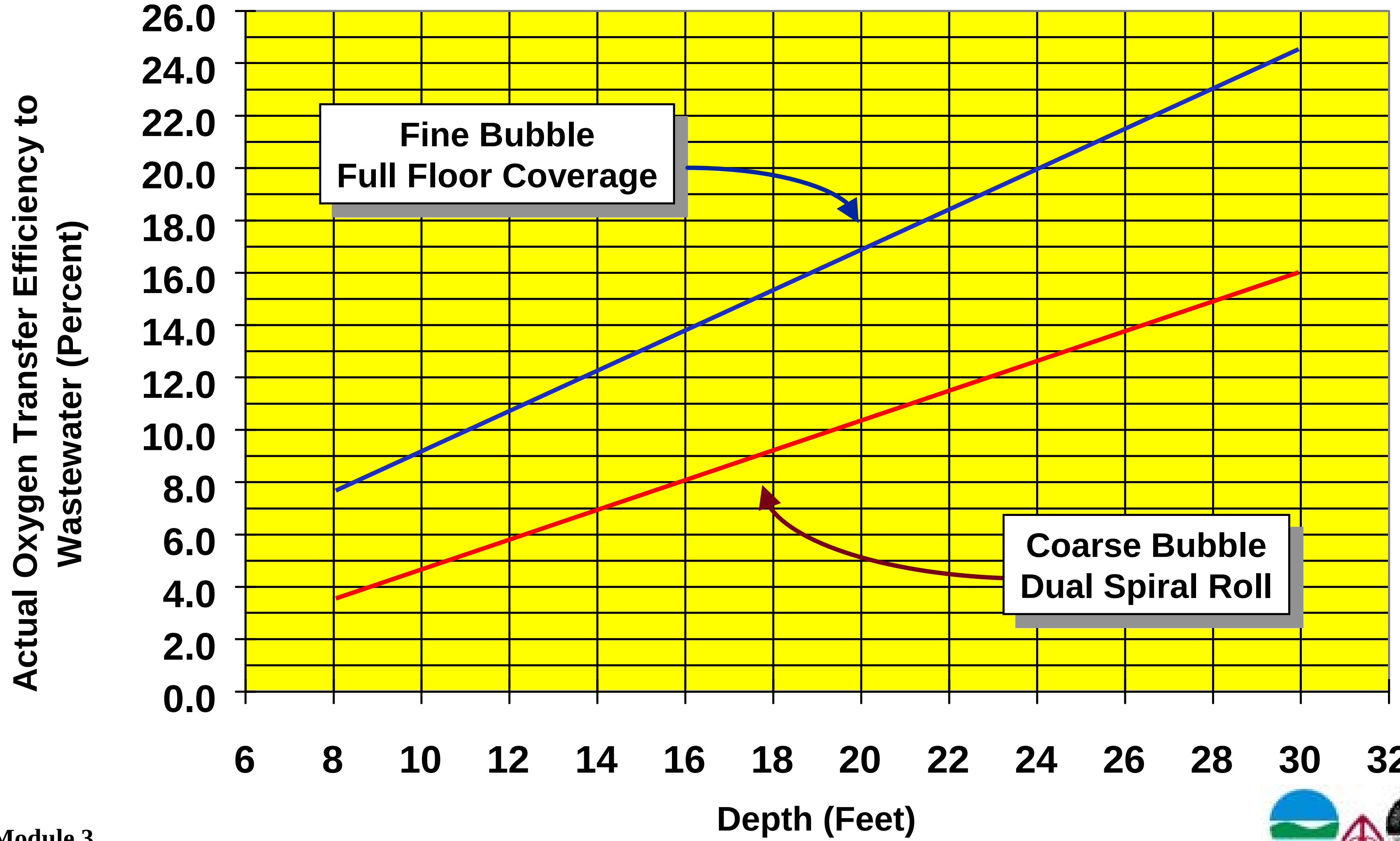
Oxygen Transfer Capacities:

- **Standard Conditions: 2 - 4 lb/hp/hr**
- **Field Conditions: 1.2 - 2.1 lb/hp/hr**

Calculate Aerator HP Required:

$$\text{Surface Aerator HP required} = \frac{\text{oxygen required (lb / day)}}{\text{oxygen transfer (lb/hp/hr)} \times 24\ \text{hr/day}}$$

Typical Oxygen Transfer Efficiencies to Dirty Water With Diffused Aeration Systems



Oxygenation Capacity (Coarse Bubble Diffused Aeration)

Standard OTE = 9.5% } **Dual Spiral Roll**
Actual OTE = 6%

Water depth above diffuser = 12 feet

Calculate SCFM required

Specific weight of air = 0.075 lb/cf

Oxygen in air = 20% by weight

= (0.20) x (0.075 lb/cf)

= 0.015 lb/cf

Oxygenation Capacity (Coarse Bubble Diffused Aeration)

- **Oxygen transferred = (0.06) (0.015 lb O_2/cf air)**
  = 9 x 10^{-4} lb O_2/cf air

- **Air required (scfm) =** $$\frac{\text{Oxygen required lb/day}}{(\text{Oxygen transferred, lb } O_2\text{/cf air})\ (1440 \text{ min/day})}$$

- **Approximate blower HP =** $$\frac{\text{Air required (scfm)}}{\text{20 scfm / HP at 12' depth *}}$$

**** Some blowers are more efficient, some are less.***

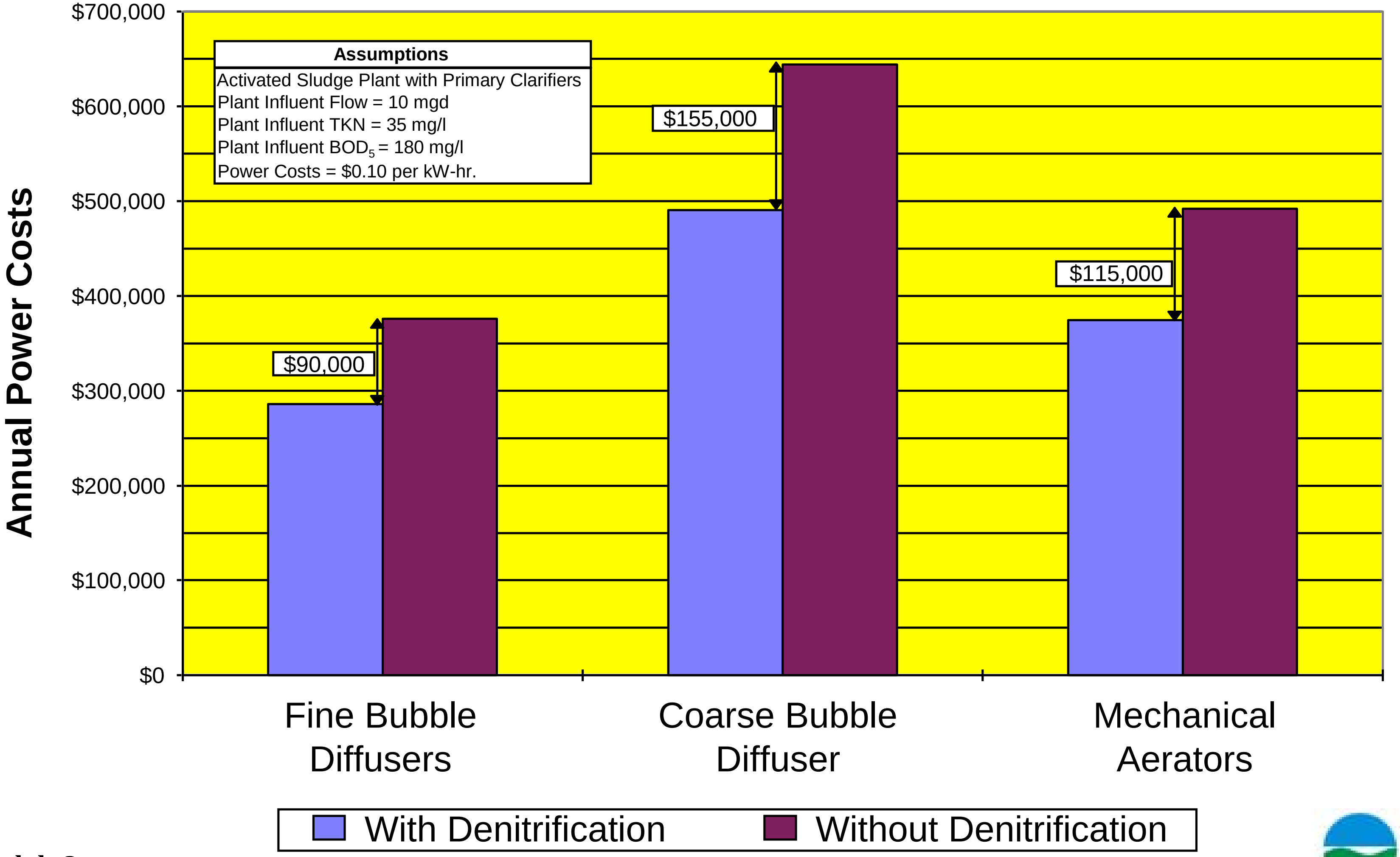
Oxygenation Capacity (Full Floor Coverage Fine Bubble Diffused Aeration)

- **Standard OTE** = **24%**
- **Actual OTE** = **11%**
- **Oxygen Transferred** = **(0.11) (0.015) lb O_2/cf air**

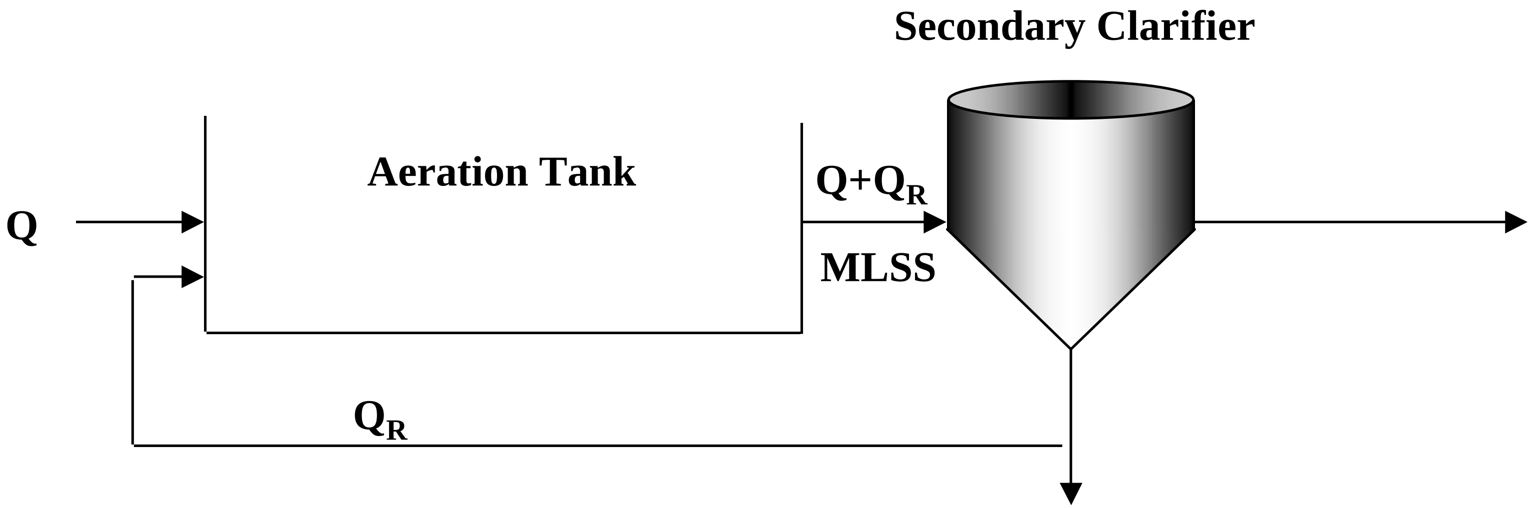
  = **1.6×10^{-3} lb O_2/cf air**

- **Air Required (SCFM)** = $\frac{\text{Oxygen Required (lb/day)}}{\text{Oxygen Transferred (lb/cf air) (1440 min/day)}}$
- **Approximate Blower HP** = $\frac{\text{Air Required (SCFM)}}{\text{20 scfm/hp at 12' depth}}$

Potential Aeration Power Savings Due to Denitrification



Clarifier Solids Loading Rate



$$\text{Clarifier Solids Loading Rate (lb/sq. ft./day)} = \frac{(Q + Q_R)\,(8.34)\,(MLSS)}{A}$$

Where; Q = primary effluent flow, mgd
Q_R = return sludge flow, mgd
MLSS = mixed liquid suspended solids concentration in clarifier feed, mg/l
A = clarifier surface area, sq. ft.
8.34 = conversion factor

Suggested Peak Clarifier Solids Loading Rates

- **BOD Removal Only = 50 lb/ sq. ft/ day ***
- **Nitrification/ Denitrification = 35 lb / sq. ft / day ***
- **Peak Solids Loading Rates based on**
  - **Maximum 24-hour primary effluent flow, mgd**
  - **Anticipated return sludge pumping rate, mgd**
  - **Design MLSS concentration, mg/l**
- **Recommended minimum depth for new clarifiers in nitrifying facilities is 13’**

*** Average daily values should not be more than 1/2 of peak values**

Calculate Maximum MLSS Concentration Based on Clarifier Solids Loading Rate

- **Clarifier surface area = 30,000 sq. ft.**
- **Average primary effluent flow = 10 mgd**
- **Peak 24-hour primary effluent flow = 27.5 mgd**
- **Typical return sludge pumping rate**

  BOD removal only = 6 mgd (60% design average daily flow)

  Nitrific / Denitrific = 10 mgd (100% design average daily flow)
- **Calculate Maximum MLSS Concentration**

$$\text{BOD Removal} = \frac{(30{,}000 \text{ sq. ft})(50 \text{ lb/sq. ft/day})}{(27.5 \text{ mgd} + 6 \text{ mgd})(8.34)}$$

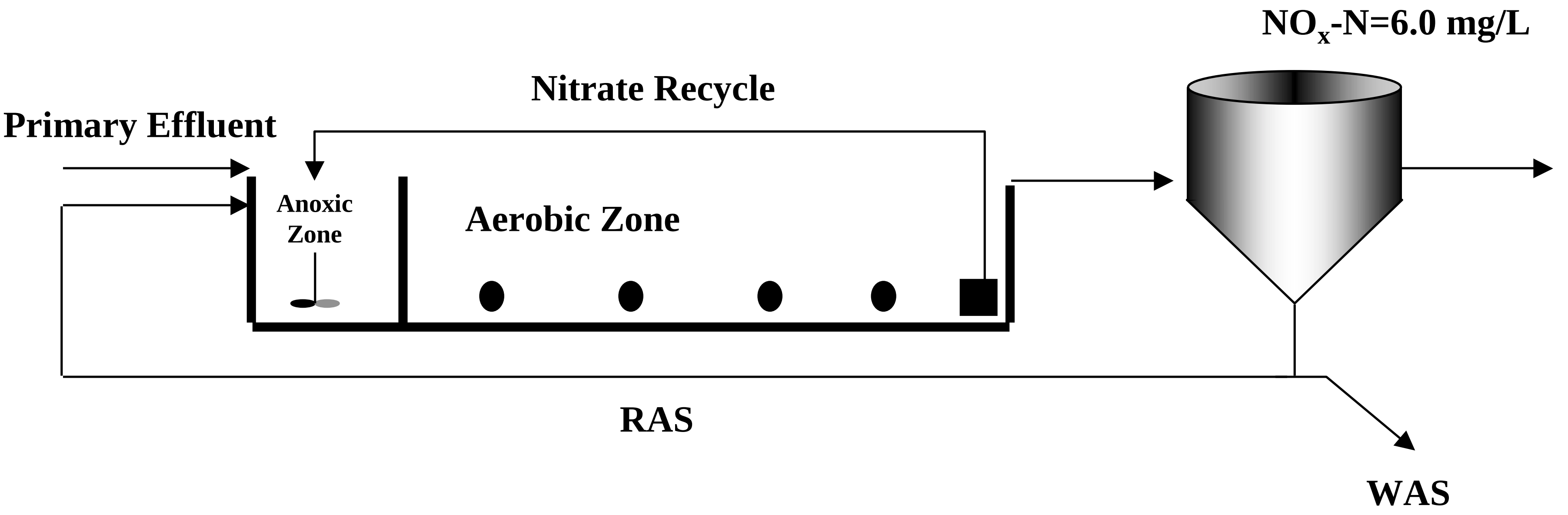
$$= 5370 \text{ mg/l}$$

$$\text{Nit./Denit.} = \frac{(30{,}000 \text{ sq. ft})(35 \text{ lb/sq. ft/day})}{(27.5 \text{ mgd} + 10 \text{ mgd})(8.34)}$$

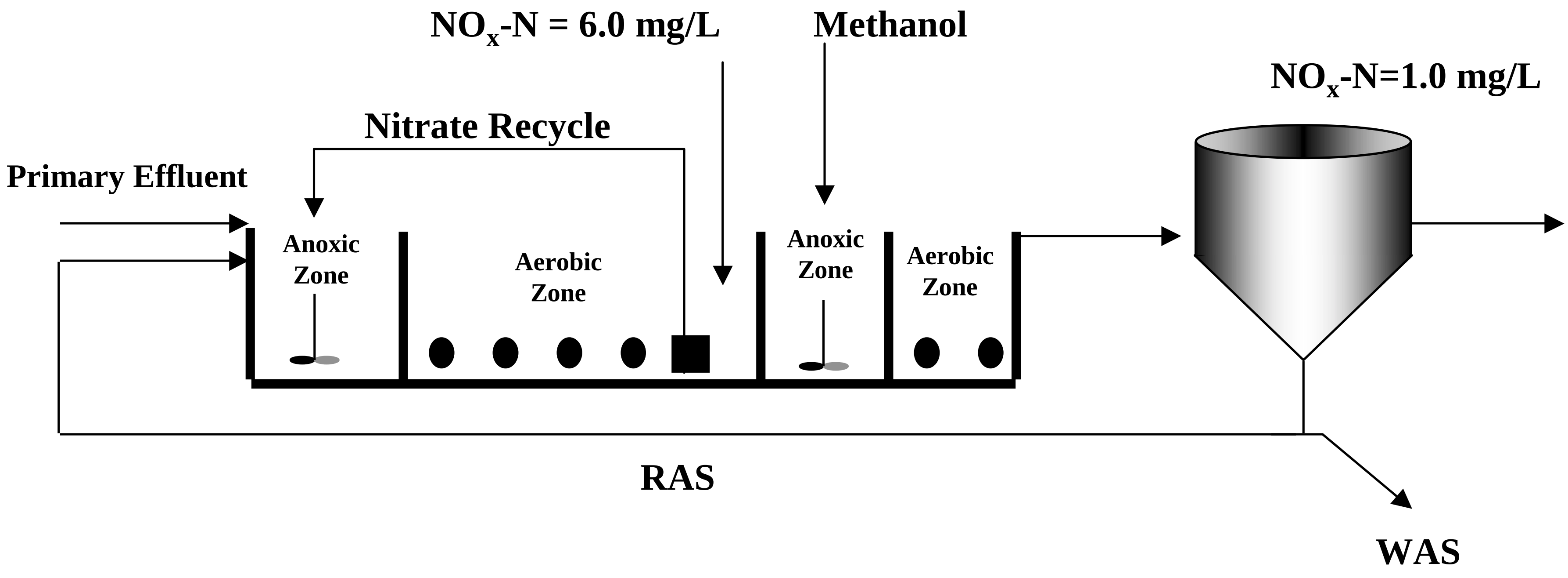
$$= 3360 \text{ mg/l}$$

Expected Performance for Various Configurations

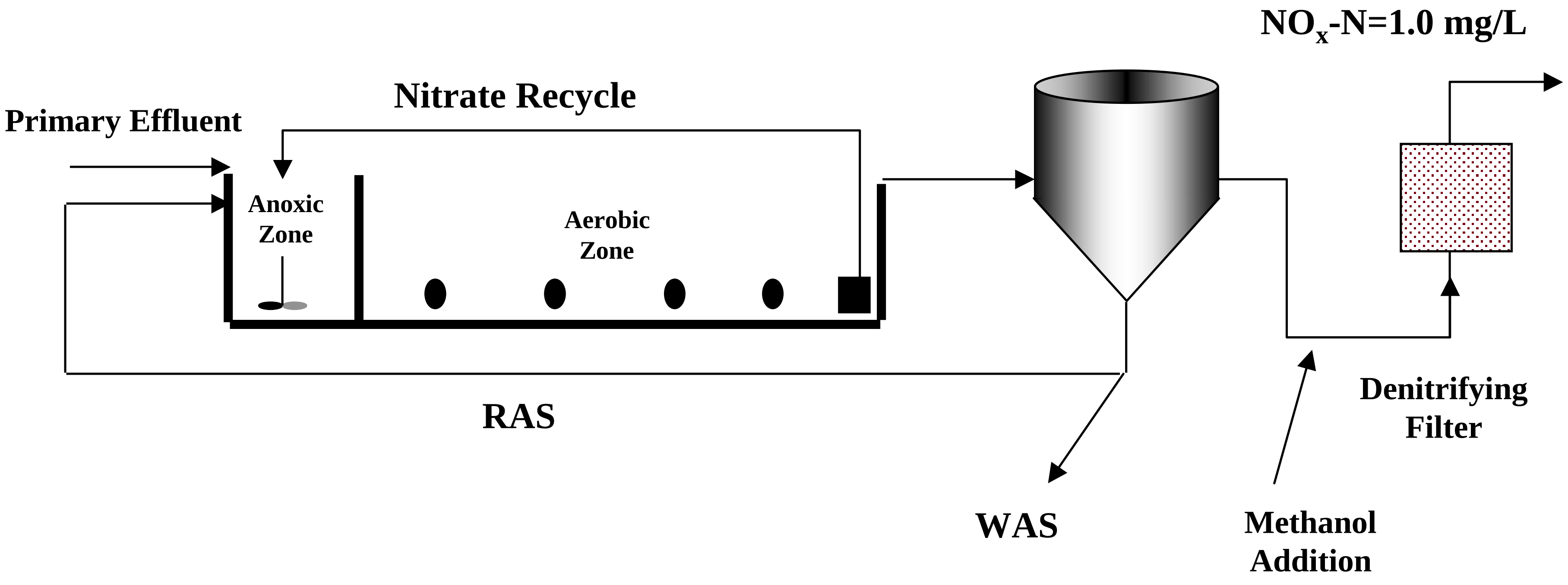
Modified Ludzack-Ettinger (MLE) Configuration



MLE Configuration with Secondary Anoxic Zone

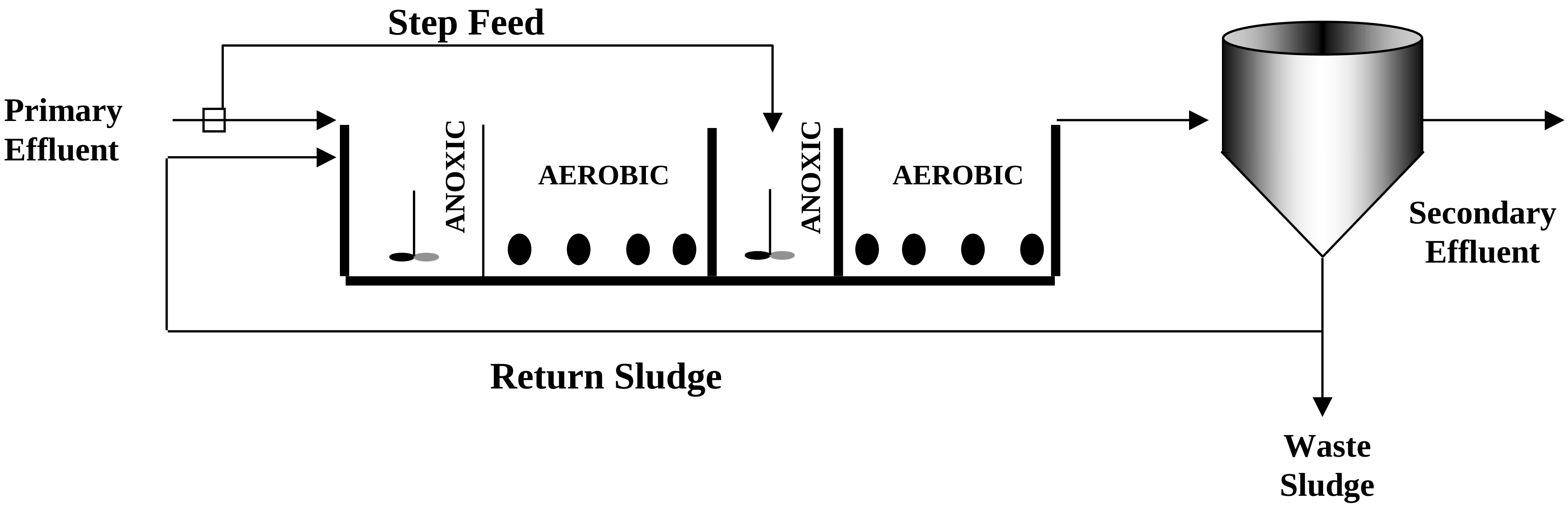


MLE Configuration with Denitrifying Filter

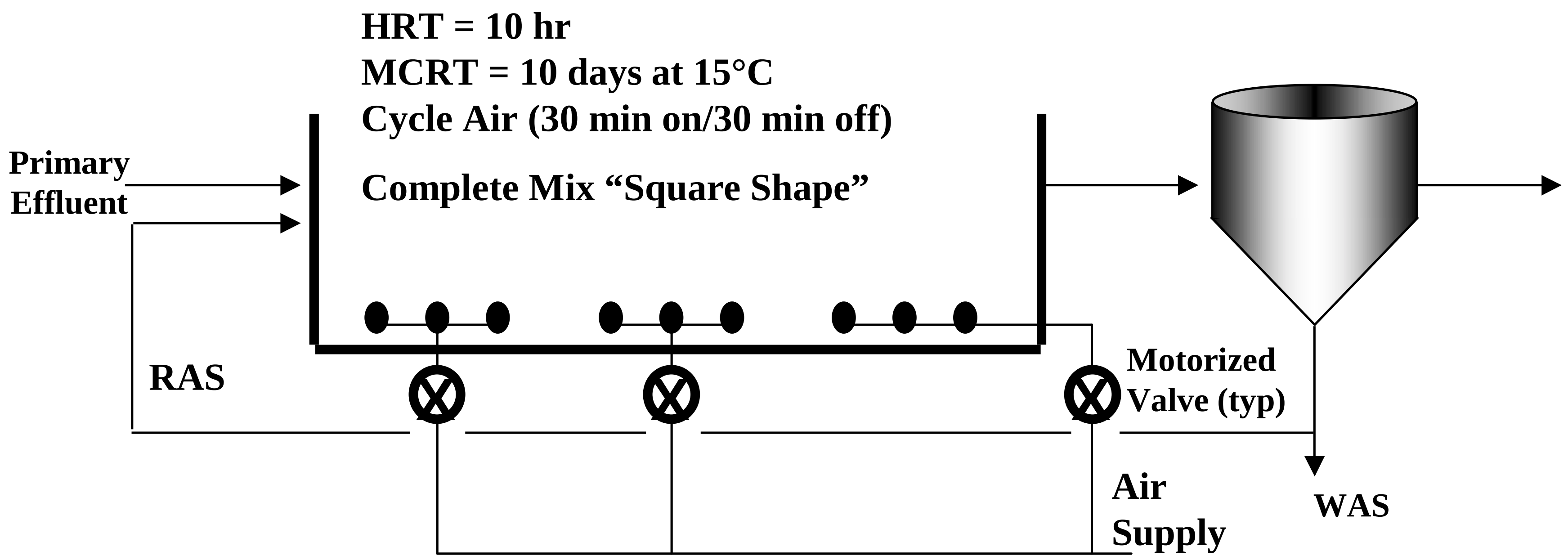


Step Feed-Denitrification Configuration

NO_x-N mg/L *0* *0.5* *6.0* *1.0* *8.0* *8.0*



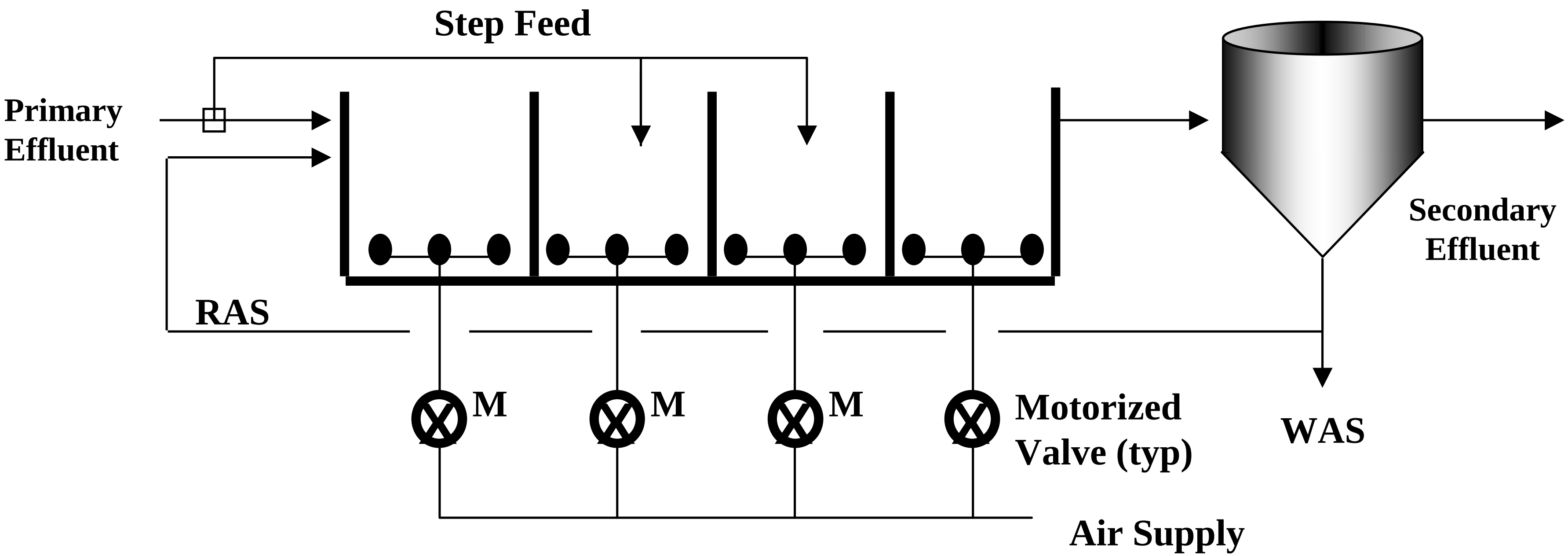
Complete Mix Denitrification with Cyclic Aeration



TIME (min)	0	15	30	45	60/0	AVG.
NH_4^+-N (mg/L)	0.2	0.8	1.5	0.5	0.2	0.7
NO_x-N (mg/L)	5.0	3.0	0.5	2.0	5.0	3.0

Step Feed Denitrification with Cyclic Aeration

NH_4^+-N mg/L	15	6	4	2	0.5	0.2
NO_x-N mg/L	0.5	2	3	4	5.5	6.0



Operating and Troubleshooting Biological Nitrogen Removal Facilities

Sampling and Test Recommendations for Activated Sludge BNR Plants

Recommended minimum sampling requirements for a 5 MGD plant (Values shown are recommended samples per week)

	Raw Influent	Plant Recycle	Primary Effluent	Anaerobic Zone	Anoxic Zone	Aerobic Zone Middle	Aerobic Zone End	Secondary Effluent	Final Effluent	RAS/ WAS	Thick-ener	Dewat-ering	Non Potable Water
Flow	7	7	7							7			7
$SBOD_5$			1 (1)	1 (1)									
BOD_5 (3)	permit	1	1						permit				
SCOD (3)			2	1					1				
COD		1	1			0.5			permit				
VSS	permit					5		2	permit				
TSS	permit		1			5		2	permit	5	1	1	
Settlometer						5							
30min SVI						5							
Microbial exam						1							
Alkalinity			1					1	1				
pH	permit		1				1		permit				
DO			2 (1)	2		5	2		permit				
Temperature						5							
NH4N			1					1					
SKN			0.5						0.5				
TKN			1			0.5			permit				
NO_2N								1					
NO_3N or NOxN					1			1	permit				
OP			1 (1)	1 (1)					1 (2)				
TSP			1 (1)						0.5 (2)				
TP			1 (2)			1 (1)			permit				

Notes
(1) with Biological Excess Phosphorus Only
(2) with Biological or Chemical P removal
(3) the number of BOD samples should be increased if COD is not analyzed at this frequency

Test Methods

- **Sample Filtration**
  - **Use same filter paper as used for TSS analysis**
- **DO Analysis**
  - **Measure in-tank; allow DO to stabilize for few minutes in anoxic tank**
- **Temperature of Mixed Liquor**
  - **Use DO probe temperature setting, measure in-tank**

Test Methods

Analysis for soluble forms:

Filter using same filter paper as for suspended solids analysis (glass fiber) unless specified otherwise.

***Analysis for DO in anaerobic and anoxic zones*:**

Use portable probe. Submerge probe in mixed liquor.

Determine time taken for reading to stabilize. This may be two to five minutes.

***Analysis of temperature of mixed liquor*:**

Use DO probe to measure temperature at mid-point of aerobic zone.

***Analysis of ammonium-N for process control purposes*: (not for permit compliance)**

Filter sample. Use Hach DR700, DR2000 or higher; or use ammonia gas sensing electrode.

***Analysis of NO_2Nand NO_XN for process control purposes*: (not for permit compliance)**

Filter sample. Use DR700, DR2000 or higher.

***Samples for process control tests can be stored for 48 hours in refrigerator (at less than 4 C) after filtration*.**

Analysis of Soluble Kjeldahl Nitrogen (SKN) and Total Kjeldahl Nitrogen (TKN)

Use micro-digestion procedures as outlined in Standard Methods.

Consider using an outside laboratory for SKN and TKN if lab time and equipment are constraints.

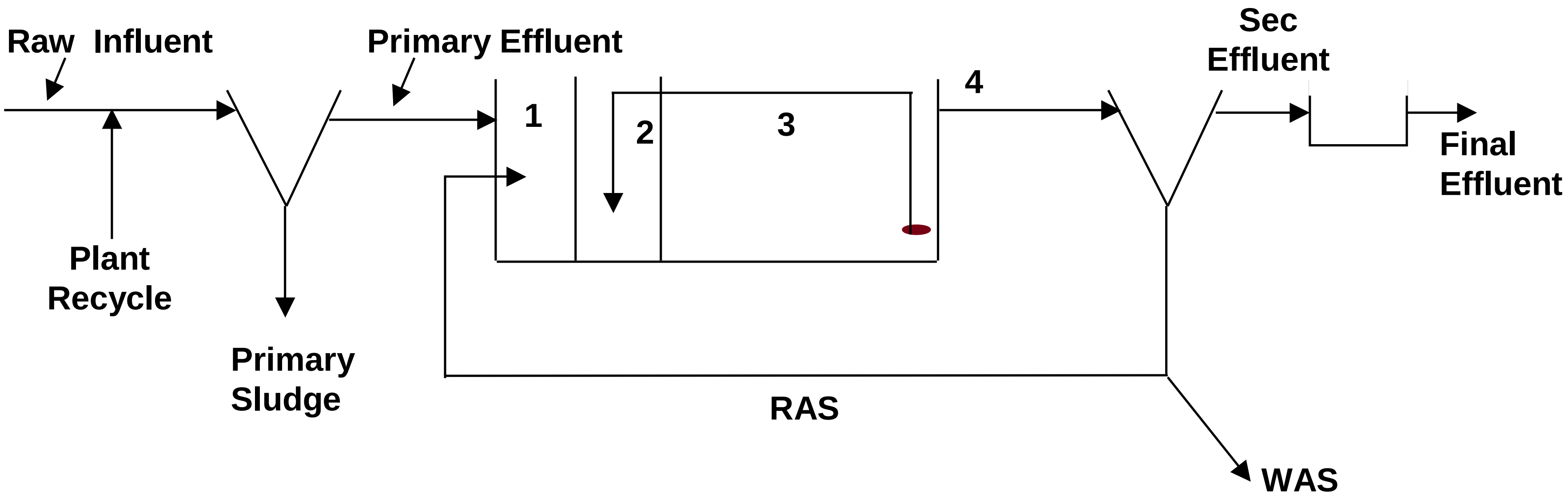
Analysis of Soluble and Total COD

Use micro-digestion procedures as outlined in Standard Methods.

Test Methods for Process Control

- **Ammonium-N**
  - **Filter sample, use Hach DR700, 2000 or higher; or**
  - **Filter sample, use gas sensing electrode**
- **Nitrite-N and Nitrate-N**
  - **Filter sample, use Hach DR 2000 or higher**
- **SKN and TKN**
  - **Use digestion followed by distillation**
- **Filtered (soluble) and Total COD**
  - **Micro-digestion**

Sampling Locations



1. Anaerobic Zone (Biological Excess Phosphorus Removal Process Only)
2. Anoxic Zone
3. Mid point of Aerobic Zone
4. End of Aerobic Zone

Troubleshooting Common Problems

1. Foam on Tanks - white or gray?
2. Final Effluent Ammonium-N high
3. Final Effluent Ammonium-N fluctuates widely
4. Fluctuations in chlorine demand
5. Fluctuations in Activated Sludge Basin DO

Troubleshooting Other Problems

6. Fluctuations in effluent NOxN above or below acceptable range
7. High NOxN in last section of primary anoxic zone
8. DO levels above 0.5 mg/L in primary anoxic zone
9. Gradual increase in Sec Clarifier blanket above acceptable levels
10. High blankets during I&I, Low basin MLSS
11. SVI increase after I&I
12. Increase in effluent soluble org-N, effluent TKN
13. Clumps of sludge floating to top of clarifier

Solutions to Common Problems

1. Foam on tanks:

Gray - brown - orange foam, viscous in nature - Nocardia type foam

May have high MCRT, trapped surface, fluctuating MCRT, fluctuating temperature

***Remove trapped surface, chlorinate foam selectively, last option is to chlorinate* RAS**

White foam - looks like soap

May have too low MCRT, not enough biomass in tank, excessive detergents

2 and 3. High effluent ammonium, fluctuating effluent ammonium-N:

MCRT or DO may not be adequate in the aerobic zone to maintain nitrification.

Increase MCRT.

Evaluate Step Feed to increase MCRT without increasing MLSS to clarifier.

4. Fluctuating chlorine demand:

Partial nitrification of ammonium-N to nitrite-N without further conversion to nitrate-N.

This may be due to inadequate aeration to handle high flows, inadequate biomass in system to handle diurnal peak nitrogen loads, or inadequate biomass to handle spikes in influent TKN (e.g.: sudden septage discharges).

5. Fluctuations in basin DO (with periods of low DO):

Check if sufficient blowers are operating to meet diurnal peak demand.

Consider adding more blowers or upgrading to fine bubble diffusers.

Excessive DO at certain times of the year or during low flow periods:

Look into ways of adjusting aeration based on time of day.

***e.g.*: manual adjustment, install timers or an automated DO Control system**

Solutions to Other Problems

6. Fluctuation in NOxN - NOxN below expected range:

Possibly under-aerating. Check effluent ammonium-N. If satisfactory, then system is O.K.

6, 7 and 8. NOxN above expected range:

Check if nitrate recycle rate is satisfactory (do calculation as shown in example problems).

Check anoxic effluent NOxN. If it exceeds 1 mg/L, check DO in anoxic zone. If DO is above 0.3 mg/L, take steps to reduce DO in anoxic zone. Reduce aerobic zone DO if possible. If further adjustments necessary, evaluate primary effluent DO level and determine if that can be reduced. Third option is to reduce nitrate recycle rate.

9. Gradual increase in secondary clarifier sludge blanket:

Evaluate the trend in SVI. Is SVI too high for the clarifier solids loading? What is the blanket level?

If SVI is high because of filaments, are they low DO filaments? Where are these filaments growing? Is the anoxic zone behaving as a low DO zone? Is the aerobic zone suffering from low DOs. Can it be corrected?

Initiate RAS chlorination to reduce SVI.

Increase sludge wasting if MCRT can be reduced.

10. Excessive sludge blanket during high flows, low MLSS in basins:

Initiate step feed during high flows to dilute the mixed liquor going to the clarifiers.

11. SVI increases during and immediately after periods of high flows:

Does infiltration increase anoxic zone DO? Infiltration may also bring in filamentous bacteria.

Plan on a maintenance dose of RAS chlorination. Use step feed to reduce the impact of primary effluent DO on anoxic zone.

Solutions to Other Problems

12.a Increase in effluent soluble organic-N - possible causes:

Reduction in MCRT below that required for nitrification.

Sudden increase in influent TKN - septage dose, etc.

Sudden addition of inhibitor - industrial chemical, pesticide, preservative, etc.

12.b Increase in effluent TKN with increase in ammonium-N:

Same as 12a.

Increase in effluent TKN with increase in effluent SS.

Check clarifier.

13. Large clumps of sludge floating to top of secondary clarifier:

Denitrification in clarifier - Increase RAS flow rate to reduce time sludge spends in clarifier, increase activated sludge tank effluent DO.

Is blanket too high? Reduce MLSS.

Check sludge scraper for proper operation.

Q&A Regarding Filamentous Growth Control

What is the problem?

- **Is the SVI too high?**
- **Is there too much foam - if so, what is the color - chocolate brown or white?**
- **Does the plant have a problem with both high SVI <u>and</u> foaming?**

Make a generic identification of the type of filament.

- **Is the filament a low DO filament?**
- **Is the filament a foam causing filament?**

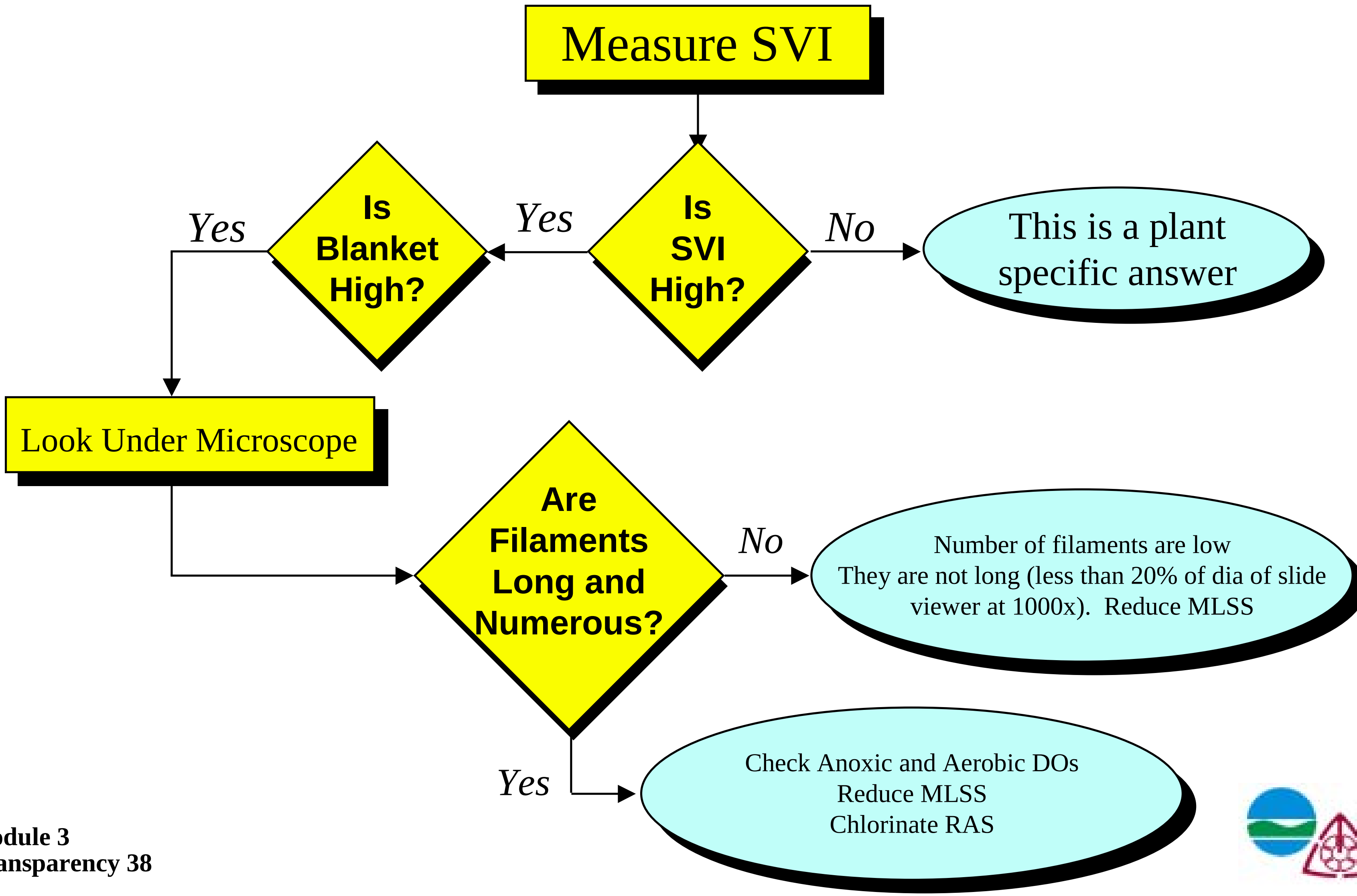
Observe filaments under the microscope.

- **Have you been doing the weekly analysis?**
- **Do you see a change in the population of filamentous bacteria?**
- **Does it correspond to a change in SVI?**
- **Is it a long spaghetti-like filament or is it a short stubby filament which looks like broken glass?**
- **Have you done a slide of the foam to see if the foam has a particular type of filament in large numbers?**

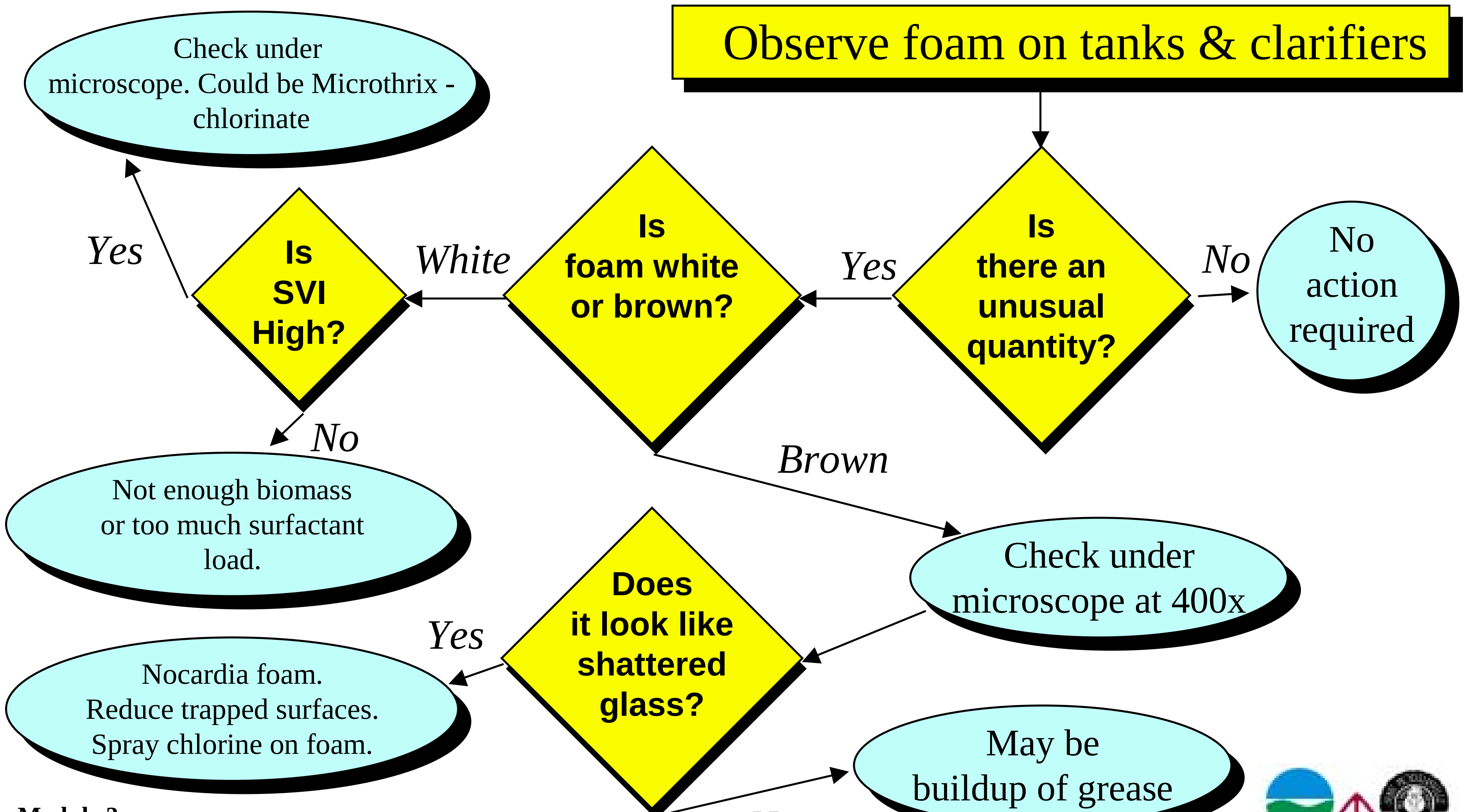
Microscopic Examination

- **Conduct examination at 400x and 1000x magnification.**
- **Try phase contrast, changing the light, and if you wish to, try staining.**
- **Low DO filament such as Sphaerotilus is relatively long (See reference book on identifying filaments)**
- **Foam causing filament such as Nocardia is short and is like shattered glass.**

Flow Sheet on SVI and Filamentous Bacteria Control



Flow Sheet on Foam Control



Filamentous Growth Control

Options to control filaments

- **If the filament is long, it has high surface area for its body mass. RAS chlorination is effective.**
- **It is recommended that the biomass get two or more exposures per day to the chlorine.**
- **Add chlorine at the point where the MLSS is the highest - in the RAS, there is minimal dilution of chlorine with water.**
- **If the filament is short, RAS chlorination will not be as effective except at high doses which can also kill some nitrifiers.**
- **Direct chlorination of the foam with water containing 15 ppm or more of chlorine is recommended.**

Alternatives to chlorination for controlling long filaments (low DO and low F/M type)

- **Some plants have tried other oxidants such as peroxide and permanganate.**
- **Others have tried adding the growth limiting nutrient (whose scarcity in low F/M systems can cause bacteria to mutate to filamentous form) - need to identify the nutrient(s) which is in short supply.**
- **Still others have tried adding vitamin B complex (folic acid) which can help grow predators of filaments.**

Alternatives to chlorination for controlling foam causing filaments

- **Some plants have added steam to kill filaments.**
- **Some plants have used polymer to coagulate the foam.**

Physical and Biochemical Changes to control filaments

- **Reduce MCRT if possible - waste more sludge.**
- **Eliminate trapped surfaces where foam accumulates.**
- **Prevent backmixing of aerated liquid into anoxic zone at the front end of the tank.**
- *Create selector zones*

Reference book: Manual on the Causes of and Control of Activated Sludge Bulking and Foaming.

Jenkins, Richards and Daigger. Lewis Publishers

Chlorine Dosing

- **Chlorine Dosing will be proportional to SVI**
- **SVI at which chlorination initiated is plant specific**
  - **Depends on clarifier sludge blanket levels**
- **Dose to terminate chlorination is plant specific**
  - **Depends on clarifier sludge blanket levels, turbidity of effluent and flocculating properties of the sludge**
- **Some plants will require a minimal maintenance dose of chlorine to control SVIs**

Filamentous Growth Control

Chlorine Dosing

Set up a RAS chlorine dosing chart based on operating SVI. ***This is specific to your plant only!***

The chart will show an SVI where chlorination would be initiated; how the chlorine dose should be decreased with drop in SVI; the SVI at which chlorination should be stopped.

Some plants may require a maintenance dose at certain times of the year (e.g.: plants which get seeded with filaments from I/I events)

Dose varies from a maintenance dose of 0.05 to 0.5 lbs/day/1000 lbs VSS in the system to a maximum short term dose of 5 lbs/day/1000 lbs VSS in the system.

Above 5 lbs/day/1000 lbs VSS, there will be a significant impact on nitrifiers.