Performance of a Pilot-scale Nitrifying Trickling Filter treating Aerated Lagoon Effluent

Presented by Kiersten Lee, EIT, MS Candidate
Erik Coats, P.E., Ph.D and Matt Hammer, WWT Manager

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Presentation Outline

- Project Background
- NTF Pilot Design
- Historical Trends
- Design Method
- Data Collection and Testing
- Model Comparison
- Conclusions
**Project Background**

- Colfax’s Population: 2,850 people
- Plant Influent: 0.360 mgd
  - Average Dry Weather Flow
- Removal Mechanisms: Aerated Lagoons, Chlorination Basin
- Current Effluent Regulations: BOD, Fecal Coliform
- Future Effluent Regulations: Ammonia-N
NH3-N Historical Trend
Lagoon 2 Effluent

\[ y = 1.0962x - 2193.4 \]
Project Questions

- Are Nitrifying Trickling Filters a “good-fit” for Colfax?

- Which design model best fits the collected data?

- Based on the data collected how would our design change?
Number of Lagoons in Northwest

- **63 in Washington**
  - 27% of NPDES Permits - Municipal Lagoons
- **59 in Oregon**
- **40 in Idaho**
  - 50% of NPDES Permits - Municipal Lagoons
NTF Pilot Design

- Flow Rate
- Influent Characterization
- Design Method
- Media Selection
- Distribution System
- Oxygen Requirements
Average Dry Weather Flow

Million Gallons/Day

Year

2004  2005  2006  2007  2008  2009  2010
Flow Rate

- Anticipated Permit Season: Dry Weather Season
  - April through September
- Historically the ADWF 0.36 mgd
- Pilot influent 5% of total plant effluent
  - 12.5 gal/min
  - Low/Med hydraulic load for media type
Average Monthly Concentration 2004-2009
Lagoon 2 Effluent

Ammonia-N Concentration (mg/L)

<table>
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<th>LOW</th>
<th>AVG</th>
<th>HIGH</th>
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<td>SEPTEMBER</td>
<td>2</td>
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<td>16</td>
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Influent Characterization: NH$_3$

- **High NH$_3$**: 15.66 mg/L
- **Average NH$_3$**: 6.26 mg/L
- **Low NH$_3$**: 0.48 mg/L
- **Design NH$_3$ influent**: 10-25 mg/L

- Steady increase in NH$_3$ concentrations
  - Increasing approximately **1.0 mg/L** per year
Influent Characterization: BOD

- Major Concern for Biofilm Growth
  - Heterotrophic (BOD) vs. Autotrophic (NH$_3$)
  - Heterotrophs will overtake at high BOD concentrations

- Historical BOD Concentrations
  - 5.0-11.0 mg/L
  - Therefore not a major concern
Pilot Design Method

- NTF Design Methods
  - Albertson and Okey Procedure
  - Line Fit Equation
  - Metcalf and Eddy
  - Gujer and Boller Equation

- New Project Objective
  - Compare and Contrast Methods with Data
Pilot Design

- Followed: **Metcalf and Eddy guidance**

**Constants and Assumptions**
- Nitrification Rates
- Half-velocity Constant \( (K_n =1.5\, \text{mg/L Ammonia-N}) \)
- Constant describing the decrease in rates as a function of depth \( (k = 0.2m^{-1}) \)
- Transition Concentrations \( (N_T) \)
Media Selection

- Requirements:
  - High Specific Surface Area (ft²/ft³)
  - Durable
  - Minimize Clogging
  - Maximize Air Flow

- Cross-Flow Media
  - Yielded positive results for NH₃ removal

- Brentwood Industries CF-1900
Distribution System

- Target Hydraulic Loading Rate (HLR)
  - Brentwood Industries
  - Metcalf Eddy Design HLR
- Translate to Upscale
- Tipping-Bucket Design
  - Mimic distribution arm
  - Even distribution- Trough System
Oxygen Requirement

- Estimated: 3.7 ft³/min Airflow
- Prevent oxygen from being the limiting factor
- Data Collected:
  - Influent: 4.0-5.0 O₂ mg/L
  - Effluent NTF: 7.0-8.0 O₂ mg/L
- Data shows sufficient oxygen
Final Design

- Two NTFs in series
- **Media Depth:** 8.0ft each
  - Total: 16.0ft
- **Width:** 4.0ft
- **Length:** 4.0ft
- **HLR:** 0.781 gpm/ft$^2$
  - Flowrate: 12.5gpm
Data Collection

- Sampling began May 30th 2010
- Parameters Tested:
  - Temperature
  - Dissolved Oxygen
  - Ammonia-N
  - Phosphorous
  - Alkalinity
- Three Locations
  - Influent, Effluent NTF1 and Effluent NTF2
NTF Performance

NH$_3$-N (mg/L)

IN

NTF1

NTF2

Data Collection

- Removal began within **two weeks** of operation

- **Full removal occurred in three weeks**
  - 95-98% removal occurred in **NTF1**
Project Questions

- Are Nitrifying Trickling Filters a “good-fit” for Colfax?
  - YES! The design yielded FULL removal in 3 weeks.

- Which design model best fits the collected data?

- Based on the data collected how would our design change?
Vertical Testing

- Began vertical sampling in NTF1
  - Calculate nitrification rate as function of depth
  - Zero and first order kinetics
- Holes drilled every 1.5-2.0ft
- Two weeks of testing
Vertical Testing Results

- Calculated Zero and First Order Nitrification Rates
- Estimated transition concentration (2.0 mg/L)
  - Between zero and first order
- Estimated the change in removal rate as function of depth (k=0.2m⁻¹)
- Used data to compare/contrast design methods
Removal vs. Depth

Ammonia-N Concentration (mg/L)

0  2  4  6  8  10  12

Influent

2.0 ft

4.0 ft

6.0 ft

8.0 ft

Effluent

Nitrification Rates (g/m²·day)

Zero Order
7/16/10 = 0.268
7/23/10 = 0.445
7/24/10 = 0.541
7/28/10 = 0.832
8/02/10 = 0.831

Transition Concentration
2.0 mg/L

First Order
7/16/10 = 0.184
7/23/10 = 0.316
7/24/10 = 0.212
7/28/10 = 0.11
8/02/10 = 0.131
Pilot Design Methods

- Compare and Contrast Models with Collected Data
  - Albertson and Okey Procedure
  - Line Fit Equation
  - Metcalf and Eddy
  - Gujer and Boller Equation
Albertson and Okey Design

\[ k_{n1} = k_{n0} \left( \frac{N_e}{N_T} \right)^{0.75} \]

- Similar to Metcalf and Eddy Model
- One Assumption: Transition Concentration (\( N_T \))
  - Transition between Zero and First Order N-Rate
  - Data collected found \( N_T = 2.0 \text{mg/L} \)
- Used the model to estimate Ammonia-N effluent concentration
Albertson and Okey Design

- Reasonable representation of data
- Model is highly dependent on zero-order Nitrification Rate

- **Over estimated** removal capacity at **high** influent concentrations
- **Under estimated** removal capacity at **low** influent concentrations
Three empirical constants

- N = Saturation Parameter (mg/L)
- $S_n = $ Bulk Liquid Ammonia-N Concentration (mg/L)
- $k = $ empirical parameter describing decrease of rate with depth ($m^{-1}$)

Estimated Effluent Concentration
Line Fit Equation

- Under estimated removal capacity
- Not representative of Colfax NTF
- Overly conservative estimation
Metcalf and Eddy

\[ n_n(N, Z) = n_{n_{\text{max}}} \left( \frac{N}{K_n + N} \right) \cdot e^{-r \cdot Z} \]

- Model used for Pilot Design
- Very similar to Albertson and Okey
- Constants: Determined by the data
  - Half-Velocity Constant \((K_n) = 2.0 \text{ mg/L}\)
  - Empirical parameter describing decrease of rate with depth \((r) = 0.2 \text{ m}^{-1}\)
- Calculated effluent concentration to compare and contrast
Metcalf and Eddy

- Omitted 7/16/10 and 7/23/10 data points
- Sensitive to low zero order removal rates
- As zero order approaches first order model does not represent data well
- Sensitive to Zero: First Order Ratio
  - As you approach 1 the model becomes unrepresentative of data
Gujer and Boller Equation

\[ h = \left( \frac{1}{-k_X} \right) \cdot \ln \left[ \frac{1 - k_X \cdot v_h}{a \cdot k_{\text{max}} \cdot e^{0.044(T-10)}} \left( N_i - N_o + N_s \cdot \ln \left( \frac{N_i}{N_o} \right) \right) \right] \]

- Model estimated design height **34.0ft**
  - Compared to 8.0ft, more than **triple** the height
- Similar empirical variables
  - Saturation Parameter (Ns) = **2.0mg/L**
  - Empirical parameter describing decrease of rate with depth (k) = **0.2m\(^{-1}\)**
- Overly conservative for Colfax
Project Questions

- Are Nitrifying Trickling Filters a “good-fit” for Colfax?
- Which design model best fits the collected data?
  - Simple models with few empirical constants. Metcalf & Eddy and Albertson & Okey appear to best fit, but more data needs to be collected.
  - Further illustrates the importance of PILOTS!
- Based on the data collected how would our design change?
NTF Conclusions

- Pilot has shown NTF’s are an excellent option for Colfax
- Established empirical constants
  - Half-Velocity Constant \((K_n) = 2.0 \text{ mg/L}\)
  - Transition Concentration \((N_T) = 1.5 \text{ mg/L}\)
  - Empirical parameter describing decrease of rate with depth \((r \text{ or } k) = 0.2 \text{ m}^{-1}\)
- Further Data Collection
Original Summer 2010 Plans for Colfax

- Double Hydraulic Loading Rate to 25gpm
  - NTF1 achieved 95-98% removal at 12.5 gpm
- However: Lagoons Nitrified (next slide)
  - Complete ammonia-N removal observed in Lagoons beginning in August
  - Therefore our NTFs were starved
  - Historically NOT abnormal....but complete nitrification not previously observed
Future Plans for Colfax

- Increase Hydraulic Loading Rate 25gpm
  - Provide Colfax with an operating range – Upscale
- Continue collecting data in 2011 (beginning in April)
Project Questions

- Are Nitrifying Trickling Filters a “good-fit” for Colfax?
- Which design model best fits the collected data?
- Based on the data collected how would our design change?
  - Increase the hydraulic capacity of the entire system to test NTF2.
Questions?