CENE 486 C: Engineering Design Capstone

Nitrification Column Design

Waste-to-Nutrients Design Team: Adrian Biggs, Siwen Li, & Emily Wheeler

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Project Description

- Nitrification Column
  - Design for Smaller Scale 1 Person Use
- Separation of Solid and Liquid Waste
- Alternative Waste Treatment
- Alternative Source of Plant Fertilizer
  - Liquid Effluent
  - Solid Growth Media

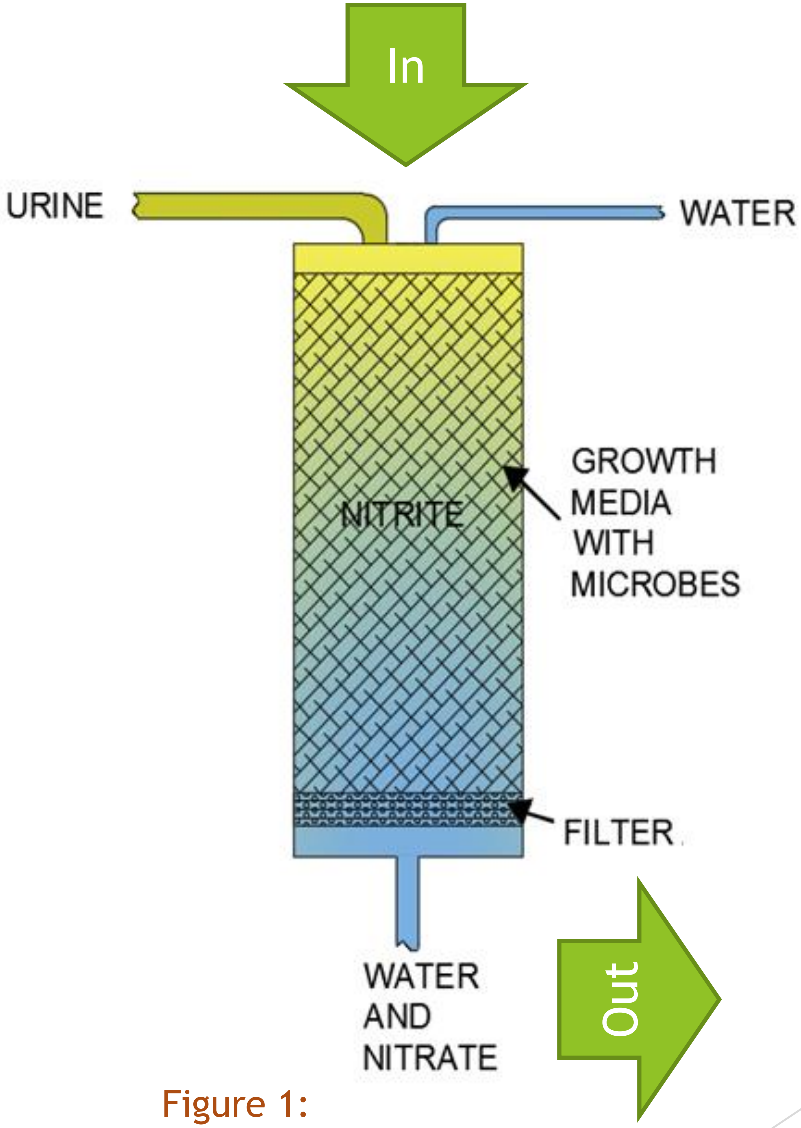

Figure 1:
Nitrification Column Illustration

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Process Description

- Nitrifying Bacteria Convert Ammonia to Nitrate
- First Step

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$$

- Second Step

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$$

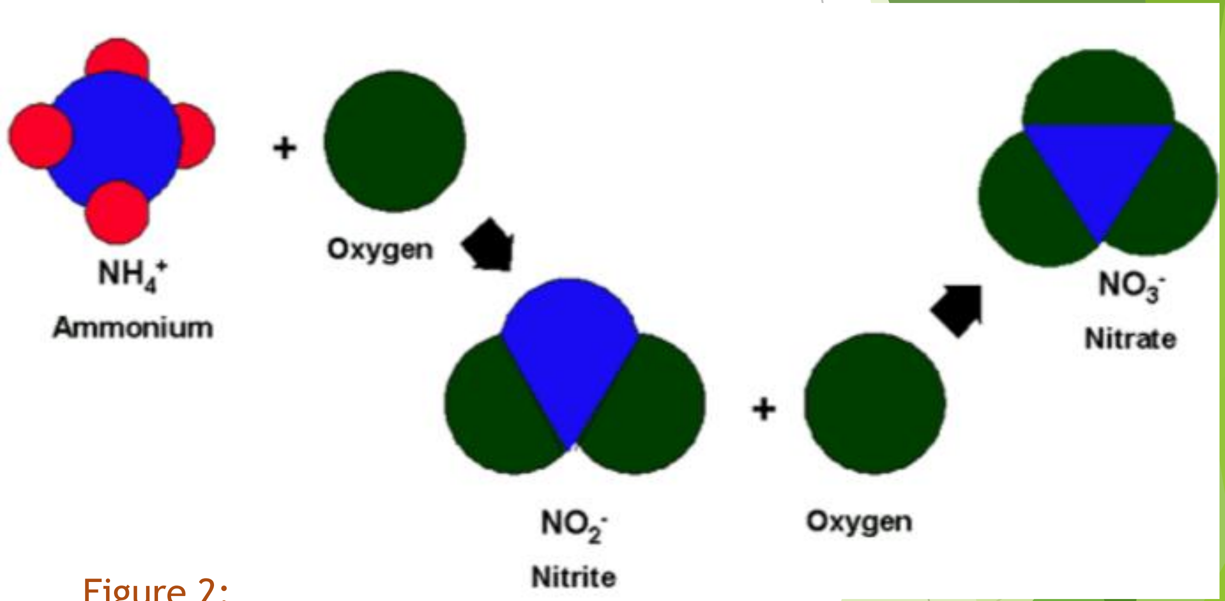

Figure 2:
Nitrification Process Illustration [1]

Project Tasks and Subtasks

- 1.0 Legality and Sanitation Aspects
  - 1.1 State Local and Federal Regulations
  - 1.2 Effluent Quality Regulations
  - 1.3 Hazards to Public Safety
- 2.0 Preliminary Lab Work
  - 2.1 List of Standard Methods
  - 2.2 Standard Method Access
  - 2.3 Lab Access
  - 2.4 Material and Equipment Accesses
- 3.0 Initial Lab Work Considerations
  - 3.1 Urine Samples
  - 3.2 Urine Dilution
  - 3.3 Bacteria Acquirement
  - 3.4 Batch Sample Establishment
  - 3.5 Growth Media Selections
- 4.0 Column Cartridge Lab Testing
  - 4.1 Cartridge Testing Method
  - 4.2 Cartridge Data Collection
  - 4.3 Cartridge Analysis
  - 4.4 Cartridge Conclusion

Project Tasks and Subtasks

- 5.0 Final Design Considerations
  - 5.1 Design Concept Generation
  - 5.2 Design Concept Analysis
  - 5.3 Design Concept Selection
    - 5.3.1 Determine Materials
- 6.0 Final Design Calculations
  - 6.1 Determine Desired Efficiency
  - 6.2 Determine Column Dimensions
  - 6.3 Request Last Minute Feedback
- 7.0 Constructions of Final Design
- 8.0 Final Column Design Testing
  - 8.1 Column Testing Method
  - 8.2 Column Data Collection
  - 8.3 Column Analysis
  - 8.4 Column Conclusion
- 9.0 Project Management
  - 9.1 TA Meetings
  - 9.2 Client Meetings
  - 9.3 Team Meetings
  - 9.4 Status Presentations
  - 9.5 Design Report
  - 9.6 Website Creation

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Legality and Sanitation Aspects

- No State Local and Federal Regulations on Effluent Quality
  - Relatively New Technology
- CFR Title 40 Chapter Restriction [2]
  - Fertilizer Manufacturing

- Hazards to Public Safety
- Ammonium Nitrate Fertilizer [3]
  - Highly Explosive Compound
  - Most Conditions Relatively Stable
- Requires a Detonator and Fuel Source [3]

Table 1: Fertilizer Regulations [2]

Constituent	Maximum	Avg. Limit
Ammonia	0.53	0.27
Organic Nitrogen	0.45	0.24

Units: 1kg Constituent/1000kg Media

Preliminary Lab Work

- List of Standard Methods [4]
  - HACH Available Online

Table 2: Standard Methods

Method	Description
HACH 8156	pH and Temperature
HACH 8221	Alkalinity
HACH TNT821	Chemical Oxygen Demand
HACH 8157	Dissolved Oxygen
HACH TNT835	Nitrate
HACH TNT839	Nitrite
HACH TNT830	Ammonia Nitrogen
HACH 10071	Total Nitrogen

- Environmental Engineering Laboratory Access
- Environmental Engineering Material and Equipment Accesses
- Materials Order Requests:
  - Nitrate TNTplus Vial Test, LR (0.2-13.5 mg/L NO3-N)
  - Nitrite TNTplus Vial Test, LR (0.015-0.600 mg/L NO2--N)
  - Ammonia TNTplus Vial Test, LR (1-12 mg/L NH3-N)

Initial Lab Work Considerations

- Human Urine Samples
  - No Antibiotics in Samples
  - Surrogate Not Used
- Urine Dilution Required
  - Average Urine Ammonia Concentration is 7mg/L
  - Bacteria Need Ammonia Concentration <15mg/L
  - Ideal Alkalinity Required the Addition of Tap Water
  - Optimal pH for Acceptable Efficiency Levels is 8

- Bacteria Acquirement
  - Wildcat Hill Wastewater Treatment Facility
  - API Quick Start

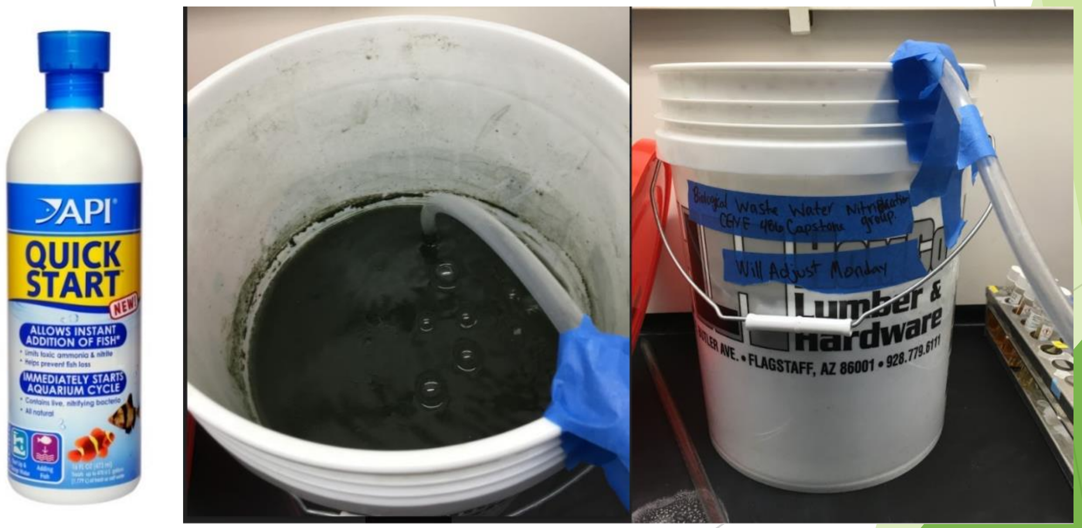

Figure 3: Bacteria Alternatives Image
Image By: Adrian Biggs

Batch Sample Establishment

Quick Start Bacteria Samples

- Easy to Buy at Local Pet Store
- Inactive Colony
- Requires Batch Colony Growth

Figure 4: Bacteria Batch Samples Image
Image By: Emily Wheeler

Wild-Cat Hill Bacteria Samples

- Monitoring:
  - pH, Alkalinity, & Temperature,
  - Ammonia Concentration
  - Chemical Oxygen Demand (COD)
- Plethora of Undesired Microorganisms
  - Removal Needed for Purification
- Minimal Evaporation
  - Addition of 500mL Tap Water Daily

Microsoft Excel Worksheet

Growth Media Establishment

- Media Alternatives
  - Pine Shavings
  - Cedar Shavings
  - Dry Straw
- Ideal Media Characteristics
  - High Absorbability
  - Low Decomposability
  - High Surface Area
- Media Beaker Lab Test Goal
  - Determine Which Media has Optimal Characteristics

- Media Beaker Lab Test Methodology
  - Six 600mL Beakers
  - Fill ~15g of Growth Media
  - Add 250mL of Tap Water
  - Allow 25 mL of Bacteria to Saturate in Samples ~24 Hours
  - Allow 25 mL of Urine to Saturate in Samples ~24 Hours
  - Add 20mL of Wildcat and API Quick Start Bacteria
  - Gather Data on Ammonia, Nitrite, Nitrate
  - Record Other Observations
  - Select Optimal Growth Media and Bacteria

Data Values

Figure 5: Growth Media Image
Image By: Emily Wheeler

Table 3: Beaker Test Data

Growth Media Test	Bacteria Sample	Growth Media Mass (g)	Day	COD (mg/L)	NH_3 (mg/L NH_3-N)	NO_2^- (mg/L NO_2^--N)	NO_3^- (mg/L NO_3^--N)
Pine #1	Wildcat	15.02	1	2145	5.9	0.15	9.22
			2	5320	12.3	0.63	16.5
Pine #2	API	15.02	1	2144	6.1	0.10	9.79
			2	5400	10.6	0.54	15.3
Cedar #1	Wildcat	15.02	1	2169	6.1	0.13	11.2
			2	2640	13.9	0.29	14.6
Cedar #2	API	15.04	1	2131	6.3	0.12	10.0
			2	3170	17.2		20.5
Straw #1	Wildcat	15.03	1	3402	20.9	0.98	20.7
Straw #2	API	15.02	1	4459	18.7	1.19	24.2

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Selection Conclusions

Bacteria

- Wildcat Hill Bacteria
  - Possible Interference from Residual Bacteria
- API Bacteria
  - Most Effective Demonstration of Nitrification
- Selection
  - API Bacteria

Growth Media

- Dry Straw
  - Rapid Decomposition
  - Foul Odor
- Selection
  - Pine Shavings
  - Higher Absorbability
  - Moderate Decomposition

Column Cartridge Lab Testing

System Start-up

- Start-up Fluid
  - Bacteria Column Flush
- Pre-Saturated
  - Preincubated Media with Bacteria

Figure 6:
Pre-Saturated
Media Image
Image By: Siwen Li

Cartridge Set-up

- Testing System Efficiency & HRT
- Prepare Three Packed Columns
  - 40 cm, 60 cm, & 80 cm Height
  - 1.25 in Diameter
  - Construct Holding Stand
- Prepare Two Pumps and Tubing
- Gather Beakers to Act as Reservoir and Effluent Collection

Column Cartridge Lab Methodology

- Dilute Urine 1:3 in Reservoir
- Determine Initial Characteristics
  - Dissolved Oxygen
  - Ammonia Concentration
  - Total Nitrogen
- 800 mL Pumped Through Column
  - 1.6 mL/min
- Determine Effluent Characteristics
  - Dissolved Oxygen
  - Ammonia Concentration
  - Nitrate & Nitrate Concentrations
  - Total Nitrogen

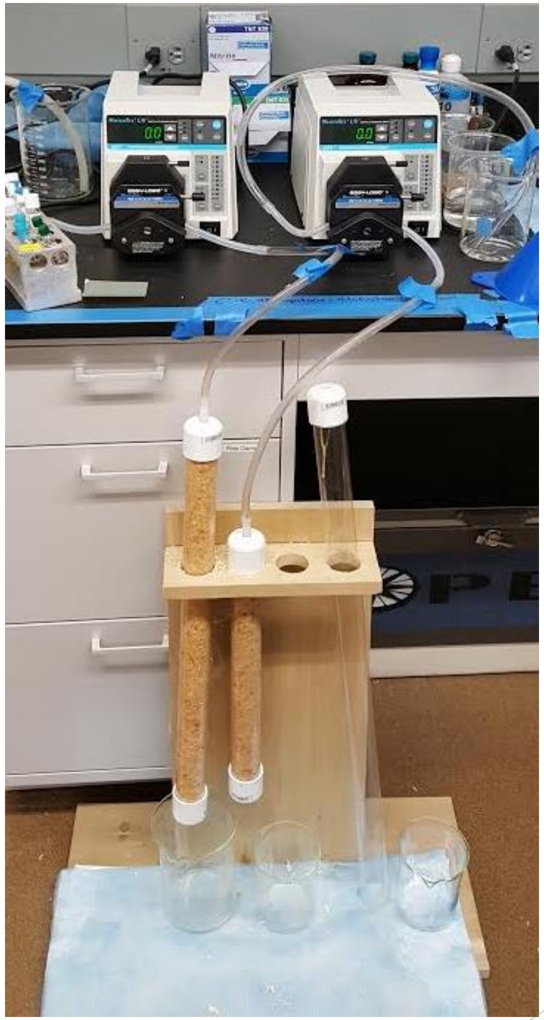

Figure 7: System Set-Up Image
Image By: Adrian Biggs

Trial #1 Cartridge Results

- Pre-saturated Cartridge
  - Ammonia Increase ~ 40 %
  - Nitrate Increase ~ -16.3 %
- Startup Fluid Cartridge
  - Ammonia Decrease ~ 34 %
  - Nitrate Increase ~ 27.5 %
- Total Nitrogen = 1565 mg/L
  - +/- 1% Loss in Effluent

Table 4: Trial #1 Data

Influent		
Ammonia (mg/L NH_3-N)	100	
Effluent	**Pre-Saturated**	**Startup Fluid**
Ammonia (mg/L NH_3-N)	140	65.9
Nitrate (mg/L NO_3-N)	6.52	9.39
Nitrite (mg/L NO_2-N)	2.12	0.57
Ammonia Converted to Organic Nitrogen (mg/L Organic-N)	-48.64	24.14

Trial #1 Cartridge Results

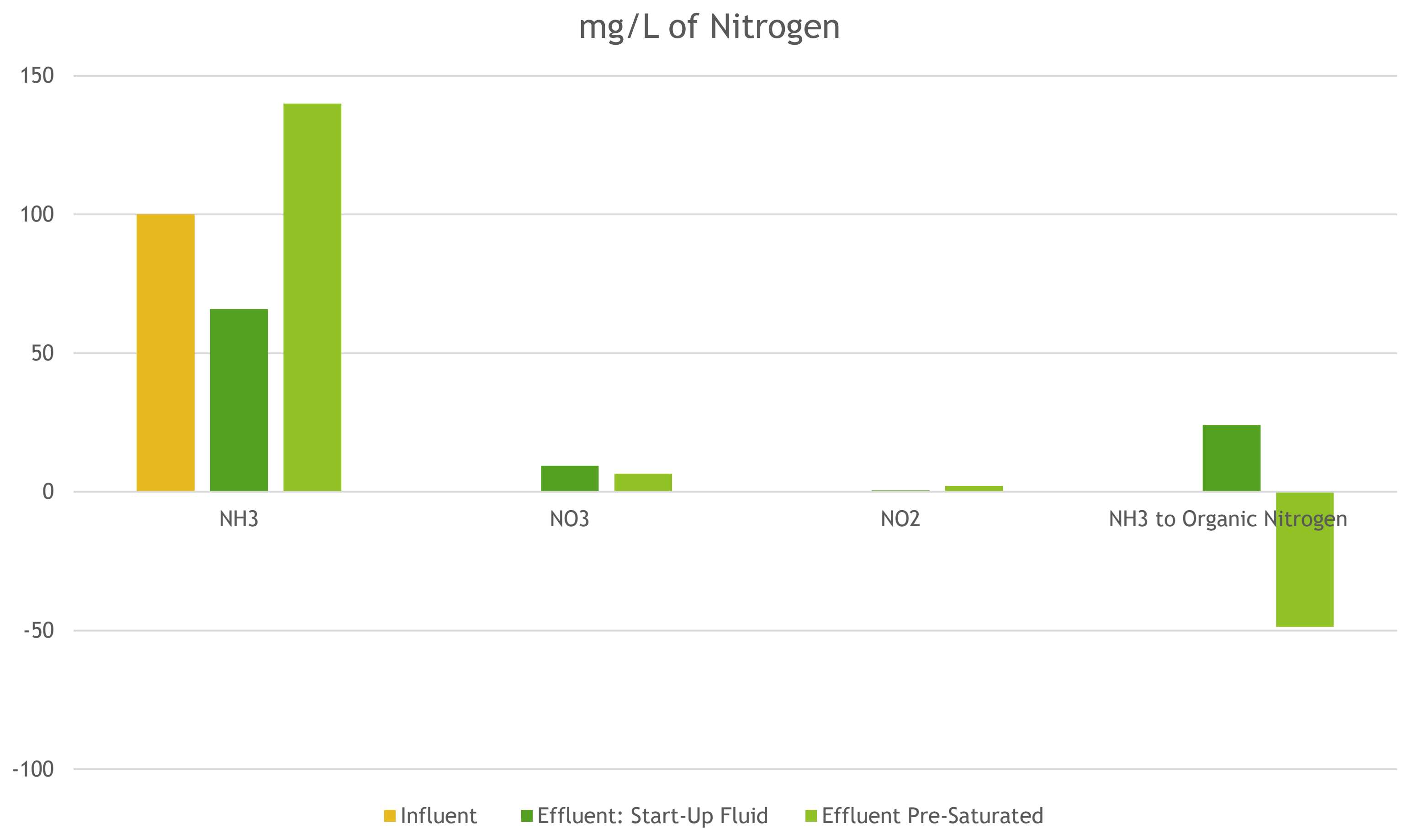

Figure 8: Trial #1 Data Illustration

Trial #2 Cartridge Results

- 40cm: Cartridge
  - Ammonia Decrease ~ 32.96 %
  - Nitrate Increase ~ 19.12 %
- 60cm: Cartridge
  - Ammonia Decrease ~ 45.04 %
  - Nitrate Increase ~ 21.32 %
- Total Nitrogen = 2260 mg/L
  - +/- 1% Loss in Effluent

Table 5: Trial #2 Data

Influent		
Ammonia (mg/L NH3-N)	125	
Effluent	**40 cm**	**60 cm**
Ammonia (mg/L NH3-N)	83.8	68.7
Nitrate (mg/L NO3-N)	7.88	12
Nitrite (mg/L NO2-N)	0.99	0.24
Ammonia Converted to Organic Nitrogen (mg/L Organic-N)	32.33	44.06

Trial #2 Cartridge Results

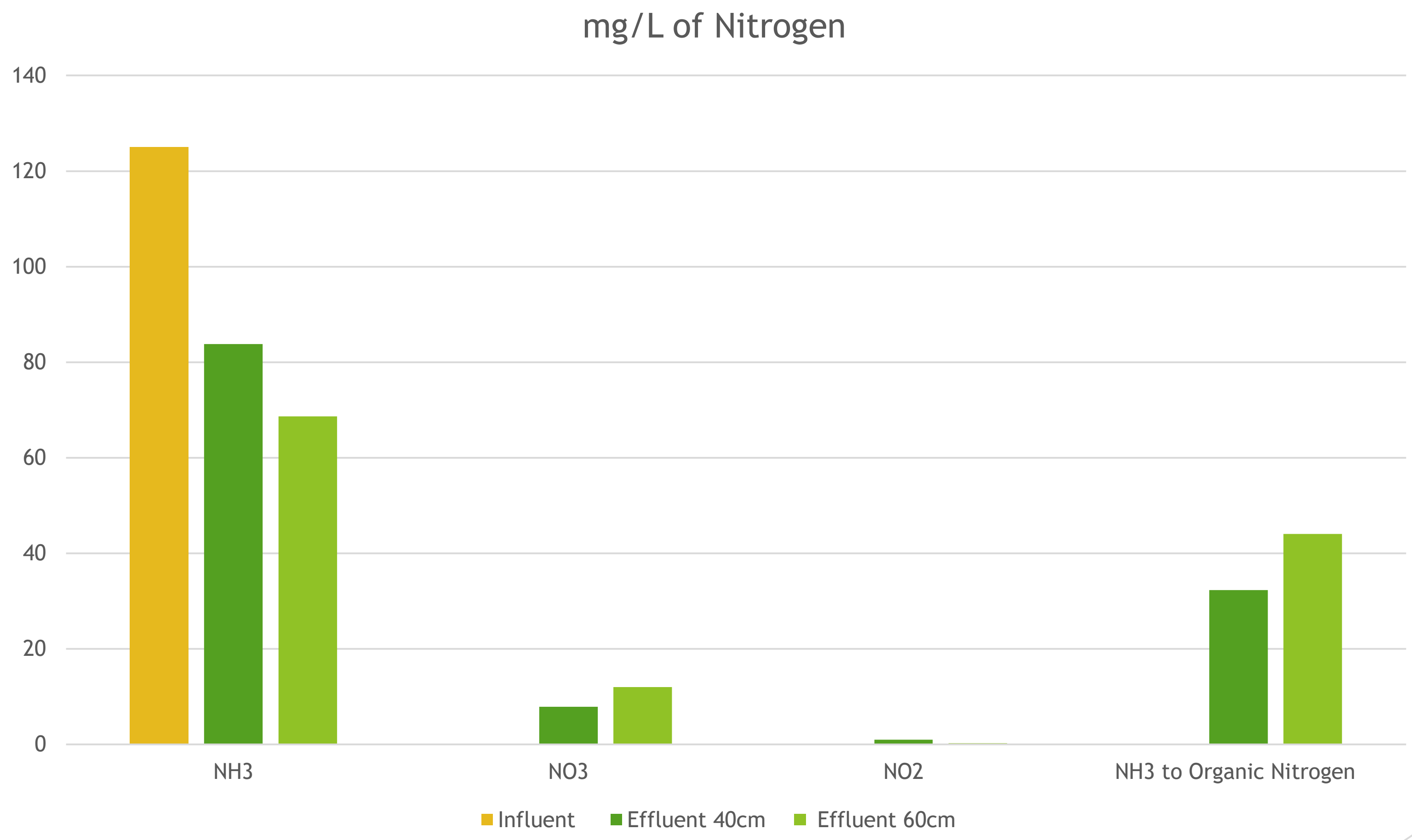

Figure 9: Trial #2 Data Illustration

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Trial #3 Cartridge Results

- 40cm: Cartridge
  - Ammonia Removal ~ 53%
  - Nitrate Increase ~ 7.6%
- 80cm: Cartridge
  - Ammonia Removal ~ 75.6 %
  - Nitrate Increase ~ 6.7 %
- Total Nitrogen = 3400 mg/L
  - +/- 1% Loss in Effluent

Table 6: Trial #3 Data

Influent		
Ammonia (mg/L NH3-N)	360	
Effluent	**40 cm**	**60 cm**
Ammonia (mg/L NH3-N)	91.5	169
Nitrate (mg/L NO3-N)	18	14.6
Nitrite (mg/L NO2-N)	1.7	3.9
Ammonia Converted to Organic Nitrogen (mg/L Organic-N)	172.5	248.8

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Trial #3 Cartridge Results

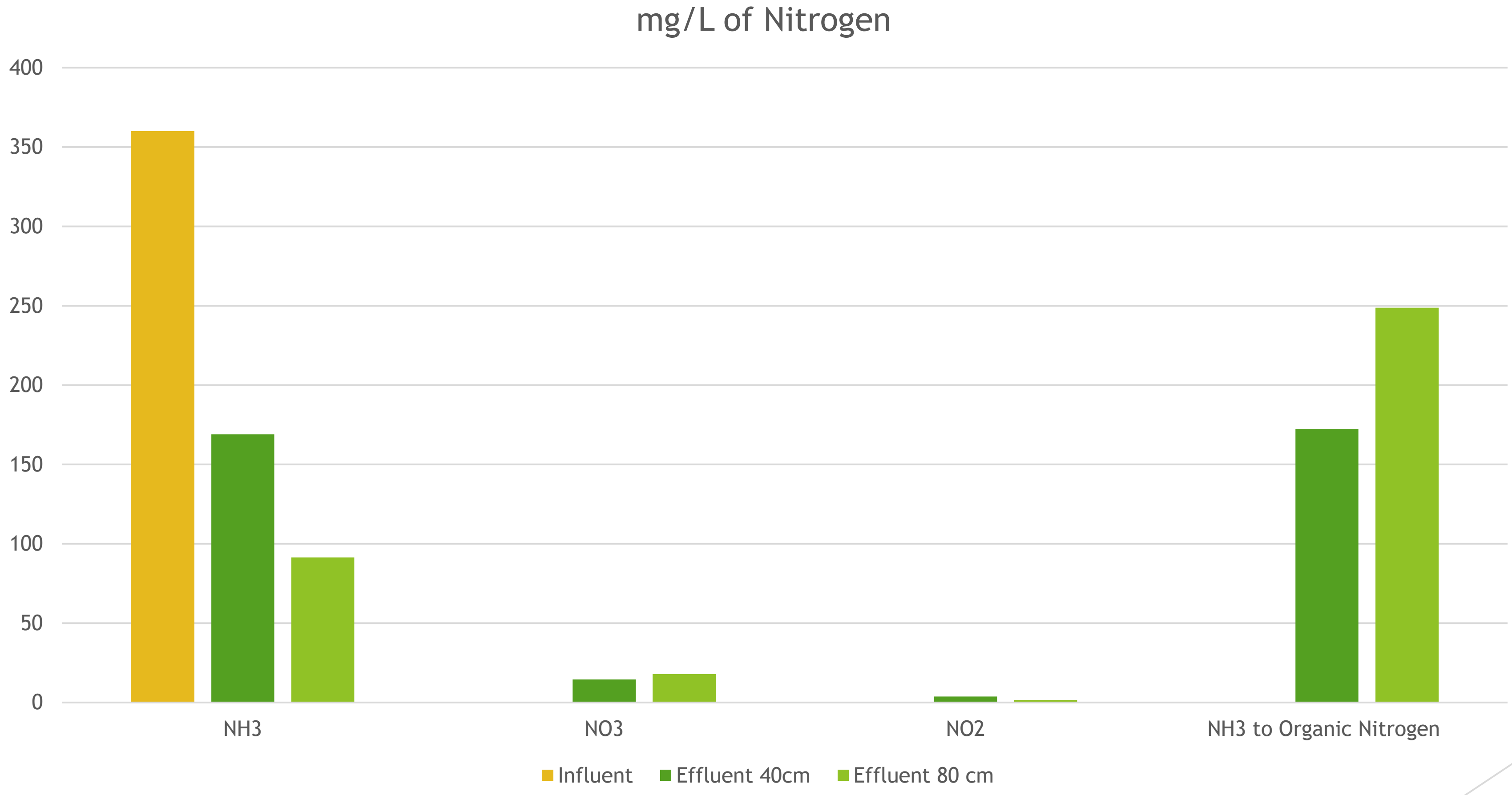

Figure 10: Trial #3 Data Illustration

Final Design Selection & Testing

Final Design Considerations

- Required Efficiency: 80%
  - Length of Column >80cm
  - Length Effects HRT
- Loading Rete
  - Increased by Change in Diameter
- Single Person Use Design
  - 120 cm Column Height
  - 2 cm Diameter
- System Start-up Fluid

Final Design Materials & Cost

Table 7: Final Design Material Costs

Items	Cost
2 Cartridge	$ 60
Housing Unit	$ 40
Miscellaneous	$ 35
Total	$135

Figure 11: Final Design Image
Image By: Adrian Biggs

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Final Design Results

- 120 cm: Column Inculcated
  - Ammonia Removal ~80 %
  - Nitrate Increase ~ 61.5 %
- Total Nitrogen = 1203 mg/L
  - +/- 1% Loss in Effluent
- Increase in Final DO: 1 mg/L
  - Initial DO = 1.6 mg/L

Table 8: Final Data Results

Influent	
Ammonia (mg/L NH3-N)	53.9
Effluent	**120 cm**
Ammonia (mg/L NH3-N)	11.3
Nitrite (mg/L NO2-N)	1.5
Nitrate (mg/L NO3-N)	26.2
Ammonia Converted to Organic Nitrogen (mg/L Organic-N)	14.9

Final Design Results

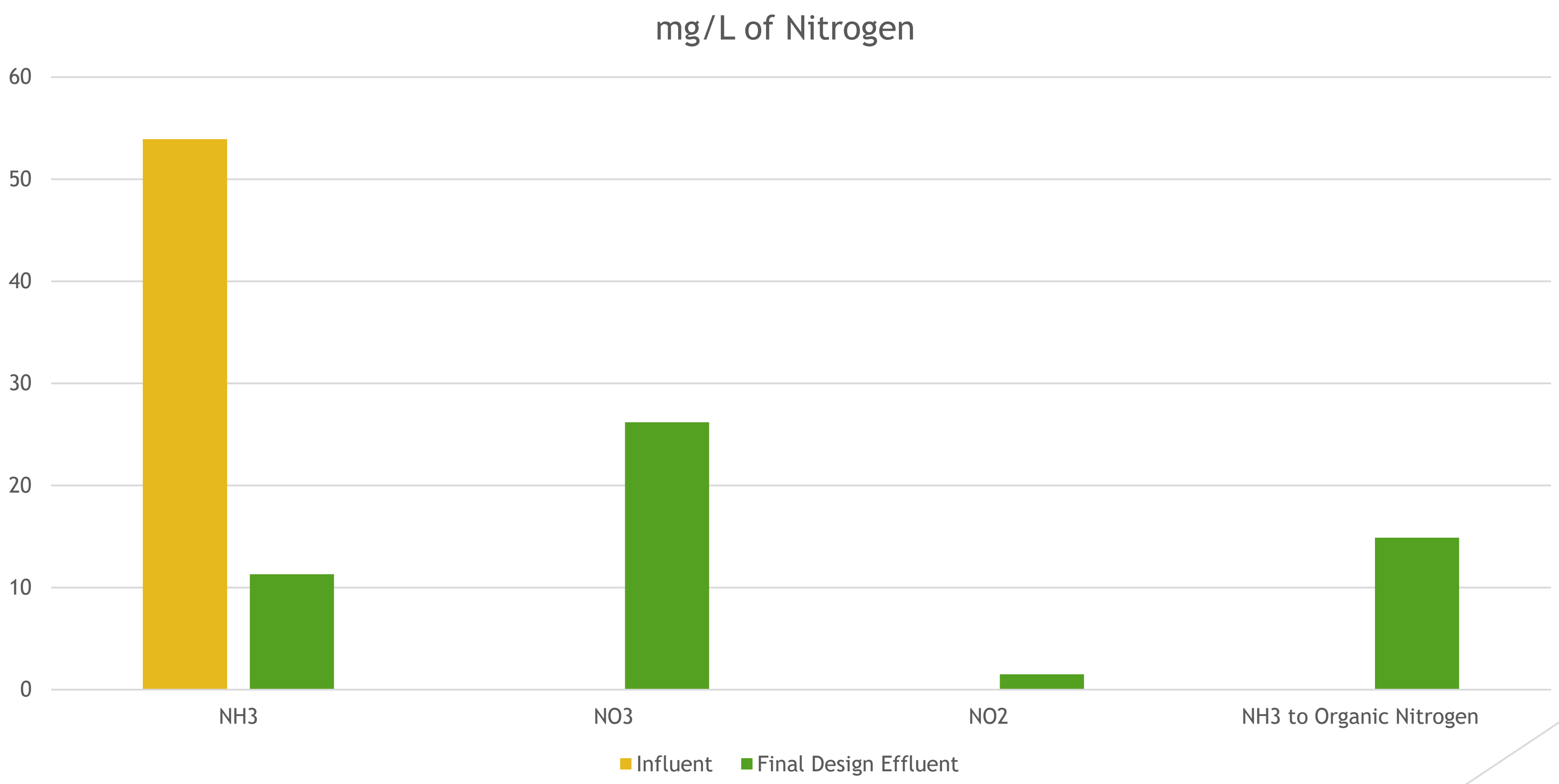

Figure 12: Final Design Results Illustration

Schedule

In Time:
Behind Schedule:

Table 9: Schedule Projected Vs. Schedule Actual

#	Task Name	Projected Start	Projected End	Actual Start	Actual End
1.0	Legality and Sanitation Aspects	8/29	9/6	8/29	9/2
2.0	Preliminary Lab Work	8/29	9/23	8/29	9/9
3.0	Initial Lab Work Considerations	9/23	10/10	9/9	10/21
4.0	Column Cartridge Lab Testing	10/10	11/6	10/21	11/4
5.0	Final Design Considerations	11/6	11/9	11/4	11/18
6.0	Final Design Calculations	11/9	11/12	11/18	12/2
7.0	Constructions of Final Design	11/12	11/20	11/19	12/2
8.0	Final Column Design Testing	11/20	12/9	12/2	12/4
9.0	Project Management	8/29	12/9	8/29	12/9

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Cost of Services

Table 10: Services Cost Projected Vs. Services Cost Actual

1.0 Staff	Classification	Rate ($/hr)	Projected Hrs	Projected Cost ($)	Actual Hrs	Actual Cost ($)
	PM	145	51	7395	165	23925
	AA	42	32.5	1365	34	1428
	MB	61	96	5856	166.5	10157
	BENG	60	141.5	8490	151.5	9090
	ENENG	80	129	10320	232.5	18600
	Personnel Total	-	450	33426	749.5	63200
2.0 Lab	Classification	Rate ($/Days)	Projected Days	Projected Cost ($)	Actual Days	Actual Cost ($)
	Lab Rental	30	60	1800	90	2700
	Equipment			250		250
	Materials			250		772
	Lab Total			2300		3722
3.0 Total				35726		66922

Cost of Services

Table 11: Personnel Classification

Classification	Abbreviation
Project Manager	PM
Administrative Assistant	AA
Microbiologist	MB
Biochemical Engineer	BENG
Environmental Engineer	ENENG

Table 12: Project Costs

Material	Cost ($)
Wood	40
Test Cartridges	5
Final Design Cartridge	150
Miscellaneous	30
PVC Piping	25
API Nitrifying Bacteria	20 (x2)
Home Nitrate/Nitrite/Ammonia Tests	30
Growth Media	30
Nitrate Lab Tests	56(x2)
Nitrite Lab Tests	56(x2)
Ammonia Lab Tests	56
COD Tests	56
Total Nitrogen Tests	56
Total	772

Triple Bottom Line

Figure 13: Triple Bottom Line Illustration [5]

Social Aspects

- ~2.5 Billion People Have No Access to Waste Treatment [6]
  - Rural Areas
- ~115 Million Tons of Nitrogen Nutrients Used Annually [7]
- More Developed Areas
  - Don't Require This Type of Sanitation
  - Not Put in the Effort to Change Cartridges Regularly

Environmental Impacts

- Benefits
  - Effluent Can Be Used in Home Gardens and Landscape
  - Effluent Can Be Used as Fertilizer for Agriculture
- Consequences [8]
  - Possible Eutrophication in Excessive Amounts
  - Excessive Bacteria/Algae Growth in Water
  - Fish Dead Zones

Economic Effects

- Low Cost and Maintenance
- Relatively New Technology
  - Not Much Information
- Sustainable Home Production of Fertilizer

Acknowledgments

- Client & Grading Instructor: Alarick Reibolt
- Project Support, Guidance, & Instruction

Figure 14: Lar [9]

- Technical Advisor: Terry Baxter
- Insight, Encouragement, & Recommendations

Figure 15: Professor Baxter [9]

- Lab Manager: Gerjen Slim
- Material, Laboratory, & Equipment Access

Figure 16: Gary [9]

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