Comparing Nitrate Removal Efficiency Between Gravel and PVC Biocarriers

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Introduction

Background

- Nitrate (NO_3^-) has an EPA mandated maximum contaminant level (MCL) of 10 mg N/L
- Ground waters with high NO_3^- are predominantly in small and intermediate sized systems that service 500-100,000 people
- Consumption of water with high NO_3^- levels can cause methemoglobinemia or blue baby syndrome, may cause colorectal cancers, thyroid disease, and birth defects

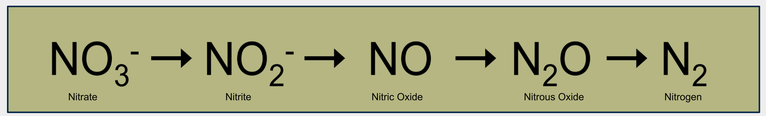
NO_3^- Removal

- Several methods for NO_3^- removal are ion exchange, reverse osmosis, electrodialysis and **biological treatment**
- Biological treatment converts NO_3^- to nitrogen gas through denitrification via anaerobic respiration
- Heterotrophic biological reactor uses acetic acid (HAc) as a carbon source and electron donor

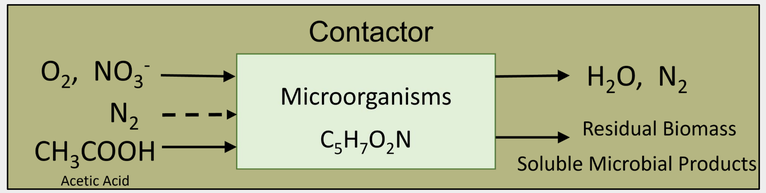
N_2 Sparge Reactor

- N_2 sparging used to create an anoxic environment in the column, lowers dissolved oxygen (DO) from 7-9 mg/L to 2 mg/L
- Pros: requires less backwashing, lower chemical costs
- Cons: large upfront cost for the N_2 generator
- Biocarriers are a medium used in contactors to anchor microbes and promote growth
- Gravel: cheaper material
- PVC: comparatively more expensive, higher surface area

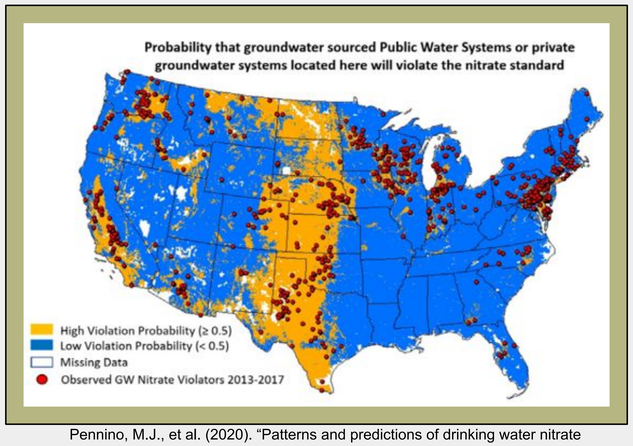
Objective: Compare NO_3^- removal of biological contactors with different biocarriers



NO_3^- Reduction Formula



NO_3^- Pilot Transformation



Pennino, M.J., et al. (2020). "Patterns and predictions of drinking water nitrate violations across the conterminous United States." Sci Total Environ 722: 137661

Materials and Methods

N_2 holding tank and generator

Contactor A and B

Contactor Dimensions:
Height: 4 ft.
Diameter: 3 in.
Bed Depth: 30 in.

Contactor A:
Biocarrier: Gravel
Biocarrier Dimensions: ½ in.
Total Surface Area: 5.38 ft^2
Biocarrier surface area: 2.24 ft^2

Contactor B:
Biocarrier: PVC
Total Surface Area: 10.5 ft^2
Biocarrier Dimensions:
Pipe size: ½ in x 1 in,
Biocarrier surface area: 7.43 ft^2

	Gravel Contactor	PVC Contactor
Flow Rate (Q) (mL/min)	200 – 75	200 – 75
Hydraulic Loading Rate (HLR) (gpm/ft^2)	1.08	0.40
Surface Loading Rate (g N/m^2/d)	8.63 – 3.24	14.8 – 5.55
Empty Bed Contact Time (EBCT) (minutes)	27.8 – 74.1	27.8 – 74.1

Reagents

- Influent NO_3^-: 15 mg N/L (target contaminant)
- PO_4: 0.4 mg P/L (essential nutrient)
- $NaHCO_3$: 105 mg/L (pH control, influent target: 7, contactor target: 7-9)
- HAc: 70 mg/L (electron donor/carbon source)

Operation and Sampling

- Duration: 2/9/2022-5/31/2022
- Intermittent operation: 9 hours/day, 5 days/week
- Flow in contactor changed to increase NO_3^- removal efficiency
- Samples were taken for benchtop analysis and submitted to analytical lab 2x/week
- Influent and effluent from each contactor was sampled
- Benchtop analysis: pH, DO, turbidity, and ATP (Adenosine triphosphate,coenzyme used in energy transference)
- Analytic lab analysis: alkalinity, nitrate and nitrite, ammonia, phosphate, and TOC

Conclusion

- Initial levels of each analyte for the PVC contactor is due to longer acclimation time; the gravel contactor had been used previously and, therefore, needed less time to acclimate
- Took approximately a month for the PVC contactor to acclimate
- Once acclimated, gravel and PVC biocarriers removed NO_3^- completely but gravel had a higher rate of removal
- Comparatively lower cell activity was observed in the PVC contactor signifying lower biomass in the contactor
- A slower flow rate heavily contributed to the lower nitrite levels for the PVC contactor
- Gravel contactor was able to remove NO_3^- and reduce NO_2^- accumulation at higher flow rates
- PVC contactor had a higher surface area but a slower rate of contaminant removal was observed
- PVC as a biocarrier may not be as conducive to microbe growth due to shape and surface charge of the material, higher and diversified biomass is imperative for denitrification

References/Acknowledgements

Metcalf & Eddy, Inc. (2003). Wastewater engineering:treatment and reuse. Boston: McGraw-Hill. Table 9-2

Tang,Y., Ziv-El, M., Zhou, C., Shin, J.H., Ahn, C.H., Meyer, K., McQuarrie, J., Candelaria, D., Swaim,P., Scott, R. and Rittmann, B.E. (2011), Using carrier surface loading to design heterotrophic denitrification reactors. Journal - American Water Works Association, 103: 68-78. https://doi.org/10.1002/j.1551-8833.2011.tb11421.x

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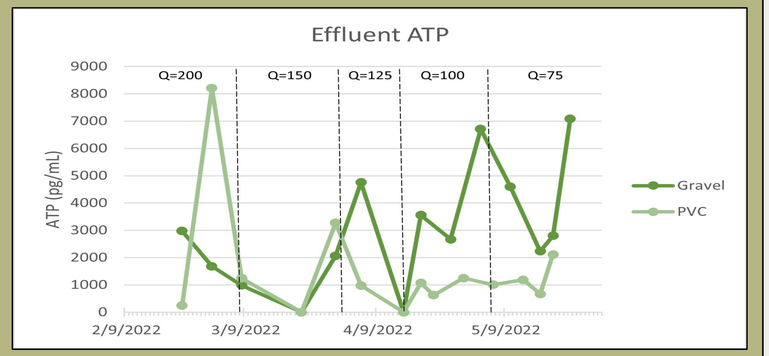
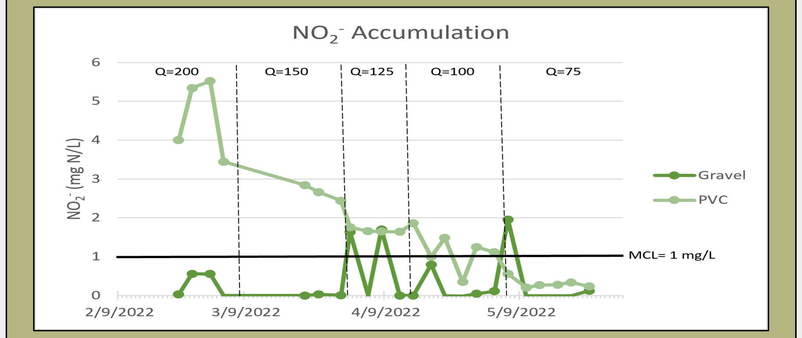
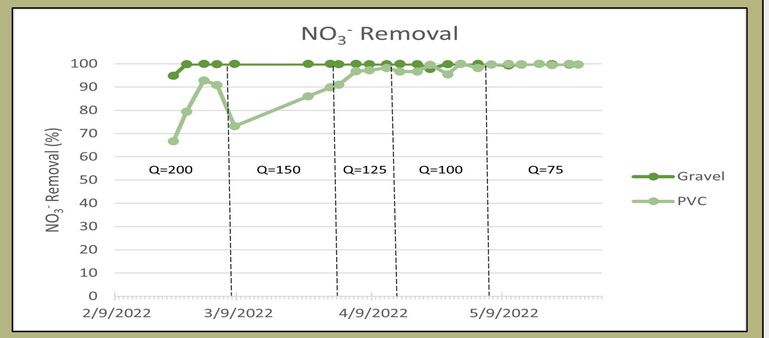
Results



Effluent ATP: Lines used to mark dates of flow rate (Q, mL/min) changes. Method utilized to measure viable cell activity, which is indicative of biomass levels in contactor. Influent ATP ranged from 21-361 pg/mL



NO_2^- Accumulation: Flow rates (Q, mL/min) shown throughout Phase III. Insufficient HAc was the cause of spikes observed for gravel biocarrier



% NO_3^- Removal: Lines signify flow rate (Q, mL/min) changes throughout Phase III. Percent removal calculated from influent and effluent nitrate levels. Effluent levels ranged from 0.001-0.082 mg N/L when Q= 75 mL/min.

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