Treatment of Winery Wastewater with Gravel Bed Vertical Flow Constructed Wetlands

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Sponsored by the Michigan Craft Beverage Council
Presentation Outline

- Overview of Wineries and Wastewater Challenges
- Gravel Bed Vertical Flow Constructed Wetland
  - Previous Applications
  - Experimental Design
- PO4Sponge
  - Overview
  - Experimental Design
- HYDRUS CW2D Model
- Results
- Conclusions and Future Work
Michigan Wineries

45th Parallel: Same latitude as Bordeaux, Burgundy, and Rhone Valley¹

148 wineries making Michigan 5th in the nation for wine production²

>1.7 million tourists per year²

2.1 billion in economic activity in 2017³

3 million gallons of wine per year²

47% increase in production over the last 5 years²

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Wine Making Process and Wastewater Production

- Wastewater produced: 7 gallons per gallon wine\(^4\)
- Wastewater is produced throughout the process, primarily during crush and cleaning\(^5\)
- Peak flows in late fall/early winter, minimal flows during “off-season” \(^5\)
- High strength\(^5\)
  - BOD\(_5\) > 2,000 mg/L
  - Total Nitrogen > 10 mg/L
  - Total Phosphorus > 5 mg/L

Challenges with Winery Wastewater

- High concentrations of $\text{BOD}_5$, Total Nitrogen, Total Phosphorus
- Seasonal, intermittent production
- Most Michigan wineries:
  - Located within 25 miles of Lake Michigan
  - Do not have access to public sewers
  - Wineries with access to public sewers are subject to surcharges

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Challenges with Winery Wastewater

- Michigan Department of Environment, Great Lakes and Energy (EGLE) recently established loading rate of 50 lbs BOD$_5$/acre/day for land application of wastewater.
- Loading rate is limited to reduce metal mobilization and groundwater contamination.
- High strength wastewater requires substantial land for land application treatment.
- To preserve vineyard space, an alternative on-site treatment method is necessary.
Gravel Bed Vertical Flow Constructed Wetlands (Contactors)

- Subsurface cells filled with gravel: roughing cell, denitrification cell, and polishing cell
- Aerobic & anoxic conditions promote biological treatment
- Wastewater is distributed 1.5 feet below ground level
- Plants were excluded in this study
Contactors

- Demonstrated success for milking facility wastewater
- Observed removal:
  - 92% COD (proxy for BOD$_5$)
  - 91% Ammonia
- Basis for NRCS standard for Gravel Contactors
- Similar cold weather designs by AQUA Treatment Technologies and GeoSyntec Consultants have been installed for sanitary sewage, milkhouse washwater, and greenhouse irrigation leachate water

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Calculated surface area requirement of 6.5 ft$^2$ per bottle produced on maximum production day using:

- Organic loading rate established for NRCS Gravel Bed design guide = 462 lb COD/acre/day
- Carbon concentration = 6,000 mg/L COD
- Wastewater production = 7 gallons per gallon of wine
- Bottle of wine = 750 mL
Experimental Design: Carbon & Nitrogen Removal Study

- PVC columns with gravel
  - Actual depth: 4-ft with wastewater inlet 1.5-ft from top
  - Scaled surface area: 4-in diameter
- Loading rate of 462 lb COD/acre/day
- Recycle ratio of 3:1 in Column 1
Experimental Design: Carbon & Nitrogen Removal Study
Phosphorus Removal

Particulate:
- Solid/liquid separation

Soluble:
- Biological
- Precipitation
- Struvite Crystallization
- Soil Sorption
- Media Sorption

Common Sorbents for Media Sorption:
- Limestone
- Furnace Slag
- Iron Filings
- Activated Aluminum
- Nano-Enhanced Iron Foam
PO4Sponge

- Manufactured nano-enhanced iron foam by MetaMateria Technologies, Columbus, OH
- Composed of iron oxide nanocrystals of oxyhydroxide with alumino-silicate bonded porous structure
- Absorption capacity ranging from 20 – 50 mg P/g media resulting from:
  - High adsorption rates
  - Large surface area
  - Increased contact time due to increased porosity
Experimental Design: Phosphorus Removal Study

- PVC Columns, 1.5-in diameter
- Quantity of PO4Sponge recommended by manufacturer
- Treated wastewater from contactor system supplemented with monopotassium phosphate to influent concentration (17.4 mg/L P)
- Received same daily volume as contactor system
Experimental Design: Phosphorus Removal Study

[Images of experimental equipment]
Experimental Design: Operational

Carbon & Nitrogen Removal Study

- Phase 1: Normal Operation
  - Loadings 4x/day at 8am, 11am, 2pm, 5pm
  - Room temperature (68°F)
- Phase 2: Intermittent Loading
  - Loadings 4x/day at 8am, 2pm, 8pm, 2am
  - Room temperature (68°F)
- Phase 3: Cool Down
  - Loadings 4x/day at 8am, 2pm, 8pm, 2am
  - Reduced temperature (50°F)

Phosphorus Removal Study

- Loadings 4x/day at 8am, 2pm, 8pm, 2am
- Room temperature (68°F)
HYDRUS CW2D Constructed Wetland

- Simulates water and solute flow in soil
- Uses the Richards’ Equation for water flow and the advection-dispersion equation for solute flow
- Considers both aerobic and anoxic transformation and degradation processes for organic matter, nitrogen, and phosphorus
- Potential for development of design criteria and operational strategies to maximize the treatment

# Results: Carbon & Nitrogen Removal Study

<table>
<thead>
<tr>
<th></th>
<th>Average Influent (mg/L)</th>
<th>Phase 1 Average Effluent (mg/L)</th>
<th>Phase 2 Average Effluent (mg/L)</th>
<th>Phase 3 Average Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>5808 ± 1229</td>
<td>22 ± 13</td>
<td>23 ± 5</td>
<td>20 ± 3</td>
</tr>
<tr>
<td>Total Nitrogen (mg/L N)</td>
<td>33.27 ± 9.21</td>
<td>2.25 ± 0.71</td>
<td>1.78 ± 0.72</td>
<td>1.55 ± 0.30</td>
</tr>
<tr>
<td>Ammonia (mg/L N)</td>
<td>13.71 ± 5.61</td>
<td>BDL*</td>
<td>BDL</td>
<td>BDL</td>
</tr>
<tr>
<td>Nitrate (mg/L N)</td>
<td>4.21 ± 5.35</td>
<td>1.47 ± 0.74</td>
<td>0.95 ± 0.50</td>
<td>0.72 ± 0.48</td>
</tr>
</tbody>
</table>

*BDL: Below Detectable Limits
COD

Influent
• Column 1 Effluent
▲ Column 2 Effluent
× Column 3 Effluent

Days from Start

COD (mg/L)
0 1000 2000 3000 4000 5000 6000 7000 8000 9000
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Total Nitrogen

Days from Start

Influent
Column 1 Effluent
Column 2 Effluent
Column 3 Effluent
Ammonia

Ammonia - N (mg/L NH₃ - N)

Days from Start

- Influent
- Column 1 Effluent
- Column 2 Effluent
- Column 3 Effluent
Results: Phosphorus Removal Study

- Average Influent: 17.55 ± 0.48 mg/L P
- Average Effluent: 0.036 ± 0.027 mg/L P
Results: Phosphorus Removal Study

![Graph showing phosphorus removal over days from start.](graph_url)
Conclusion

- Robust treatment system that can handle:
  - High strength waste
  - Varying loading concentrations and frequencies
  - Reduced temperatures
- Effluent concentrations are substantially better than septic effluent allowing for conventionally sized drain field
- Reduction in surface area by 80% in comparison to traditional land application
Future Work

- Field demonstration to:
  - Determine additional design and installation considerations
  - Allow producers to observe system maintenance and operational procedures
- Data collection for calibration and validation for HYDRUS CW2D model
Acknowledgements

Sponsor: Michigan Craft Beverage Council

Project Participants:
- Joanne Davidhizar, MSU Extension
- Sarina Ergas, Ph.D., P.E., Department of Civil & Environmental Engineering, University of South Florida
- Geosyntec Consultants
- MetaMateria Technologies

Project Construction:
- Phil Hill
- Steve Marquie

Data Collection:
- Brynn Chesney
- Rachelle Crow
- Kiran Lantrip
- Matt Wholihan
- Corrine Zeff