Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

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Biosystems Design Projects

Phosphorus Reduction through Electrodialysis in Pharmaceutical Reverse Osmosis Reject

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Perrigo

(Under NDA)

Background

Overview

Perrigo, a pharmaceutical company located in Allegan, Michigan, produces United States Pharmacopeia (USP) purified water for use in their manufacturing processes. A reverse osmosis (RO) system is used to filter this water. Figure 1 shows Perrigo's plant 4. Allegan has a high phosphorus concentration in the city water supply, and when that water undergoes RO the phosphorus is concentrated further. The RO reject water exceeds the Total Maximum Daily Load[1] for phosphorus discharge, shown in Equation 1. Therefore, treatment at the city sewer treatment facility is required which costs thousands of dollars yearly. Figure 2 shows an example of what a commercial RO system looks like.

$$TMDL = \sum WLA + \sum LA + MOS \quad (1)$$

WLA = Waste load Allocations (point source) (mg/L)
LA = Load allocation (nonpoint source) (mg/L)
MOS = Margin of Safety (mg/L)

By implementing an in-house phosphorus treatment system onsite, the team aims to reduce costs and introduce a long-term solution for further regulations on discharge.

Figure 1. Perrigo Tablet Manufacturing Plant 4

Problem Statement

Design and perform a feasibility analysis on in-house phosphorus treatment systems to reduce phosphorus levels in Perrigo's RO reject water.

Figure 2. Example of Reverse Osmosis system

Assumptions

- Without current NPDES permits and updated EPA limits, the team will aim for a phosphorus limit between [redacted] mg/L
- Cost calculated using the six-tenths rule[4] is accurate to the actual cost from the manufacturer in contact with Perrigo.
- Implementation costs are between $20,000 - $150,000.

Objectives

- Maintain RO rejected Phosphorus water levels between [redacted]mg/L
- Phosphorus removal system return on investment (ROI) ≤ 3 years
- Phosphorus removal system can maintain an average flow rate of [redacted] gpm
- Develop system design with available room size of [redacted] ft^2
- Analyze contaminant levels within RO reject water

Constraints

- Adherence to EPA regulations
  - Clean Water Act[3]
    - Regulations on industrial non-point source pollution of recreational waterways
    - Mandates updated SWPPP's
- Adherence to EGLE regulations (Electronic Code of Federal Regulation, n.d.)
  - NPDES Wastewater Discharge General Permit
    - Regulates discharge limits for potentially contaminated wastewater into lakes and rivers
  - Michigan Act 451[2], parts 31 and 41
    - Pt. 31: companies should not knowingly discharge contaminated water into any water sink leading to the Great Lakes
    - Pt. 41: regulation of sewer system standards in companies and ensures sewer discharge is not harmful to the environment
- Keep annual operating cost below $[redacted]

Design Alternatives

Design alternatives were scored using a decision matrix based on the following weighted criteria:

1. Phosphorus removal rate – 20%
2. Regulation adherence – 20%
3. Operational cost -15%
4. Flow rate – 14%
5. Return on Investment – 13%
6. Design size – 11%
7. Time to Implement – 7%

Disc Filtration (355)

- utilizes a high-rate tertiary filter
- Spatial capacity, system capacity, and potential operating costs causes concern for feasibility.

Lateral Sand Filtration (375)

- Wastewater pumped through the filter bed.
- Purified as it is pumped upwards through the sand.
- Systems capacity exceed spatial and time implementation requirements.

Electrodialysis (430)

Selected Design

Selected design: Electrodialysis

- Easiest adherence to regulations
- Projected removal rate of up to 95%
- Return on investment < 3 years
- Ease of scalability

What is electrodialysis?

- Placement of anion and cation exchange membranes between two electrodes in a flow chamber
- Ions are separated out from the water input, creating a concentrate and dilute stream. Figure 3 shows an example system. Figure 4 is a process flow of our proposed solution

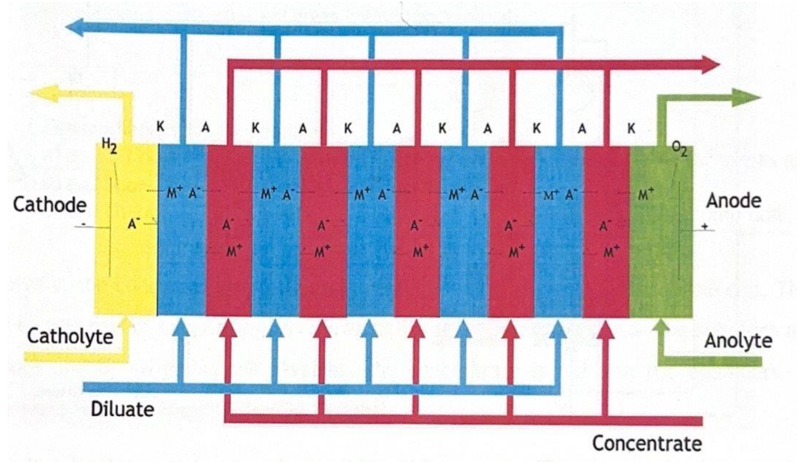

Figure 3. Diagram of electrodialysis process to be used in the manufacturing line.

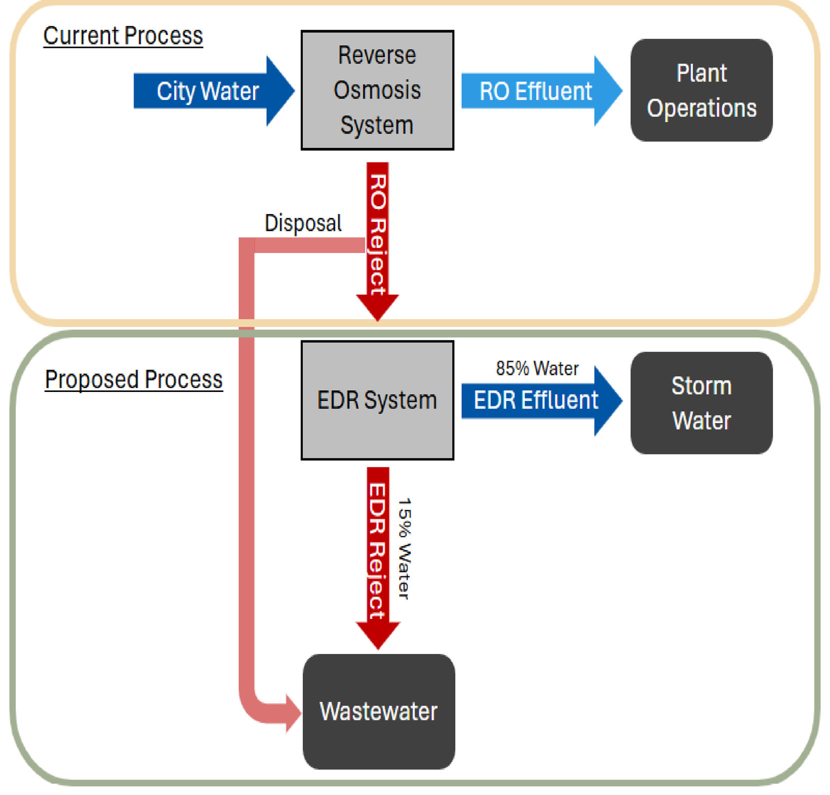

Figure 4: Process flow diagram of the current vs proposed new system involving electrodialysis.

Safety Considerations

- Operating safety warnings
  - Electric shock
  - Production of concentrated/new chemical
  - Danger of automatic start up
  - Production of dangerous media at the electrodes
- Safety Measures
  - Accident prevention regulations
    - OSHA Electrical Standard 1910.301
  - Safety and operating provisions
    - Standard Operating Procedures
    - Proper Training
  - Environmental protection provisions
    - NPDES Wastewater Discharge General Permit
    - Michigan Act 451, parts 31 and 41.

Data Collection

- RO reject water was collected from Perrigo's Plant with the highest phosphorus concentration
- Tested on a small scale electrodialysis system at the Anaerobic Digestion Research and Education Center (ADREC), shown in Figure 5
- Three total runs were performed. Testing for:
  - Phosphorus
  - Sulfate
  - Sulfide - negligible
- Each run was conducted until the conductivity was below 0.1 mS cm

Figure 5. Anaerobic Digestion Research and Education Center (ADREC) electrodialysis system used for testing.

Results

- Conductivity decreased as experiment progressed, shown in in Figure 6
- The average phosphorus removal efficiency from this test was 75.69%, shown in Figure 7
- This experiment confirmed that electrodialysis can successfully remove phosphorus within the approved range, specified by Perrigo

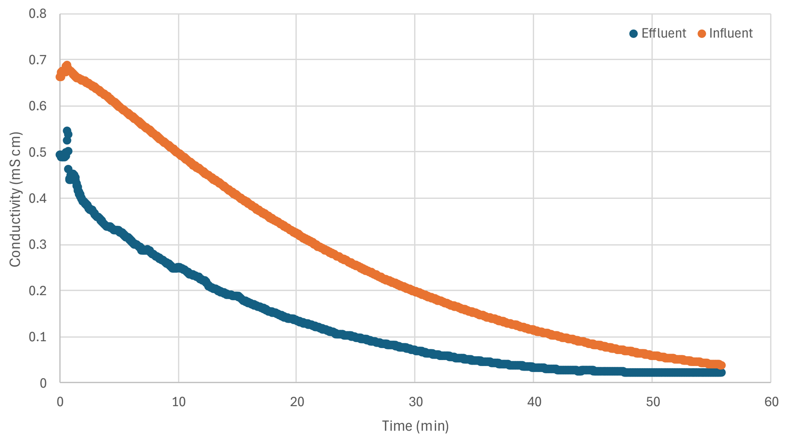

Figure 6: Dilute stream conductivity (mS cm) over time of influent (before membranes) and effluent (after membranes) during experiment 1.

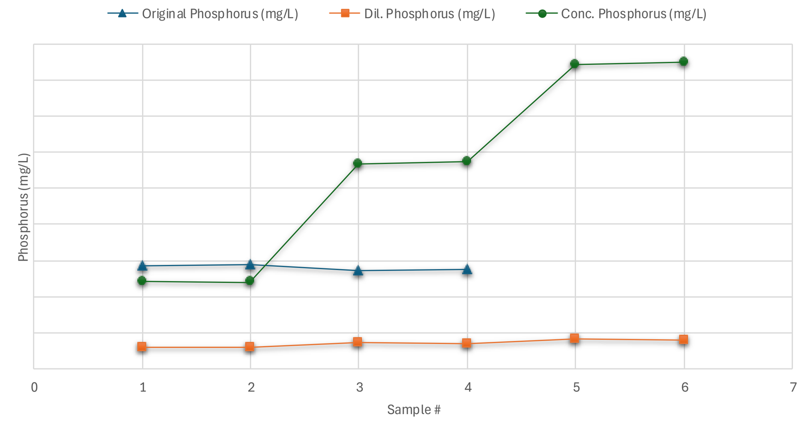

Figure 7: Phosphorus concentration during electrodialysis testing.

Economics

- Table 1 - 2 shows example calculations, for completing the economic analysis. Mock numbers are used
- The cost analysis expects:
  - An ROI between 2.7 - 3.9 years
  - Yearly ROI reject operating cost savings of 52%

Table 1. Example cost calculations initial investment, energy, and sewage costs.

Variable	Calculation
Cost estimation of two systems using six-tenths rule ($)	$C_{Perrigo} = C_{system}\left(\frac{Size_{Perrigo}}{Size_{System}}\right)^{0.6} \cdot 2 = \$61,840$ $Size_{Perrigo}$ = 2,102,400 (gal/year) $Size_{System}$ = 91,250,000 (gal/year) C_{System} = $297,000
Energy costs based on current Allegan rates ($)	$\left(4 \frac{kWh}{1000\,gal} \cdot \frac{2102400\,gal}{1\,year} \cdot \frac{\$0.19}{1kWh}\right) \cdot 2 = \$3,195\ per\ year$
Sewage costs based on current Allegan rates and literature review ($)	$\left(2{,}102{,}400\frac{gal}{year} \cdot 0.15 \cdot \$0.00702\right) \cdot 2 = \$4,427\ per\ year$

Table 2. Example cost calculations maintenance, ROI low, and ROI high cost.

Variable	Calculation
Maintenance cost of system based on literature review ($)	$\$3195.65 \cdot 0.15 = \$479\ per\ year$
ROI based on lower implementation cost and literature review ($)	$ROI_{Low} = \frac{C_{Initial.L}}{C_{Operating} - C_{New.Operating}} = 2.7\ years$ $C_{Initial.L}$ = $ 24,117 $C_{Operating}$ = $16,997 $C_{New.Operating}$ = $8,102
ROI based on higher implementation cost and literature review ($)	$ROI_{High} = \frac{C_{Initial.H}}{C_{Operating} - C_{New.Operating}} = 3.9\ years$ $C_{Initial.H}$ = $34,517 $C_{Operating}$ = $16,997 $C_{New.Operating}$ = $8,102

Summary

- Implementing an electrodialysis system is expected to:
  - Reduce RO reject operating cost by up to 52%
  - ROI between 2.7 - 3.9 years
  - Reduce RO reject Phosphorus water levels between [redacted]mg/L
- Recommendation
  - Perrigo should implement the electrodialysis system
  - Continue contacting manufacturers to gather design specifications

Acknowledgments

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Select References

[1]Environmental Protection Agency. (2023, November 14). *Overview of Total Maximum Daily Loads (TMDLs)*. EPA. https://www.epa.gov/tmdl/overview-total-maximum-daily-loads-tmdls

[2]Michigan Legislature. (1994). Natural Resources and Environmental Protection Act, Act 451 of 1994. https://legislature.mi.gov/Laws/MCL?objectName=MCL-ACT-451-OF-1994

[3]U.S. Environmental Protection Agency. (2013, August 20). *Clean Water Act (CWA) and Federal Facilities*. US EPA. https://www.epa.gov/enforcement/clean-water-act-cwa-and-federal-facilities

[4] Sweeting, J. (1997). Project Cost Estimating: Principles and Practice. IChemE. https://books.google.com/books?hl=en&lr=&id=7K8rjPtiwlwC&oi=fnd&pg=PA6&dq=six+tenth+rule+cost+estimation&ots=eLIWVKR9GS&sig=bnTeCgjkvlqWbkFdulX1UeF9u2k#v=onepage&q=six&f=false