CAPSTONE/SENIOR DESIGN EXPERIENCE 2019

Water Purification Process

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Introduction

Access to clean water is an increasing problem in developing countries and developed countries as pollution increases.

Major Contaminants of focus:

- Bacteria
- Lead
- Fluorine
- Chloride

The goal of the filter is to provide a portable filter with changeable components at a small enough size to fit under the sink of an average kitchen household. The model focused on maximizing the purity of the water by testing the components ability to remove extreme concentrations contaminants from water.

Impact, Sustainability, and Factors

Impact

- Compact water treatment product
- Able to remove contaminants of varying size
- Minimal maintenance costs

Sustainability

- Heat pump reduces biofouling of membranes for subsequent filters
- The system is a zero waste model
- Requires minimal energy input

Factors Affecting Decisions

- Environmental: low power use
- Global: availability to developing countries
- Economic: affordable solution worth the price

Alternatives

Heat Pump

- Goal: purify contaminated water stream of large sediment, output water at a constant temperature and flow rate
- Evaluated different layouts of evaporation and condensing
- Chose layout where evaporator and condenser are combined

UV Irradiation

- Goal: kill at least 90% of organisms in the water
- Evaluated different bulb types: LED and mercury vapor
- Chose LED bulbs due to their longevity, safety, and effectiveness

Reverse Osmosis

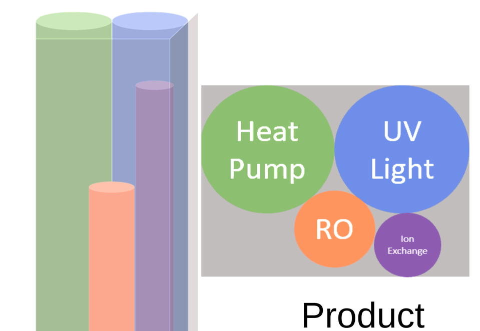
- Goal: remove smaller contaminants like chlorine and lead
- Evaluated other types of filters
- Chose RO due to its versatility when it comes to filtering different sized particles

Ion Exchange

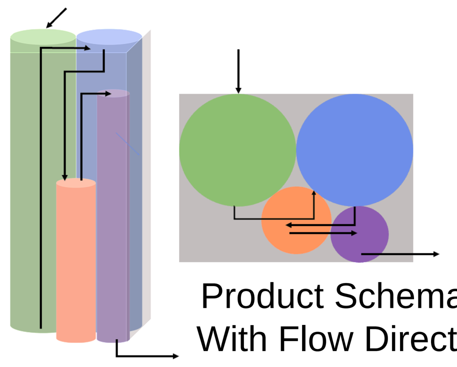
- Goal: remove salts and small contaminants like fluoride
- Evaluated different resins and resin cartridges
- Chose smaller resin cartridge that is optimal for our flow rate

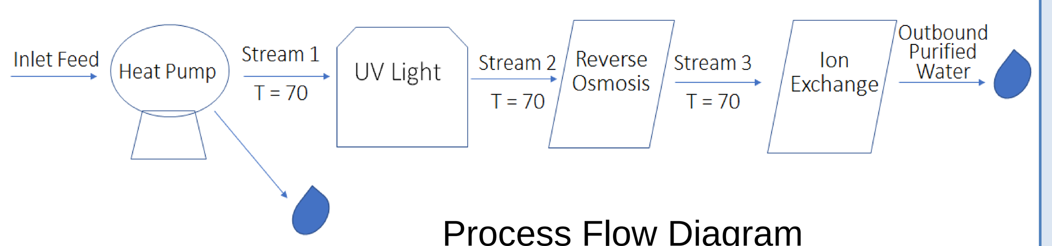
Process Description

The water filtration system removes contaminants in decreasing order of size through a four step process consisting of a heat pump system, a UV germicidal irradiation system, reverse osmosis system, and an ion exchange system. The entire process is contained within a 24”x10”x7.46” box able to fit inside a standard kitchen cabinet.



Product Schematic


Product Schematic With Flow Direction



Process Flow Diagram

Model Description

Our group was unable to do experiments because we could not get all the equipment we needed. Instead, we designed a high level MATLAB model.

Heat Pump

The heat pump code uses established literature values that the heat pump kills 99% of contaminants.

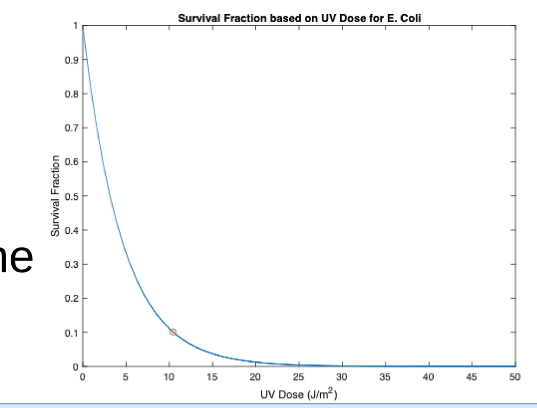
UV Irradiation

We found the dose of radiation for the UV bulb.

$$(Watts\ (J/s) * m^3)/(vol\ flow\ rate\ (m^3/s)) = J$$

Then we found the survival of the bacteria based on the dose.

$$S = (1-f)e^{-k_1 D} + fe^{-k_2 D}$$

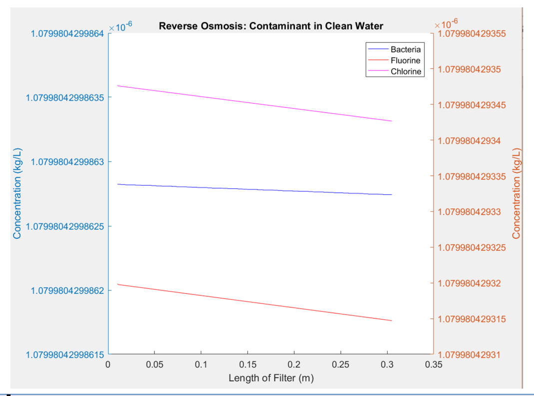


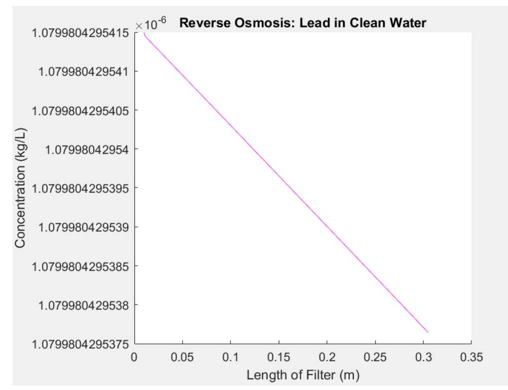
Reverse Osmosis

For the reverse osmosis code, we found the flux of each contaminant and used that perform a mass balance.

$$N_w = A_w(\Delta P - \Delta\pi) \qquad M_{in} = C * q$$

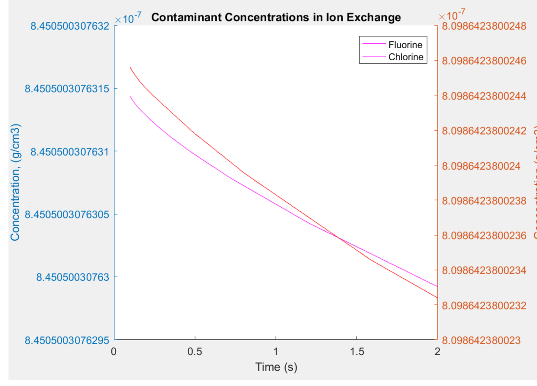
$$M_{out} = N_s * CA * \rho \qquad M_{new} = M_{in} - M_{out}$$

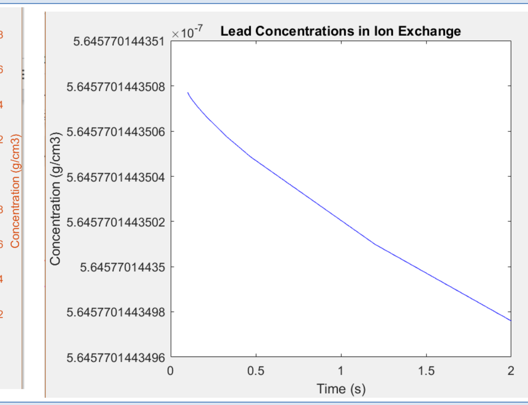




Ion Exchange

For ion exchange, we used established literature equations to determine how particles bound to the resin.





Economic Results

Cost analysis of each unit process was simulated by code calculated to be an annual cost of $11,412.18. The heat pump optimized the cost as a function of the piping diameter to increase the internal pressure and minimize energy costs. The initial cost of the stainless steel heat pump is steep. The UV irradiation optimized cost by minimizing energy of the light to kill the bacteria and minimizing equipment and maintenance costs. Both the reverse osmosis filter and ion exchange minimized equipment and maintenance costs. To make the system more cost effective, alternative material and sizing for the heat pump equipment could be investigated. Stainless steel was originally chosen due to its resistance to corrosion via contact with water. Overall, the net rate of return is profitable in the estimated service life of 10 years.

Optimization

Each unit operation was optimized based on the lowest operating cost and the effectiveness of impurities being removed.

Heat Pump

- Determined the optimal diameter size to output water at 3 gal/min to the sequential filters without dramatically increasing pressure drop. This was found to be 0.118 inches.

UV Irradiation

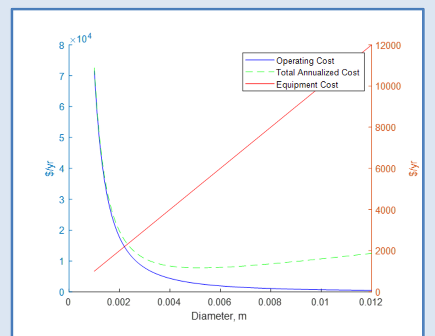
- Determined the optimal height of the UV tank, while keeping flow rate constant.
- Was found to be 8.5 inches.

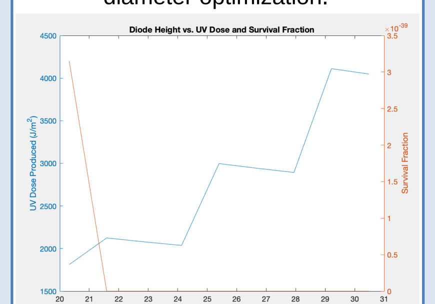
Reverse Osmosis

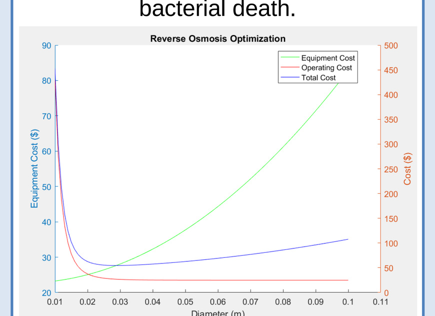
- Determined the optimal diameter of the filter while keeping length, change in pressure, and the friction factor constant
- Was found to be 1.14 inches.

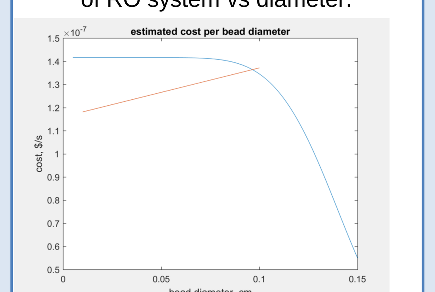
Ion Exchange

- Determined ideal resin bead size, which was found to be 0.1 cm.


Heat pump cost analysis based on diameter optimization.


UV dosage related to diode height and bacterial death.


Operating, equipment, and total cost of RO system vs diameter.


Comparison of commercial resin vs estimated cost of operation.

Conclusion

The filtration system is a zero waste model outputting highly purified water (pharmaceutical grade). The initial outflowing stream from the heat pump maintains the purity of that resembling tap water. For areas in which are not exposed to high levels of specific toxins, the filtration system can be reduced by omitting select components depending on need.

Optimum output was found to be 3 gal/min for economic cost of $11,412.18 per year and water purity of 99.99% . The service life of the filters was estimated to be 10 years. The output of contaminants in the water after passing through all of the filters was approximately zero on orders of $10^{-7}\ \frac{g}{cm^3}$ for ions and $10^{-39}\ \frac{g}{cm^3}$ for bacteria.

Technical Advisor:
Dr. Martin Okos

Instructors:
Dr. Martin Okos

Acknowledgements:
Alyssa Christoffer