Point-of-Use Water Treatment: MadiDrop+ and Copper Mesh

A Technical Report submitted to the Department of Civil and Environmental Engineering

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Jeffrey Nutt

Spring, 2022

Technical Project Team Members
Kevin Barnes

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

James A. Smith, Department Civil and Environmental Engineering

Point-of-Use Water Treatment: MadiDrop+ and Copper Mesh

Research Problem and Problem Statement

Globally, over 2 billion people lack access to safely managed drinking water at home. Contaminated household water causes public health concerns through direct consumption. These stagnant-water breeding grounds spread pathogens like *E. coli*, *V. cholera*, *Salmonella*, *Shigella*, and *Cryptosporidium parvum* that lead to increased disease transmission. In areas where centralized water treatment is not available, households must rely on local, possibly contaminated water storage. Point-of-use (POU) treatment methods can be used to disinfect stored water to avoid waterborne illnesses. Current technologies like the MadiDrop+ achieve POU water treatment through the release of silver ions. Recent research has focused on the efficacy of other metals to be used in tandem with silver to improve disinfection rates. Our work focused on designing, building, and testing a device that combined the MadiDrop+ with a copper mesh to better understand the release rates of the copper mesh as a supplement to preexisting POU water treatment technologies.

Scope and Goal of Project

The goal of creating a device that combines the MadiDrop+ and copper mesh is based on in vitro decontamination efficacy against waterborne pathogens. This occurs when silver and copper ions are attracted to negatively charged pathogen cells. Silver then penetrates the cell wall and inhibits growth by bonding to parts of the cell, eventually killing it. Conversely, copper ions adhere to the cell wall and disturb permeability, disrupting nutrient intake and killing the cell. Together, these ions are capable of continuous pathogen disinfection and should be combined into a singular POU treatment device. To best achieve this synergistic disinfectant effect, the

MadiDrop+ will be used in tandem with a ion-releasing copper mesh. A hypothetical device should be designed to be practically applied in developing communities where POU treatment is needed for access to clean water. This successful device would be inexpensive, small, simple, and have cross-cultural compatibility without compromising disinfectant properties.

Schedule

The original schedule can be found in Appendix A and the final schedule is found in Appendix B. Between these two schedules there was significant delay with each step. Our original schedule sought to have us begin double-layer mesh testing on November 14, 2022, which we did not begin in the final schedule until February 17, 2023. These substantial delays were due to struggles finalizing the experimentation methods and familiarization with CAD modeling for mesh case 3D printing; however, we remained on track to complete the project in a timely manner. We did so by working over January to finish case models and print before February began. While conducting the experiment, we were able to successfully adhere to the planned schedule which can be seen in Appendix C.

The second most significant schedule change was conducting sample analysis following collection. Unfortunately, we were unable to process our samples until April 28, 2023, because the Atomic Absorption (AA) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) machines were broken for extended periods of time. This caused massive delays to the overall schedule but we were able to complete the initial analysis prior to concluding the study because the ICP-MS machine was repaired.

Finally, we decided to modify a minor portion of the project. Initially, we planned to "redesign and retest" the double-layer models following our first round of experimentation and analysis. However, because of the delays in receiving data from the ICP-MS machine, this had to be removed due to project time constraints. Overall, we do not believe this change is detrimental to the project, as we were able to test the efficacy of a basic double-layer mesh design and can confidently draw conclusions from the information collected.

Methods and Design Standards

The design goals behind this project were twofold: CAD modeling and subsequent 3D printing, and the experimental process for evaluating the double-layer copper mesh.

<u>CAD Modeling and 3D Printing</u>

The demands of the project required the modeling of several devices capable of holding the MadiDrop+ and the 10 grams ($63.75in^2$) of fine copper mesh. Hypothetically, these devices could be mass-produced and used globally to treat household water containers. To do so, SolidWorks was used to create CAD models that effectively house the necessary components, which could then be 3D printed for prototyping and experimentation in the second half of this design process. Designs must meet the following standards and parameters:

- Capable of mass production at a low cost
- Foldable and able to fit into common household water containers (10L jerry can)
- Simple implementation and realistic behavioral design to reduce user confusion
- Limited size and weight to reduce shipping costs

Initially, models were created using a simplistic single-layer layout, which would be inefficient and too large for commercial implementation. Furthermore, this large model would complicate the technology by introducing additional failure points.

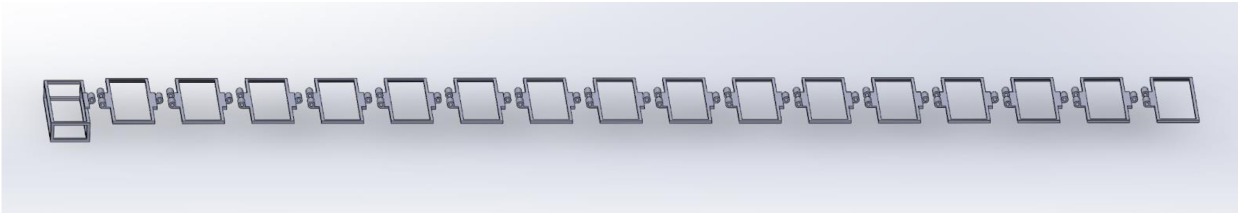


Image 1. Single-Layer Mesh and MadiDrop+ Container

Instead, we created a folding double-layer model (Appendix D) that reduced overall product size, complexity, and cost by increasing the total area within each mesh cell.

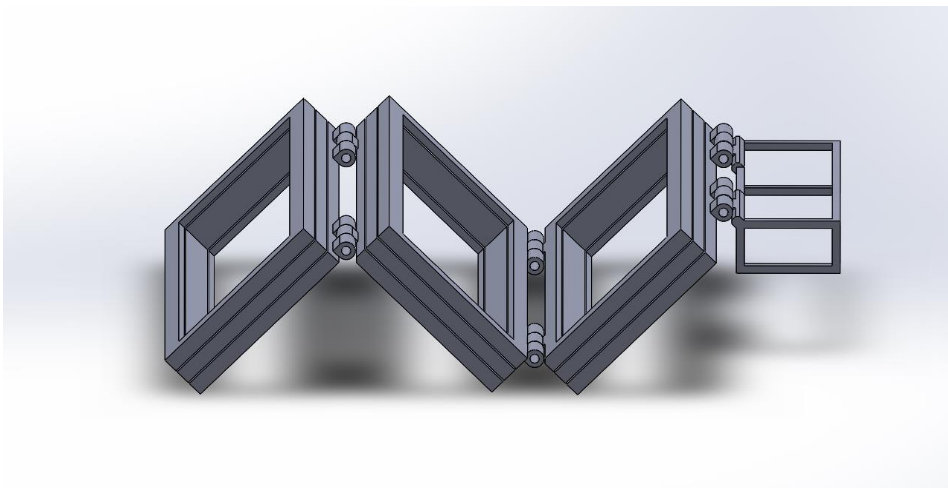


Image 2. Double-Layer Mesh and MadiDrop+ Container

This design, if viable, would be capable of silver and copper ion delivery to contaminated water. To determine the design's viability in POU water treatment, we must evaluate the copper ion release rate from the double-layer mesh with an experimental process. As per PhD. Candidate Jamie Harris' research, the copper ion concentration benchmark for effective disinfection is 200 ppb. The double-layer mesh must meet this design standard to be considered capable of POU water treatment.

Experimental Process

1. Print six frames to hold the double-layer mesh and obtain three new MadiDrops for the experiment.
2. Prepare all six meshes by inserting a total of 63.75 in^2 of copper mesh into the frame. Fill six 10L buckets with deionized water.

Image 3. Step 2 Example

3. Insert one frame and one unwrapped MadiDrop (MD) into three of the six buckets. Place one frame into the remaining three buckets of deionized water. (Three Mesh+MD and three Mesh)

Image 4. Step 3 Example

4. Let sit for 24 hours.
5. Return to the lab, stir buckets and remove frames and MadiDrop+ for cleaning (rinse off for three minutes).

6. Label six centrifuge tubes with the following naming convention:

“*Day# Mesh Sample(#1-3)*” or “*Day# Mesh+MD(#1-3)*”

7. Extract 20mL sample from each bucket into separate 50mL centrifuge tubes using pipettes.

a. If using 15mL centrifuge tubes only take 14.57mL sample from each bucket

8. Acidify samples for storage by adding 575uL to 20mL samples (50mL centrifuge tubes) or 429uL to 14.57mL samples (15mL centrifuge tubes).

9. Wrap samples in aluminum foil and place in the fridge. Exposure to sunlight will impact samples.

10. Rinse out buckets and refill each with 10L of deionized water. Insert one frame and one unwrapped MadiDrop into three of the six buckets. Place one frame into the remaining three buckets of deionized water. (three Mesh+MD and three Mesh)

11. Repeat step 4-10 until six samples are collected for each day over a full week.

The only process changed was switching from 50mL centrifuge tubes to 15mL centrifuge tubes for the samples because the lab ran out of the larger tubes. This forced us to change the acidification ratios but had no impact on the samples and analysis.

Results

The results below were synthesized following the outlined experimental process. 42 samples were analyzed on the ICP-MS machine to measure Copper-63 ion concentration in parts per billion (ug/L). Due to the use of the ICP-MS machine, Silver-107 concentration was too low to be measured accurately, therefore, further analysis between copper and silver ion interaction is impossible.

	Cu 63 Concentration (ppb)								
Day #	Mesh1	Mesh2	Mesh 3	MD+Mesh1	MD+Mesh2	MD+Mesh3	Average (ppb)	Expected Daily Value* (ppb)	Variance from Expected Values (ppb)
1	66.9	218.3	31.5	150.0	165.3	138.1	128.4	206.93	78.6
2	120.9	112.9	129.7	119.6	131.5	190.7	134.2	263.4	129.2
3	138.0	142.7	99.5	140.9	113.2	112.4	124.5	278.2	153.7
4	160.0	76.9	117.3	89.6	41.2	111.8	99.5	330.8	231.3
5	143.7	79.3	54.8	183.8	198.9	140.9	133.6	333.3	199.7
6	188.6	850.0	190.9	198.4	206.8	181.3	302.7	279.4	-23.3
7	268.6	242.1	189.0	161.3	152.4	260.4	212.3	249.6	37.3

*from PHD Candidate Jamie Harris' research

Figure 1. ICP-MS Sample Analysis Results for Copper Concentration

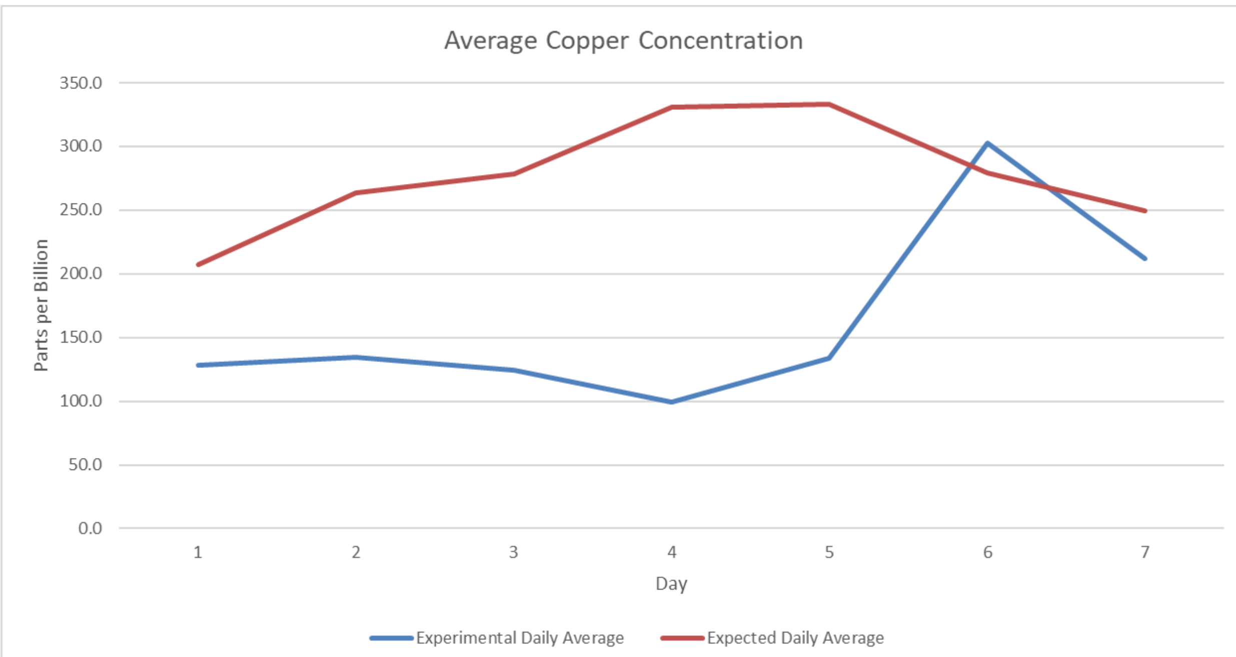


Figure 2. Experimental versus Expected Average Copper Concentrations over Time

Analysis

From the data above, there is extreme variance between the experimental copper ion concentration and the expected daily value. On average, experimental copper ion concentration was significantly lower than the expected concentration. Within the first 5 days, this experimental concentration was as low as 30% of the expected concentration. Furthermore, there is no consistent daily increase in experimental concentration over these first 5 days, unlike the expected concentration values. This lower copper concentration would render the design ineffective for disinfection against the pathogens of concern over this time period as the concentration falls below the 200 ppb benchmark. We attributed the decreased copper ion concentration to the double-layer design that was implemented, as this was the only difference in this data set versus data obtained from previous experiments.

From observation during testing, it is believed that the lack of flow across the double-layer mesh barrier provided little opportunity for the inside portions to distribute the copper ions throughout the 10L sample. This effectively cut the surface area available for ion dispersion in half, which roughly correlated with the decreased results found in the experimental copper concentration samples seen in Figures 1 and 2. With the experiment design consisting of samples that remained stagnant for the 24-hour time period, it is uncertain how much the addition of a stirring component would have affected the copper ion release rate, but it is a worthwhile consideration for future work.

On days 6 and 7, the experimental concentration exceeded that of the expected concentration. It is unclear what caused this and further analysis is required. We believe this increase is potentially due to our optimization of the daily experimental process or damage to the double-layer mesh causing greater ion release, but no conclusions can be drawn.

Limitations and Future Work

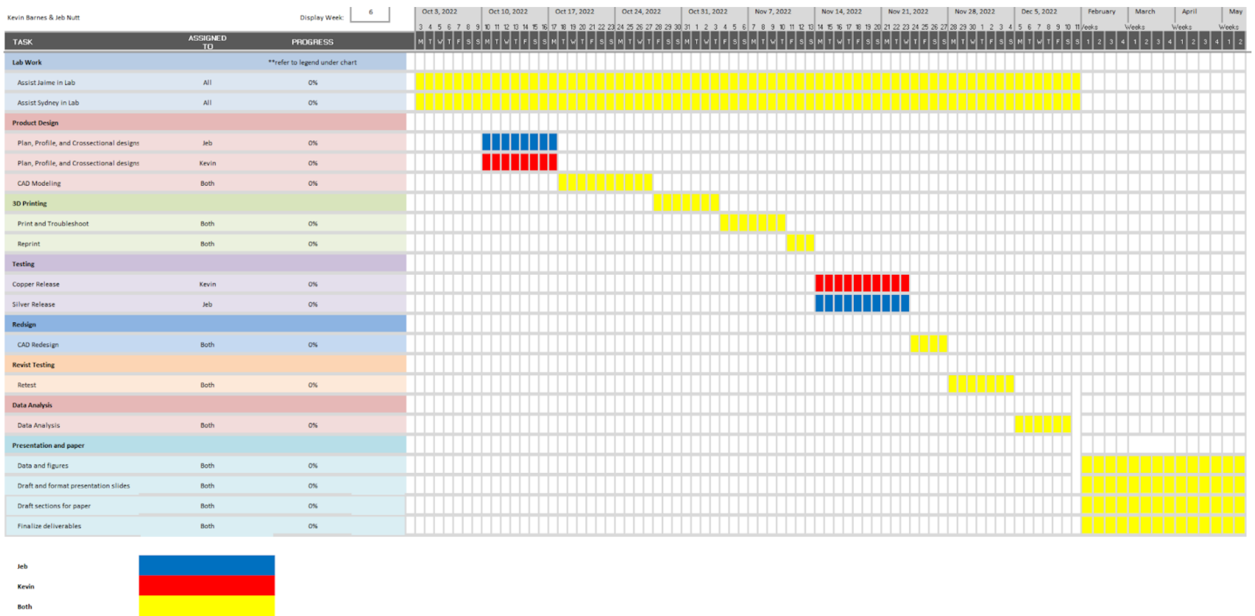
There were considerable limitations in our ability to receive and analyze the experimental results due to failures in the AA and ICP-MS machines that were needed to measure the copper ion concentration in the collected samples. This subsequently made us unable to adjust the experiment for another round of testing and address the initial results. The ICP-MS was eventually used to obtain the full data set. With the ICP-MS less accurate at low concentrations, the data was limited to solely the copper concentrations, as the silver concentrations were too low to be measured.

In future experiments, there are two avenues worth pursuing to counteract the insufficient copper ion results from the double-layer mesh. The first option is to explore other copper mesh designs that avoid a double-layer frame. While this would likely alleviate the issue of low ion concentration levels, it brings about other unique problems that would need to be addressed, including a lack of efficiency in packaging and usage, greater design costs, and more points of failure. The second option involves incorporating greater flow through the double-layer design to encourage ion release. This could be accomplished behaviorally, by requiring intermittent stirring of the samples. While manual stirring would complicate real-world application, water can also be naturally circulated when it is poured through a bucket spout whenever it is used. A realistic implementation of this device would see regular water disturbance through household use which could induce this flow and should be reflected in future experiments. This could be simulated in the lab through regular pouring during the 24-hour period, potentially improving ion release rates. Alternatively, the copper mesh could have an increased pore size to better allow flow through the medium; however, this would require a greater mesh area to meet the 10 gram requirement.

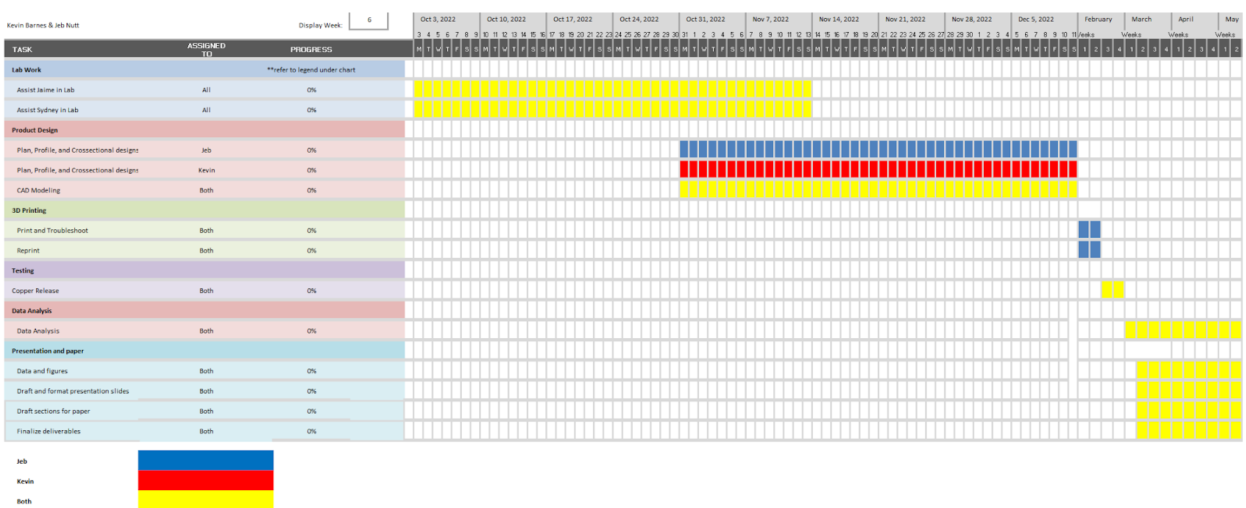
Conclusion

The results of the experiment proved that the double-layer design, in its current state, is ineffective at providing sufficient copper ion release to neutralize pathogens. Overall, while many future considerations can be drawn from this project regarding the feasibility of a double-layer mesh and potential designs for the MadiDrop+ and copper product, more investigation is necessary to determine a final design. Further iterations may provide greater insight into the efficacy of copper mesh, its compatibility with the MadiDrop+, and its impact on POU water treatment capabilities on a global scale.

Appendix A – Initial Schedule



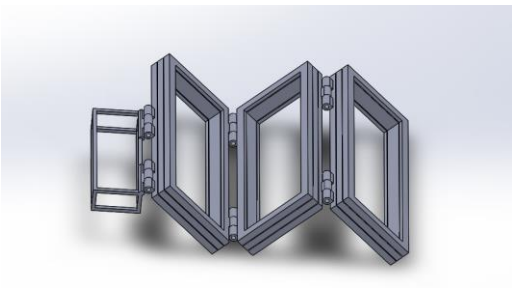
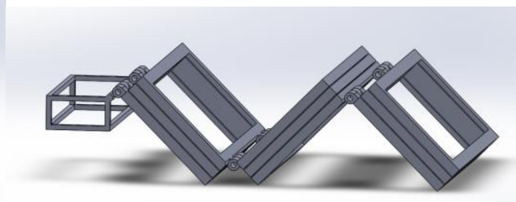
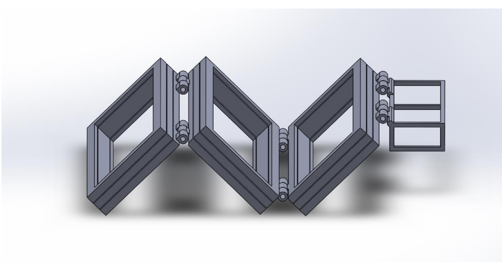
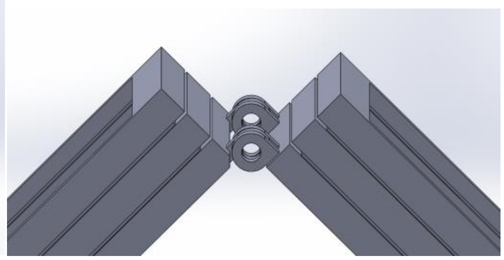
Appendix B - Final Schedule



Appendix C – Experiment Daily Schedule

Date	2/13/23	2/14/23	2/15/23	2/16/23	2/17/23	2/18/23	2/19/23	2/20/23	2/21/23	2/22/23	2/23/23	2/24/23
Day of Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Task	Frame Prep	[redacted]			Initial Setup	Sample Day 1	Sample Day 2	Sample Day 3	Sample Day 4	Sample Day 5	Sample Day 6	Sample Day Final
Who?	Kevin/Jeb				Kevin	Kevin	Jeb	Jeb	Kevin	Kevin	Jeb	Jeb
Time:	1000				1700	1700	1700	1700	1700	1700	1700	1700
Complete?	Yes	N/A	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Appendix D – Initial Double-Layer Mesh and MadiDrop+ Device Models

Appendix E - Double-Layer Mesh Experimental Container Model