

Madidrop for Passive Silver Dosing

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Madidrop is a rectangular ceramic tablet originally designed to dose a 10-20-liter volume of water with silver to act as a biocide for remote communities with unreliable water sources. Silver as a biocide is a proposed method to control bacteria on the International Space Station or future Artemis missions. This would replace iodine currently used due to issues with a dual biocide system in place between Russian and US segments and the extra cost of iodine removal required before consumption. NASA has been reviewing this Madidrop technology and its potential application with a water reclamation system on orbit to dose silver after purifying the water. While there are a couple alternative methods to dosing silver on station, this method is like the existing passive dosing method used currently to dose iodine. Tests conducted characterize the manufacturer's original intent to leave the tablet in a tank for a specified amount of time before removing and testing alternative passive flow-through methods. Passive flow testing involved two options: keeping the tablet intact or crushing the tablet into smaller particle sizes to increase the surface area while varying particle sizes. The results of these tests revealed a large amount of silver output at first that quickly reduced to a constant lower output within a reasonable dosing concentration range. The initial high concentration peaks after a couple days of quiescence and could be useful for shocking the initial tank water contents. Madidrop used as a passive particle doser could act as a stand-in replacement for iodine in future spaceflight water reclamation systems.

Nomenclature

<i>Ag</i>	=	Silver
<i>AgF</i>	=	Silver Fluoride
<i>COTS</i>	=	Commercial Off the Shelf
<i>DI</i>	=	Deionized (water)
<i>EC3</i>	=	Life Support Systems Branch
<i>ICP-MS</i>	=	Inductively Coupled Plasma Mass Spectrometry
<i>ISE</i>	=	Ion Selective Electrode
<i>ISS</i>	=	International Space Station
<i>JSC</i>	=	Johnson Space Center
<i>MCV</i>	=	Microbial Check Valve
<i>NASA</i>	=	National Aeronautics and Space Administration
<i>ppb</i>	=	Parts per billion (µg/L)
<i>ppm</i>	=	Parts per million (mg/L)
<i>SWEG</i>	=	Spacecraft Water Exposure Guidelines
<i>TOC</i>	=	Total Organic Carbon
<i>TRL</i>	=	Technology Readiness Level
<i>WPA</i>	=	Water Processing Assembly

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I. Introduction

A. Silver as a Biocide

A biocide is required to prevent bacterial growth in water. Currently, the United States segment of the International Space Station (ISS) is using iodine as a biocide. However, the Russian segment uses silver (Ag). Both methods have been proven to control bacteria; however, a dual biocide system creates complications, especially if sharing water. If a silver biocide treated water is mixed with an iodine biocide treated water, a silver iodide precipitate will form, both negating the biocide effect and adding particulates in the water that can cause system issues and clog filters. This requires extra equipment to remove one biocide and dose the other if transfers are needed.¹ Additionally, there are issues using iodine. At the effective concentrations needed to kill bacteria, iodine is unsafe to drink and causes problems with the thyroid gland. Therefore, extra equipment is required to remove iodine before consumption.² Because of these reasons, silver is being considered as the biocide of choice for future missions because it is effective at low concentrations, is compatible with Russian segment water, and can be consumed directly by the crew.

There are three principal methods of adding silver in water. The first is adding chemical solutions, using silver salts such as silver fluoride (AgF) or silver nitrate (AgNO₃).³ The second is electrolytic, which utilizes silver electrodes to dose water with silver ions.⁴ The last is a passive dosing technology such as Silver Foam and Madidrop, the focus of this paper.⁵ Passive dosing allows water to be flowed or left in a medium and doses silver with no power required.

The concentration of silver is a balance between the maximum allowed for health and the minimum required to kill bacteria. The National Aeronautics and Space Administration (NASA) has Spacecraft Water Exposure Guidelines (SWEGS) that state 400ppb of silver water is acceptable over at least 1,000 days to avoid Agyria.⁶ To kill bacteria on station, 200ppb is needed to ensure all bacteria will be killed. Therefore, the target range is between 200-400ppb of silver concentration in the system.

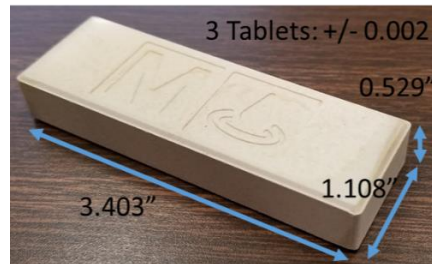
B. Madidrop Tablet

A potential new material of passive silver dosing has been developed by a company called Silivhere and is called Madidrop.⁷ According to the company, each tablet is low cost and reportedly lasts for 12 months dosing up to 20 liters per day for a potential total of over 7,000 liters over a year. The advertised use case is to purify tanks of water, particularly in remote communities with unreliable drinking sources. The Madidrop is a tablet made of ceramic and silver. The tablet can passively dose silver on contact with water. According to the manufacturer instructions, the minimum time to dose and kill bacteria is 8 hours and the maximum time it should be left in a tank is 72 hours (3 days). The maximum and minimum volume are 20L and 10L, respectively.⁷

Figure 1 below shows a picture of this Madidrop with dimensions. The measured weight and volume of the tablet is 54.5 +/- 1g and 1.66in³ (32.7cm³), giving an approximate density of 1.67g/cm³.



A) Madidrop Tablet in Package



B) Madidrop Tablet Unpackaged with Dimensions

Figure 1. Madidrop tablet.

The ability of the silver in Madidrop tablet to control bacteria has been studied using water with E. Coli and coliform bacteria. The total coliform bacteria influent ranged between 1-2.5 log. It has been shown that the effluent tested remained below 1 colony forming unit/100mL for up to four weeks.⁸ The same source also tested using Kohler Clarity filters, which reportedly released 20-60ppb of silver using Madidrop halves. The Kohler Clarity filter tests also showed significant removal of bacteria with none being detected after 8 hours.⁸

C. Concept of Operations

Currently on the ISS, iodine is passively added after processing before entering the product water tank.⁵ While the manufactured use case of Madidrop is to place it in a tank, this research looks at the possibility of flowing water over

the tablet to act as a passive flow-based dosing method. The tablet could provide a dose of silver right after water production and before entering the product water tank. In this case the Madidrop could be configured such that it would act as a stand in replacement for the iodine doser to instead dose silver in the same method as the iodine doser. Alternatively, these tablets could also be used as a contingency biocide system to add the tablet directly to a volume of water and kill bacteria.

D. Testing and Measurement

To test the Madidrop, a set of tests were developed as shown in Table 1. The first control test was in a tank to measure silver output over time to characterize the tablet based on usage instructions from the manufacturer. This test aims to verify the manufacturer claims on silver output, get real and extended data on its output over time, and lastly characterize contaminants if any. A second test was developed as an extension of the first test to measure the silver output of many Madidrops at one time each in their own beaker. A variant of the beaker test left the Madidrop in the beaker for an extended period measuring the maximum concentration of silver the Madidrop will output. After characterizing the tablet in a static amount of water, a set of tests looked at flowing water around the Madidrop to assess the possibility of using it in a flow-through configuration instead of the nominal tank configuration that would be difficult to replicate in zero-g. These flow-through tests varied the number of tablets and even looked at making the tablets into a type of crushed particle media to maximize silver output.

Table 1. Tests Conducted

Silver output over time (Static)
Max concentration level (Static)
Impurities in the tablet (Static)
Tablet flow-through configuration
Particle flow-through configuration

To measure the concentration of silver, there are a couple different technologies shown in Table 2. The most reliable method used to measure silver is Inductively Coupled Plasma Mass Spectrometry (ICP-MS). It also can return concentrations of other metals found in the solution to determine if there is any undesirable leaching of other materials. However, this machine is large, requires significant resources to run, and takes a while to return results, so it was used sparingly to detect impurities and cross reference with the other methods used. A secondary method, ion selective electrode (ISE), is a technology being developed and tested to measure silver ions. It is less accurate than the ICP-MS, but it was able to return real-time results and can be hooked up in flow-through configurations to get real-time data rather than single-point data. This measurement method was used extensively to gather data in this report. To measure other trace contaminants Total Organic Compound (TOC) measurements and Ion Chromatography were used.

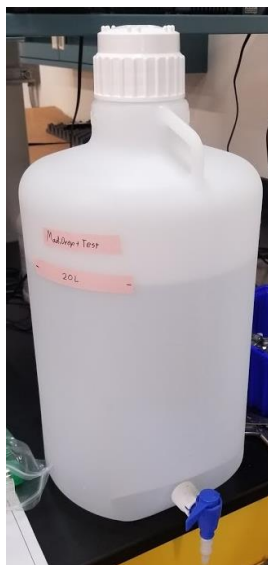
Table 2. Measurement Options

ICP-MS-Metals
ICP-MS-Silicon
Total organic carbon
Ion chromatography
Ion selective electrode

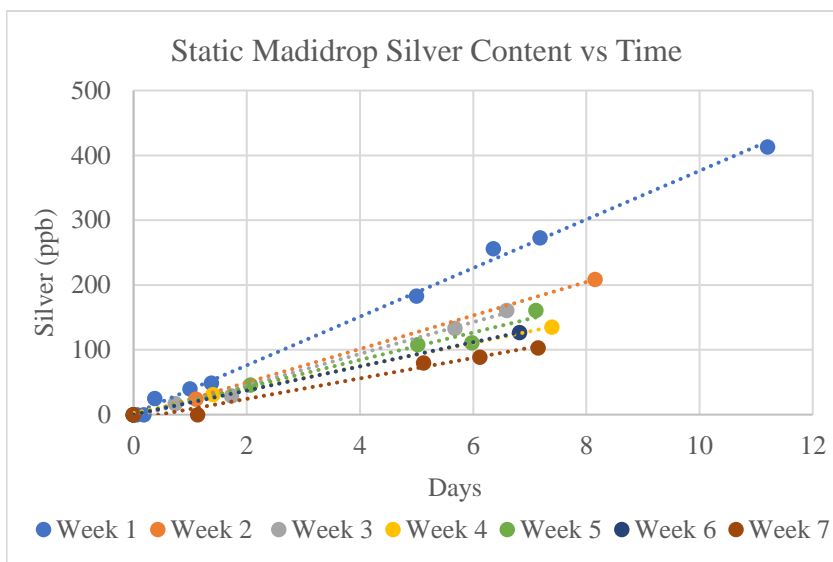
II. Static Madidrop Tests

A. Tank Test

A test with the Madidrop in a 20L tank was set to run for approximately one-week intervals while semi-regularly taking samples. At the end of the week, the water would be replaced, and the test would restart with the same Madidrop. The test shown in Figure 2 below measured silver using the ICP-MS for silver and other impurities in the water and ran for 7 weeks. The graph shows the output of silver each week tested at intervals plotted. Some weeks had slightly more or less output, but the overall trend is decreasing output as weeks increase. This is assumed to be representative of the silver in the tablet being used up. On week 3, the tank was stirred before measurement to see if the silver content was evenly distributed. This did not have any noticeable effect on the results, so the silver solution is evenly distributed after dosing.



A) Madidrop Test Tank



B) Madidrop Tank Test Results

Figure 2. Madidrop tank test and results.

While testing silver, samples were also tested for leaching of other materials into the water from the Madidrop. For ion chromatography, everything was less than detection limit (0.5 ppm). This test was discontinued after the first two weeks. For silicon, there were some initial readings at a max of 119 ppb, although this was beyond the standard 3-day timeframe for the tablet in the tank that the manufacturer recommends. The rest of the samples were non-detect (less than 100 ppb). The silicon is assumed to be from the ceramic of the tablet. For TOC, there was no significant increase or decrease from the starting deionized (DI) water reading. There was typically less than 1 ppm TOC, with DI water having approximately 700 ppb to start. For the ICP-MS metals other than silver, sodium (Na) and potassium (K) gave off up to approximately 150 ppb the first week but did not give off much after that. They were also nondetectable after a couple weeks. The Na and K are assumed to come from the plastic tank since a separate test revealed Na and K in the water tank reading after a day with DI water only. All other metals were very low, less than 30 ppb max or non-detectable.

Filtering was performed to see if any particles were present. Of the eight non-zero samples tested, the unfiltered sample on average read 8% higher than the filtered samples.

A separate comparison was made between measuring ICP-MS and ISE measurement methods. Of the four samples compared, the ISE probe read on average 28% +/- 4% higher than the ICP-MS. The exact cause of the difference is unknown, but it was consistent and repeatable for these four samples.

B. Beaker Test

To test many Madidrop tablets at once, the tank test was scaled down to beakers available in the lab. This test is used as a comparison of silver output for many tablets. For this test, Madidrop tablets were placed in beakers with 800mL DI water as shown in Figure 3. Each day, water measurements were taken, most being daily although sometimes measurements were taken after a couple days due to weekend breaks. The water was then replaced with fresh DI water.



Figure 3. Beaker test setup.

The first round only tested three tablets but indicated a large variability. The test was expanded three additional times for a total of four different test iterations to gather more data due to the large variability. All these tests are very similar or the same, with the primary goal being to increase the number tested. All the tests were combined in one graph in Figure 4 with a legend in Table 3 showing some minor differences in setup. Sample numbers denote different days the beakers were measured and reset, typically one day but up to 4 days for weekends and converted to ppb/day for comparison. The only notable difference between the used or set overnight before starting (test 1 & 3) and new (test 2 & 4) Madidrop was the first-day output. The first-day output releases on average 80% more than the average for each individual tablet.

Table 3. Beaker Test Graph Legend

Test 1	New Madidrops rinsed and left in water overnight before starting	Sample 1 – 9: Each time the tablet was sampled. Each sample was between 1-4 days apart.
Test 2	New Madidrops (only rinsed)	
Test 3	Previously Used Madidrops added to test	
Test 4	New Madidrops (only rinsed)	

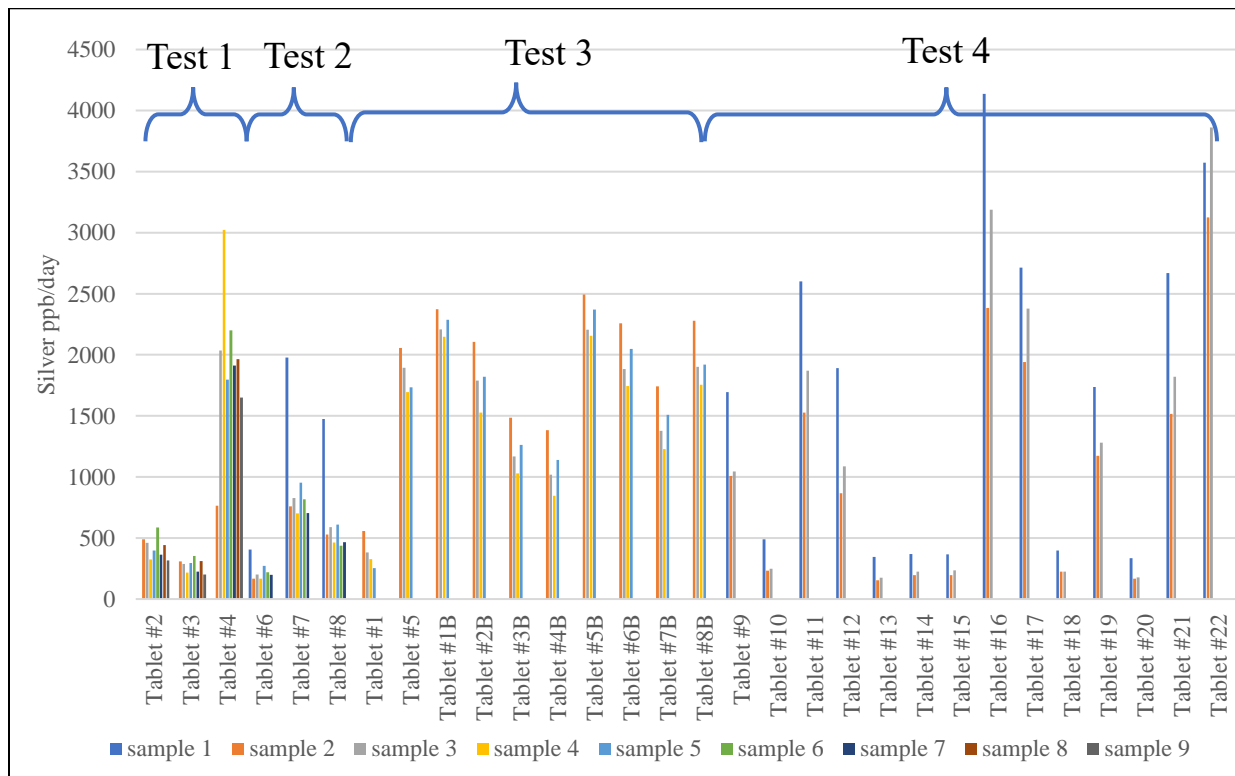


Figure 4. Results from beaker test.

The plot in Figure 4 demonstrates a large variability in silver output from each tablet, up to a 10x magnitude difference. While there are outputs for all ranges, if viewed on a histogram there appears there are two groupings. This could denote two different batches, with peaks around 400 ppb/day and another around 2000 ppb/day, though more testing may be needed to confirm. If adopting this technology, this may need to be addressed either by improving quality control or testing and selecting acceptable ones upon receipt. Furthermore, if many Madidrop tablets are included in a flow-through system, the output could average out to get a more desirable and predictable outcome. This data was then averaged to get statistics about the population. Because of the first-day output increase, the series 2 & 4 first day of output was not included in this average. For 800 mL beakers, an average of 1226 ppb rise was seen over one day with a standard deviation of 912 ppb. Converting directly for a 20L tank reveals approximately a 49 ppb/day rise in concentration on average, However, the higher concentration in a smaller volume may affect the output leading to a slightly decreased result for the smaller beaker volume as described in the next section.

C. Concentration Versus Output

Some applications in space may require long quiescent periods and, depending on the exact implementation of this tablet, it may be important to characterize the maximum concentration a Madidrop tablet can reach. Therefore, a test was set up to determine if the Madidrop tablets dose less or reach equilibrium as they reach high concentrations. This test used the same beaker setup with 800mL DI water measured once a day or after a weekend; however, this time water was not replaced between measurements. Only the amount taken for measurement (30mL) was replaced and accounted for in calculations. The silver rise in ppb/day is an incremental difference between initial and final measurements and is plotted in Figure 5. As the concentration of silver in water surrounding the tablet goes up, the amount it outputs goes down. The maximum value after days of testing varied substantially, likely due to the same variability seen in the beaker test above. After 9 days of testing, the maximum concentration ranged from 720ppb to 8,700ppb of silver with the average around 4,550ppb. After these 9 days, the tablets were putting out very little silver at high overall concentration relative to their initial output, demonstrating that they have most likely hit equilibrium.

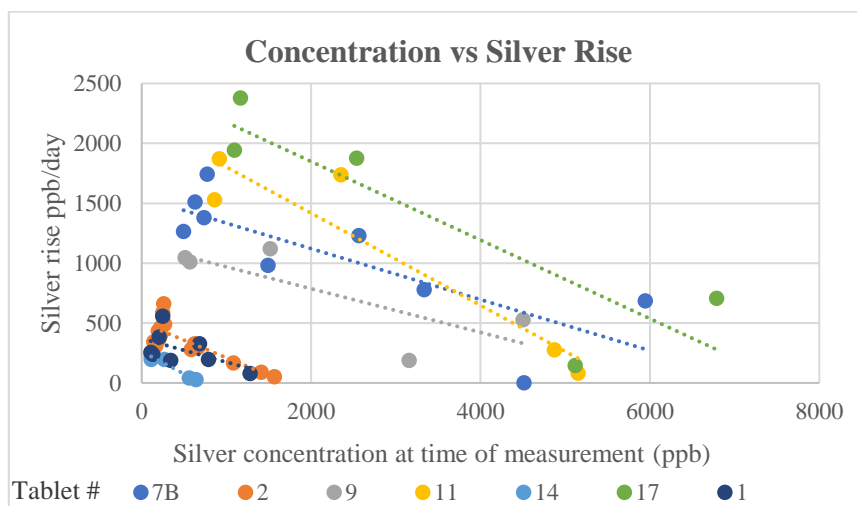


Figure 5. Concentration vs daily dosing.

D. Discolored Madidrop Tablets

When running the beaker tests, discoloration was noticed when using the tablet. According to the manufacturer, the discoloration is due to oxidation. It appeared that the tablets with more discoloration have higher output of silver, but this was not easily quantifiable, and more testing is required to confirm. Additionally, wetted, dried, and rewetted between tests also caused more discoloration, as shown in Figure 6. After this was noticed, Madidrop tablets were left in a tank of water for storage between tests to avoid this excessive discoloration to help reduce this variable. Lastly, it was noticed that, when tears existed in the Madidrop shrink wrap packaging before opening, the area on the tablet where the tears resided was also discolored and oxidized.



Figure 6. Discolored Madidrop tablets after wetting and drying.

III. Passive Flow Tests

For use in the water reclamation system aboard the ISS and potential future missions, a flow-through dosing method would be needed to mimic the existing iodine dosing system. Currently there is a Water Processing Assembly (WPA) on the ISS. After the water is processed from condensate or urine, the last step is to impart a biocide in the water. Currently, the WPA passes processed water through an iodine resin with a flowrate of 0.1L/min. To mimic the existing system, several passive flow-through tests were conducted to run water over Madidrop tablets in different configurations to explore its being used as a potential replacement for iodine in future spacecraft.

A. Test Setup

For the flow-through test, a single-pass setup is used as shown in Figure 7. Water starts in a DI water tank, then is pumped through the system at 0.1L/min. Then it runs through a Madidrop doser to add silver. Next, the effluent is measured for silver concentration by an ISE probe. Lastly, the silver is removed using an ion exchange resin to test silver removal for other systems. Two types of dosers were tested, a filter housing with a 3D-printed internal structure to hold full size Madidrop tablets and a crushed Madidrop doser that packs crushed and sieved Madidrop particles into a small volume. The filter housing doser tested different 3D printer holders for different numbers of tablets, while the crushed Madidrop doser tested different sizes of crushed particles.

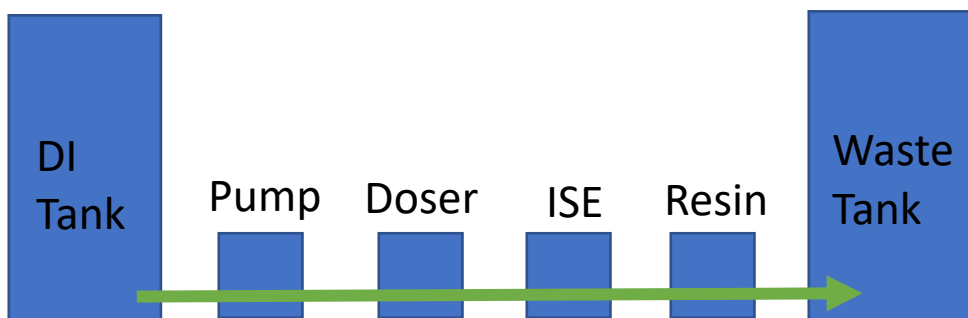


Figure 7. Flow-through setup diagram.

For all flow-through tests, the actual setup shown in Figure 8 was run from 3 to 9 hours over a workday. The test article would have water flowing through 1-5 days before to condition it, and then flow would be stopped for a period of time to mimic standby mode on the ISS WPA. While the standard test added a 1-day quiescent period, one series looked at up to 5 days of standby. The ISE probe was calibrated at the beginning of the day before any test.



Figure 8. Flow-through setup.

B. Test Articles

The first type of doser tested was a full tablet doser. Using a standard filter housing, a holder was designed and 3D printed with PETG filament to replace the standard filters used in these. A one-tablet doser was made first, but the output was extremely small. Therefore, a six-tablet, and subsequently a 12-tablet, doser was made as shown below in Figure 9. These dosers force water through a central column in the middle and back up and across the tablets, allowing as much surface area and flow across the tablets as possible.



A) Six-Tablet Doser



B) 12-Tablet Doser

Figure 9. Madidrop tablet dosers.

The second type of doser tested was a crushed Madidrop doser as shown in Figure 10. Multiple Madidrop tablets were broken apart and sieved into two sizes of particles, large and small, detailed in Table 4. Each size was then placed within a prototype housing. This housing had a removable diffuser and screen at the top and bottom with an O-ring to seal the edges. The top cap is then inserted with a spring between the top and the screen/diffuser, which keeps the Madidrop packed in. The top is held in place with a clip ring.



Figure 10. Crushed Madidrop particles and housing.

The first large-particle doser contained 84g of crushed Madidrop (approximately 1.55 tablets assuming a 54g tablet) so the small-particle doser was fabricated to test an equivalent amount of material by weight. Table 4 shows the particle size and surface area for the dosers. The large-particle doser has about 10x more surface area than the full tablet doser with comparable weight and the small-particle doser has twice the surface area of the large-particle doser.

Table 4: Particle Size and Relative Surface Area

Doser Type	Sieve Used & Particle Size	Average Size	Relative surface area for 84g (1.55 Tablets) of Madidrop
Full tablet doser	N/A	Rectangular (1.1" x3.4" x0.53")	123 cm ²
Large particle doser	0.132" to 0.0469" (No.6 and No.16 Sieve)	Spherical (assumed) 0.0895"	1320 cm ²
Small particle doser	0.0469" to 0.0234" (No.16 and No.30 Sieve)	Spherical (assumed) 0.03515"	3380 cm ²

C. Large-Particle Doser Results

As a first look at the silver output curve, a particle doser is shown first instead of a tablet doser to demonstrate an ideal output curve using the smaller crushed particle package option. Figure 11 shows an output curve testing the large particle doser for 5 hours. All following flow-through tests look very similar to this curve whether it was a particle or tablet style doser. There is always a high spike at the beginning due to the large concentration built up in the doser sitting stagnant to mimic quiescence. The doser releases this high concentration silver solution but quickly reduces to a more reasonable range for operation. For this case, the first measurement is 630 ppb of silver with a reduction to approximately 90 ppb after 5 hours. The output also matches a power decay function almost perfectly with a 0.988 R² value.

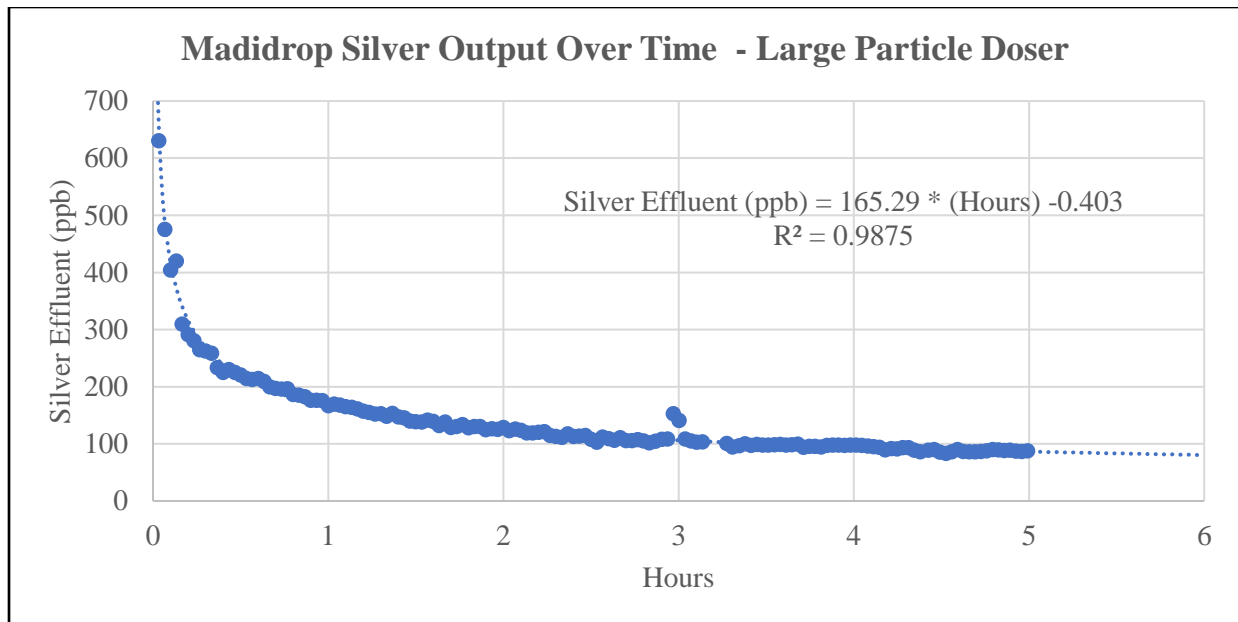


Figure 11. Large-particle doser output curve.

D. Tank Dilution Concept of Operations

This high concentration spike at the beginning could be a cause for concern with dangerous levels of silver in the water if drinking from the initial output. However, dilution with the lines and the rest of the system should make this acceptable. According to the SWEG, silver can be up to 5,000 ppb for 1-10 days, 600 ppb for 100 days, and 400 ppb for 1000 days. This means that even if the crewmember somehow directly drinks the effluent at the beginning, they would still be safe to drink if it stays below 5,000 ppb. Looking at the concentration test data from earlier, there were only a couple of data point that exceeded 5,000 ppb after sitting for an extended period, with that amount being the expected ceiling. However, as soon as the system starts running, the output will immediately become diluted both in the lines and with the tank that is being filled. For instance, for the large particle doser graphed in Figure 11, it is assumed that the concentration directly inside the test article may be much higher than the 630 ppb initial measurement after sitting overnight. But between the doser and the ISE, including the volume in the ISE probe cavity, the concentrated water immediately mixes and dilutes the measurement at startup. Furthermore, under expected usage, this system will be feeding a tank that is unlikely to be empty and, even if it is, the output will be averaged over time to reduce the water to safe concentration levels for drinking.

To understand the effect tank dilution will add to the actual concentration dispensed to a crewmember, a graph is shown in Figure 12. Integrating the power decay function from Figure 11 will output the tank concentration given an empty tank to start. If the tank is not empty and for instance starts with an initial 10 L of 400 ppb silver water, a different concentration curve is seen. In this case, the silver concentration goes up slightly at the beginning then goes down slowly toward the final output but stays much more stable. The doser particle size and amount of the Madidrop tablet in the doser could be altered to create different output curves more suited to maintain a water processing system, depending on the typical run time and allowable concentrations. Alternatively, if the initial high concentration spike is still an issue, the first several minutes could dump to a waste system or return to the start of the WPA. For this test article plotted, the doser may be slightly undersized to ensure at least 200 ppb minimum consistently, so it may be ideal to double the size of the doser or change other variables as a final product.

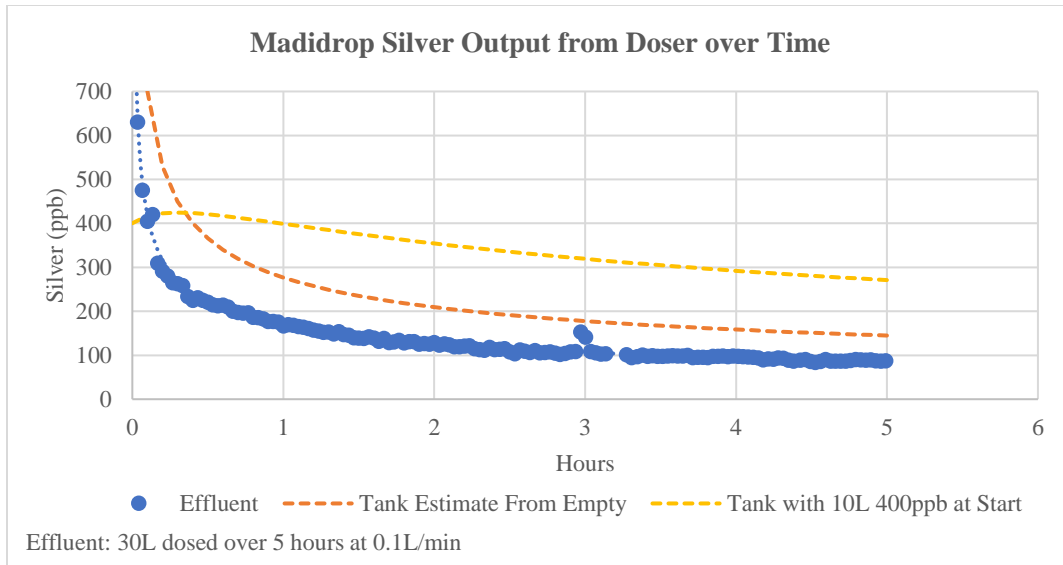
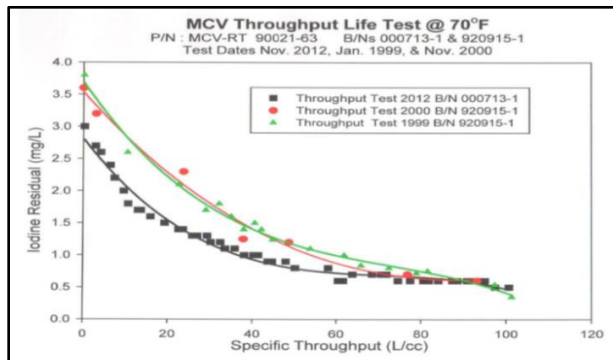


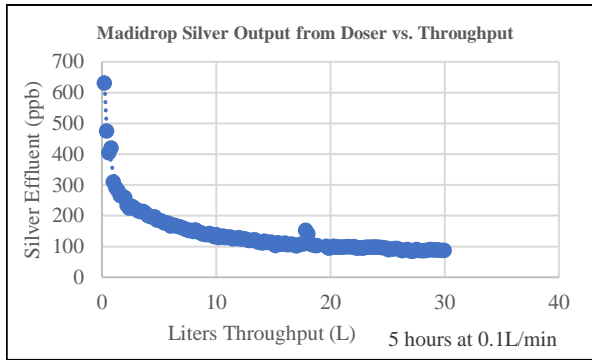
Figure 12. Large-Particle Doser with Tank Dilution Concept of Operations Model.

E. Comparison to Existing Iodine Dosing Technology

When considering adoption of this technology, Figure 13 makes the comparison to the iodine biocide doser used on the ISS WPA.⁹ The graph on the left in Figure 13 shows the output curve of iodine over 100 liters of output for three different batches across different years. The graph on the right shows the same curve as Figure 11, but with the x-axis now showing 30 liters throughput instead of hours to match the existing iodine output graph. This indicates a similar curve as used currently on the ISS, which could make it easier to adopt as a replacement for future missions. The primary difference appears to be the output at the beginning, for the Madidrop doser is quite a bit higher and drops very quickly compared to the iodine doser.



A) Iodine MCV Output



B) Silver Doser Output

Figure 13. Iodine output vs liters throughput compared to large-particle silver doser.⁹

F. Additional Doser Results & Comparison

For the other test articles discussed, Figure 14 shows the output comparison of these different dosers tested. This plot shows that the small-particle doser approximately quadruples the output, which could be very desirable from an output-per-weight standpoint. However, further studies are required to ensure that the lifetime for these smaller particles isn't significantly reduced. The base output from the 12-tablet doser shows it to be between the small- and large-particle doser; however, this is for 12 tablets by weight compared to the approximately 1.55 tablets by weight in the small- and large-particle dosers. Therefore, a second curve multiplies the 12-tablet doser output by 1.55/12 to generate a comparable curve given the same relative weight.

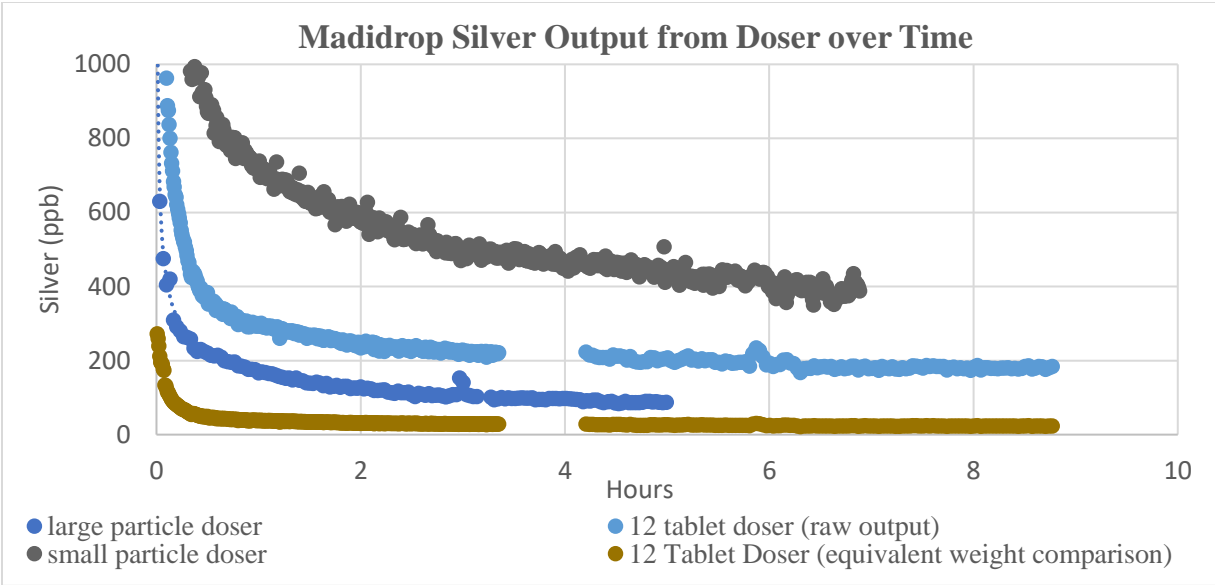


Figure 14. Madidrop doser type comparison.

G. Standby Mode Testing and Results

For the tests above, there was a standard one-day standby period between flow-through preparation and the day the test data is recorded. On the ISS, more realistically, there could be many days or maybe even weeks or months between running the WPA, which means the doser could be sitting stagnant for quite a while. It is expected that the doser would likely achieve the max concentration level and these tests attempt to determine when that might occur. In Figure 15 below, an additional two tests for 3-day and 5-day wait periods were plotted against the original 1-day wait period in Figure 11 for the large-particle doser. All three plots show the final output after running it for several hours to be approaching about 90 ppb. However, both the 3-day and 5-day wait periods show a higher initial concentration output at startup. The 3 and 5-day results also look very similar if not the same, which could allow us to conclude that the water in the doser had reached maxed concentration equilibrium with the Madidrop tablet. Therefore, because 1 day was a lower concentration and 3 and 5 days had the same concentration, it appears that it takes about 2-3 days to reach peak concentration saturation internal to the doser. The silver output curve will not increase output further after waiting more than 3 days. Further tests may be required to verify this max output curve based on standby time.

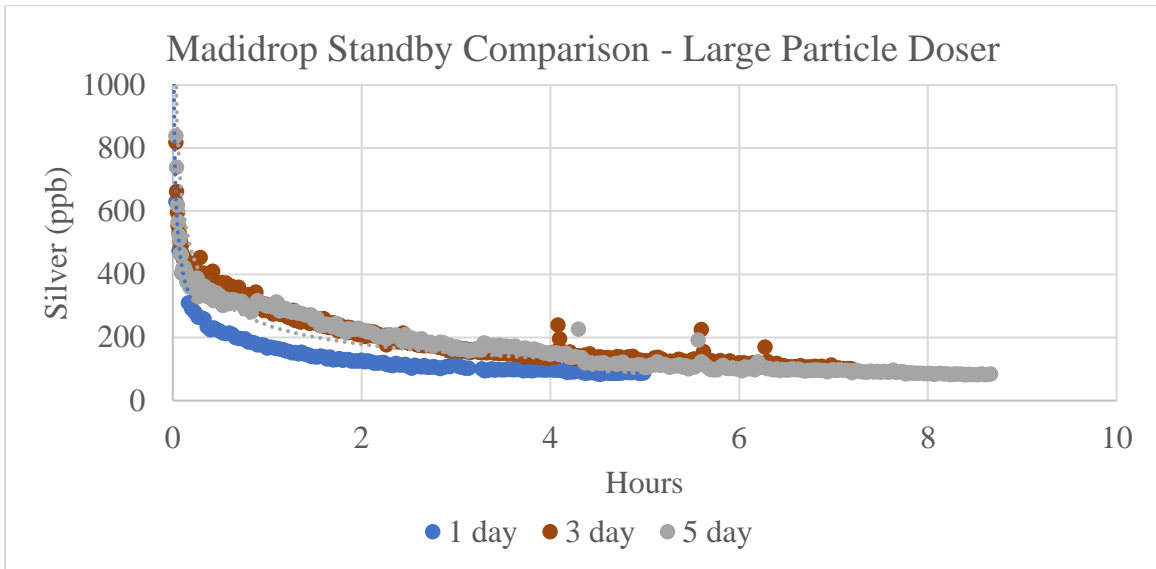


Figure 15. Silver output for different standby times.

IV. Light Sensitivity and Silver Particle Size

When running the static beaker tests at high concentrations, orange or pink solutions were found as shown in Figure 16, which was unexpected. This was found after the Madidrop had been left in the beaker for a very long time, then removed, and the water was left in light. Some changed color quickly, others took a few days. It was noticed that the ones in the dark had not changed, but the ones in light did; therefore, these silver solutions from Madidrop are sensitive to light.



Figure 16. Colored Madidrop solution.

Looking into literature, some articles were found that may describe this phenomenon. Surface plasmon resonance (when light interacts with metals) changes the surface charge of the silver particles and causes them to agglomerate creating larger particles that cause color.^{10,11} Size in the nm range is close to the wavelength of visible light, causing a light absorption and scattering effect that creates the color we see.^{10,11} Once the particles become large, they become grayish, and the particles become visible and distinct. In fact, if looking to purchase different size silver nanoparticle solutions, there are images showing particles from 10nm to 100nm with a color range between yellow and light white or pink.¹² Therefore, light interacting with Madidrop particles creates silver nano particles.

When this effect was found, an extreme light exposure test was performed with a 6,500 K lamp placed over a small beaker of Madidrop solution. The solution was created by placing eight tablets in a beaker for multiple days to achieve a very high concentration. The results over time of this test are shown in Figure 17. After several hours, the solution changes from clear to orange-yellow-colored to dark. After multiple days, distinct particles form at the bottom of the solution. This same test was also run with AgF 5 ppm solution and a 50 nm 400 ppb silver particle solution and there was no visible change after one day. The 50 nm solution used a citrate buffer that may stabilize it from increasing particle size, there may have been too low a concentration to tell a difference, or the particles are too big already and require ionic silver to grow. The AgF is assumed to be stabilized with the fluoride in solution. Further investigation

may be necessary to determine if this light sensitivity will be a problem, if it can be mitigated by just keeping the solution in the dark, or if there is a buffer that could be added to stabilize the solution but still be effective as a biocide.

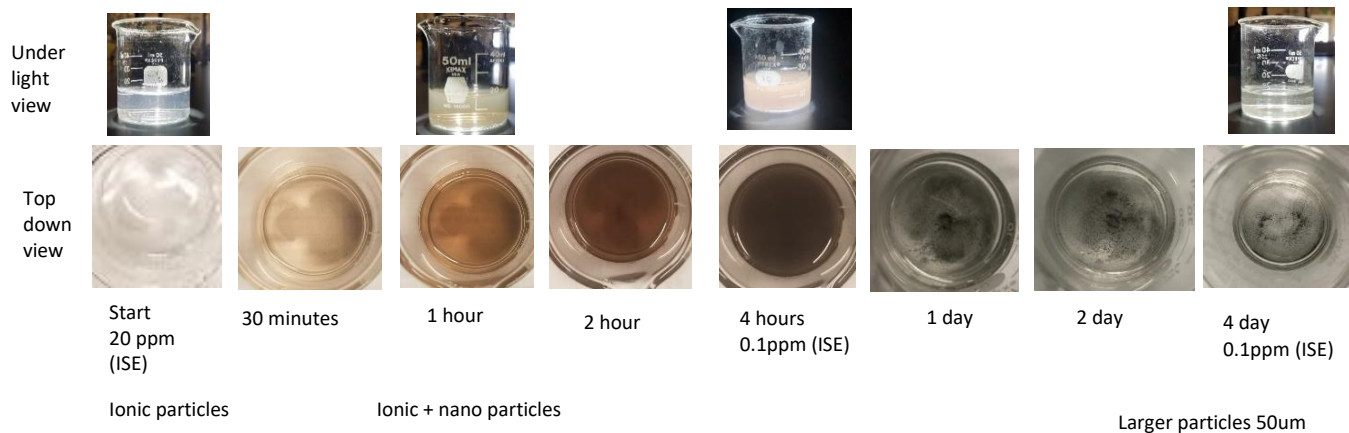


Figure 17. Color change over time from high-intensity light exposure.

V. Next Steps

To continue to raise the Technology Readiness Level of this technology and integrate into a space system, a few further items need to be tested. First, a long-term study needs to be conducted to measure the output of a flow-through setup over time and for different test articles and particles sizes. This long-term study could also determine lifetime in these alternate configurations. Additionally, it may be beneficial to compare the output with varying dissolved oxygen and pH levels to determine if these factors affect silver output of the Madidrop. Additional research could also explore ways in which the output curve could be improved to reduce initial output at the beginning. Furthermore, quality control methods could be implemented to achieve a more consistent output from each Madidrop, so the output doesn't vary so wildly between tablets. Lastly, the colored solution may require further study for any use cases of the water that may involve light, ensuring the solution is kept in the dark during processing and storage, or finding an additive to stabilize the solution without compromising biocidal effects.

VI. Conclusion

The Madidrop tablet has a lot of promise as a silver dosing method. It can dose a tank of water or be configured in a flow-through configuration to dose water as it flows over the Madidrop. The tablet is also very low weight and could easily be swapped for replacement as they are used up. It also has a similar operational curve to the current iodine dosing system for the ISS WPA. However, the output curve has quite a bit higher initial output than the iodine doser. It could be difficult to maintain within the 200-400 ppb range required, though assuming dilution with the water tank, a procedure could be designed to calculate output and keep the tank concentration within bounds. There is also a large range of output between different tablets that may require additional quality control methods to choose ones that have the most similar output. Lastly, the concern for the solution to agglomerate into larger particles may pose an additional risk if the biocide solution is exposed to light. However, all these hurdles have potential workarounds and could be resolved given more time and testing. In time, a flight-ready version of a Madidrop silver doser could be ready to integrate into next-generation spacecraft.

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