# Understanding the CO2 Scrubber Used at the Space Analog for the Moon and Mars

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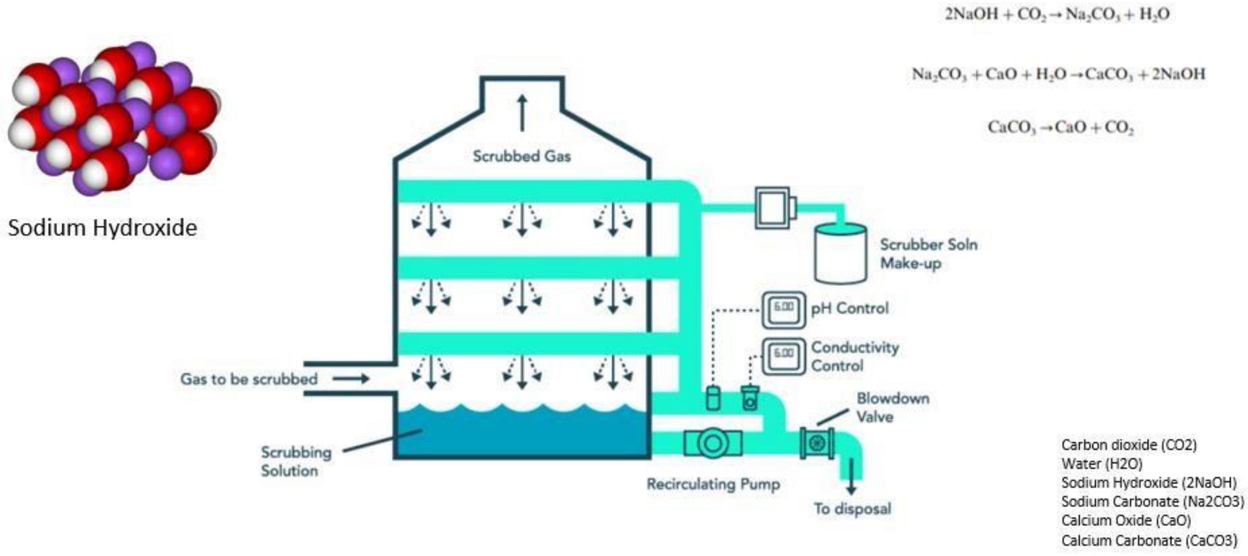
One of the major research and development pillars to be explored at the Space Analog for the Moon and Mars (SAM) is to understand the established technology of physicochemical CO2 scrubbers and research what it would take to transition to full bioregenerative systems. Human life support systems in space can encompass many aspects including but not limited to thermal regulation, pressure, oxygen production, moisture regulation, water purification and carbon dioxide sequestration. Physicochemical life support systems use physical/mechanical and chemical processes to accomplish the desired outcome i.e. breathable air and drinking water.

Bioregenerative life support systems accomplish the same tasks by using complex relationships between plants and animals. It is believed that to establish long term human presence in space, we will be required to rely on robust bioregenerative systems.

Here we will be briefly exploring the specifics around CO2 sequestration or “scrubbing” air to remove said carbon dioxide and the initial system used at the University of Arizona’s Space Analog for the Moon and Mars.

SAM itself is ingrained in a history of understanding the relationship between these bioregenerative and physicochemical systems for space. In the 1980’s the test module of SAM was filled with plants that were used to clean the air of a single occupant. This was the precursor to Biosphere 2. The much larger Biosphere used both plants and physicochemical processes to clean its atmosphere and given the complications of the systems was still required to introduce oxygen for the safety of the crew on mission one.

Outside of the plants used in the Biosphere to stabilize atmospheric composition for humans, there was a Sodium Hydroxide scrubber in the Technosphere located under one of the habitat biomes.


$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

$Na_2CO_3 + CaO + H_2O \rightarrow CaCO_3 + 2NaOH$

$CaCO_3 \rightarrow CaO + CO_2$

*Figure 1 Example of a potential scrubber system used in Biosphere 2. It is not the exact technology used.*

In this type of CO2 scrubber system, we observe the gas to be scrubbed or cleaned enter into the chamber. The CO2 is “rained” on with the sodium hydroxide solution and sequesters the CO2 as carbonate. Through these chemical processes the CO2 is absorbed and “cleaned” air is released. There is an important differentiation to be made between absorption and adsorption as both processes can be used in the sequestration of CO2. Absorption involves molecules being drawn into a material where adsorption is where molecules adhere to the surface of a material.

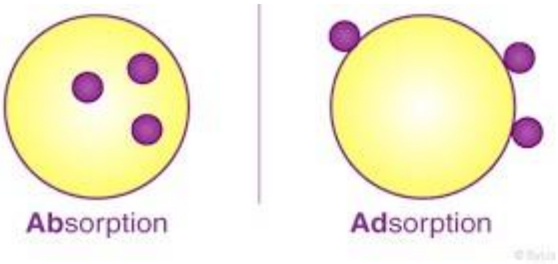


*Figure 2 Visual representation of Absorption and Adsorption*

Though both the Biosphere system and the scrubber initially used inside of the SAM habitat can sequester CO2, SAM currently uses soda lime and/or zeolite materials to adsorb CO2 in the atmosphere which is as shown is a different process than that used in Biosphere 2. There are many types of sorbent materials that can be used for removing atmospheric CO2 including: amines, soda lime, lithium hydroxide, sodium hydroxide, zeolites as well as using electrochemical processes. The SAM scrubber system which was tested in the Test Module was lent/donated to the University of Arizona to support these system development efforts. There however was a proposed custom solution for SAM from this same organization dubbed BATMAN or the Biosphere-2 Analog Test Module ARS Network. In this instance ARS stands for air revitalization system. The goal of said system was to of course provide a solution to maintain harmful gas concentration requirements, sustain oxygen levels, control trace contamination while providing real time monitoring.

BATMAN was required to maintain atmospheric free oxygen between 19.5% and 23.5% at STP. Atmospheric carbon dioxide below 10,000ppm, carbon monoxide below 25ppm, and atmospheric methane below 10,000ppm. The system would be for four crew members for a minimum of fourteen days.

In the end, the donated system was used. Upon receipt of the unit in 2021 it was notated that the 3D printed system was originally designed for a NASA project where soda lime was to be used as the sorbent medium. It was then placed as a display once retired from producing data.

The system itself was meant for 1-7 persons in a volume of air smaller than the SAM TM. It uses three fans to pull air through the filter compartments. These fans were custom manufactured by Safran Ventilation Systems. They are 28vDC each with a max of 25amps.

There are 6 main chambers of the design, the air enters on the left notated in figure 4 with the number 1. Here we find a HEPA filter before the air gets sucked to area 2 filled with activated carbon, 3 the sorbent bed, 4 another dust filter, 5 the Perma Pure Nafion membrane (used for humidity control) and finally chamber 6 where the three fans are located.

*Figure 3 Fans inside scrubber*

## SAM’s CO2 Scrubber

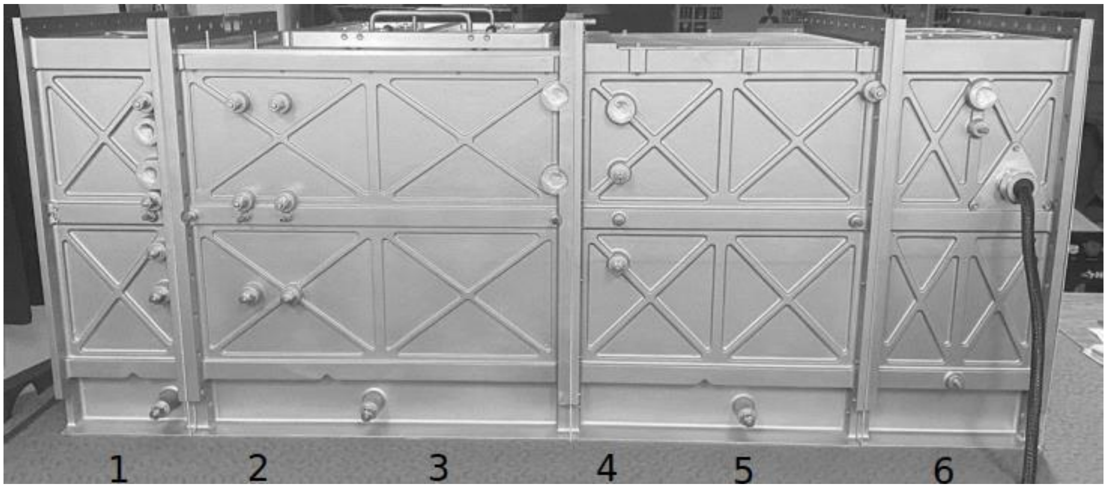


*Figure 4 1) HEPA Filter 2) Activated Carbon 3) Sorbent Bed 4) HVAC Dust Filter 5) Vacuum Chambers 6) Fans*

In the redesign phase of the system, the Nafion membranes were removed and the new sorbent bed was built from AL6061T6 to accommodate zeolite 5a and/or 13x. Three aluminum tubes were selected to hold sorbent which after saturation would be reheated and regenerate (release the sequestered CO2 to be used again). Vernier sensors were installed to determine temperature, humidity and co2 levels before and after the sorbent bed.

*Figure 5 View inside the sorbent bed where the three sorbent tubes are found.*

Each of the three sorbent tubes can hold approximately 131.59 cubic inches of sorbent material for a total of 394.77 cubic inches. This can be expanded or reduced depending on adsorption requirements.

The tube shape was chosen to allow for modularity and the ability to remove and replace tube canisters of sorbent to be regenerated using heat and pressure.

Using a power supply, the first full scale tests were completed in the SAM Test Module (TM) summer 2021 when it was solely a 16,951 cubic foot structure without its expansion. 5 subjects entered the TM and remained sealed inside for the course of approximately 4 hours.

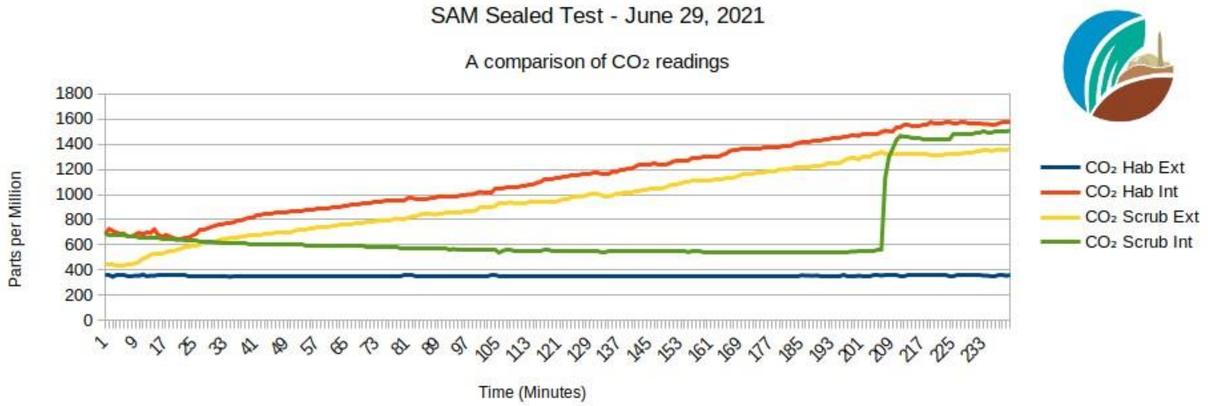
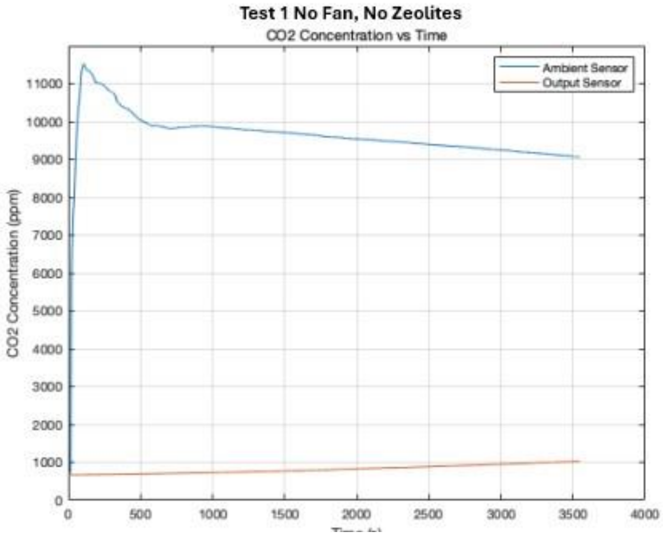


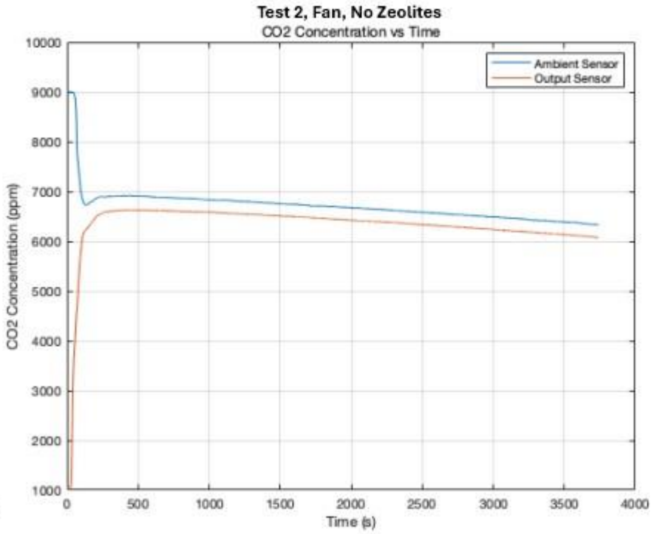
*Figure 6 Data used from the SAM website: https://samb2.space/2021/07/04/sam-4-hours-sealed-test-run-data-analysis/*

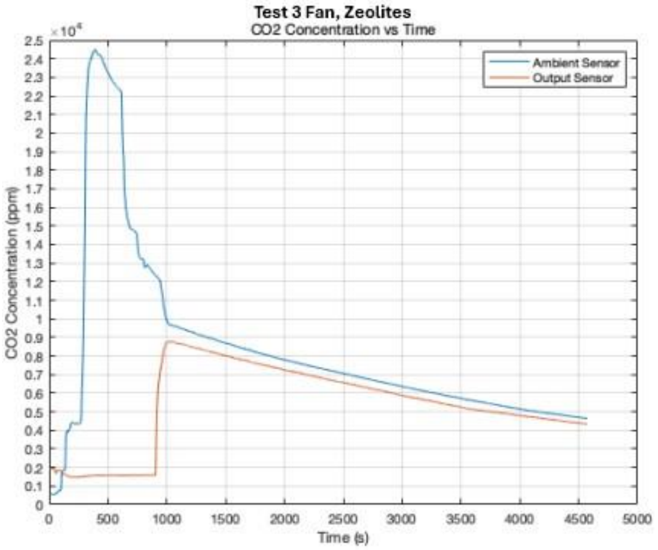
Here we see that the ambient air outside the Test Module remained constant CO2 levels for the entire mission (blue). Over time we get a gradual internal rise in the CO2 as shown by the habitat internal sensor (orange) which is paralleled by the scrubber's external sensor (yellow) due to human activity. The rate increase is a similar slope between these two however not reading the same. This could be due to calibration errors or simply correct readings in the different locations. Perhaps created by internal air flow dynamics. The internal scrubber sensor doesn't rise rapidly until we turn the system on at about 209 minutes (green). From this point on until the end of the mission at around 241 minutes we see the total internal CO2 levels flatten without increase.

This was the initial demonstration of and the successful use of the full scrubber system in the SAM volume with 5 persons. The test shows that with approximately 394.77 cubic inches of zeolite sorbent, we were able to flatten the internal habitat CO2 curve for about 32 minutes keeping it stable at ~1600ppm. A more in-depth look at the above data set by my colleague Kai Staats can be found online at the link shared in Figure 6.

In a second test, under a NASA X-Hab grant, a team of University of Arizona engineering students with the SAM team created a smaller sealed volume made of 6-mil polyethylene plastic and steel rack. The volume of this closed system was 133,980 cu inches and was constructed to be as airtight as possible using HVAC ducting tape. In this system, the same CO2 scrubber was placed inside along with the vernier sensors needed for data collection. Only one tube of zeolite was used in the scrubber in these tests shown below, 1/3 sorbent (131.59 cu in) of the previously described full habitat test. A CO2 tank was then used to add carbon dioxide into the system by hand. There were three tests done, two out of three were run for over an hour. The second test was run for 45 minutes for an unknown reason to the author. In test one, the goal was to seal the system and measure CO2 concentration after an hour, to determine any leak rate of the built volume, no fan, no zeolites. The second test was to repeat the same test while running the internal fan, no zeolites. Then third, adding zeolite 13X to the scrubber and running the fan. The fan's velocity flow rate was always 0.569 m/s.







In the three charts above we are looking for the two vernier sensors to read CO2 as closely as possible, tracking their slope over time. In Test 1, lack of gas mixture produces two vastly different readings, one decreasing and one increasing. Test 2 looks as if we may have had a slight leak in the sealed system or the gas was still settling to find a state of equilibrium. No sorbent was in use though we see a constant decline in CO2. In Test 3 we could correct for any leak rate if that was the determined cause of CO2 loss over time in Test 2. Here we do see a downward slope assuming unknown system leaks and CO2 adsorption simultaneously.

Further testing must be done to better control CO2 released, to determine any sealed system leaks and determine adsorption rate of the CO2 scrubber in its current configuration. New sorbent material should also be explored. It takes approximately 200 degrees C to 300 degrees C to desorb CO2 from zeolite 13x and regenerate it for use again. COF-999 (covalent organic framework 999) captures CO2 without degradation by water or contaminants. 200 grams of this material can adsorb up to 44lbs in a year and can be regenerated at between 60 degree and 140 degrees C. This new material among others could be great candidates for future space CO2 scrubbers.

## Photos

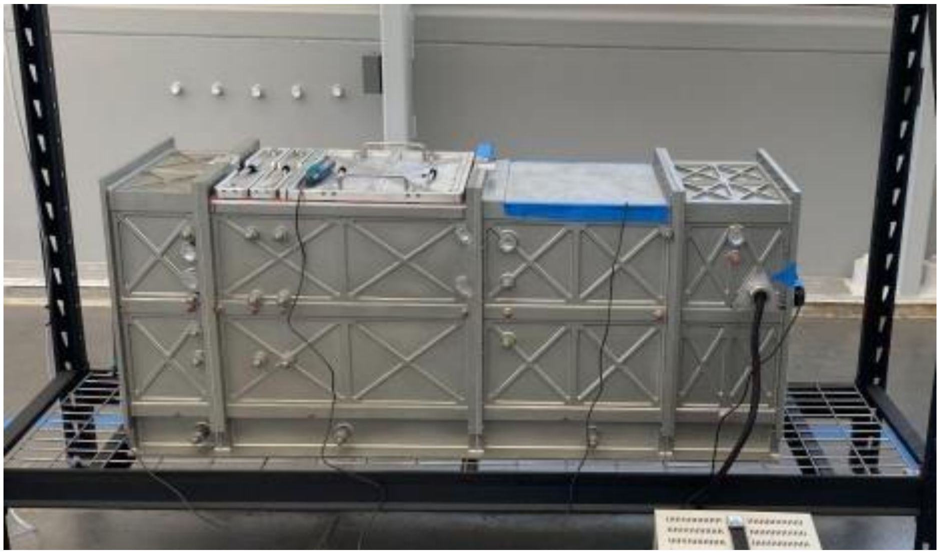


*Figure 7 Full CO2 scrubber unit*

*Figure 8 Students setting up their experiment in SAM*

*Figure 9 Student containment system for scrubber tests*

*Figure 10 Students working inside SAM*

*Figure 11 Author with scrubber used for SAM Test Module experiment*

*Figure 12 Power supply for the scrubber*

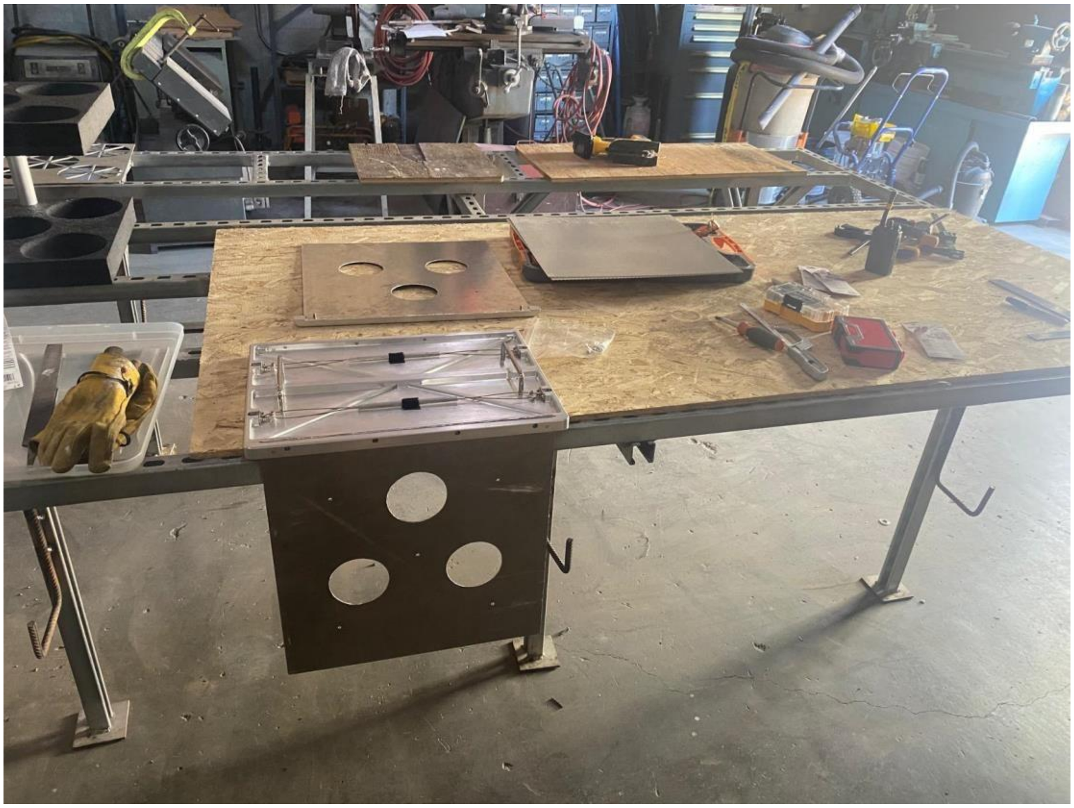


*Figure 13 Machining new internal wall components for the sorbent bed*

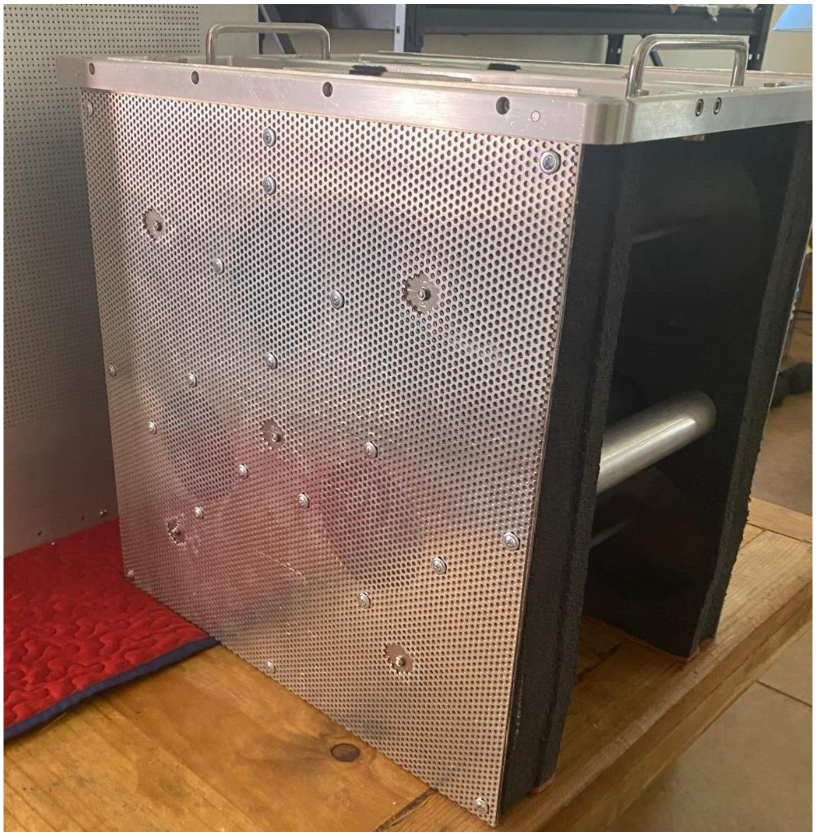


*Figure 14 View of sorbent bed outside of scrubber*

*Figure 15 Scrubber fan controls and settings*

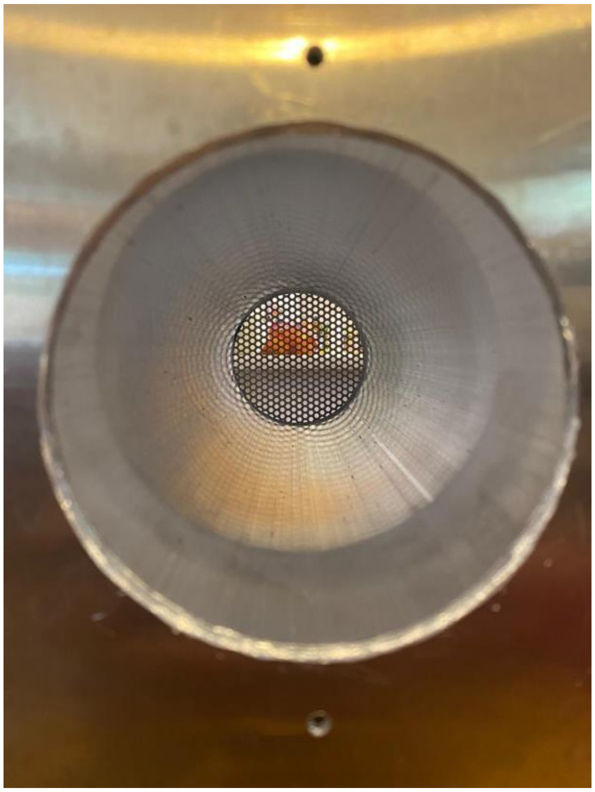


*Figure 16 One of three sorbent bed tube volumes.*