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Design and Implementation of Combination Charcoal and HEPA Filters for the International Space Station Cabin Air Ventilation System

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The International Space Station (ISS) was designed to have the cabin air filtered through High Efficiency Particulate Air (HEPA) filters which filter out particles and bacteria to protect the crew and downstream condensing heat exchangers (CHX). Currently, there are a total of 21 HEPA filters installed throughout the United States On-Orbit Segment (USOS) in Nodes 1, 2, and 3, US Lab, and the Airlock.

The increase of Total Organic Compounds (TOC) within the Water Recovery System (WRS) and the Oxygen Generation System (OGS) throughout the life of the International Space Station (ISS) has been tied to the level of dimethylsilanediol (DMSD) within the closed loop system. The likely source of the DMSD has been identified as polydimethylsiloxane (PDMS), which degrades in the air and goes through hydrolysis on the CHX within the Common Cabin Air Assembly (CCAA).

The use of a charcoal media to scrub the air of PDMS was successfully used within the Node 1 cabin air system for ~2.5 years. Since Node 1 does not have a CHX there was no need for HEPA level filtration at that location. However, due to high fungal counts registered by the air samples taken by the crew, the charcoal-only filters were removed in lieu of HEPA filters. Review of the Air Quality Monitor (AQM) data following the installation of the charcoal-only filters proved that the station air side levels of volatile siloxanes were greatly reduced with only four filters installed in Node 1.

To increase the filtering capacity on the air side, filters were designed to combine the volatile siloxane scrubbing capability of charcoal along with the filtering capability of HEPA filters. The following paper will detail the Charcoal HEPA Integrated Particle Scrubbers (CHIPS) and provide a status of their impact on the overall air and water quality on-board the ISS.

Nomenclature:
AQM = Air Quality Monitor
CCAA = Common Cabin Air Assembly
CDRA = Carbon Dioxide Removal Assembly
CHIPS = Charcoal HEPA Integrated Particle Scrubbers
CHX = Condensing Heat Exchanger
cfm = Cubic Feet per Minute
DMSD = Dimethylsilanediol
dP = Delta Pressure
ECLSS = Environmental Control and Life Support System

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ESA = European Space Agency
FOD = Foreign Object Debris
FIT = Failure Investigation Team
HEPA = High Efficiency Particulate Air
HX = Heat Exchanger
IMV = Inter Module Ventilation
ISS = International Space Station
JEM = Japanese Experiment Module
MER = Mission Evaluation Room
NPRV = Negative Pressure Relief Valve
OGS = Oxygen Generation System
PDMS = Polydimethylsiloxane
RMO = Remote Manual Override
THC = Temperature and Humidity Control
TOC = Total Organic Content
USOS = United States On-Orbit Segment

I. Introduction

The filtration of the air on the International Space Station is performed by 21 HEPA filters installed throughout the modules. The HEPA filters are designed to capture at least 99.97% of particles 0.3 micron or larger. This filtration is essential for protecting the heat exchanger from contamination and also protects the crew from airborne debris. The HEPA filtration does not filter out the volatile siloxanes that dissolve in the humidity condensate that makes its way to the water processing hardware.

Air Quality Monitor (AQM) data is used to track the various contaminants in the atmosphere. In an effort to draw down the air side siloxanes levels, four charcoal filters were built for use in the Node 1 module. The charcoal filters were based off of the design of the catalyst filters that were installed for first ingress of Node 1 and the US Lab when the trace contaminants levels needed to be drawn down before the crew first ingressed. The charcoal filters were installed in the Node 1 instead of HEPA filters for 2.5 years. During that time, the AQM data showed that the siloxanes level in the atmosphere was reduced following the installation of the filters. Returned water samples were analyzed during that time and unfortunately showed there was no substantial change to the amount of dimethylsilanediol (DMSD) found in the water. This is believed to be due to several factors: currently installed Common Cabin Air Assembly (CCAA) Heat Exchangers (HX) have contaminated coatings, there was no scrubbing directly in front of the CCAA HXs as there is no heat exchanger in Node 1, and the 4 filters installed in Node 1 did not provide the quantity of charcoal required to effect a change. The continuous low siloxanes level in the atmosphere indicated that the charcoal still had capacity for removal at the time they were replaced. The decision to replace the charcoal filters was based on a high level of fungal counts in Node 1 and surrounding modules that was discovered following reports of crew symptoms consistent with the presence of fungi. Once the charcoal filters were replaced with the standard HEPA filters, the fungus counts were reduced, and the crew symptoms subsided. Although later testing of the returned charcoal filters proved that they were not the source of the fungus, it did seem to show that the HEPA filtration helped to capture and contain the airborne fungus levels in a way that the charcoal filters could not.[1]

The health of the heat exchangers require HEPA filtration and, as the Node 1 experience proved, the quality of the atmosphere is greatly improved with HEPA filtration throughout. Therefore, the new filter design included HEPA filtration.

II. Charcoal HEPA Filter Design

The design of the new filters needed to be a balance between maximizing the amount of charcoal within each filter, and minimizing the differential pressure across each filter to ensure that the overall system air flow would be acceptable. Testing and calculations completed by MSFC showed that as the amount of charcoal being used in the filtration system increased, the overall volatile siloxanes level in the atmosphere greatly reduced and the overall installed life of the charcoal filters was extended. It was estimated that if each of the 21 filter locations were filled to half height with charcoal that the total mass of charcoal on the ISS would lead to just over 6 years of life for each charcoal filter. Therefore each filter was designed to contain as much charcoal as possible. The starting point in the design was to allow half the height to contain charcoal and the other half HEPA filtration media. If the testing of the filter showed that the pressure differential across the filter did not pass specifications, then the balance between the HEPA and charcoal would be adjusted. Testing of the integrated filters encountered some challenges reaching the specifications, but in the end a half and half design showed to be effective. The expected life of the HEPA paper material is estimated based on the current installations on the ISS using similar paper material. This life is dependent on installation location in the ISS and has been determined with previous ground testing of the delta pressure following various installation durations. It is expected that the new filters will have a similar installation life even at half height of the original because of the added upfront filtration of the charcoal section. The new design places the charcoal portion upstream of the HEPA, which means the HEPA filter will not be subjected to weekly vacuuming, which should aid in the life of the filters since vacuuming has been the assumed reason for damage to the top of the pleats of some HEPA filters. The expectation is that the HEPA portion will be removed and replaced, as described below, every 2 years in Airlock, 2.5 years in Node 2, Node 3 and Lab, and 5 years in Node 1. Existing HEPA filters have shown good durability at this exchange schedule throughout their 20 year service so it is expected that the new filters will have similar longevity.

Due to the different installation life expectations between the charcoal and HEPA sections of the filter, the assembly was designed to easily remove and replace one section at a time. To accomplish this feature a number of considerations had to be taken into account. First of all, to minimize crew time, the sections needed to be separated without the use of hand tools. Therefore the two sections are held together with Velcro strips affixed to each side of the filter (Figure 1).

Figure 1: Integrated Charcoal and HEPA Filter (CHIPS)

Second, to ensure that the air flows through the filter sections and does not leak out around the sections, a seal was installed in the top of the HEPA section that the charcoal section seats onto. The overall filter seal to ensure that no unfiltered air bypasses the HEPA section is controlled by a seal at the bottom of the HEPA filter that makes contact with the housing in the plenum. Third, electrical bonding is required to prevent static charge build up from causing an unsafe condition. Since the HEPA section made contact with the existing grounding tabs, a continuation of bonding was required up through the charcoal section. This was accomplished with a spring loaded grounding tab installed in the bottom of the charcoal section that makes contact with the HEPA section. Finally, a cloth material was used at both the inlet and outlet of the charcoal section to reduce any fines from reaching the HEPA filters and loading the filters prematurely.

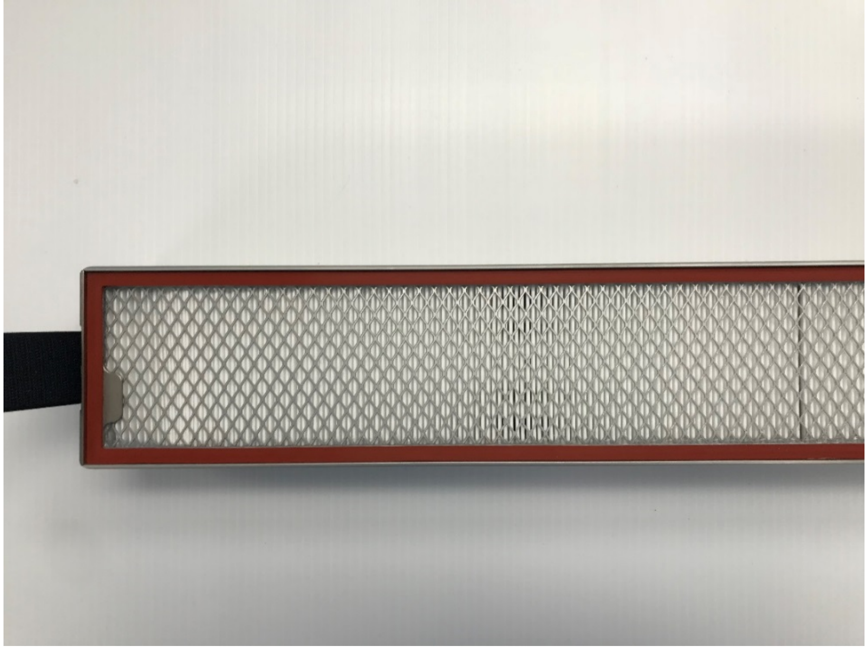


Figure 2: Top of HEPA Section with Seal for Between Sections

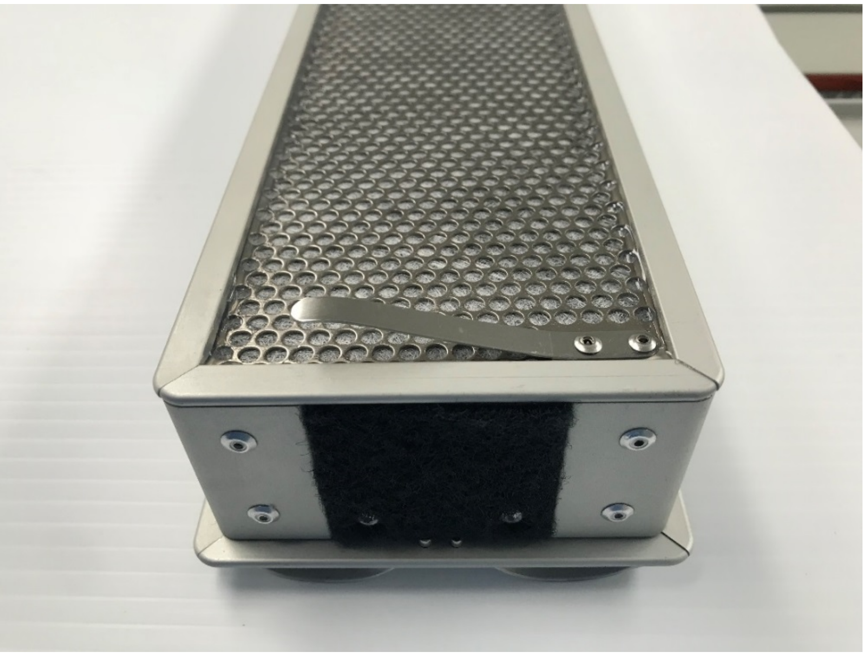


Figure 3: Bottom of Charcoal Section with Grounding Tab

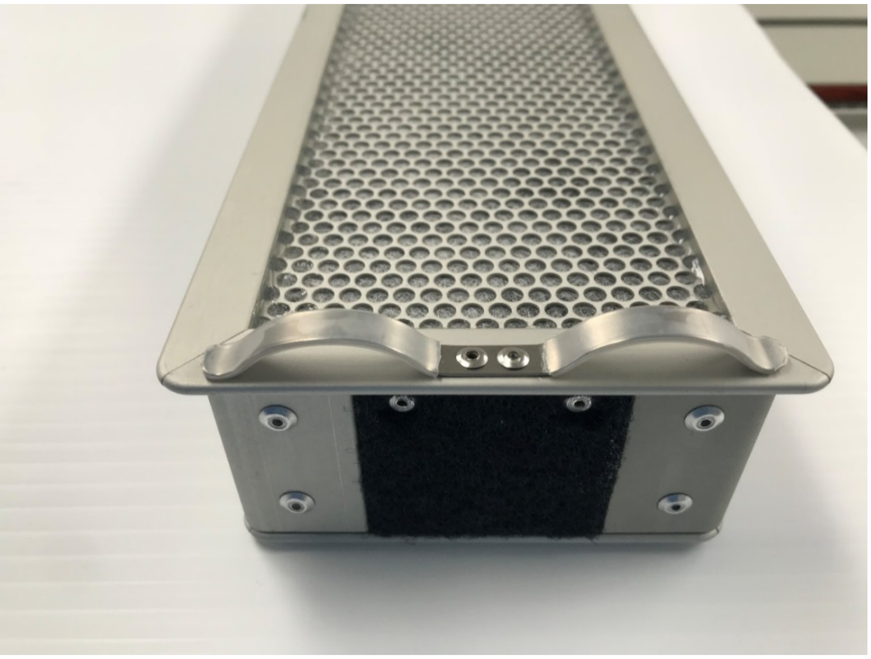
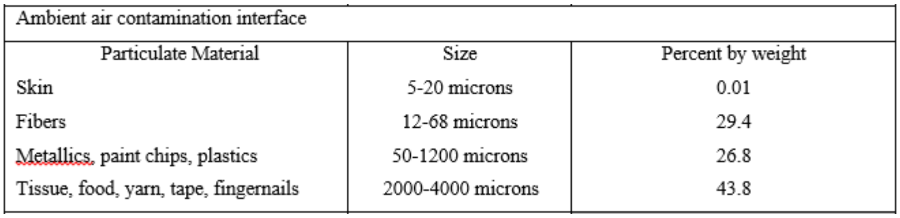


Figure 4: Top of Charcoal Section with Loading Springs

III. Testing Challenges

During official delta Pressure (dP) testing, the filters were tested at the nominal test point of 66.7 cfm and the contingency maximum flow rate of 100 cfm, both with and without loading. The initial loading value of 32 grams was based off of the previous specifications for HEPA with quartz of various sizes to simulate the Foreign Object and Debris (FOD) per the distribution found in Figure 5 below.



Ambient air contamination interface		
Particulate Material	Size	Percent by weight
Skin	5-20 microns	0.01
Fibers	12-68 microns	29.4
Metallics, paint chips, plastics	50-1200 microns	26.8
Tissue, food, yarn, tape, fingernails	2000-4000 microns	43.8

Figure 5: Particle Loading Specification

Loaded testing performed at the nominal flow rate of 66.7 cfm resulted in a dP of 1.43" H_2O. The requirement for this test was 1.5" H_2O. This is considered a passing result.

Loaded testing performed at the contingency flow rate of 100 cfm resulted in a dP of 2.6" H_2O while the requirement was 2.1" H_2O. This is considered a failed test.

Observing the amount of FOD on the face of the integrated filters led the team to believe that the requirement of 32 grams of FOD was excessive. The history behind the 32 gram requirement was found in documentation from United Technologies from 1992 showing the assumptions included 4 crew and 10 total filters installed in Node 1 and Lab. Based on the FOD generation rate of 1.77 grams/day for 4 crew it would take 180 days to accumulate 32 grams on each filter with no housekeeping. Crew currently vacuums the filters weekly therefore the assumption that 32 grams of FOD could accumulate on a filter is not realistic. The loading was reduced to 16 grams and the dP was run again, resulting in passing numbers.

Figure 6: Loaded Filter Testing

IV. Integration of Filters on the ISS

Outfitting all modules with the new filters will happen in phases based on launch manifest schedules. At the time of this paper the first delivery of filters on-orbit will be 8 filters, which is enough to outfit Node 2 and Node 3. Once in place, the downstream heat exchanger in Node 2 is expected to be removed and replaced with the on-orbit spare CHX due to existing degradation on that heat exchanger that is limiting its use for condensation collection in that module. It is expected that the CHIPS installed upstream of a new heat exchanger will result in reduced Total Organic Content (TOC) in the condensate water at that location. Once there are enough filters on-board, the order preference of the final installations will be the Lab and then Airlock as the only remaining locations with heat exchangers downstream. Node 1 will be the last location of preference as it does not have a CHX and therefore the charcoal will not provide a direct upstream benefit to the hardware. The benefit of installing the CHIPS in Node 1 is the added amount of charcoal on board the station to scrub siloxanes from the atmosphere. It is expected that the overall charcoal mass installed with all 21 filter locations will lower the siloxanes to a level that will allow the charcoal to have capacity to remain installed for just over 6 years.

V. Conclusion

The design and delivery of combination Charcoal and HEPA filters, CHIPS, was an effort to maintain HEPA filtration while also adding the scrubbing capability of charcoal to help reduce the siloxanes level in the atmosphere. The ability to change out each section independently will reduce the overall launch weight over the life of the station. Challenges of the design and testing were addressed, and the final product is expected to maintain a clean atmosphere and help extend the life of the downstream hardware that is impacted by DMSD and other siloxanes. At the writing of this paper, it is unknown how much the added charcoal scrubbing will reduce the DMSD levels in the water system.

Following the installation of CHIPS in all 21 locations, water samples will be returned to ground for analysis to determine how the DMSD has been lowered.

Acknowledgements

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References

[1] Dunlap, D., Weir, N., Wilson, M., Bowman, E., “Microbial Analysis of Return-To-Ground Node 1 Charcoal Air Filters from ISS”, ICES-2019-53, *49th International Conference on Environmental Systems,* Boston, Massachusetts, 7-11 July 2019,