Gas Effluent Analysis of the Heat Melt Compactor

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The Heat Melt Compactor (HMC) reduces the volume, heat sterilizes, stabilizes, and manages gas and water effluent of the International Space Station (ISS) trash. Processing the trash at high temperatures produces volatile gas compounds that need to be treated before venting to the cabin and/or to the Vacuum Exhaust System (VES). If the gas effluents are vented to the cabin, then the vented gas must meet the Spacecraft Maximum Allowable Concentrations (SMAC) requirements. If the gas effluents are vented to the VES, then the gas effluent components must be compatible with VES hardware and meet VES venting requirements. Before the design of mitigating systems (e.g. the catalytic oxidizer), the HMC gas effluent streams are characterized. This paper will present different HMC gas collection and analytical methods. In addition, results from the grab sampling and continuous sampling test campaign are presented for acrolein, carbon disulfide, ammonia, and water vapor.

Nomenclature

"Hg	=	inches of mercury
ARC	=	Ames Research Center
CatOx	=	catalytic oxidizer
ECLSS	=	Environmental Control and Life Support Systems
EPA	=	Environmental Protection Agency
FTIR	=	Fourier-transform infrared spectroscopy
GC	=	gas chromatography
GCMS	=	gas chromatography-mass spectrometry
Gen 1	=	Generation 1
Gen 2	=	Generation 2
GWT	=	gas and water test
HMC	=	Heat Melt Compactor
ISS	=	International Space Station
JSC	=	Johnson Space Center
KSC	=	Kennedy Space Center
MMI	=	Materials Modification Inc.
MS	=	mass spectrometry
ppm	=	parts per million
psia	=	pounds per square inch, absolute
psig	=	pounds per square inch, gauge
PTR	=	proton transfer reaction
SCCS	=	Source Contaminant Control System

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SMAC = Spacecraft Maximum Allowable Concentrations
TCCS = Trace Contaminant Control System
TCPS = Trash Compaction and Processing System
TEC = thermoelectric cooler
TD = thermal desorption
TGA = thermogravimetric analysis
TOC = total organic carbon
VES = Vacuum Exhaust System
VOC = volatile organic compound(s)

I. Introduction

The Trash Compaction and Processing (TCPS) is being developed for a flight demonstration on the International Space Station (ISS). The TCPS uses heat and pressure to reduce both the wet and dry trash volume into a suitable form, to physically and biologically stabilize the trash, and to manage the gas and liquid effluents.

During the TCPS operation, a complex mixtures of gas components are evolved that must be mitigated before release into the ISS cabin or vented to the Vacuum Exhaust System (VES). The gas effluent streams must be compatible with the ISS Environmental Control and Life Support System (ECLSS), the VES, and the Source Contaminant Control System (SCCS). The SCCS performs similar functions as the Trace Contaminant Control System (TCCS) on ISS, except the SCCS treats the contaminant at its source, the TCPS.

In order to determine which is the best mitigation methods for gas contaminants, the TCPS gas effluents are characterized. As part of a risk reduction campaign, the Heat Melt Compactor (HMC) Generation 2 (Gen 2) at NASA Ames Research Center (ARC) was used to test TCPS operation, performance, and minimize technical risks associated with a long-duration ISS flight demonstration.[1] The gas effluents collection during this test campaign were characterized as part of the risk reduction activities.

The objectives of the test campaign were to analyze the gas effluent stream and to use these results to drive system design and to help determine unit operation, and effluent management strategies.[2] This includes identifying and quantifying components coming off of the HMC processed trash under specific operational conditions. If the gas is vented to the ISS cabin, the gas effluent stream must meet Spacecraft Maximum Allowable Concentrations[3] (SMAC) relevant to atmospheric contamination. On the other hand, venting gases directly to space requires meeting VES[4] requirements such as a dewpoint temperature less than 15.5 ˚C, a maximum temperature less than 45 ˚C, an acceptable mass flow rate into the VES, and gas constituents that are approved as being compatible with the VES.

Delzeit et. al.[5,11] previously characterized the gas components from HMC Generation 1 (Gen 1) using the gas chromatography-mass spectrometry (GCMS) headspace methods. Although the GCMS results for Gen 1 indicated 74 contaminants, the data can only be used as a reference because the system operated at atmospheric pressures and the trash batches were not standardized. Previous research identified characteristic contaminants from single trash constituents.[6] However, this data only attests as qualitative and does not test for a mixed trash batch. HMC Gen 2 operates at 0.3 psia vacuum pressure; therefore, water will boil and are collected at 60 ˚C.[7] In order to fully characterized the gas and liquid effluent streams, efforts were made to standardize the trash input, define standard operational conditions, and standardize the gas collection and analysis techniques used. This paper outlines the methods used to characterized the gas effluent stream exiting the HMC Gen 2.

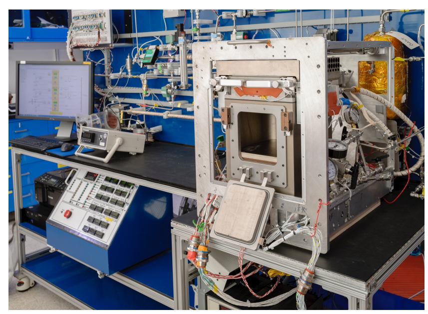

Figure 1. HMC Gen 2 at NASA ARC.

II. HMC Gen 2 Process Overview

The HMC is a closed system that operates at sub-atmospheric pressure in a two-steps temperature ramp for a 24-hour cycle. A simplified process diagram is displayed in Figure 2. Figure 3 shows a theoretical temperature profiles and an example of the temperature profile for one trash run. The HMC process starts with loading the trash into the system chamber and applying vacuum to 0.3 psia via a dry vacuum pump. When the system reaches 0.3 psia, the heaters are turned on and the first ramp temperature is set at 60 °C. This low temperature period allows for the removal of free or loosely bound water from the trash (water boils at 60 ˚C and 0.3 psia). Gas effluent exits the chamber and water vapor is condensed by a thermoelectric cooler (TEC). Once the volume of water collected is stabilized, the temperature is increased to 150˚C. The high temperature allows for sterilization, plasticization, and the release of volatile gases from the trash. Gas effluents are also released at the low temperature phase. After the trash remains heated and compacted for 3 hours, the trash and system enters a 12-hour cooling period. The trash tile is removed at room temperature.

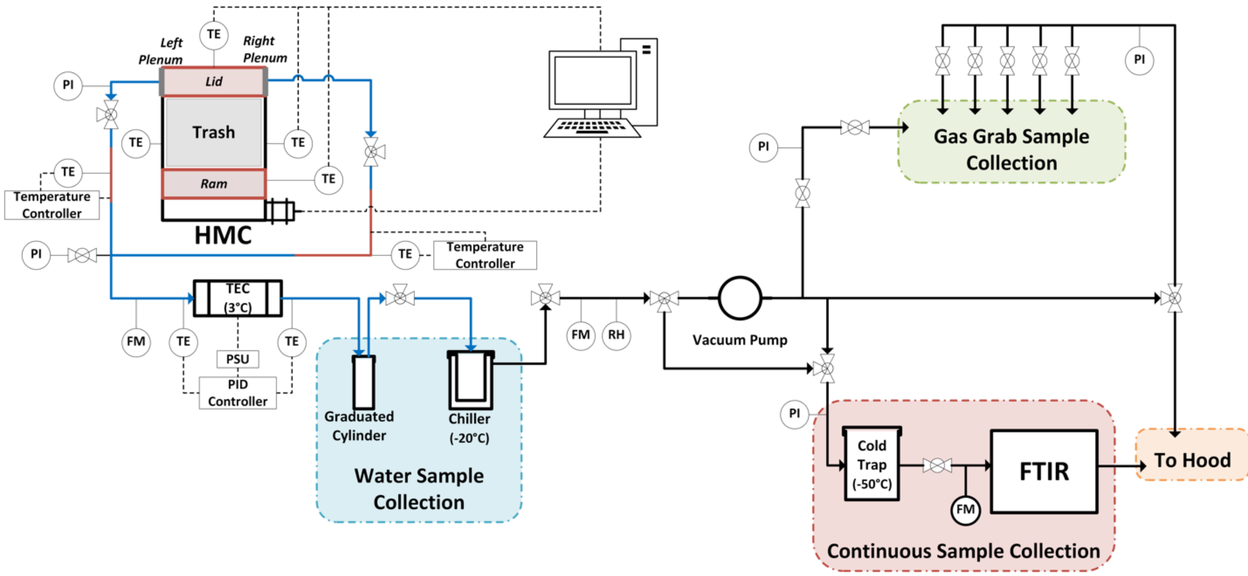

Figure 2. A simplified process diagram of the current HMC Gen 2 setup for water and gas effluent collection. *The wet gas effluent exits HMC chamber through the side plenums. Water is collected after the TEC. Both the chiller (20˚C) and the cold trap (-50˚C) capture the remaining water to prevent liquid water from entering the gas cylinders and the FTIR.*

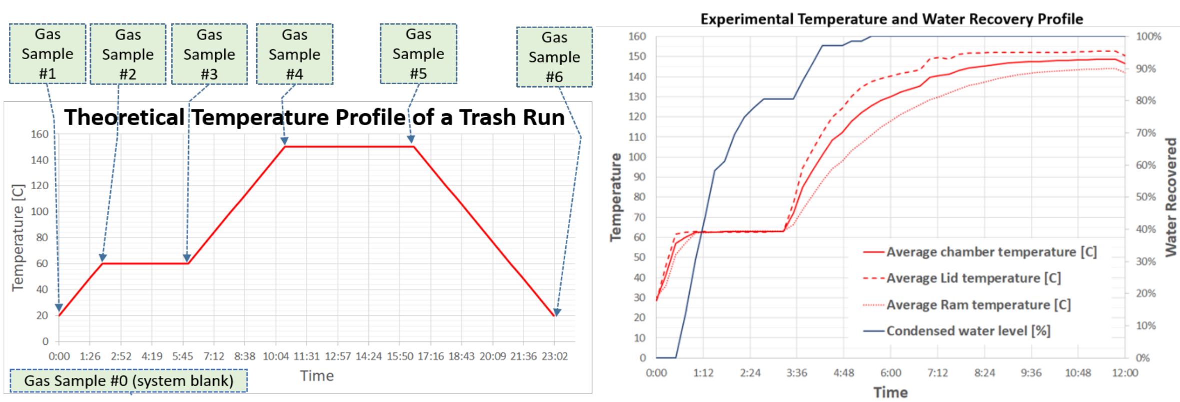

Figure 3. (Left) The theoretical temperature profile of the HMC Gen 2 process. **(Right)** The experimental temperature profile of the HMC Gen 2 process, along with a water recovery profile. *Low temperature set-point of 60 ºC shows 80% of water recovery.*

III. Gas Collection Method

Environmental Protection Agency (EPA) TO-15 and TO-17 methods are used to establish a standardized method for HMC gas effluent collection and analysis. Gas samples are collected from the HMC exhaust stream into canisters, sorbent tubes, and/or bags and are analyzed by gas chromatography (GC), GCMS, and Fourier-transform infrared spectroscopy (FTIR).

These EPA methods refer to the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air.[8] For sampling, the TO-15 method utilizes specially-prepared canisters for GCMS analysis.[9] TO-15 analyzes both polar and non-polar volatile organic compounds (VOCs). The Toxicology and Environmental Chemistry Laboratory at Johnson Space Center (JSC) uses EPA TO-15 methods for post-flight toxicology analysis of ISS air samples. TO-17 method uses multi-bed sorbent tubes to collect polar and non-polar VOCs from ambient air samples.[10] This method also uses the same GCMS analytical approach as TO-15. However, for TO-17 analysis, the sample is thermally desorbed onto an analytical sorbent trap. Both of these methods have the same target compound list, which is a subset of 97 VOCs listed as hazardous pollutants. Utilizing both canisters and sorbent tube monitoring improves the quality of data produced.

Figure 4 shows the various gas collection methods. Previous work for gas effluent analysis of HMC trash include GCMS[11] and a Gasmet DX4030 FTIR.[12] There are advantages and disadvantages to both methods. GCMS can readily detect and identify unknown compounds based on mass. However, since an inline GCMS is not available, grab samples are used. The Gasmet FTIR can detect some components that are not easily analyzed via the GCMS (e.g. ammonia) and can be used for continuous measurement. However, the Gasmet FTIR can only analyze components that are pre-selected in the available library[§§] and it cannot detect contaminants at below ppm range. Here, both methods were used as each offer unique features that are valuable in characterizing the gas effluents evolving from the process. For the GCMS analysis, grab samples are collected from the exhaust at 7 sample points as listed in Figure 4 and Table 1. The collection points are chosen to examine the gas, liquid, and solid phase change behaviors and the effectiveness of the temperature hold times throughout the run. For example, gas samples are collect at the onset of 60 ˚C to determine which gas contaminants evolved when water begins to boil from the trash batch. The Gasmet FTIR is placed in line with the HMC and gas samples are continuously analyzed.

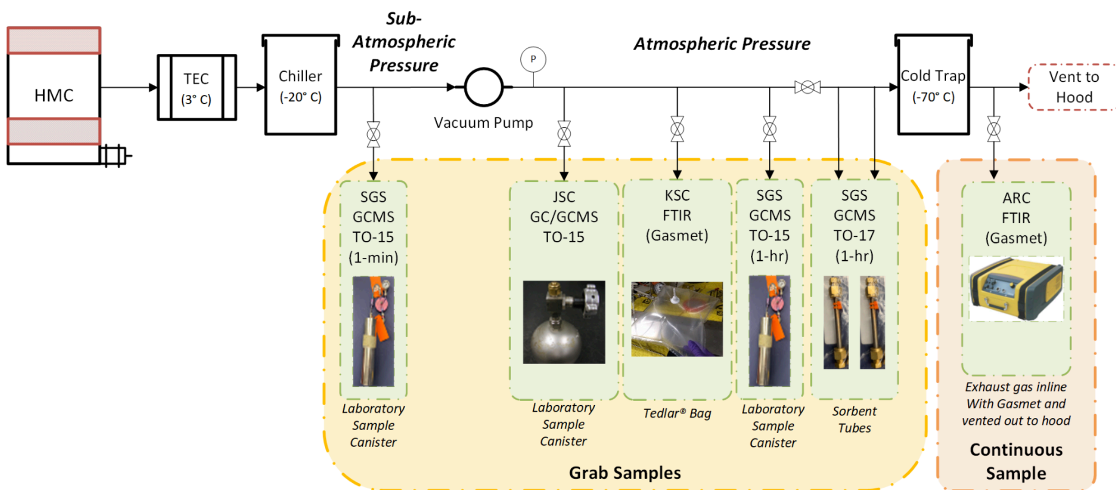

Figure 4. A schematic showing the various collection methods using gas canisters and sorbent tubes.

Table 1. A summary of the gas sample points with corresponding temperatures, pressures, and description.

Sample #	Temperature (˚C)	System Pressure (psia)	Description
0	20	14.7	System blank. No trash present in the chamber. Provides a baseline to check for existing contaminants.
1	20	0.5	Low temperature phase: Load trash. Vacuum pump turned on. Heaters set-point 60 ºC.
2	60	0.5	Beginning of low temperature step. Sample collection begins upon approaching the boiling point of water (~60 ºC).
3	60	0.5	End of low temperature step. When water collected remains constant, implying most of the water has been collected. Heaters set-point to 150 ºC
4	150	0.5	Beginning of high temperature step. Sample collection begins upon approaching the sterilization and melting point of plastics (~140 to 150 ºC).
5	150	0.5	End of high temperature step. Sample collection begins upon approaching the end of the 3 hour hold time. After collection, pump is turned off overnight.
6	20	0.5	End of cooling period with compacted tile in system. Pump is turned on.

A. JSC Collection Method

The JSC analytical laboratory operates under the ISO 9001/AS9100 quality plan. The laboratory provided pre-vacuum gas canisters for sample collection and analyzed the samples according EPA TO-15 (GC/GCMS). HMC

[§§]The GASMET 4030 can detect unknown constituents, but the components must be defined in the library through identification and calibration.

samples are collected at atmospheric pressure (after the vacuum pump) and filled from a pre-evacuated cylinder to 25 psig. After collection, the grab sample canisters are shipped overnight to JSC. JSC's analytical methods are built around sample pressures of atmospheric and higher. If samples are collected at sub-atmospheric pressure, then samples must be repressurized, which in consequence dilutes the sample and leads to a 10-20 fold increase in the detection limits.[13] The detection limit is defined as the minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results.[14] In other words, an increase in detection limit lessens the confidence of that measured concentration.

B. SGS Galson Collection Method

SGS Galson is an ISO 9001 certified lab and analyzes the gas effluents by GCMS for both EPA TO-15 (using gas canisters) and EPA TO-17 (using thermal desorption (TD) Tenax sorbent tubes). After collection, both the canisters and sorbent tubes are shipped overnight to SGS Galson.

For EPA TO-15, the gases were collected in the pre-vacuumed (-29"Hg) 1-L (liter) Silonite coated minican grab sample which have pre-calibrated pressure regulators/gauges. The gas regular diffusion rate is set according to the 1-hour collection time. The regulator is set such that the gas cannot be filled above atmospheric pressures. Therefore, the HMC Gen 2 gas effluents is connected inline to the system and allowed to filled up to atmospheric pressure (approximately 1 hour).

For the EPA TO-17, the gases were collected in two TD Tenax sorbent tubes. This method utilizes distributed volume tube pairs (one tube is a 1-L sample and the other a 4-L sample) in parallel when monitoring for specific analytes using a validated sorbent tube but in an uncharacterized atmosphere.[8] Samples are collected for 1 hour with a sampling rate of 16.7 mL/min for the 1-L tube and 66.7 mL/min for the 4-L tube. After collection, samples are kept refrigerated at 4 $^{\circ}$C or stored cool to avoid desorption. This is crucial as the lab does the thermal desorption from the sample and into the sorbent trap of the lab's analytical system.

C. KSC Sample Collection Method

Grab samples for Kennedy Space Center (KSC) are collected after the vacuum pump at atmospheric pressure to a 3-L Tedlar bag and shipped overnight to KSC. Bags are filled to 2 to 2.5 liters to allow for expansion during transport. The gas in the Tedlar bags are "squeezed" into the Gasmet DX4030 FTIR 1-liter gas cell. This methods does allow some gas to diffuse/permeate out. A predefined 25 component library developed from previous studies is used and the components are listed here:[6]

2-butanol	butyl aldehyde	formaldehyde	nitrous oxide
2,3-pentanedione	carbon dioxide	furfural	nonanal
5-methylfufural	carbon disulfide	hexanal	pentane
acetaldehyde	carbon monoxide	methane	sulfur dioxide
acetone	dimethyl sulfide	methanol	toluene
ammonia	ethanol isopropanol	nitrogen monoxide	water vapor

D. ARC Gas Collection Method

For the later trash runs, the Gasmet DX4030 was plumbed inline downstream of the vacuum pump for continuous real-time measurements (Figure 2). The advantage of this collection method is maintaining the integrity of the gas effluent stream as it enters the instrument sample cell directly from the process thus minimizes possible sample contamination and providing real-time pollutant concentration levels. Although a maximum of 50 components can be detected, the more components are added to the library, the more noise that will be introduced into the readings, resulting in less accurate measurements. An additional -50˚C chiller is installed upstream on the Gasmet to prevent water from condensing on the cell mirrors.

IV. Test Conditions

A. Test Matrix

The GWT campaign consisted of 18 trash processing runs with different trash models: nominal, high liquid, and high cloth. The majority of our tests were grab samples. Fewer tests were continuous samples and for those we made sure to test each trash model with-and-without trash containment bag scenarios for comparison. Table 2 provides a summary of this test campaign.

Table 2. GWT test matrix.

Trash Model		Grab Samples	Continuous Samples	
Nominal	No Bag	4	1	
	With Bag	0	1	
High Liquid	No Bag	4	1	
	With Bag	1	1	
High Cloth	No Bag	3	1	
	With Bag	0	1	
Total		12	6	18

B. Trash Models

The trash models represent trash components typically generated on the ISS. For this test campaign, a trash batch mass of 500 grams is used. The models differ in the mass of each component. For example, the high liquid model has a higher liquid mass. The components and mass for each model are listed in Appendix A.

C. MMI Bags

The trash containment bags used are fabricated by Materials Modification Inc (MMI).[15] The main objectives of the MMI bags are to encapsulate the trash and retain contaminants, while remaining water vapor permeable (but less permeable to other gases). The bags are designed to assist in the HMC process, including trash loading to contain the trash components, prevent gunk build-up within the compaction chamber, and reduce clogging of plumbing and sensors. The MMI bags were used on selected runs.

V. Results and Discussion

From the grab sample results, over 100 compounds were analyzed. Due to multiple grab samples being taken for each trash model and at each sample point, maximum concentrations are chosen to represent the grab sample results. In addition, the continuous results will evaluate the effectiveness of the MMI bag.

A. Evaluating Effluent Management

Contaminant concentrations must not exceed or violate known SMAC values if gases are vented to cabin. The analytical concentrations are compared to the 24-hour period SMAC[3] values, which apply to off-nominal situations such as accidental releases, and this time period is appropriate given the HMC 24-hour operational cycle. Not all contaminants have a defined or known SMAC, so an alternative is to utilize JSC Toxicology and Environmental Chemistry reports,[16] which provide toxicological assessment of current, acceptable ISS air quality.

A comment is provided in the results if the contaminant is an acceptable exhaust gas to vent in the ISS VES. If a vented gas is not on the list, it is not necessarily excluded from venting, as the gas may not have been assessed yet for VES compatibility.

B. Results of Significant Components

The results of four components (acrolein, carbon disulfide, ammonia, and water vapor) are reported here because they are present in comparatively large amounts. Other components are either lower than the detection limit or do not violate SMAC.

1. Acrolein

Acrolein is an acceptable exhaust gas compatible with the VES, but it is of interest as it appears consistently in the GCMS grab samples and it was not analyzed before Gen 2 testing. Acrolein is significantly present in the high temperature phase of the process and analytical concentrations exceed its known 24-hr SMAC value of 0.08 mg/m^3, Figure 5. For the nominal model, the concentration spikes at 140-150 ˚C. For the high liquid model, the concentration spikes earlier, at the end of the low temperature step at 60 ˚C, while the high cloth model has lower concentrations than the other two models.

A potential source of acrolein is the beef patty and frankfurter used in the trash models. Acrolein can be formed by heating animal and vegetable fats, oils, and proteins at high temperatures.[17] Packing of the food components in the trash batch is done by placing them in a bag, such as the overwrap (a part of the trash model). Upon compaction, the food components will spill out as there is evidence of gunk build-up on HMC surfaces from caramelized food. The increase in acrolein with temperature and compaction indicates that the beef patty and frankfurter escaped from the overwrap. The relative masses of beef patty and frankfurter used in the trash models (Table 3) correspond to the high acrolein levels in the accompanied trash models (Figure 5).

Table 3. The table showing the mass of beef patty and frankfurter in the three trash models.

Trash Model	Beef Patty (g/500g trash)	Frankfurter (g/500g trash)
Nominal	5.08	4.86
High Cloth	2.38	2.27
High Liquid	4.51	4.31

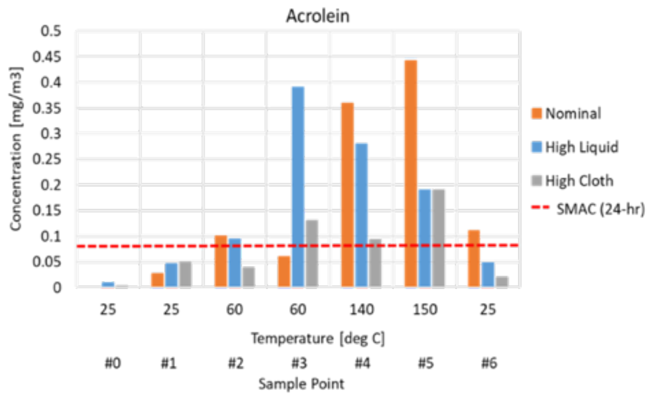

Figure 5. Grab sample results of acrolein in the nominal, high liquid, and high cloths trash models. *Sample points correspond to the temperature profile in* **Figure 3**.

2. Acetaldehyde

Acetaldehyde is a contaminant that appears consistently in the GCMS grab and continuous samples, Figure 6. This contaminant is significantly present in higher temperatures and analytical concentrations exceed its known 24-hr SMAC (5.55 ppm). Previous work showed acetaldehyde offgas from fruits as it is used as preservative, flavoring agent, and trace amounts are present in ripe fruit.[18]

High concentrations of acetaldehyde appear around 130-150 ˚C, which is in agreement with the grab sample data. For the nominal model, the MMI bag shows some acetaldehyde containment. The high liquid model does not show distinct containment as both bag and no bag cases have nearly the same offgas trend. This may be due to the relatively large amount of liquid in the trash model. Since the bag allows water vapor transport and acetaldehyde is a polar and water-soluble component, theoretically it is expected to permeate through the bag. The high cloth model does not show bag containment of the contaminant, nor does it show a distinct outgassing, and this may be due to the small amount of liquids in the model. Acetaldehyde is also an acceptable exhaust gas compatible with the VES.

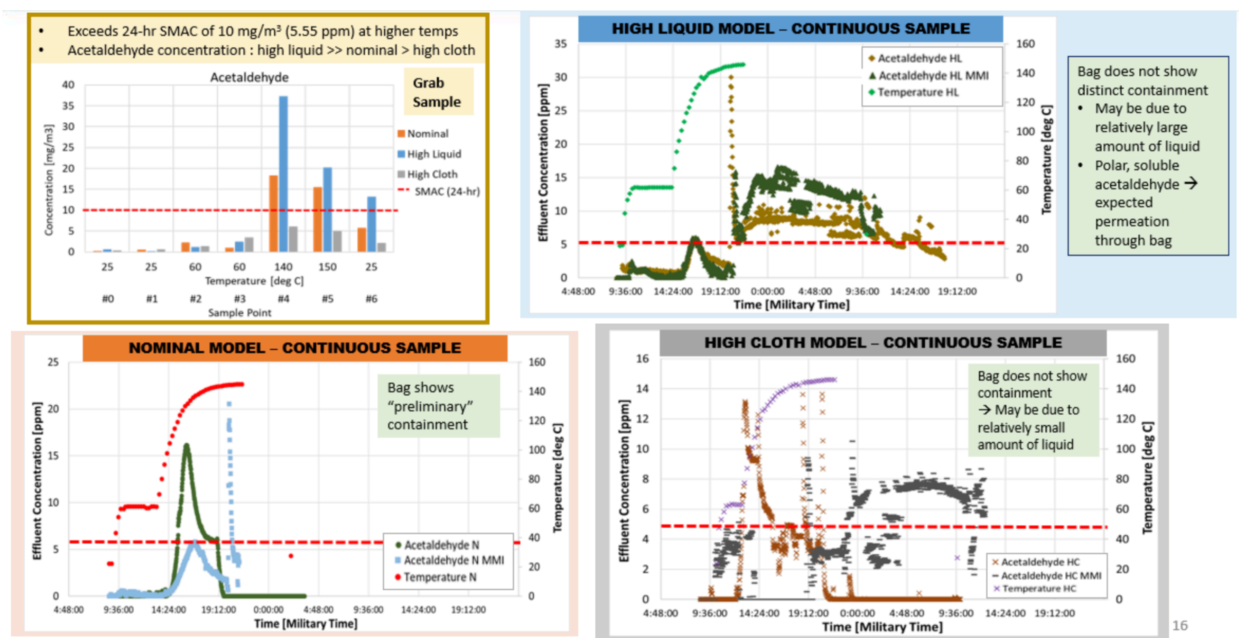

Figure 6. Four graphs showing the acetaldehyde grab samples and continuous FTIR analysis for the nominal, high liquid, and high cloth models.

3. Carbon Disulfide

Carbon disulfide is derived from purple, nitrile gloves. This contaminant has no known SMAC nor is it listed in the VES compatibility list. In a Toxicology and Environmental Chemistry report, 0.14 mg/m^3 (0.05 ppm) is the maximum analytical concentration of carbon disulfide that is acceptable on ISS air quality. The gas results of all trash models exceed that maximum concentration during higher temperatures.

From the continuous results, the outgassing of carbon disulfide is very distinct, Figure 7. A peak in concentration occurs at 140 ˚C and a subsequent spike usually follows at 150 ˚C. The nominal model produces high concentrations of carbon disulfide, followed by the high liquid then high cloth. This is also followed by the amount of nitrile gloves present in each model. Evaluating bag effectiveness, the containment of carbon disulfide is observed in all models with the bag. This contaminant is a nonpolar compound, so it is expected that the bag can contain this compound to a degree. As for the abrupt, subsequent spikes in concentration, this could be trapped gas escaping from the trash as it is heated and compacted.

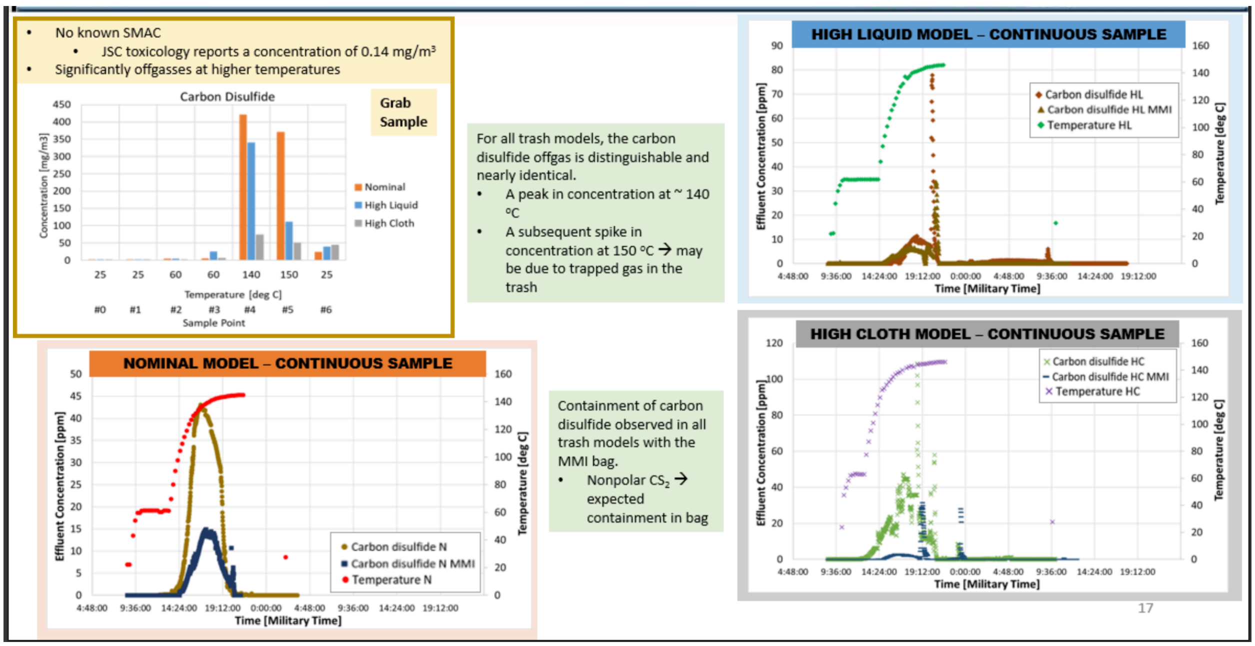

Figure 7. The four graphs showing the carbon disulfide grab and continuous results.

4. Ammonia

Ammonia is a contaminant that can be detected via FTIR, but not GCMS. This contaminant has a known 24-hr SMAC of 20 ppm and the analytical concentrations of all the trash models do not exceed this SMAC. Ammonia concentration spikes at the high temperature phase (140 ˚C), Figure 8. The high cloth model is expected to have the most ammonia as liquid ammonia is used in textile industry, specifically for treating cotton.[19] Previous work analyzed the water sample for a group of t-shirts, which resulted in a high concentration of ammonium (NH_4^+) as ammonia can dissolve in water.[6] Ammonia is not contained by the MMI bag as ammonia is a highly polar compound.

This contaminant is also a concern for the catalytic oxidizer as it can produce nitrogen oxides. So the CatOx design may need to accommodate ammonia scrubbing, depending on the typical amount exhausted from the HMC.

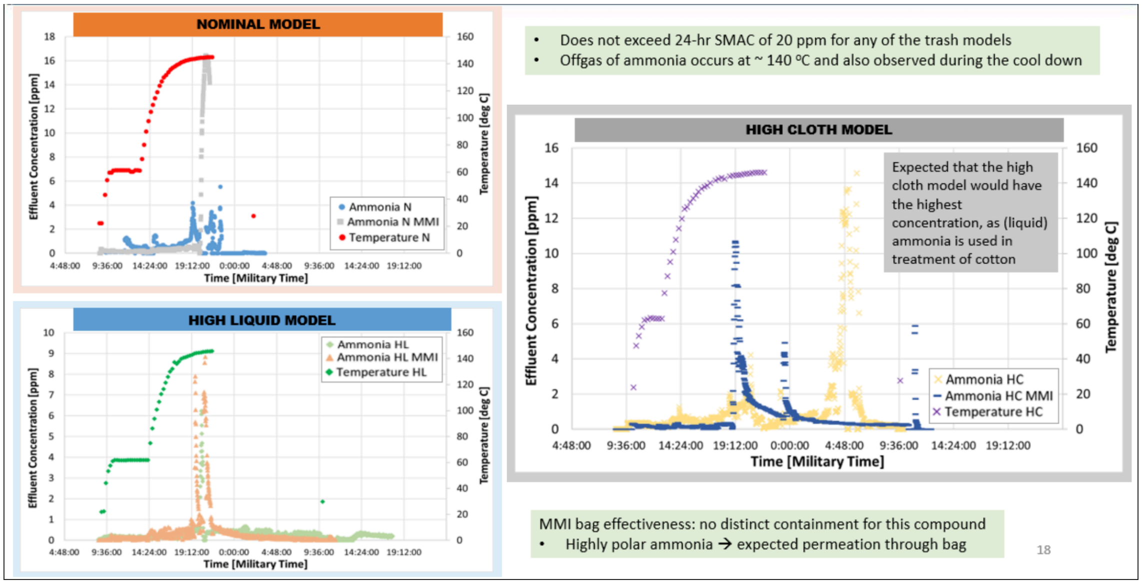

Figure 8. The four graphs showing the ammonia grab and continuous analytical results.

5. *Water Vapor*

These water vapor results represent the gas effluent stream after the liquid water collection system (after the TEC), and after the chiller and cold trap (Figure 2). This does not represent the total water volume coming off of the trash. The TEC and chiller are used to remove as much water as possible from the trash. The cold trap before the FTIR prevents liquid water from entering and damaging the FTIR.

Investigating water vapor from a "dry" effluent stream prevents interference of a "wet" gas stream. Venting to cabin requires a CatOx and its design must be able to treat a humid gas stream. Venting to VES requires the dewpoint of water vapor and other gases to be < 15.5 ˚C and to meet VES exhaust compatibility, in which water vapor is a compatible gas. The continuous results also provide insight into the behavior of water vapor outgassing quantity during the evolution of the HMC operation and its associated heating curve as it processes the various trash models.

From the continuous results, it can be seen that the MMI bag demonstrates water permeability. There is no considerable inhibition or resistance to water vapor from the bag material. The low temperature step provides a near constant release of water vapor for the nominal and high liquid models, Figure 9, while it is more variable in the high cloth model. Water vapor peaks at 140 ˚C, perhaps from the remaining or trapped water in the trash, or due to volatile gases laden with water vapor evolving at high temperatures.

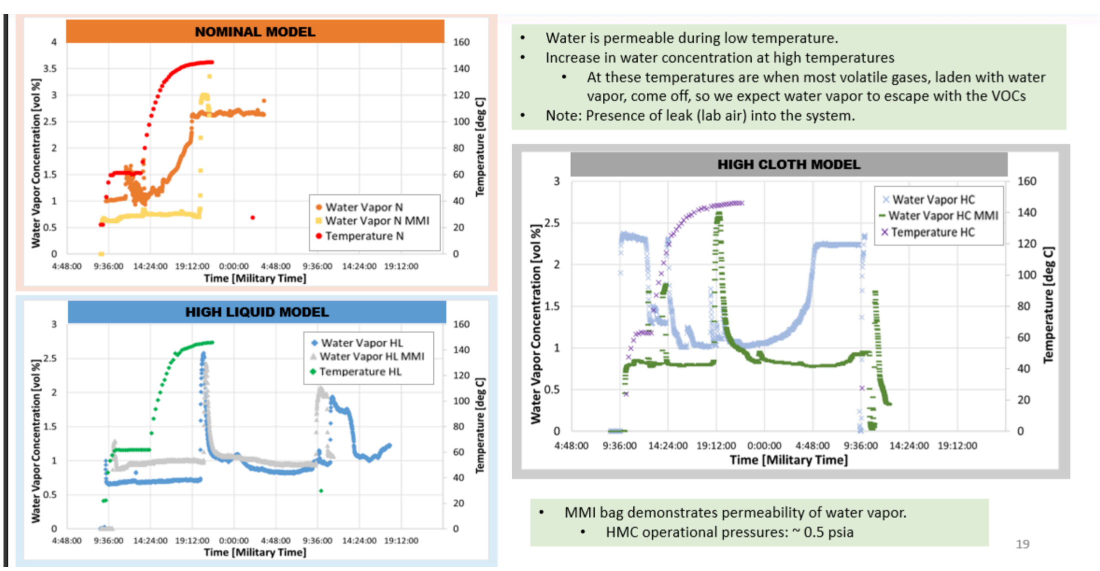

Figure 9. The graphs showing the grab and continuous results for water vapor.

C. Lessons Learned

There are many lessons learned from the gas collection and analysis methods during the HMC Gen 2 risk reduction campaign. The lesson learned are being implemented in future HMC test runs as well as in the designs of auxiliary system. A few of the lessons learned are listed here:

1) The method of packing the trash in the chamber can cause variability in off gassing. Gases can be trapped within pockets or inner regions of the tile and, upon heating and compaction, can result in sudden spikes in concentration.
2) A "dry" gas effluent stream produces better data than a highly humid stream since water vapor can cause sample interference.
3) Figure 10 shows the graph of ethanol in the grab and continuous samples. Here, grab samples collected at discrete points may not capture the maximum component concentration, in which sudden peaks in concentration throughout the process can be overlooked. While the grab sample gives us data on more components via GCMS, the reported concentrations may be under or overestimated depending on the sample collection point. On the other hand, the continuous sample provides real-time analysis, but it is limited by the amount of components we want to detect. An ideal sampling method would be an inline, continuous GCMS.

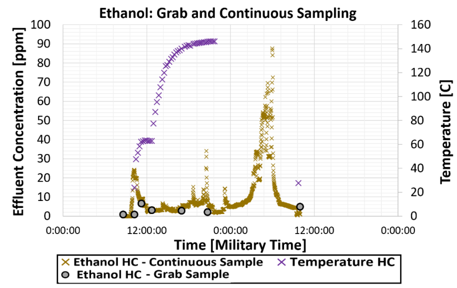

Figure 10. Graphs showing the ethanol in grab sample and the continuous sampling with the Gasmet FTIR.

D. Future Work

The HMC has a leak which resulted in lab air input into the gas effluent streams. The leaks must be characterized such that the contaminants external to the system can be accounted for.

Alcohols are contaminants of concern in the TCCS system. Therefore, all source of alcohol production (e.g. methanol, ethanol, and isopropanol) must be defined and reduce. If the source of alcohol in the individual trash components can be identified, those trash components could be eliminated from the trash input stream administratively.

Aspen Plus modeling and analysis will be done and its' goal is to model the vapor-liquid behavior of the gas effluent and evaluate scenarios in which compounds can condense. The VES venting option requires specific interface requirements. Therefore, azeotrope formation and reactivity of gas effluent compounds are to be investigated.

Evolved Gas Analysis (EGA) will be done on individual trash components and group of components to trace the offgas contaminants to the input trash. This will provide design options to remove certain components from the trash input model in order to prevent unwanted trash offgas contaminants. EGA methods use the thermogravimetric analysis (TGA) with FTIR, mass spectrometry (MS), or Proton Transfer Reaction (PTR) with MS.

This also leads into investigating a "benign" trash batch, in which the release and process of toxic effluent gases are mitigated by replacing those trash components with a benign replacement. For example, the carbon disulfide from purple nitrile gloves can be avoided if a different type of glove is used. We also plan to test the MMI bag solely under temperature to see if it contributes to off gassing.

VI. Conclusion

Throughout testing, we have improved our collection methods, modified the system configurations to accommodate proper sample collection, used different analytical methods to characterize the effluent stream, and learned that continuous monitoring is the better representation for the effluent stream characterization. Acrolein, carbon disulfide, ammonia, and water vapor show that contaminants can be traced back to the source of the individual trash components. In addition, the results will be used to optimize HMC operation and determined the best gas effluent management method.

Appendix A. Trash Models

General Category	HMC Batch Constituent	Moisture	Nominal (N) Model: Total mass	Nominal (N) Model: Component Mass/batch Required	High Cloth (HC) Model: Total mass	High Cloth (HC) Model: Component Mass/batch 500g Total Mass	High Liquid (HL) Model: Total mass	High Liquid (HL) Model: Component Mass/batch 500g Total Mass
		%	g/CM/day	g	g/CM/day	g	g/CM/day	g
Cloth	Cotton T-shirts	6.00%	173.3	98.51	868.17	230.94	173.3	87.34
	Towels	6.00%	76.1	43.26	381.23	101.41	76.1	38.35
Wet wipes	Huggies Natural Care Wet Wipes	70.00%	59.8	33.99	59.8	15.91	59.8	30.14
Dry Wipes	Dry lab. Chem Wipes	6.00%	29.9	17	29.9	7.95	29.9	15.07
Wet Disinfectant Wipes	Disinfectant Wipes	70.00%	4.6	2.61	4.6	1.22	4.6	2.32
Personal Hygiene	Nitrile Gloves	0.00%	23.5	13.36	23.5	6.25	23.5	11.84
	Shampoo on Towels	70.00%	7.3	4.15	7.3	1.94	7.3	3.68
	Toothpaste on Towels	70.00%	3.7	2.1	3.7	0.98	3.7	1.86
	PET (polyethylene terephthalate) plastic	0.00%	3.7	2.1	3.7	0.98	3.7	1.86
	Chewing Gum	30.00%	7.3	4.15	7.3	1.94	7.3	3.68
Paper	Computer Paper	6.00%	20.2	11.48	20.2	5.37	20.2	10.18
Duct Tape	Duct Tape	0.00%	3.8	2.16	3.8	1.01	3.8	1.92
Velcro	Velcro	0.00%	5	2.84	5	1.33	5	2.52
Food Packaging and storage	Bite Size Pouch	0.00%	31.8	18.08	31.8	8.46	31.8	16.03
	Thermo Pouch	0.00%	56.3	32	56.3	14.98	56.3	28.37
	Beverage Pouch	0.00%	18.3	10.4	18.3	4.87	18.3	9.22
	Septum	0.00%	8.2	4.66	8.2	2.18	8.2	4.13
	Septum Adapter	0.00%	6.2	3.52	6.2	1.65	6.2	3.12
	Rehydrateable Pouch	0.00%	64	36.38	64	17.02	64	32.25
	Overwrap (white laminate food packaging)	0.00%	69.3	39.39	69.3	18.43	69.3	34.93
	iron packs dessicant	0.00%	6.4	3.64	6.4	1.7	6.4	3.23
	BOB	0.00%	29.2	16.6	29.2	7.77	29.2	14.72
Sweat Solids	Sodium Chloride	4.00%	18	10.23	18	4.79	18	9.07
Food & Drink	Beef Patty	70.00%	8.94	5.08	8.94	2.38	8.94	4.51
	Scrambled Eggs	80.00%	8.34	4.74	8.34	2.22	8.34	4.2
	Frankfurter	80.00%	8.54	4.86	8.54	2.27	8.54	4.31
	Macaroni	10.00%	10.63	6.04	10.63	2.83	10.63	5.36
	Tortilla	20.00%	10.36	5.89	10.36	2.76	10.36	5.22
	Rice pilaf	80.00%	9.55	5.43	9.55	2.54	9.55	4.81
	Sweet & Sour Chicken	80.00%	16.82	9.56	16.82	4.47	16.82	8.48
	Cream Spinach	80.00%	5.19	2.95	5.19	1.38	5.19	2.61
	Orange-Pineapple Drink	97.00%	16.06	9.13	16.06	4.27	53.47	26.95
	Apple Cider Drink	97.00%	15.88	9.02	15.88	4.22	52.87	26.64
	Pineapple Drink	97.00%	16.35	9.29	16.35	4.35	54.44	27.44
	Dried Apricots	50.00%	4.17	2.37	4.17	1.11	4.17	2.1
	Peaches	75.00%	9.55	5.43	9.55	2.54	9.55	4.81
	Macadamia Nuts	2.50%	6.06	3.44	6.06	1.61	6.06	3.05
	Strawberries	90.00%	0.61	0.34	0.61	0.16	0.61	0.31
	Vanilla Pudding	80.00%	6.67	3.79	6.67	1.77	6.67	3.36

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