

# Generation 2 Heat Melt Compactor Development

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NASA has been developing a waste management device for human space exploration missions called the Heat Melt Compactor (HMC) as part of the Advanced Exploration Systems (AES) Human Spaceflight Logistics Reduction and Repurposing (LRR) project. Human space missions typically generate trash with a quantity of plastic that is twenty percent or greater by mass. The plastic rich trash contains valuable water entrained in food residue and sanitary wipes blended with paper, duct tape, rubber gloves, and other sundry trash items. The Heat Melt Compactor was designed to provide high trash volume reduction, microbial stabilization, and resource recovery including water and potentially radiation shielding material from the trash. The Heat Melt Compactor dries, compresses, and encapsulates the waste inside the plastic producing a tile that has the consistency of hard plastic. This paper provides an overview of the engineering efforts associated with development of a second generation HMC. The Gen 2 HMC is a ground based prototype unit that has been designed to function within the physical and environmental constraints of an International Space Station (ISS) Express Rack and serves as a precursor to developing proto-flight hardware.

## Nomenclature

<i>ARC</i>	=	Ames Research Center
<i>AES</i>	=	Advanced Exploration Systems
<i>CFM</i>	=	Cubic Feet per Minute
<i>DMLE</i>	=	Double Middeck Locker Equivalent
<i>HMC</i>	=	Heat Melt Compactor
<i>ISS</i>	=	International Space Station
<i>LRR</i>	=	Logistics Reduction and Repurposing
<i>MCTB</i>	=	Multipurpose Cargo Transfer Bag
<i>SMAC</i>	=	Spacecraft Maximum Allowable Concentration
<i>WRS</i>	=	Water Recovery System
<i>COS</i>	=	Contaminant Oxidation System
<i>MTL</i>	=	Moderate Temperature Loop
<i>I/O</i>	=	Input/Output

## I. Introduction

The Heat Melt Compactor, HMC, is a waste management technology that is under development by the NASA Exploration Life Support Project for human space explorations ranging from low earth orbit to Mars and beyond. Currently there are no waste management practices that are being implemented in the space environment other than manual compaction of waste into a plastic bag that is then sealed with duct tape. The current practice does

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not recover critical resources such as water, does not prevent the growth of potentially harmful microbiological pathogens, and provides only limited volume reduction.

The HMC is a device that compacts, dries, and then encapsulates wastes containing plastic into a microbiologically safe tile<sup>1,2,3,4</sup> that can be safely handled by the crew. The resulting tile is dry and has the consistency of solid plastic. The shape of the tile is predictable and maximizes the efficiency of storage volume. The tiles are high in hydrogen content from the plastic, food, and cloth components (hydrogen is known to be a preferred material for radiation shielding) and it is proposed to use the tiles to provide additional radiation shielding. The HMC can process both wet and dry trash. Space missions generally generate trash with a substantial amount of plastic (generally 20% or greater by mass). The trash also contains water trapped in food residue and paper products and other trash items. The water that is driven off the waste can be collected and returned to the Water Recovery System. Mission benefits analysis of the HMC has shown that it has substantial potential benefits for exploration missions including increased habitable volume, water recovery, radiation shielding, and improvement in the hygienic aspects of trash handling and storage.<sup>5</sup>

The first generation Heat Melt Compactor (HMC), known as Gen 1, developed by NASA Ames Research Center (ARC) over a number of years,<sup>6,7,8,9,10,11,12,13,14,15,16</sup> has served as a proof of concept prototype to demonstrate the capability of compressing the waste, drying it to recover water, and melting the plastic to encapsulate the compressed trash. The resulting waste tile represents an approximately ten-fold reduction in the volume of the initial trash loaded into the HMC.

The second generation Heat Melt Compactor, known as the Gen 2 HMC, is a ground based test demonstration unit that is currently under development as part of the Advanced Exploration Systems (AES) Logistics Reduction and Repurposing (LRR) Project. The Gen 2 HMC will serve as a precursor to a flight demonstration unit that will be demonstrated for use in an Express Rack on board the International Space Station (ISS).

The primary differences between the Gen 1 HMC and the Gen 2 HMC are as follows:

- The Gen 1 HMC produces round trash tiles while the Gen 2 HMC produces larger 9" x 9" square tiles with rounded corners so that the tiles can be stored within the multipurpose cargo transfer bag for storage. Developing and testing a square ram head with rounded edges introduces additional design challenges.
- The Gen 2 provides extensive data acquisition, semi-autonomous operation and control system safety logic which did not exist in the Gen 1 HMC.
- The Gen 2 hardware is constrained to the geometry of an ISS Express Rack and the resources available such as power and heat rejection. The Gen 2 has also been designed to address ISS imposed constraints such as acoustic profile. These attributes were not addressed in the Gen 1 HMC.
- The Gen 2 HMC employs the use of stainless steel for the compaction chamber and ram with nonstick coatings applied to the surfaces in contact with trash. The Gen 1 HMC used uncoated aluminum surfaces on which sticky components of the trash accumulate.
- The Gen 1 HMC uses pneumatic pressure on the back of a piston-ram to provide compaction pressure and displacement. The Gen 2 HMC uses a mechanical scissor jack to provide mechanical compaction pressure and to enable piston-ram position control. Position control means that the Gen 2 will be able to move the ram to specified positions during the compaction process. This feature is intended to enable the ability to minimize squeezed out water and entrapped water.

## II. Requirements

The goal of the Gen 2 development effort is to demonstrate the feasibility of compacting trash to a reduced volume, sterile, stable, and dry tile that can be used for radiation shielding while operating within the resource constraints of the ISS Express Rack environment. Specifically the operational requirements are as follows:

- The dimensions of the flight like portions of the Gen2 HMC shall conform to those of a double middeck locker equivalent, DMLE, Express Rack Payload (~22x22x18 inches)
- The Gen 2 HMC shall be designed to function using no more than 500 Watts.
- The Gen 2 HMC shall be designed to operate within avionics air cooling limits for a double middeck locker equivalent. (~320 Watts)
- The Gen 2 HMC shall be designed to operate within the ISS acoustic limits.
- The Gen 2 HMC shall be designed to operate under human factor limits for ISS.
- The Gen 2 HMC shall be designed to process a tile (produced by processing approximately 810 cubic inches of hand compacted trash) within a 14 hour operational cycle.

Since resources are a valued commodity for any manned space habitat or vehicle, the system has been designed with an emphasis on increased thermal efficiency, reduced power needs, and minimum overall mission cost. The Gen 2 HMC architecture has also taken into consideration using only avionics air for cooling instead of relying on the ISS Moderate Temperature Loop, MTL, as this resource is highly valued for science payloads.

A tile size of 9" x 9" x ~1" was chosen for the Gen 2 HMC so that tiles could be adapted to fit in a Multipurpose Cargo Transfer Bag (MCTB). The 9" x 9" tile size was also considered a realistic size for compacting trash since thermal analysis suggests that producing larger tiles may present a challenge given resource limitations of power for heating and avionics air for cooling the tiles within the prescribed 14 hour operational cycle.

One of the principal objectives of the Gen 2 unit is to demonstrate the feasibility of packaging the hardware within a DMLE while still providing operational flexibility as a ground test unit. Since the Gen 2 HMC unit will be used to better understand and evaluate the physics involved with melting trash while separating the water from the trash, there will be more control electronics and sensors than what would be expected in a flight unit. Hence, for the ground based Gen 2, much of the control electronics will be external of the HMC. In addition, specialty items unique to a microgravity environment such as an air/water separator are not included in the Gen 2 development effort.

## III. Design Description

The Gen 2 HMC has been designed to replicate to the extent practical, the system architecture, volumetric packaging, and hardware that would be used on a flight unit. The primary subsystems of the Gen 2 HMC are as follows:

- A. Main Compaction Chamber
  - i. Chamber Housing
  - ii. Compaction Chamber Actuator Assembly
  - iii. Compaction Chamber Sliding Lid Assembly
- B. Water Removal Subsystem
- C. Source Contamination Control Assembly
- D. Thermal Management
- E. Control Electronics
- F. HMC Structural Housing Assembly

Figure 1 shows a schematic of the overall layout of the Gen 2 HMC. Figure 2 shows the physical layout of the actual hardware.

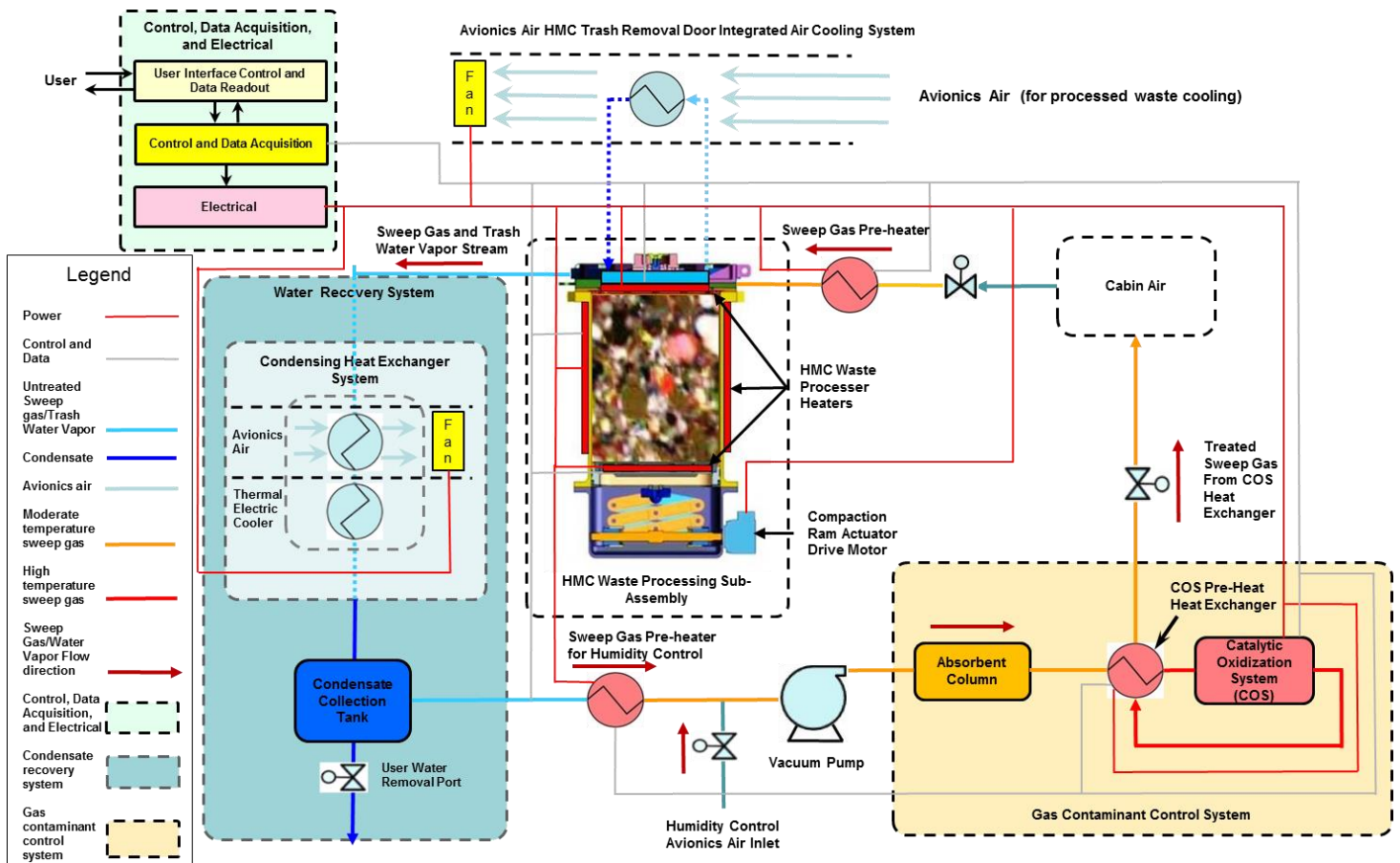


Figure 1. Gen 2 Heat Melt Compactor Schematic

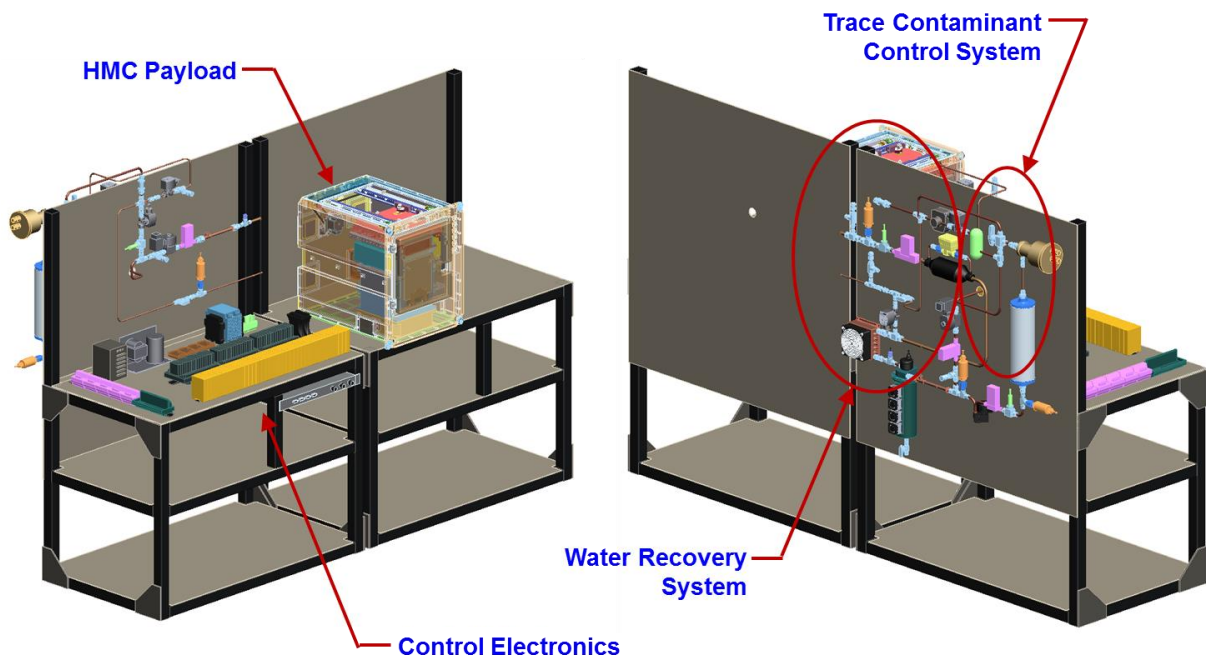
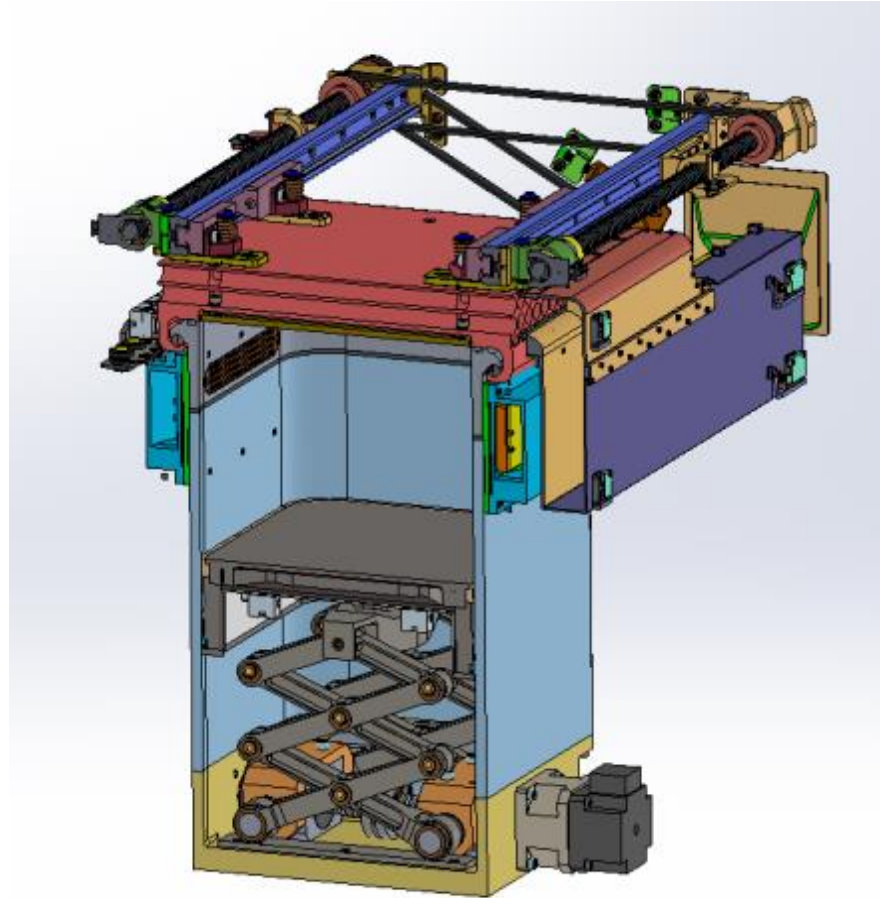


Figure 2. Gen 2 Heat Melt Compactor Hardware Layout

## A. Main Compaction Chamber

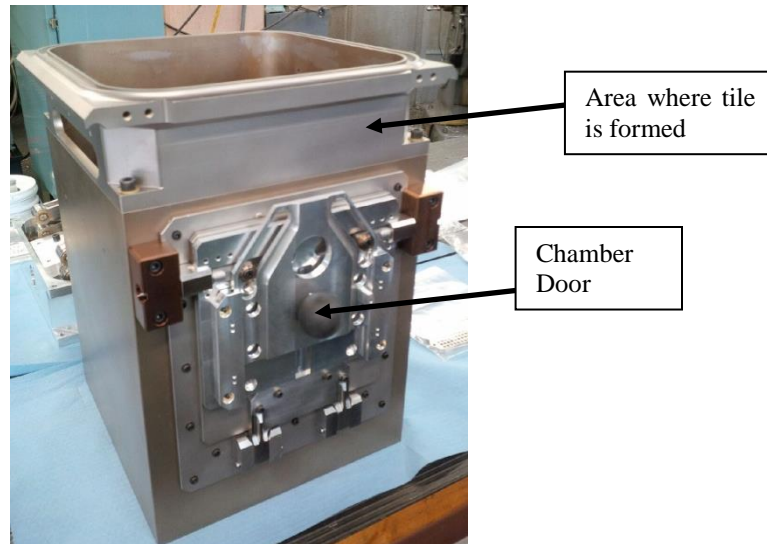
The main compaction chamber is made up of three sub assemblies shown in cut away view in Figure 3. Each sub assembly is modular to facilitate potential upgrades and modifications during the test and evaluation phase of the project.



**Figure 3. Cut Away View of the Gen 2 HMC Compaction Chamber**

### i. Compaction Chamber Housing

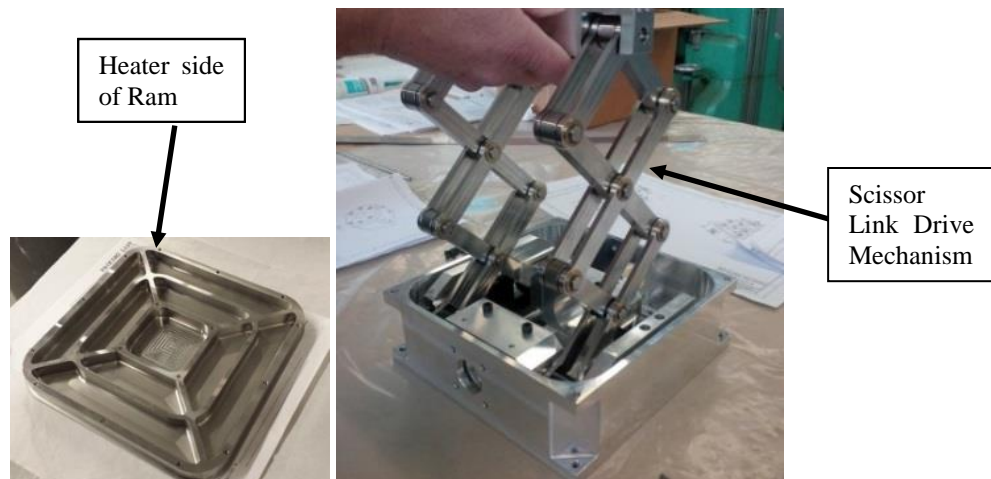
The Main Compaction Chamber structural elements are all made out of stainless steel to provide a rigid structure that can withstand differential pressures during the compaction cycle. All stainless steel surfaces of the chamber that will come into contact with the trash are coated with a Nedox® nonstick coating made by General Magnaplate. It is expected that the coating will help minimize the accumulation of caramelized residual food and waste products on the walls, which could impact the ability the HMC to maintain internal pressures. Tests have been conducted showing that the coating reduces the forces needed to separate processed tile material from metal surfaces. Thus it is expected that the coatings will facilitate lower forces for removal of the compacted trash tile from the chamber. Figure 4 shows the compaction chamber housing during fabrication.



**Figure 4. Compaction Chamber Housing**

## ii. Compaction Chamber Actuator Assembly

The Compaction Chamber Actuator Assembly uses a scissor linkage driven by two ball screws and is designed to deliver ~55 psi of pressure to compress the trash. The brushless DC stepper motor provides precision control of the location of the ram head. Figure 5 shows the Actuator Assembly during fabrication.



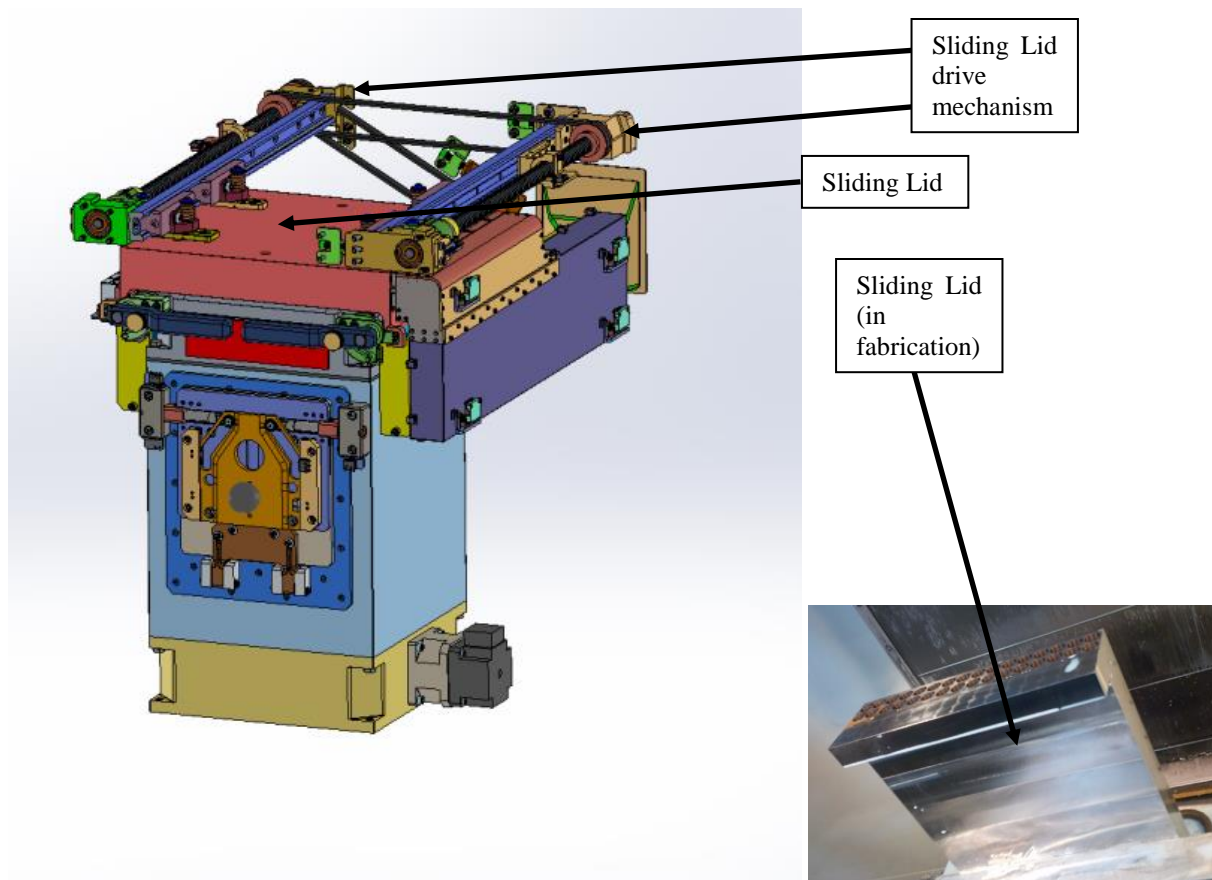
**Figure 5. Compaction Chamber Ram and Actuator Assembly**

## iii. Chamber Sliding Lid Assembly

Heaters on the Ram Head and the top of the chamber melt the plastic in the trash while boiling off the water in the trash. Once the trash is compacted, levers on the chambers sliding lid assembly are manually released and the lid is retracted with the aid of a motorized ball screw assembly. The trash tile is pushed out of the chamber by the ram head and actuator assembly.

The front door of the HMC is opened and the trash tile is then pushed forward and ejected by the sliding lid assembly approximately 1-2 inches. Figure 6 shows the Sliding Lid Assembly drive mechanism and the Sliding Lid during fabrication.





**Figure 6. Compaction Chamber Sliding Lid Assembly**

## **B. Water Removal Subsystem**

The purpose of the water removal subsystem is to capture and reclaim the water from the trash that has been heated and converted into steam. This is accomplished by partially compressing the trash and heating it using a series of heaters on the ram face, chamber lid, and wall heaters. Steam is ejected through a baffled chamber designed to capture any water droplets that inadvertently get pushed through the vent holes during compaction.

The water removal system can operate anywhere from atmospheric pressure down to a partial vacuum of 3 psia. Steam is condensed using a fin tube heat exchanger which utilizes avionics air for condensing the steam. A secondary heat exchanger powered by thermal electric coolers condenses out the remaining moisture and collects it in a reservoir. The trace contaminant control system is located downstream of the water removal system and requires a humidity level of under 60% relative humidity to operate.

The water collection system is currently designed for a one-g environment. A separate effort is underway to develop an air/water separator which can meet the operational requirements for the HMC operating in a microgravity environment.

## **C. Source Contaminant Control System**

As trash is heated in the compaction chamber various volatile compounds are released into the effluent gas stream along with vaporized water. After the water is condensed some volatiles are left in the off gas, and have to be destroyed before releasing the off gas to the cabin. These compounds include aldehydes, ketones, furans, alcohols, aliphatic hydrocarbons, aromatic hydrocarbons, and sulfides that are released from food and other waste during heating and water boiloff.<sup>17, 18</sup> Processing of foam produces a somewhat different mix of volatile compounds in the off gas compared to general trash, although many of the volatiles from foam are also present in general trash

volatiles. With few exceptions the concentrations of volatiles in the foam off gas were not greatly different from the concentrations in trash off gas. Exceptions include carbon disulfide and toluene, which were present in significantly higher concentration in general trash off gas as compared to foam off gas. One foam, Minicel foam, produced significantly higher concentrations of carbon monoxide as compared to all the other foams and the general trash.<sup>19</sup>

The purpose of the Source Contaminant Control System is to reduce the concentrations of these volatile compounds from the effluent gas stream to levels that meet Spacecraft Maximum Allowable Concentration (SMAC) limits to comply with ISS cabin air quality requirements. The two primary components of the Source Contaminant Control System are the catalytic oxidizer and the adsorption bed. The catalytic oxidizer oxidizes hydrocarbons that are present in the gas stream.<sup>17</sup> The adsorbent bed is located upstream from the catalytic oxidizer primarily to prevent sulfur poisoning of the catalyst. Key adsorbent bed design compounds are carbon disulfide and 2-chloroethanol. Dichloromethane is used as the model compound for 2-chloroethanol in the bed sizing calculations.

#### **D. Thermal Management**

The HMC relies on avionics air cooling from the rear of the Express Rack. There are two sets of air inlet and outlet ducts available for use by the HMC. Each duct set allows for up to 15 CFM with an air inlet temperature of 29.4 C and outlet temperature of 48.9 C thus allowing for approximately 157 watts of heat removal per duct. As the unit has two avionic duct sets available, approximately 314 Watts are available for heat removal. Thermal management is required for three distinct purposes in the Gen 2 HMC:

- a. Removal of heat from the trash tile after the trash has been compressed and melted.
- b. Removal of waste heat from the water recovery system as water is removed from the trash.
- c. Waste heat from support hardware such as the internal computer, fans, pumps and motors.

To remove waste heat from the trash tile, a centrifugal blower is used to draw avionics air across the top lid of the compaction chamber. The exit duct from the chamber was designed to minimize pressure losses in order to reduce the acoustic output from the blower and duct. Residual waste heat from the computer, fans, pumps, motors and solenoid valves is removed by avionics air being drawn in by the blower used for cooling the tile. Smaller spot fans may be used in specific locations if there is insufficient airflow detected during the testing phase of the project.

Operationally, the trash undergoes several stages of processing. First, the trash undergoes low temperature heating of 70-100 C to heat the trash and boil off most of the water that is loosely bound to the trash. This stage takes 2-4 hours. The second stage of the process dries and sterilizes the trash at an elevated temperature of approximately 150 C for 3-5 hours. The final stage is the cool down of the trash tile. Thermal Analysis predicts cool down of the trash tile to a safe touch temperature of 44 C (112 F) will take approximately 5 hours. As shown in Figure 7, the total cycle including heating, sterilizing, and cooling of the trash tile has been calculated to be approximately 12 hours.



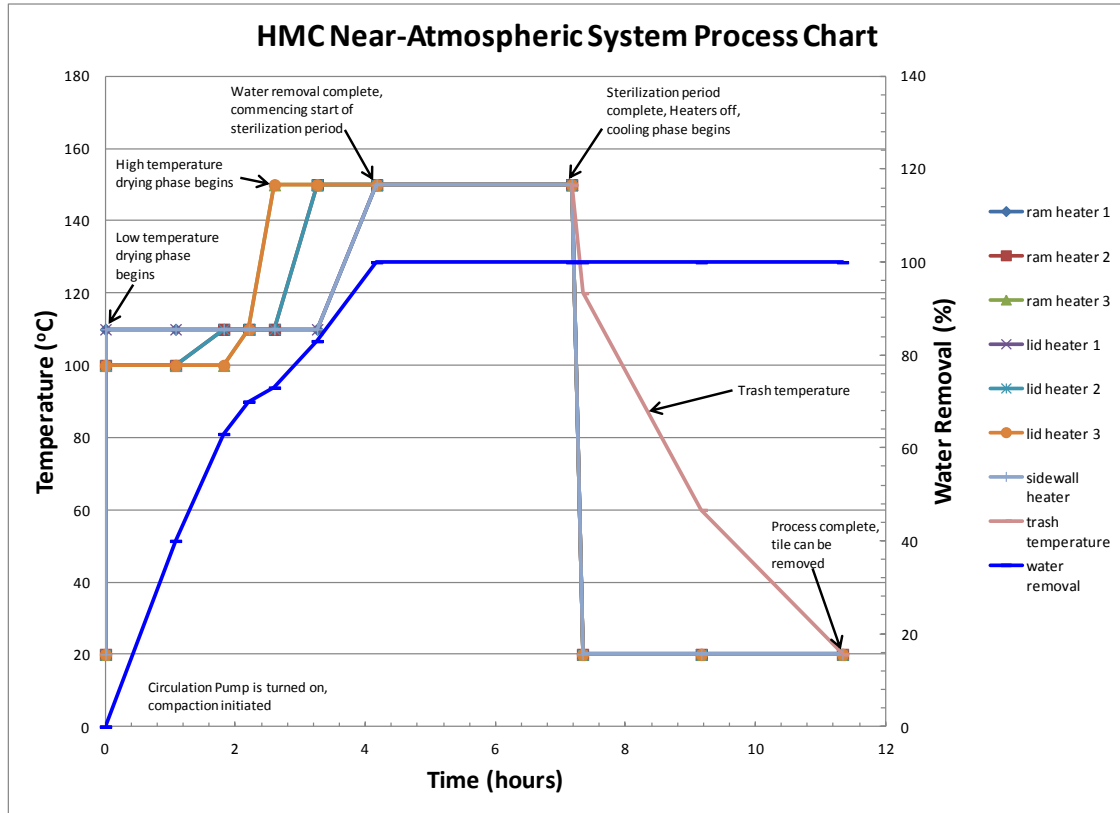


Figure 7. Calculated Thermal Profile of Processing Cycle

## E. Control Electronics

The control electronics system for the Gen 2 HMC serves two functions. The control system's primary function is to control a normal processing cycle consisting of partially compacting the trash, heating the trash, removing the water in the trash by converting it into steam, fully compacting the trash, and finally cooling the trash tile. The secondary function of the control system is to support a variety of experimental heat melt process variations in order to optimize the removal of water from the trash while preventing the overheating of plastic which could flow into the steam exit ports of the chamber and block the steam vents. Additionally the control system will be used to enable several hazard controls to prevent inadvertent operation that could cause crew member injury or hardware damage.

The requirements for the control system include:

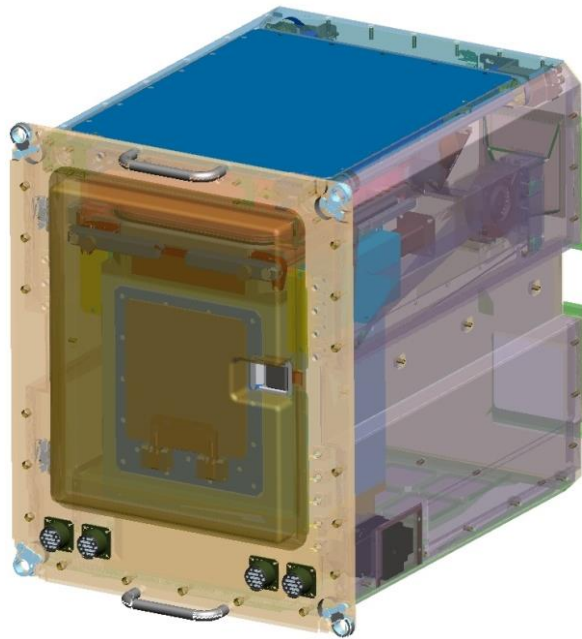
- Flight compatible controller and I/O (Input/Output) cards
- Remaining components and layout for testing in a lab environment
- Support Water Recovery System (WRS) near atmospheric operation
- Support WRS sub-atmospheric operation
- Provide hard-wired safety logic for personnel and system safety
- Support unattended operation
- Provide data logging of essential data
- Provide semi-automatic operation
- Provide user-friendly graphical user interface on separate computer
- Enable real-time operation
- Provide software support for problem recovery and maintenance

An external laptop computer is used to program the functions of the Gen 2 HMC. The laptop interfaces with a UEISIM 600 I/O chassis which runs Simulink applications that drive I/O boards. As the Gen 2 HMC is used as a

laboratory prototype, the electronics will be mounted external to the Gen 2 HMC to accommodate additional sensors that would not be included for a flight unit.

#### **F. HMC Structural Housing Assembly**

One of the objectives of building the Gen 2 HMC is to demonstrate the viability of packaging the hardware into a flight like configuration. The hardware has been designed to fit within a double middeck locker equivalent payload housing. The outer shell structure would have the same interfaces to demonstrate compatibility with an ISS Express Rack. The outer shell can be seen in Figure 8. The HMC hardware is mounted on an internal aluminum chassis that attaches to the outer shell with slides to allow for maintenance and repair. The Water Removal Subsystem and the I/O boards that control the Water Removal Subsystem will have a majority of its components located external to the structural housing to allow for experimental flexibility as shown in Figure 2.



**Figure 8. Heat Melt Compactor Structural housing**

### **IV. Conclusion**

The Gen 2 HMC represents a substantial evolution from the existing laboratory based Gen 1 HMC which served as a proof-of-concept to demonstrate that trash could be compacted into a sterile and physically stable trash tile that could someday be used for radiation shielding. It is estimated for a one year 4 person deep space mission, the HMC could process ~1100 kg of trash, provide ~800 kg of tiles for radiation shielding, recover ~300 kg of water, and increase the habitable volume by 8 m<sup>3</sup>.<sup>1</sup> The Gen 2 HMC will serve as a laboratory model that can demonstrate the technical feasibility of packaging flight like hardware into an acceptable payload volume for both ISS and future deep space habitats. As power is a limiting factor for both the ISS and future deep space vehicles, proving the technology used for the HMC can be operated with minimal external resources such as power and cooling is critical to the success of a follow-on flight unit that would be used on the ISS.

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