Development of an Adsorption System for the Trash Compaction Processing System designed for operation in the International Space Station Express Rack

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A water recovery system that utilizes adsorption to work with the Trash Compaction Processing System, formerly known as the Heat Melt Compactor, is being designed at NASA Ames Research Center as an option to current state of the art micro-gravity water management systems and contaminant control systems used in space. The adsorption system will be used in conjunction with the International Space Station Vacuum Exhaust system to avoid both the complexities of gas liquid phase separation in micro-gravity and venting of Trash Compaction Processing System effluents to the spacecraft cabin. The adsorption system will allow the water and gaseous effluents generated during the Trash Compaction System operation to be removed in a matter that meets the Vacuum Exhaust System venting rate requirements. The Trash Compaction Processing System is planned to fly as a Technology Demonstration on the International Space Station in the space station EXPRESS Rack facility. This paper describes the trade space that the adsorption system must operate in using the EXPRESS Rack facilities resources including the use of the Space Station Vacuum Exhaust System. Also described in this paper are design solutions to allow the adsorption system to function within the Express Rack and Vacuum Exhaust System Parameters.

Nomenclature

AdWRS = Adsorption Water Recovery System
ARC = NASA Ames Research Center
BAA = Broad Area Announcement
CFD = Computational Fluid Dynamics
COTS = Commercial Off The Shelf

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HMC = Heat Melt Compactor
ISS = International Space Station
Pa = Pressure units, Pascal
P_{sat} = Saturation Pressure
SG B = Silica Gel Beads
TCPS = Trash Compaction Processing System
T_{dew} = Dewpoint Temperature
VES = ISS Vacuum Exhaust System

I. Introduction

WASTE management is a critical element of the life support element of human space exploration missions that has largely lagged behind the development of the other two fundamental life support areas of focus; air revitalization, and water recovery technologies. NASA has supported an ongoing effort to develop a technology currently called the Trash Compaction Processing System that can process a wide range of trash such as food packaging including unfinished food, clothing, hygiene wipes, sundry items such as tape and many other waste items[1].

Currently the only waste management hardware and practices that are actively used on the International Space Station and other human space flight missions are the toilet to process human waste and the placement of trash into plastic bags that are then wrapped in duct tape to maintain and enhance compaction. The Trash Compaction Processing System (TCPS), formerly known as the Heat Melt Compactor, melts and compacts trash into small, dense, and rigid tiles that are easy to manage and minimize required storage space for trash[2]. As heat is applied to the trash the water is driven off removing water that microbes need to survive and also the heat kills many of the microbes in the trash rendering it innocuous. The water that is removed can be recovered to reduce the amount of resupply needed for a missions such as ISS and also advanced life support missions beyond low earth orbit. For missions beyond low earth orbit, a substantial savings can be gained by recovering water from waste as the launch costs can be up to an order of magnitude greater than launches to low earth orbit.

A water collection system that uses adsorbents as an option to current state of the art micro-gravity water management systems and contaminant control systems is being explored at NASA Ames Research Center called the Adsorption Water Recovery System (AdWRS). The AdWRS is an option for water collection that would eliminate the need for microgravity phase separators and other microgravity liquid management devices within the trash management system. The AdWRS may utilize the International Space Station Vacuum Exhaust System (VES) to avoid having to vent gaseous effluents into the spacecraft cabin and meet the stringent contaminant control requirements associated with such a practice. This paper details the efforts to develop the AdWRS that will work in tandem with the TCPS.

II. Operational Parameters

The TCPS operation will consist of four primary phases which are the Initial Purge Phase, the Trash De-watering Phase, the Trash Melting and Sterilization Phase, and the Process Trash Cooling and AdWRS Desorption Phase. The process starts by purging the air in the TCPS and AdWRS to the ISS VES. There may be some flash boiling that will occur in the system during the Initial Purge Phase. After the TCPS and AdWRS system has been purged, the trash dewatering phase will commence in which the water will be vaporized then adsorbed onto the sorbent. After the water has been removed from the trash, the trash will be heated to its final melting and sterilization temperature at which it will remain until the sterilization heat soak period has been completed. The final stage of the process includes the simultaneous cooling of the trash and the removal of the water from the sorbent via desorption.

The proposed adsorption system must adhere to a strict set of requirements for venting into the VES. The ISS documents SSP 52000[3] and SSP 57000[4] detail the VES requirements. The TCPS system will be housed in the ISS EXPRESS rack and will also need to adhere to requirements for that system as described in the SSP 52000 and SSP 57000. The application of adsorbents to the proposed technology within the EXPRESS Rack and VES parameters present a significant design challenge and this paper details those challenges and solutions that were devised to make this concept operable.

A. ISS EXPRESS Rack and VES requirements pertinent to the TCPS and AdWRS

The requirements of both the EXPRESS Rack and VES system pertinent to the TCPS AdWRS are listed below.

- **EXPRESS Rack Resources** *(Per Rack Space)***:**
  - Power: 500 Watts
  - AAA cooling air:
    - Flowrate: 15 scfm +/- 3 scfm per single rack space
    - Inlet Temperature (for cooling): 18.3ºC to 29.4ºC
    - Outlet Temperature Max: 48.9ºC
    - Approximate cooling rate: 200 Watts
  - EXPRESS Rack volumes:
    - Single rack space: 0.06 m^3
    - Double rack space: 0.12 m^3
- **VES:**
  - Gaseous effluent allowable temperature range: 16ºC to 45ºC
  - Gaseous effluent maximum dewpoint: 15.5ºC
  - Effluent composition limits (currently under study because not all items generated during process are in the current VES acceptable gas component list)
  - VES Worst Case Flow Rates:
    - $5.230\text{x}10^{-3}$ kg/min and 66.66 Pa for 1 minute
    - $1.658\text{x}10^{-4}$ kg/min and 10.67 Pa for 5 minutes
    - $6.953\text{x}10^{-8}$ kg/min and $23\text{x}10^{-3}$ Pa for 15 minutes

Initial Purge Phase:

The initial system purge will remove air that is in the TCPS and AdWRS system. The total internal volume of the combined TCPS and AdWRS system is small enough that initial gases in the system will be able to vented in a manner that fits within the VES Venting profile. The challenge that is anticipated during the initial purge phase is the entrainment of liquid water in the vented airstream in combination with water vapor resulting from flash boiling as the system pressure is reduced. Typically when flash boiling occurs, the water droplets are carried downstream into hardware that is sensitive to liquid water.

The current TCPS program requires that the system be able to process 2.2 kg of trash per day with a desired goal of 4.4 kg per day. The TCPS program requirements states that the trash be based on the current "nominal" waste model that has been used for Heat Melt Compaction studies at NASA Ames Research Center. The nominal waste model contains approximately 20% water. The amount of water that could be evaporated during the purge phase under the conditions specified would be approximately 2% of the total not including entrained water droplets. The amount of water droplets entrained in the water vapor is difficult to predict but can be significantly higher than the water vaporized during the initial system purge. The amount of entrained water is dependent on the state of water i.e. is the liquid adhering to the surface of the trash or is it tightly bound in items such as food. Analysis needs to be performed to determine the total quantity of water that is removed from the trash during this phase in order to assess proper methods of capture to protect the adsorbent.

Trash De-watering Phase:

After the initial purge of the TCPS system has completed, a valve will be closed isolating the AdWRS process gas outlet from the VES. Once the TCPS has been isolated from the VES, the trash will be heated driving water off the trash which will be captured by the adsorbent. The de-watering phase consists of two phases; a low temperature phase and a subsequent high temperature phase. The selection of the most effective temperature to perform the low temperature portion of the de-watering phase is still a subject of study but the temperature range of interest is between 25ºC to 30ºC. The primary reason for boiling off the water at the previously mentioned temperature range is to produce a clean vapor stream. If it is found that the temperature range specified is not high enough, then it will be required that the de-watering temperature be raised. Raising the temperature will increase contaminants in the vapor stream. The increased temperature will have to be reduced to a temperature that allows acceptable performance of the adsorbent. Reduction of the temperature of this vapor stream will be accomplished by use of a heat exchanger

In addition to maintaining the temperature of the vapor leaving the trash, the AdWRS must also be maintained at a temperature low enough for the adsorbent to function efficiently (not more than 30ºC). Also, it is important that the process pressure be low enough to prevent water from condensing before entering the AdWRS.

Ideally the combined TCPS and AdWRS would be leak free and no noncondensibles would be released or produced during the process. A leak free system would allow the system pressure to be maintained solely by the removal of heat being generated from the adsorption of water vapor. The reality is that the TCPS and AdWRS will not be leak free and that the system must be purged periodically to bring the process pressure back within the required range for AdWRS operation. In order to be able to maintain the correct process pressure, the conditions within the AdWRS must be maintained in a manner to meet VES requirements. The AdWRS system must always keep the dewpoint at 15.5ºC or less and the gaseous effluent temperature between 16ºC to 45ºC

Trash Melting and Sterilization Phase:

During the trash melting and sterilization phase, the trash will be raised to the final process temperature, which is 150ºC. The trash will remain at that temperature for a period of time that meets Dry Heat Sterilization protocols for that particular temperature.

One issue that has been observed during heat melt compaction tests is that not all of the water in the trash is removed during the lower temperature phase of the process. It is theorized that the reason for this is that the water remaining in the trash after the low temperature water removal phase has completed is tightly bound or trapped in materials such as food items. The food items hold water in its structure and it is assumed that the water is released from these items as the vapor pressure of the trapped water is increased during heating. The increase in vapor pressure ruptures the structure that the water is bound in. The water removed at higher temperatures is dirty.

Two options for managing the water that is removed at higher temperatures are described below.

One option is to adsorb the water vaporized at high temperatures after passing through a heat exchanger to cool water vapor down to a temperature that is within the range at which the adsorbents will perform effectively. The drawback of using this method is that the adsorbent will be contaminated by the dirty waste stream that results from processing at the higher temperature. It is not currently known how this contamination will affect the performance and longevity of the adsorbent. This will be investigated after the AdWRS system is built.

The next option is to vent the higher temperature water vapor directly into the VES. The primary issue with this is exceeding the allowable VES venting rates and the possible condensation of volatiles in the VES. Studies are being conducted at NASA Ames Research Center to determine what volatiles are off-gassed from the trash and the effect of the different components on dew points of the combined effluent gas. Application of this method requires a heat exchanger to cool the waste stream below the maximum allowable VES effluent temperature of 45ºC.

After the water is removed from the trash, volatiles will still be generated during the melting and sterilization process. It is currently assumed that the quantity of volatiles generated during the process will be small and can be vented directly to the VES and will be below the threshold that would trigger the VES Rack Isolation Valve from closing and isolating the TCPS/AdWRS from the VES. This stage of the process will also require a heat exchanger.

Desorption Phase:

After the adsorption process is complete, the water will be removed from the adsorbent. Different options for how to manage the desorption process have been conceptualized. A final decision of what option to implement will be based on the ability to meet the VES requirements regarding the allowable rate of venting and the contaminant level in the waste stream.

At the start of the investigation into the use of adsorbents to collect water vapor produced in the TCPS process, it was thought the most of the water could be boiled off of the trash at temperature ranging from 20ºC to 25ºC. The hope was that the water vapor would be clean enough to be diluted with cabin air and released into the cabin. Testing has not been performed yet to determine the quality of water boiled off the trash at the previously specified temperature range. The lower temperature range of most testing on the HMC system at Ames has been greater than 40ºC. In addition to determining the quality of water released at that temperature, the percentage of water in the trash that can be boiled off at that temperature needs to be investigated. If the water removed at the lower temperature proves clean enough to vent back into the spacecraft cabin, the amount that must be vented into the VES will be reduced.

If it is found that the water removed at lower process temperatures is not clean enough to vent to cabin, it must be vented into the VES. The use of adsorption allows greater control over how the water is vented to the VES. The VES is used by multiple experiments and the rate at which each individual can vent is limited by the total amount of effluent being vented into the system. The application of sorbent will allow the delay of the desorption process adding more flexibility with scheduling the use of that limited resource. The issue with desorbing into the VES is that it would not fit into the VES venting profile and would need to get a waiver to allow it to do so. The venting profile of the AdWRS is constrained by physics and the ability to change it to try to fit into the VES standard profile is limited. It is not clear if the AdWRS venting profile can be adjusted enough to receive a waiver for use on VES. Testing of the AdWRS prototype will provide a better understanding of the operational limits of the system.

Another possibility that could provide a solution to the venting rate issue would be the division of desorption period into smaller segments with each segment being sized to fit into an acceptable venting profile for use in the VES. Due to the limitations imposed by the use of the VES, it is likely that the TCPS will not be able to be utilized on a daily basis.

B. Parameters imposed by use of adsorbents and the effects of interdependency on bounding conditions

The TCPS AdWRS must operate within physical boundaries that pose a significant challenge to the design of such a system. The variables that define the bounding parameters are dependent on each other and are described below:

Ideally, the AdWRS will operate in a pure water vapor environment (no leakage of air into the system). This forces the application of low process pressures to prevent the dewpoint from exceeding the VES upper limit of 15.5ºC. The combination of low process pressure and lack of available cooling resource temperatures negatively impact the sorbents water retention capacity. The required process pressure creates a design challenge due to significantly increased pressure drops resulting from the increased volumetric flowrates that are a result of operating at low pressures.

The EXPRESS Rack cooling systems have the following limitations. The two primary EXPRESS Rack cooling systems, MTL and AAA, have a nominal cooling temperature between 20ºC to 22ºC which limits the effectiveness of the sorbent capacity to retain water. The AAA cooling system is the prime choice for the TCPS due to increased availability of AAA over the MTL. Also, both the available cooling systems nominal temperature limit places a lower boundary on the process pressure due to decreased water retention capacity of the adsorbent as the operating pressure decreases.

There are other factors that limit TCPS trash water removal rate. The rate of vaporization of water from the TCPS must be limited to prevent too high of a pressure drop across the AdWRS which could cause the VES dewpoint limit to be violated. Also, the rate of vaporization of water from the TCPS must also be limited to not overwhelm the AdWRS cooling system which is bound, as previously discussed, by the available ISS cooling resource quantities and temperature.

The maximum rate of removal of water from the trash is limited by the thermal resistivity of the trash. As the water is removed from the trash, the thermal conductivity of trash is reduced from approximately 0.16 Watts/meter/K to 0.12 Watts/meter/K. In addition to the reduction in thermal conductivity due to removal of the water component, the thermal resistivity of the trash is also reduced because the distance across the lower thermal conductivity dry trash to the higher thermal conductivity wet trash increases throughout the process.

In addition to the aforementioned constraints, the following conditions add challenges to designing the AdWRS and are listed below.

- The rate of vaporization needs to be high enough to allow the TCPS system to meet daily processing rate requirements
    - Increasing the quantity of the sorbent will allow it to maintain a higher rate of collection but due to the fixed amount of cooling capacity, the cooling per unit of volume of sorbent will decrease countering the effect of adding more sorbent.
    - Increasing the sorbent quantity will allow more water to be collected at the lower pressures but the amount of sorbent required may become prohibitively large and not fit within the EXPRESS Rack geometric constraints.
- Desorption of water from the adsorbent:
    - Ideally, all water in the waste would be vaporized at a temperature equal to or less than EXPRESS Rack cooling systems nominal temperatures and the water adsorbed is theorized to be clean
    - The clean water could then be desorbed and vented back into the spacecraft cabin
    - Previous testing has indicated that a significant amount of water remains in the trash at the end of the cool temperature portion of the water removal process and that the only way to remove the remaining water is to heat the waste up to temperatures at which the production of VOC becomes significant.
    - The higher temperature portion of the process requires a heat exchanger to cool hot gas to the temperature that fits within the both the adsorbent performance parameters and VES temperature requirements
    - The higher temperature gas is dirty making it not possible to vent it back into the cabin

- It is not possible to desorb all the water collected in the adsorbent and meet VES venting requirements without a waiver
    - A waiver may be possible but the venting rates resulting from desorption rates may be too great to get an exception
    - It may be necessary to perform partial desorption processes over a period of more than one day, limiting the frequency at which TCPS cycles can be performed on ISS

It is extremely difficult to design a TCPS that does not have some kind of leakage. This is due to the nature of the hardware in which both the trash input door and valves have to be opened and shut regularly. The seals and seal surfaces around the waste input door will vulnerable to scratching or trash getting caught between the seals and seal surfaces. Scratches and trash on the seal surface can seriously compromise the ability of the TCPS to seal. Trash collecting around and on the sealing surfaces within valves can have the same effect that was described for the TCPS door and piston seals.

As mentioned previously, the potential for leaks require that the process pressure and temperature be maintained at values that meet the VES dewpoint temperature and temperature range requirements should the system need to be periodically purged to maintain correct operating pressure.

The cooling sources that would be used for a TCPS/Adsorption System will nominally range from 20°C to 22°C. The adsorbent that will be used in the AdWRS is Silica Gel SG B125.

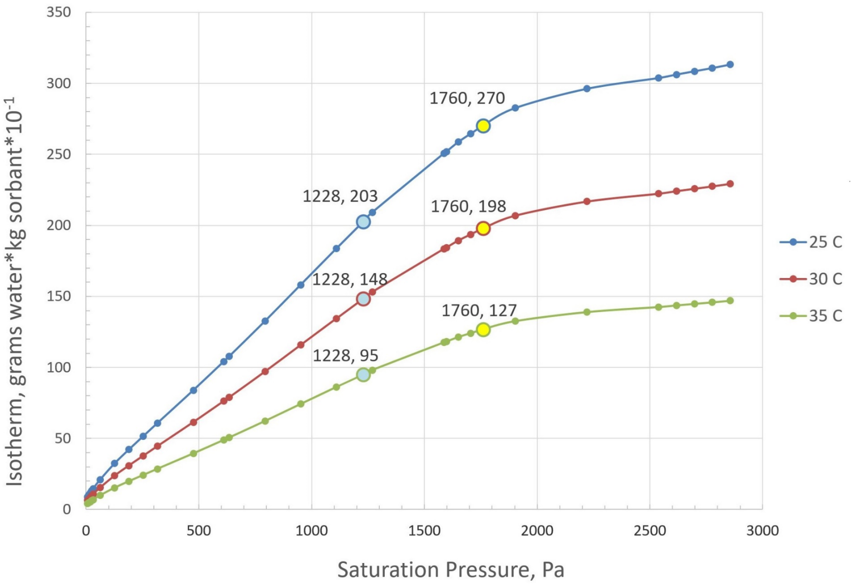

Figure 1. Adsorption isotherms for Silica Gel SG B125

Adsorption isotherms for Silica Gel SG B 125 were produced at Ames that give the performance of the sorbent within the expected operating ranges dictated by ISS EXPRESS RACK cooling resources and resulting process pressures. Figure 1 shows the isotherms for three different temperature ranges.

The currently selected process pressure range is highlighted in Figure 1 with the lower process limit being at a dewpoint of 10°C and 1228 Pa and the maximum upper process limit being at a dewpoint of 15.5°C and 1760 Pa. The 30°C line was based on the interpolation of the 25°C and 35°C line since the sorbent characterization was not performed at the 30°C temperature. The 30°C values are important because CFD analysis shows that the adsorption columns designed for the AdWRS can maintain that temperature while removing heat from the adsorbent at a constant rate of 60 Watts. Currently, analysis indicates that removing water at a rate of 60 Watts allows the AdWRS to function within the pressure drop and ISS EXPRESS RACK cooling limitations while maintaining a reasonable rate of water removal.

Based on limitations imposed by available cooling, it was decided that the process pressure for the AdWRS should be maintained around 1228 Pa which corresponds to a dewpoint of 10°C. The mass fraction of the water/adsorbent continues to fall off as the pressure decreases which limits the quantity of water that can be adsorbed as well as the rate at which the process can take place.

Based on the stated trash processing rate requirements and the percent water in the nominal waste model, the minimum water that must be processed per day is 444 grams with the desired amount being 888 grams. Figure 2 below was based on data at 1 atmosphere, 25°C, 70% humid air, adjusted to reflect water vapor adsorption rates at a lower pressure of 1228 Pa and a temperature of 30°C in a pure water vapor environment.

Figure 2 shows the reduction in the rate of adsorption as the sorbent gets closer to is maximum water holding capacity. If the total daily water adsorption requirement is difficult to meet when using the sorbent to its full capacity, the amount of sorbent can be increased allowing a higher rate of adsorption which is negatively offset by the previously mentioned cooling resource and volumetric constraints.

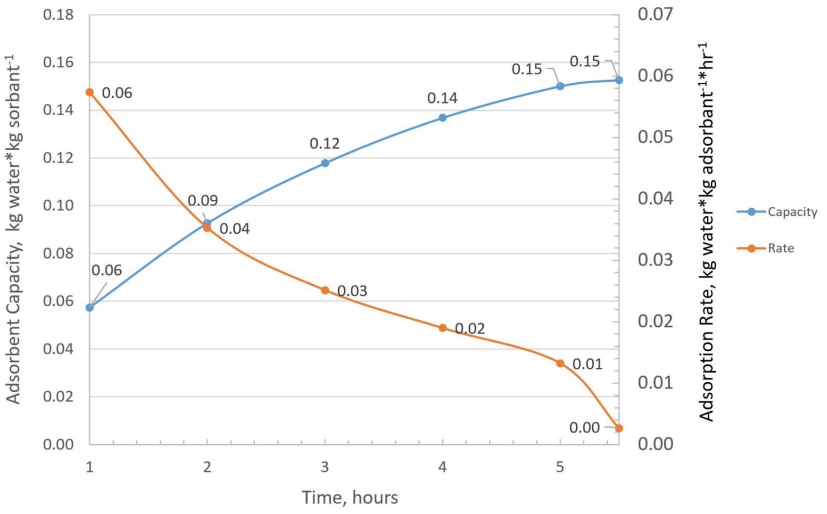

Figure 2. Rate of Adsorption as a function of capacity over time at 1228 Pa and 30ºC

The change in the thermal properties of the trash is another bounding factor that will affect processing time and may limit the total quantity of water that can be removed from the trash during a 24 hour period.

As mentioned previously, as the water is removed from the trash, the thermal conductivity decreases from approximately 0.16 W/m/K for wet/dry trash composite down to a value of 0.12 W/m/K for the remaining dry trash composite. The thermal conductivity of water is approximately 0.7 W/m/K, 5.8 times greater than the dry trash. The volume fraction of the water component of the wet trash at the start of the process is approximately 0.07, small compared to the volume fraction of the dry trash, but the water is assumed to be distributed equally amongst the trash.

III. Hardware Design

The AdWRS design shown in Figure 3 will collect water vapor being driven off the trash during heating. The primary AdWRS components and sub-assemblies are the adsorption column, custom flow meter, F1, and the custom heat exchanger, HX1. The remaining components consist of COTS absolute pressure, P, , COTS delta pressure, dP, temperature, T, humidity sensors, RH, valves, V, heaters, HTR, fans (not shown), a vacuum pump, and a liquid water collection chamber (not part of the payload but is for lab purposes).

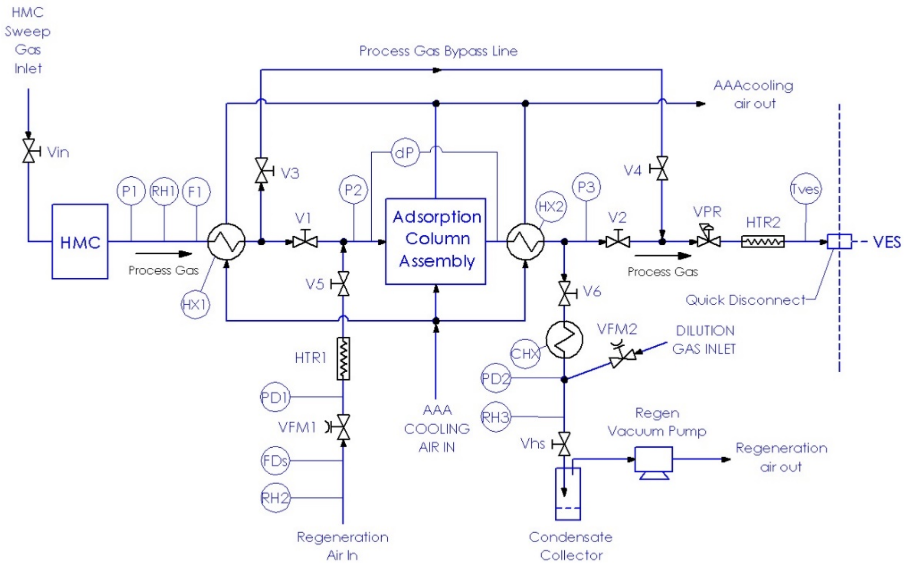

Figure 3. HMC/TCPS Adsorption Water Recovery Process and Instrumentation Diagram

A major challenge in the design of this system was ensuring that the sum of the pressure drops across all components fall within maximum pressure drop that will allow the system to function within all the previously mentioned constraints. The process gas flow path of the system includes a heat exchanger, flowmeter, adsorption column, inline heater, and must pass through numerous bends, tees, junctions, from which sensors tap into the system.

The AdWRS will connect with a VES simulator at NASA Ames Research Center. The VES simulator consists of a valve to simulate the ISS VES Rack Isolation Valve (RIV), a 50 mm inside diameter glass tube to allow visual observation of possible condensate, a Piranhi and Tungsten pressure gage to measure extremely low pressures, and a vacuum pump to create the conditions that simulate the vacuum of space.

C. Heat Exchanger Design

An effort was made to find a COTS heat exchanger that would perform under the AdWRS operating conditions. The heat exchangers that were considered had a pressure drop that exceeded the total allowable pressure drop for the entire AdWRS. The solution was to divide the single process gas tube in the COTS heat exchanger into separate short parallel tubes. The basis of the design was a twelve turn COT heat exchanger. Figure 4 shows the modifications to the COTS product. CFD was used to determine both the pressure drop and heat removal capability of the modified heat exchanger. Figure 5 shows the pressure distribution within the modified heat exchanger and both the process gas inlet and outlet temperature and pressure. The analysis showed a total pressure drop across the system equaling 48 Pa. The AAA cooling air inlet temperature was 20°C. The process gas inlet temperature was 150°C and the outlet temperature was approximately 26°C. The heat capacity of the hot fluid which in this case was the process gas, was smaller than then heat capacity of the AAA and the resulting effectiveness of the heat exchanger was 0.96.

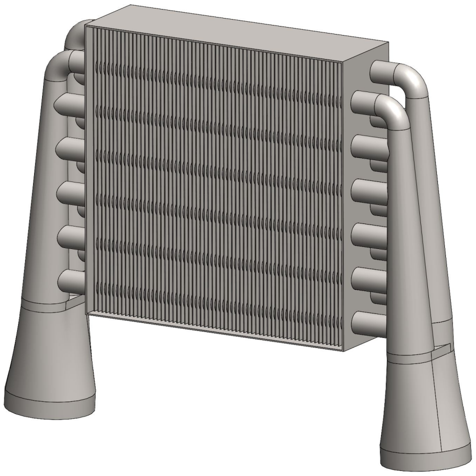

Figure 4. Modified Commercial Off The shelf heat exchanger

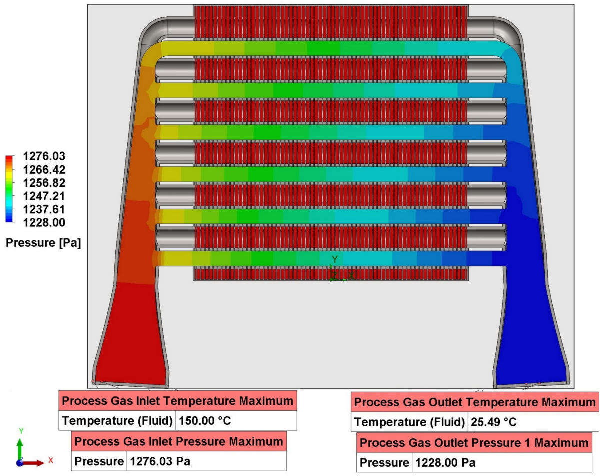

Figure 5. Pressure Distribution, Inlet Pressure and Temperature, and Outlet Pressure and Temperature

D. Flow Meter Design

A custom solution was required that could operate with a total pressure drop of less than 100 Pa at an absolute pressure corresponding to a dewpoint of 10°C which was 1228 Pa. The flow meter would need to measure the mass flow rate of water vapor being evaporated at a rate up to 120 Watts. The flowmeter is a variation on an orifice meter but uses an adjustable mechanical iris in place of a fixed orifice. The principle of operation is to maintain a constant pressure drop across the orifice by actively adjusting the iris diameter while monitoring the iris position using an angular potentiometer. Figure 5 shows the flow meter concept including the gear motor that actuates the iris and the angular potentiometer to correlate the iris opening diameter at the specified pressure drop across the iris. Also included in figure 5 is an image of the mechanical iris that is part of the design.

Figure 6 below shows the results of CFD performed at an absolute pressure of 1228 Pa and mass flowrates of water vapor generated at a rate of 30 Watts and 90 Watts. CFD was performed at boil-off rates ranging from 10 Watts to

120 Watts. The current design is based on use of 25.4 mm (1in) outside diameter tubing and is capable of measuring boil-off rates significantly higher than 120 Watts indicating that this current design is oversized for the current application.

The reason for the selection of the current flowmeter's design diameter is to match the diameter of the AdWRS process stream tubing diameter. Analysis indicates that a smaller diameter tubing (for the meter) would be a better fit for the range of operation in the AdWRS. The company that produces the iris shown in figure 5 also produces another smaller version that would be better suited for the range of planned range of AdWRS operation. A study will be conducted to determine whether or not the diameter step down and subsequent step up of a smaller diameter meter would introduce too great a pressure drop or if the change in precision is worth a deviation from the current design.

Another potential benefit of the iris is that it may be self-cleaning to some degree as the iris leafs move in and out. Testing of the device in the actual dirty waste stream will reveal whether or not this occurs and to what degree.

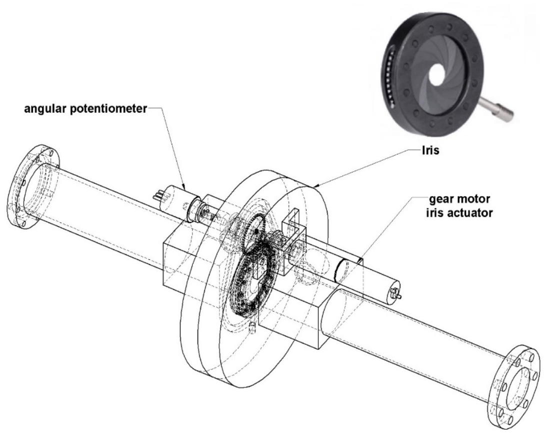

Figure 5. Orifice Type Flow Meter using mechanical iris.

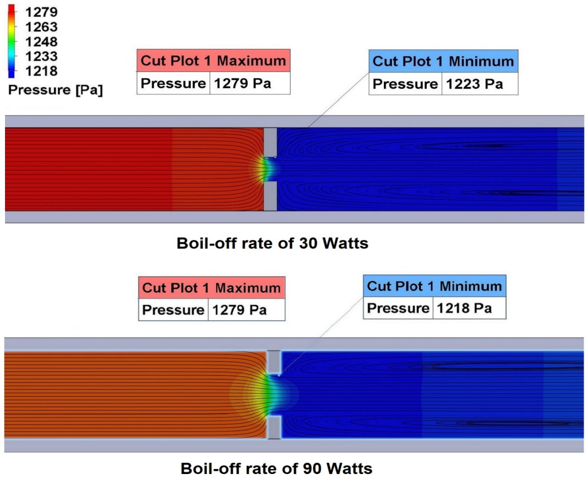

Figure 6. An example of usage of mechanical iris to measure flow using constant pressure drop and varying iris opening diameter

E. Adsorbent Column Design

The primary element of focus on the AdWRS was the adsorbent column. The design of this element of the system included many significant challenges and variables that were inter-dependent of each other. The column would need to be able to adsorb water vapor at a pressure that does not exceed the VES dewpoint yet is not too low is to limit the adsorbent performance while removing heat from adsorption with limited resources.

In order to maintain a low pressure drop across sorbent column the sorbent column was shortened in length and the flow cross section area was increased. By changing the sorbent column design as described, the residence time of the water vapor within the adsorbent column is increased by reducing the velocity of the process gas through the adsorbent.

A focus of the design was to provide uniform cooling across the column to prevent localized areas of reduced adsorption capacity. The method that was chosen was the use of impinging jets or slots to provide uniform cooling across the adsorption column as shown in figure 7. Ideally, a counter-flow cooling scheme would concentrate the heat removal capability on the area that is generating the most heat as the wave of adsorption propagates across the media. It has proven extremely difficult to implement the counter flow type of cooling scheme due to physical limitations imposed by attempting to fit the inlet and outlet of two separate gas streams, the AAA and the process gas, on or near the same column face.

The current design of the impinging jet and slot adsorption column includes the application of the a heat spreader which is sheet version of a heat pipe. Vendor information stated that the heat spreader that is being considered has an equivalent thermal conductivity of approximately 6000 Watts/meter/Kelvin. The addition of the heat spreader achieves the same effect as having a counter-flow cooling scheme. Figure 8 is a cutaway view of the sorbent column showing the sorbant temperature at the center of the sorbent, farthest away from the wall in which the heat is being removed from. The results shown in Figure 8 were based on a model that utilizes the heat spreader. In this example a volumetric heat generation rate was applied to the sorbent portion of the model that was equivalent to a 60 Watt boil-off rate divided amongst six individual columns that collectively receive a total of 0.0118 m^3/s (20 scfm) of AAA cooling air. The figure shows the uniformity of cooling across the sorbent that was maintained at a temperature of approximately 29°C.

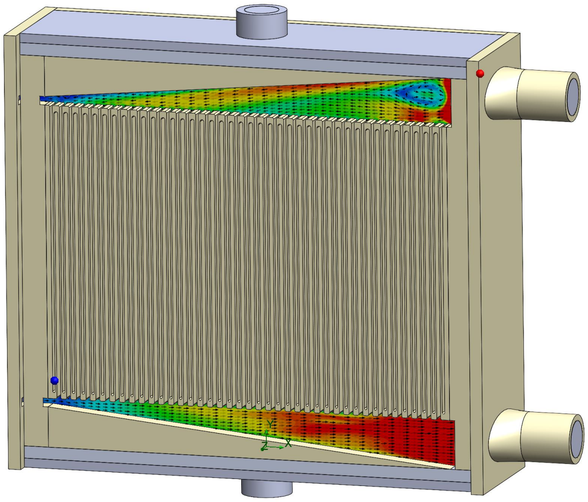

Figure 7. Individual Impinging Jet/Slot Adsorption Column

The design is modular in nature and additional individual columns can be combined in parallel to increase capacity without increasing the pressure drop across the column assembly. Three column assembly configurations have been evaluated that consisted of individual columns being combined in parallel having a total of four, five, or six columns for each assembly respectively. The model shown in Figure 8 was designed solely for CFD analysis. A separate model has been developed that includes details for fabrication.

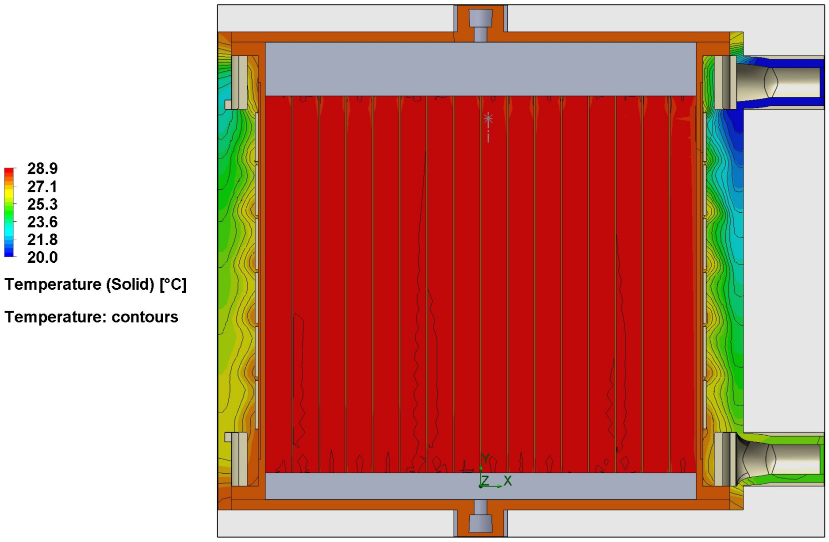

Figure 8. Individual Impinging Jet/Slot Adsorption Column

In order to get reasonable heat transfer, the spacing between the heat fins within the box containing the sorbent had to be relatively close. The minimum distance between the cooling fins was limited by maintaining a minimum number of beads, quantity 12, and the sorbent bead diameter which average size was measured to be 2.06 mm. Channeling or short circuiting of the process gas along the walls due to less obstruction was a concern. A scheme was devised that would significantly reduce short circuiting while simultaneously improving heat transfer between the adsorbent beads and the wall of the box containing the adsorbent. The scheme employed the use of a Face Centered Cubic (FCC) packing arrangement. This scheme was not intended to provide perfect packing. The primary purpose of the setup was to get rid of the flat column walls and heat transfer fins thereby forcing the water vapor to take a more torturous path through the column. The elimination of the straight walls lengthens the vapor path and causes it to more effectively impinge on the heat transfer surface and the silica beads. The FCC arrangement consists of a repeating 6 bead by 6 bead adsorbent layer on top of a 7 bead by 7 bead layer which arrangement repeats itself longitudinally along the process gas flow path with the column. Testing will measure the effectiveness of this method. The internal heat fin assembly and internal surfaces of the box received grooving allow the FCC packing to be possible. Figure 9 shows the FCC packing grooves on the inside of the sorbent box. Figure 10 shows a close up of the grooves.

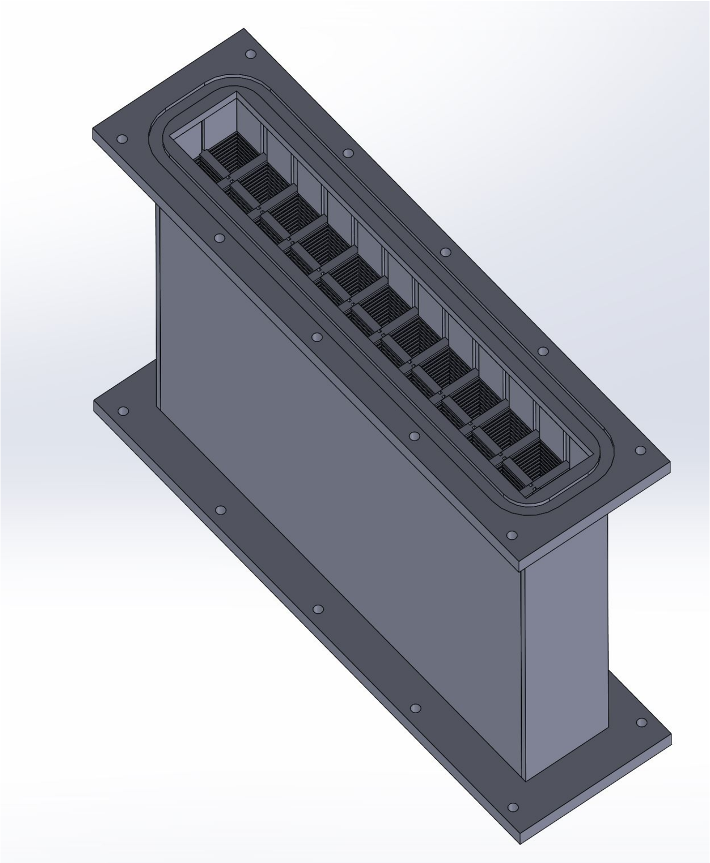

Figure 9. Adsorption box internal wall treatment to accommodate Face Center Cubic packing of the sorbent beads

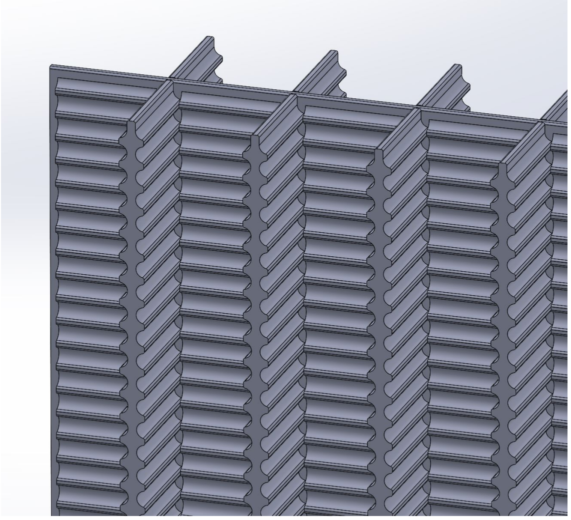

Figure 10. Close-up view of the adsorption box internal wall treatment to accommodate Face Center Cubic packing of the sorbent beads

F. Final Assembly

At the time of this writing, the model of the final assembly that includes all components has not been completed. The remainder of the parts not detailed previously in this paper are primarily COTS sensors and components such as solenoid ball valves, hand actuated valves, temperature sensors, pressure sensors, humidity sensors, COTS inline heaters.

For this unit the focus will be on fitting these items into a compact space to demonstrate that the system could be fit into an ISS EXPRESS rack. The goal for this design is to attempt to make it fit into a double rack space. The internal configuration of TCPS that the AdWRS would be connected to are not currently known. It is possible that a portion of the AdWRS concept can be fit in the same space as the TCPS and that the remaining hardware could possibly fit within a single rack space. The current effort will focus on a stand-alone system that can be used independently of the final version of TCPS that is selected.

IV. Conclusion

The purpose of this development effort was to see if adsorption used in combination with the ISS VES was a viable option to venting TCPS waste gas effluent stream back into the spacecraft cabin. There are pros and cons in the application of this type of system. The study included a significant effort to discover and better understand what the limiting factors are in the application of sorbent to manage water effluent being generated during the TCPS process. After gaining an understanding of the bounding parameters of operation, analysis both through formulae and the use of Computational Fluid Dynamics was conducted and indicates that an AdWRS system could be designed to function within the limitations imposed by the ISS EXPRESS RACK and VES resources.

Acknowledgments

The authors would like to acknowledge NASA's Advanced Exploration Systems Program Office and the Logistics Reduction Project for their continued support.

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