TAMUK Space Engineering Institute

Laundry in Space: **G**ravity **I**ndependent **L**aundry **S**ystem (GILS)

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The overall objective is to create a process to wash and dry the clothing of personnel as well as other fabrics aboard the space station and perhaps a lunar colony. The apparatus must a) effectively wash, disinfect, and dry garments, b) be a closed system, c) be energy efficient, d) be safe to the sterile environment of a space station/lunar base, and e) be easy and convenient to use and maintain. The initial configuration, Alpha, was a sealable bag with an input and output. The input is attached to a liquid solvent (water) source, and the output is connected to a vacuum. Ideally, the free-flowing solvent is drawn out and circulated throughout the bag and garment. Once the garment has been cleansed and disinfected, the vacuum will continue to draw solvent, and effectively dry the garment.

This semester's current configuration accounts for the closed system requirement. As this configuration is the fifth generation, energy efficiency is now becoming a more central part of our testing. Whereas washing/disinfecting the garment is a part of the fundamental criteria, drying the garment is the most critical problem and our experiments so far are focused on that process. The 5th Generation's test results look promising as to further improving the performance of the extraction process of the pump. Adding a woven mesh above and below the garment appears to have had a positive effect on drawing more water out of the sealable bag. Also, the addition of heated air circulating through the system appears to be better than merely using a higher quality vacuum. Current experiments have focused on testing new equipment, and developing baseline data from which future drying data comparisons can be made. It does appear that a vacuum bag configuration will force more water from an article of clothing than placing the same article of clothing in a rigid, fixed container, and using a high quality vacuum on it, but more tests must be conducted.

I. Introduction

A relatively unknown problem for astronauts on a mission in space is their inability to wash and dry clothing. They can spend months aboard a spacecraft at a time. Without these abilities, the crew is left to pack for their entire mission and have refills launched to them. For instance, packing enough underwear for three members of an ISS Expedition crew to have a clean pair for every day of a 6-month stay would mean launching at least 540 pairs of underwear into orbit. Furthermore, astronauts typically tend to have favorite garments and want to wear certain garments repeatedly. Aside from the apparent hygiene and comfort concern, the cost of sending so much clothing into outer space and the actual room it consumes aboard a spacecraft adds up. There is hardly any actual space aboard a spacecraft for excess. When it costs approximately $12,000 per pound of weight to be launched into space,

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clothing becomes rather expensive to launch. As a result, astronauts typically have to stretch how long they wear their clothing in order to have it last the entire mission.

In his series of "Space Chronicles," ISS Expedition Six Science Officer Don Pettit wrote that he changes his underwear once every 3 or 4 days[1]. That's not quite as bad as it sounds, since clothes don't get dirty as quickly on the Space Station as they do on Earth. Astronauts on the Station are living in a controlled environment, so the temperature stays at a constant, comfortable level. When everything around you is virtually weightless, you don't have to exert yourself physically the same way you do in the gravity on Earth's surface. However, astronauts do have to spend a substantial amount of time each day exercising so that their bodies don't succumb to atrophy in microgravity. In an interview during the month of February, Pettit said that he was still wearing the same pair of shorts he had been wearing since he first arrived on the Station - in November! Even though they have more shorts to change into, Expedition Six Commander Ken Bowersox also has a favorite pair he chooses to wear frequently. Even though there's no laundry facility on the Station, Bowersox figured out a way to wash his shorts using a plastic bag.

The idea for creating a system to do laundry in space, using a vacuum bag system similar to those used to fabricate composite parts, was first proposed by Prof. Peel to NASA and the TAMU Space Engineering Institute in Spring 2007, and was initiated as a project for the fall 2007 semester. He proposed it after he heard about the problem from Victoria Bailey who had begun working on a project to wash, disinfect, and dry clothing in space during her time as a high school student. She had discovered that the common solution to “dirty laundry” in space is prolonging the time astronauts would wear of clothing, or completely disposing of the items and bringing in new ones. Victoria proposed a rigid system that employed pressure and a vacuum to wash and dry clothing in space, and brought her ideas to The Space Engineering Institute at Texas A&M University-Kingsville in the fall 2007 semester.

II. Previous Work and Current Objectives

The Space Engineering Institute at Texas A&M University – Kingsville have proposed a solution to this problem, and have begun designing a configuration that can wash and dry clothing in space. The system must take into account the microgravitational environment of outer space, and must also account for the limited resources available aboard a spacecraft. The design criteria are:

- Effectively wash, disinfect, and dry clothing garments
- Consume minimal resources, including power usages and cleaning solvent
- Easy to use and maintain
- Be compact and lightweight
- Be non-hazardous and a closed system to account for the sterile environment of a spacecraft

A. Discussion and Configuration

The initial configuration, dubbed “Alpha”, is a sealable bag with an input and output. The input is attached to a liquid solvent source, and the output is connected to a vacuum. Ideally, the free-flowing solvent is drawn out and circulated throughout the bag and garment. Once the garment has been cleansed and disinfected, the vacuum will continue to draw solvent, and effectively dry the garment. Alpha and its components are illustrated in Fig. 1. Typically aboard a spacecraft, common soils include bodily soils and food/drink soils; therefore, our design will be tailored towards these types of relatively minor soils. This way, the overall efficiency of the system will be greater, as deeper soils will obviously require a longer cycle and hence more power and resources to clean and disinfect them. These heavier types of soils will require individual attention, such as manual pre-washing.

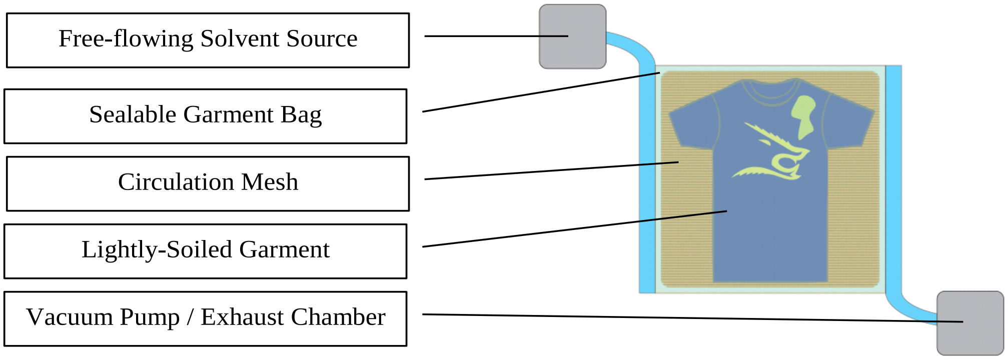


Figure 1. Configuration "Alpha". *System with source, bag, and pump.*

B. Choice of Cleaning Solvent

Due to the sterile environment of a space station/craft, certain considerations must be made in choosing a solvent used for washing/disinfecting clothing garments in our system. Water and detergent would be a clear and obvious choice; however, conventional detergents contain chemicals that can be harmful to a spacecraft and its crew. Furthermore, our configuration proposal is hardly related to conventional washing/drying methods used on Earth, and these types of detergents are simply not applicable. However, conventional dry-cleaning methods and the substances used in dry-cleaning have been useful in determining a solvent that can be used in our system. Although conventional dry-cleaning solvents are even more harmful than ordinary detergent, alternatives have begun development in response to the hazardous attributes of these chemicals in general.

A possible choice of cleaning solvent includes a carbon dioxide (CO2) solvent. It uses non-toxic, liquid CO2 (the same form used to carbonate soda) as the cleaning solvent, along with detergent. CO2 cleaning also uses less energy than traditional dry cleaning. Another possible choice of cleaning solvent includes a silicone-based solvent. The solvent degrades to sand, water, and carbon dioxide; however, it has caused cancer in lab animals in EPA studies. Finally, a petroleum-based solvent manufactured by ExxonMobil called DF-2000 is another possible cleaning solvent that could be implemented in our configuration. However, the EPA lists DF-2000 as a neurotoxin and a skin and eye irritant for workers, and poses the same sort of hazards as most petroleum-based substances. These solvents could prove valuable later in the testing and design process because it may later be proved that a cleaning solvent will disinfect clothing better than water.

For experimental purposes, water was used rather than a more complicated solvent, as emphasis was not yet placed on actually cleaning and disinfecting a garment, but on drying the garment, for reasons which will soon be discussed.

C. Free-Flowing Solvent Source

The source of cleaning solvent requires no independent power, as the solvent is drawn by the vacuum at the opposite end of the system. This source will consist of a closed container that holds the solvent, and is controlled by an electrical value. The container will hold only the solvent, as not to allow any gas to needlessly enter the system.

D. Vacuum

The vacuum is the only component of the system that requires power, which accounts for the design criterion concerning power efficiency. Power must be conserved as resources are limited aboard a spacecraft. Since the system is being operated in a micro-gravitational environment, the vacuum is the only force acting on the system. Once the system is sealed, the vacuum will remove all gas and excess from the system. The solvent will then be drawn and circulated into the cleaning bag, and will be vacuumed into and exhaust chamber. After an appropriated amount of time, which will perhaps depend on how heavily a garment is soiled and the power allotment of a particular situation, the flow of solvent will cease, but the vacuum will ideally continue to draw solvent until the garment is completely dry. Depending on the solvent chosen for disinfection, a "rinse cycle" of water may be implemented to do as the name implies.

E. Exhaust Chamber

Gas and liquid cannot be separated aboard a spacecraft as simply as it is on Earth. In space, gravity cannot be relied upon for this separation. Therefore, it is essential that our apparatus be a closed system, among other reasons. Furthermore, it is NASA's policy that any sort of device or proposal must firstly be a closed system if it is to be implemented aboard a spacecraft/station. Our configuration accounts for this separation; the system will initially exhaust any gas that is present upon sealing the clothing bag into a gas collection chamber. The solvent source is already closed, and nothing but the solvent is present within it. Once the gas is exhausted into this chamber, the vacuum exhaust will switch from the gas chamber to the solvent collection chamber, which will then collect the solvent.

F. Sealable Garment Bag

The sealable garment bag will contain the garment, and be sealed much like a conventional "Ziploc" bag. The bag will then be exhausted of any gas by the vacuum, and then the washing/drying process will begin. To ensure complete and maximum circulation of the solvent within the bag during flux, the inside of the bag will be lined with a circulation mesh that will "guide" the flow of solvent uniformly throughout the bag.

III. Test Configuration

A. Generation I

Initial assembly of Alpha consisted of assembling the configuration with materials readily available in the TAMUK composites lab. Using composite vacuum bagging and sliding clamps to seal the plastic at its otherwise loose ends, we used two vacuum connectors that enabled flux of liquid though the bag. A vacuum connector was connected to a source of liquid, vacuum foot was connected to a chamber where the exhaust of gas and liquid ended up in the system. The chamber was connected to a vacuum pump that created the vacuum of the system. As far as the separation of gas and liquid is concerned, gravity was relied upon for this separation during this demonstration: the pump connection was located at the top of the chamber, so as water entered the chamber, it simply accumulated at the bottom of the chamber, and the gas was simply pumped and exited at the top. This separation is obviously not applicable for our stated purpose and configuration, but the purpose of this specific generation of assembly was for demonstration and evaluation purposes. Fig. 2 is a photograph of the generation I configuration.

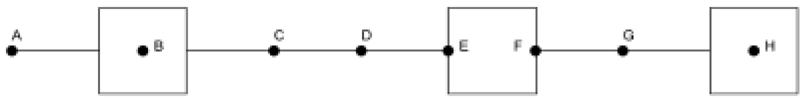
Figure 2. Generation I Configuration. *The assembly of the initial configuration.*

During this experimentation, a plain white t-shirt was inserted into the bag that had been marked with different colors of marker. Once the system was fully assembled soapy water was run through the apparatus. Approximately 4.5 liters of the water went through, and once the solvent source had been exhausted the source hose was pinched off as not to allow gas to pass through the system. This was not entirely effective, but a completely closed system was not all that necessary for the purpose of demonstration. At this point we allowed our vacuum to continue to draw the solvent from the bag and garment for approximately 30 minutes in an attempt to dry the garment. Incidentally, running it no more than 30 minutes was decided upon for the sake of efficiency; conserving power consumption is an integral part of the overall objective. Depending on exactly how much power is required to run the sort of system we propose, a system that takes a relatively large amount of time to effectively wash, disinfect, and dry a garment will consume, could render the system inefficient for our purposes. Therefore, it was not run in excess of 30 minutes for this particular experiment. After which the garment was still heavily saturated.

From this demonstration, a few things were concluded. One: the closed system was essential, and that the materials chosen for the system needed to meet this task. A thick and large polyethylene bag would be required, as well as hoses and connections that would create this closed system. Two: the pump used created a vacuum that met the purpose at hand, though the vacuum is still not strong enough. The second generation of the Alpha design would use a tighter system to evaluate this. The main priority and our first objective should be to create a means to dry the garment, meaning that at this point drying the garment takes precedence over cleaning and disinfecting the garment. Therefore, experimentation with cleaning and disinfecting has been forgone until an effective process of drying the saturated garment by vacuum can be determined.

B. Generation II

There is a specific purpose in creating a process to dry a garment by vacuum; materials have been selected for assembling a system that could meet this purpose. For the sealable garment bag, Ziploc brand press-to-close plastic bags are used with dimensions of 2 ft. x 1.7 ft; commonly used for storage of clothing, etc. To connect the bag to the solvent source and vacuum, there is an assortment of nylon fittings, a vinyl hose, and valves to regulate solvent flow and vacuum. For the rest of the system, the same components were implemented as the prototype of generation I. One of the marked differences between this generation and the former is the way in which the connection between the hoses and the bag that allowed flux of the solvent was made. This generation used plastic fittings to create a permanent connection with the bag rather than using the vacuum connectors. Fig. 3 is a diagram of the connections, and Fig. 4 is a photograph of the generation II prototype.



Legend	
A	Vacuum Pump
B	Exhaust Chamber
C	Vacuum Gauge
D	Valve #1
E	Vacuum Connector #1
F	Vacuum Connector #2
G	Valve #2
H	Solvent Source

Figure 3. Connection Diagram

Upon assembly, the procedure used to evaluate generation II was nearly the same as generation I, both under the Alpha design. A garment was placed within the bag and sealed inside, the pump was started and vacuum created. Once all the gas was removed from the system, the value that regulates the flow of solvent was released (point G in Fig. 3), and water flowed through the system. Water was allowed to flow through the system for 10 minutes, at which point the flow of water was cut, and the vacuum continued to draw water from the system for an additional 20 minutes. Once this time was up the garment was still heavily saturated, and there was little difference between generation I and generation II as far as that aspect is concerned. The procedure was repeated several times; all the while leaks of air and water were being repaired and tweaked.

Figure 4. Generation II Configuration. *The assembly of the configuration with improvements.*

When hosing was elevated above the bag, water was stuck within the hose that wouldn't have been had the exhaust chamber, bag and hosing been at the same elevation. This meant the vacuum was lacking in strength. The plastic hosing was also being compressed due to the vacuum, and stouter hosing was in order. Lastly, this technique of connecting the bags and hoses with plastic fittings was puncturing the inside of the plastic bags—as the vacuum compressed the bag, the rigid fittings were pressing on the other side of the bag and creating leaks.

Generation II experimentation lead to a few conclusions: The system of fittings was problematic, because leaks were being created. It was decided to resolve this by reverting back to connecting the bag to the hoses by way of the vacuum connectors. The vacuum connectors do not have a damaging component that would be present within the bag, therefore eliminating the threat of puncturing the other side of the bag. Also, it was concluded that the hoses were inadequate and that threaded hoses were needed. Finally, and most importantly, it was concluded that a way in which to measure the pressure created by the vacuum and its consistency was needed, and the decision was made to implement a vacuum gauge to measure the amount of vacuum of the system. It was also ultimately important to figure out if the vacuum could “boil” water, or if it could create a strong enough vacuum to exert enough force on water and “suck it up”, creating a situation where the water would boil. In order to test this, a plastic cup containing water was placed into the exhaust chamber, and the pump was started to create a vacuum. After a few moments, water did indeed begin to “boil” within the cup. This led to the conclusion that water could be vacuumed in the intended way, although a shirt saturated with water is obviously acting as frictional surface between the water and the force of the vacuum.

C. Generation III

Considering the conclusions made from the experimentation with generation II, certain changes were made for the generation III configuration. For the sealable garment bag, 8 mm thick polyethylene press-to-close bags dimensioned at 28 ft x 30 ft were implemented. The vinyl hoses were replaced with braided PVC hose, and the vacuum connectors used in the generation I configuration were reintroduced.

The change of bags was a response to the vulnerability due to the puncturing of the previous bags. The new bags were thicker, and also larger, so as a regular t-shirt could be spread within the bag completely. The vacuum connectors were implemented to further eliminate the threat of puncturing. The digital vacuum pressure gauge was implemented to readily measure the strength of vacuum within the system and its consistency. Fig. 5 is a photograph of this assembly.

Figure 5. Generation III Assembled. *The assembly of the configuration with improvements.*

D. Generation IV

After analyzing the system and fixing its mechanical weak points and inefficiencies, it seemed fit to further research the effect of heat on the system. After establishing the fact that the system could possibly dry the garment through the use of a vacuum, other avenues were looked toward making it more efficient. Generation IV focuses on the testing of different heating and air flow configurations. In this set of tests, as opposed to Generations II and III testing, the garment was pre-soaked in water instead of running water through the system. This eliminated the input of a water source, and allowed the implementation of an air source. Accordingly, water loss reduced dramatically since water was no longer running through the system; yet the removal of water from our system proved to be more difficult. In contrast to previous trials where 87% of water was “removed” from the garment, Generation IV managed to remove the water that was actually soaked into the garment. In addition, Generation IV testing maintained a 30 minute time trail. In configurations where air was cycled through the system, our valve was closed initially. Every ten minutes subsequent to releasing the vacuum valve; the air input valve was opened, cycling air for one minute and closing the valve until the next cycle. Air cycled through the garment bag measured an average of 74°F for the room temperature configurations and 170°F for inclement temperature configurations. In comparison to the Generation III system setup, Generation IV testing used nearly the same setup; with the exception of disconnecting water source to allow for airflow, which was the primary difference.

E. Generation V

The focus is with Generation V is to asses the effectiveness of a different size of mesh placed with the garment. In previous generations, a small area of mesh was placed on top of the garment at the outlet of the vacuum bag chamber. This was believed to assist the flow of water as it passed from the shirt into the vacuum hose. What is now hypothesized is that a bigger area of mesh would further assist in channeling the excess water from the entire garment toward the vacuum hose. Using the collapsing effect of the atmospheric pressure, the mesh’s weave would essentially act as tubes to help draw out more water than the garment’s fabric alone.

F. Baseline Testing

This part of the project was to asses the ability of the vacuum pump to pull water from the garment purely by vacuum alone. Until recently, a flexible chamber has always been utilized in all generations. The reason for this was that it was believed the atmospheric pressure would press out the water thus drying the garment. This semester our team wanted to examine a system using a rigid container, also known as a desccicator. It was decided not to use the vacuum bag due to its compressing effect on the garment. This characteristic of the bag was not ignored but simply taken out of the equation for the time being. What was looked at in this testing was the boiling effect on a water-soaked garment in a vacuumed atmosphere. The mesh that was used in Gen. V was used in the baseline testing. Having mentioned the garment would be exposed to a vacuumed environment, no airflow or heat was applied to the chamber.

IV. Test Results of Generation II

A. Procedure

The purpose of the experimentation with the generation II prototype was to measure the efficiency of the system, i.e. how much water was removed from the system compared to how much was put in by vacuuming the saturated garment. The procedure was much like that of the generation I demonstration, with the marked difference being measuring the mass of water put in and taken out. The affect heat would have on the system had been considered and whether a heating phase should be incorporated into the system design. So in addition to a rinse cycle, a heat cycle was introduced, in which the system was placed in an industrial oven at a temperature of 120°F. The system remained intact when placed in the oven, the vacuum continued to attempt to draw water from the system, and the solvent source was closed.

B. Gen. II, Rinse Cycle

The surrounding environment was verified at an ideal room temperature of 68°F, checked the equipment, and tested the system for functionality and leaks. The mass of the water placed into the solvent source that was to be drawn into the system was measured, and the experiment was commenced. The exhaust chamber was placed on a scale so to measure the mass as it entered. At specific time intervals we recorded this mass for a total of 30 minutes. Ten minutes into the experiment, the value at point G in Fig. 3 was closed, cutting the flow of water. Fig. 6 is a line chart illustrating the mass of water that was collected in the exhaust chamber over time. In summary, the amount of water that entered the system was 4.6 kg, and the amount of water exhausted by the vacuum was 4.0 kg, meaning that 590 g of water remained saturated on the shirt. Considering this data, the system was calculated to have removed of 87.2% of the water during the rinse cycle.

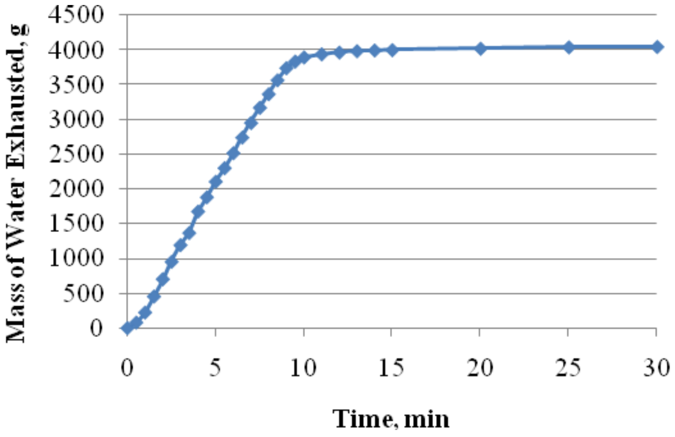


Figure 6. Rinse Cycle. *Line graph related the mass exhausted vs. time of rinse cycle during testing of the generation II configuration.*

C. Gen. II, Heated Cycle

Once the oven reached a temperature of 120°F, the system momentarily was paused and placed into the oven. Experimentation resumed, and in the same manner as in the rinse cycle, the mass of water exhausted was recorded against time. The system ran within the oven for a total of 30 minutes. Fig. 7 is a line chart illustrating the mass of water that was collected in the exhaust chamber over time, which over 30 minutes, totaled 130 g. Furthermore, during the heated cycle the system removed an additional 2.8% of the amount of water put into the system.

D. Discussion

Considering Fig. 6, a noticeable drop in the amount of water exhausted is observed ten minutes into the rinse cycle. This stands to reason, as the solvent source was closed at ten minutes. The implication is that the garment reached a point of maximum saturation rather quickly, at which point most of the water that was exhausted was not necessarily vacuumed from the garment itself, and likely “went around” the garment. In essence, the true test of the functionality of the system came after the water source was closed, or 10 minutes into the experiment. During the last 20 minutes of our experiment, a mere 150g of water was exhausted.

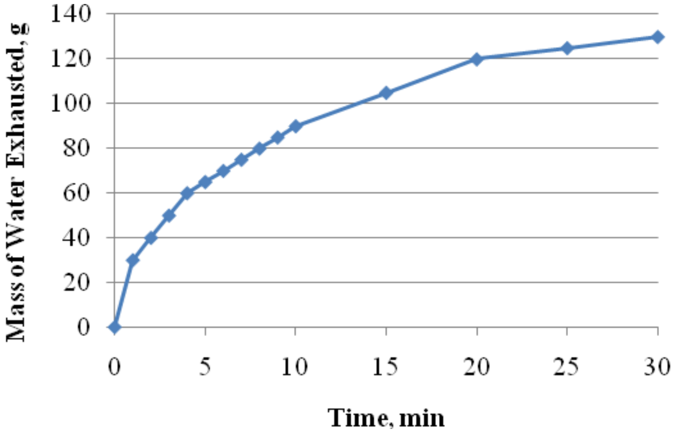


Figure 7. Heated Cycle. *Line graph related the mass exhausted vs. time of rinse cycle during testing of the generation II configuration.*

The heated cycle demonstrated that the introduction of heat to the system will increase the amount of water exhausted, as could be predicted. The garment was already saturated upon entering the oven cycle, and the total mass of water exhausted was 130 g over 30 minutes. In consideration of the discussion over the rinsing cycle: Whereas the calculated efficiency of the heated cycle was markedly lower than that of the rinsing cycle, it could be concluded that in all actuality the heated cycle and rinsing cycle were much closer in effectiveness.

Upon experimenting with the generation II prototype, it was concluded that several changes were in order. Firstly, the experimentation demonstrated the possibility that attempting to dry a garment with the quality of vacuum is implausible. In order to prove that this was indeed the case, the intensity the vacuum was actually creating needed to be known. In addition, during experimentation a constant amount of vacuum pressure was also necessary. Fixing leaks before and after experimenting with the generation II prototype was rather common. This made it unclear if the essential problem was because of these leaks, or because the configuration was overall ineffective. A vacuum pressure gauge was needed to discern between the two. A recurring source of leaks as mentioned was the nylon fittings that connected the hoses to the garment bag. When the bag was under compression, the fittings would puncture the other side of the bag from within. It was then decided to revert back to the use of the vacuum connectors used in generation I.

V. Test Results of Generation III

A. Procedure

The purpose of the first experimentation with generation III was to determine the effectiveness, or ineffectiveness, of drying a garment by vacuum considering the improvements made on the new prototype. In other words, and depending upon the results, this experiment was to determine if drying a garment by vacuum was a plausible idea. Compared to generation II, the generation III prototype was a more controlled experiment since the new materials made leaks less likely and vacuum pressure more intense. For example; the garment bags featured relatively thicker plastic and vacuum feet were used rather than nylon fittings.

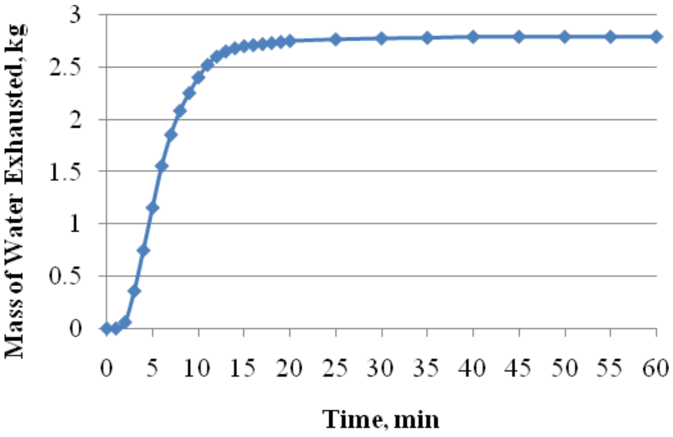


Figure 8. Rinse Cycle. *Line graph related the mass exhausted vs. time of rinse cycle during testing of the generation II configuration.*

Furthermore, a vacuum gauge allowed for a way to monitor and verify the vacuum pressure.

A major goal for this set of experimentation included reaching and maintaining a vacuum pressure of 740torr. At this pressure, a “boiling” effect of water within a cup placed inside the exhaust chamber was observed. Hopefully, with this vacuum pressure, more water within the bag and on the garment would be vacuumed than had been in the previous experiments.

The procedure of this experiment was nearly identical to the rinse cycle phase of the experimentation with the generation II prototype. A heated cycle was forgone for this experiment to reflect the purpose this time around. Also, rather than 30 minutes, the total time the system acted upon the garment was one hour, during which the mass was recorded at specific time intervals. Fig. 9 is a line graph illustrating the mass of water exhausted against time.

Ten minutes into the trial, the solvent source was closed, and water ceased to enter the system. As in the generation II experiment, a marked drop in exhausted water is observed, illustrated in Fig. 9. The amount of water exhausted during the last 50 minutes was 390 grams. This represents an improvement from generation II, and Fig. 10 represents a comparison of the amount of water exhausted from the generation III prototype during the time at which the water source was closed, and that of the generation II prototype II. The amount of water placed into the system was 3.1 kg, and 91% of this water was removed from the generation III configuration. However, as in the generation II configuration, most of this water entered the system after our shirt had reached maximum saturation, and this water merely “went around” the garment.

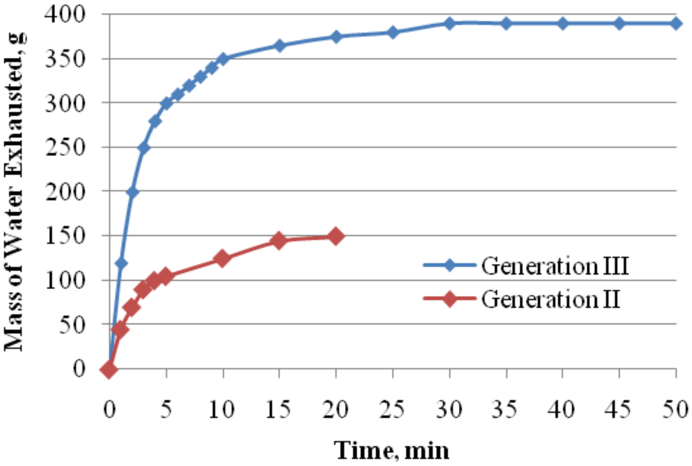


Figure 9. Generation III vs. Generation II. *Line graph relating the final moments of generation III and generation II rinse cycles.*

Vacuum pressure was monitored during this experiment. The vacuum pressure at point D in Fig. 3 was measured at 741.2 torr. However, once the vacuum was released over the entire system, a drop in pressure was observed. The value of this pressure fluctuated throughout the experiment at a value of 730.9 ± 3.4 torr, which is a departure from the objective by approximately 10 torr. However, the “boiling” effect of water at 730 torr was absorbed, so this pressure was in fact adequate for these purposes.

B. Discussion

Although this experimentation marked an improvement from generation II, the amount of water being vacuumed from the saturated garment was still small. The garment remained heavily saturated upon being vacuumed for 60 minutes. Perhaps under different conditions, such as longer time intervals in vacuum, or under a large amount of heat, this might be plausible. However, due to large amounts of power required for such conditions, the proposal would be rendered relatively inapplicable for the purpose at hand.

VI. Test Results of Generation IV

A. Procedure

In this generation, five different configurations of air flow and heating cycles were tested. The first configuration, configuration I, was kept at room temperature, which was 74°F, and with a constant vacuum of 730.9 ± 3.4 torr. The second configuration, configuration II, was kept at an elevated temperature of 170°F with a constant vacuum of 730.9 ± 3.4 torr. Configurations III and IV implemented the cycling of air through the system. The peak vacuum achieved in both of these cycles was 730.9 ± 3.4 torr; though since air was cycled, the values ranged. The main difference between Configurations III and IV was the temperature of air being cycled through the system, which like configurations I and II implemented the same room temperature and elevated temperature. The final configuration, configuration V, took the best of configurations I and II, and configurations III and IV, and combined them to form the highest efficiency of the set.

B. Configurations I & II

In configurations I & II of Generation IV testing, no air was cycled through the system. Instead only the surrounding temperature of the garment bag was altered. In configuration I, the surrounding temperature of the system was an average of about 74°F; while in configuration II testing, the surrounding temperature of the garment bag was increased to 170°F. In Fig. 10, configuration 1 is shown. As shown the configuration only has one connection. Since the only source being applied to the bag is the vacuum and to reduce the possibility of leaks; the output tube and valve that would circulate air in future trials was not fixed onto the bag. Hence the only leaks made should have been the ones around the vacuum fitting or tiny pinholes created by the vacuum. Also shown in the figure is the digital pressure gauge, which we used to measure the level of vacuum we were achieving. The same setup was used in configuration II, again because an input tube for air was not necessary. However, whereas the same setup was used, the results were far from similar. Heating the garment bag proved to be almost four times more efficient than tests run at room temperature.

Figure 10. Configuration 1. *Generation IV testing.*

C. Configurations III & IV

Configurations III and IV of Generation IV, tested the cycling of air through the system. After configurations I and II, another connection to cycle air through the bag and into the vacuum chamber was added as can be shown in Fig. 11 to the right. Every ten minutes for a final time of thirty minutes, air was cycled through the system for one minute intervals. In both configurations the garment bag had a surrounding air temperature of 74°F. Configuration III implemented room temperature air into the system and configuration IV implemented elevated temperature air, as stated earlier. At a vacuum which reached its peak at 730.9 ± 3.4 torr, the obtained results were unexpected. Though air cycled through the system in configuration IV was approximately 96°F higher in temperature, it managed to remove less percentage of water from the system. A possible reason for this occurrence is that; in the heated air cycle of configuration IV, the garment was less saturated in water by about 12 grams. Hence if these 12 grams of water had been saturated into the garment in the heated air cycle, it is possible, that this may have allowed for a higher efficiency. Another reason for these contradictory results may have resulted in the length of the air inlet tube. It is possible that the air may have cooled down by the time it reached the garment bag resulting in invalid results.

Figure 11. Configurations 3 & 4. *Generation IV testing.*

Table 1. Generation IV collected data

	Ambient Temperature (°F)	Injected Air (°F)	Water Vacuumed (g)	Efficiency (%)
Config. 1	74	N/A	13	7.65
Config. 2	170	N/A	42	25.61
Config. 3	74	74	25	15.15
Config. 4	74	170	23	15.03
Config. 5	170	170	56	39.16

D. Configuration V

By far the projects most efficient drying cycle, configuration V implemented both a heated environment with heated air cycles. Running the same air cycles as configuration IV and placing the bag in the same heated environment as in configuration II, configuration V removed 39.16% of the water soaked into the system. Remarkably, the shirt started of with a lower amount of water soaked in than in any of the previous configurations.

E. Discussion

As predicted the application of heat on the system, both internal and external, resulted in much more efficient drying cycles. One advantage of this generation was the pre-soaked garment. This cut the running time in half, and proved more efficient than previous testing. It is possible that with a higher vacuum or higher temperature, a higher percentage of water will be removed. The only problem with heat is that it will require a large amount of power to be attained. This problem can be solved by reducing the run-time of the system. Still, pin-holes in the bag have proved to be a problem creating inconsistent vacuum readings. If a stronger vacuum were used, it may be possible to increase the drying efficiency using configuration V. Table 1. Shown Above shows the results of Generation IV testing as gone over in this section.

VII. Test Results for Generation V

A. Procedure

The environment used was that of the ambient temperature of the room. There was no addition of heat to the surroundings of the bag or to the atmosphere pumped into the system. A single layer of mesh was placed on top of the garment having an area slightly greater than the shirt itself. Once the first trial data was analyzed, it was deduced that a second layer placed on the bottom of the shirt would generate an even higher efficiency as can be shown in Table 2 to the right. This "sandwich" configuration would allow any water on the bottom, not collected by the top mesh, to be carried away towards the outlet. The system was allowed to run for a total of 30 minutes for both trials.

Table 2. Generation V Collected Data

	Mass (g)		
	Initial Dry Shirt	Wet Shirt	*Efficiency (%)
1 Mesh	500.8	719.4	26.97
2 Mesh	552.5	805.6	32.6

* Efficiency calculated after a 30 minute time interval

B. Azeotropes

Upon researching different ways to lower the boiling point of the water inside the vacuum in attempt to boil off the water quicker, the idea of possibly incorporating azeotropes into the system came about. A positive azeotrope is a mixture of two or more liquids, which will boil at a lower temperature than any other ratio of its constituents. One of the most common azeotropes is the mixture of water and ethanol (95.6% ethanol and 4.4% water (by weight)). It was found however that NASA had implemented an alcohol ban, prohibiting any kind of alcohol use in space. This would include any items or materials that contain alcohol. It was also found that most azeotropes are toxic and/or flammable, putting an immediate end to this seemingly probable idea.

C. Discussion

From the data examined, a significant improvement was observed on the amount of water extracted. The increase in area of the mesh did in fact help recover more liquid when compared to the results of past testing. It is now believed that the mesh component of the vacuum bag takes part in a much more significant role then previously thought. A few more tests need to be conducted to asses if the orientation of the fibers plays a role in the extraction of the solvent as well as to observe the 5th configuration of Generation IV with this new development. This coming spring semester, it will be strongly attempted to combine the two: Gen. IV's 5th configuration with its addition of heat and Gen. V's "sandwich" mesh setup.

VIII. Current Work

A. Baseline Test

Our team decided to observe the effect of the garment being in a close-to-vacuum environment using a rigid container. In order to see how much water could be pulled, an initial weighting of the shirt was taken before the test. This would be compared to a weigh-in of the garment after a specific amount of time. Using a new vacuum desiccator as the drying chamber, the vacuum pump was allowed to evacuate the initial air in the chamber, to bring the pressure close to -29.921 in.Hg. Once the vacuum gauge indicated the desired level, the system was left alone for approximately 30 minutes. In light of the previous testing, it was decided to continue using the same sized mesh that Generation V had clearly benefited from.

Figure 12. Baseline Testing
New desiccator and pump

B. Observations

The efficiency that was observed was around 6-7%, which indicates that a system utilizing an near vacuumed environment was not as effective as previous experiments. We believe this is due to the capillary effect that cotton has on water molecules. It is believed that there is a molecular binding by the cotton fibers with the saturated water within the garment that prevents it from being physically pulled away. Another observation that was noticed was the apparent temperature difference of the shirt after the test compared to its initial state. In other words, the shirt was cool to the touch. We believe this to be the result of an adiabatic saturation processes occurring within the bag as the pressure was lowered. The water molecules essentially take the energy from the air and use it as the latent heat of evaporation. This allows evaporation to take the heat from the shirt and result in a cooler garment. Once the air is evacuated there is no longer any energy to achieve further evaporation at the cooler temperature.

The actual chamber was manufactured with a valve too small to use with the current fittings. Due to this incompatibility, the desiccator needed to be retrofitted in a manner so that the vacuum hose could be fixed effectively. Holes were drilled at the top of the desiccator, about 1 inch in diameter. Using vacuum hose quick-release connections, sealed with zinc chromate tape, the desiccator was fitted with a port for the hose, as well as a second port for a second vacuum gauge. The preexisting valve was closed off, in addition to being sealed with a layer of chromate tape before the test began.

In the beginning of the testing, there was a discrepancy with the two vacuum gauges, the analog model at the base (where the vacuum pump was directly connected to the hose) and the digital model, which was placed at the desiccator (the second port). Initial readings from the digital gauge showed reading of only -14 in.Hg, while the analog was reading on average -29 in.Hg. Upon investigation in the matter, both gauges were swapped and the observed while the system was active. As was hypothesized, the digital gauge continued reading the same faulty -14 in.Hg even at the source of the vacuum. Needless to say a new analog gauge was ordered so that it may replace the defective one.

C. Adiabatic Saturation Process Research

As a well known thermodynamic process, adiabatic saturation occurs when relatively dry air is blow across a source of water. In turn, water leaves from the source and is absorbed into the air. As an example of an ideal situation, imagine a thermally insulated duct with a pool of water in the middle. It has warm, low humidity air being blown into it on one end and comes out more humid and cool on the other. The pool of water will start to decrease its water content unless being continually supplied. This indicates that moisture is being picked up from the pool and being driven away from its source without heat being applied to the air or water source. The air is transferring its own heat to the water in order to facilitate the evaporation process. One may also observe that the temperature of the now humid air will be less than the input (dry) air. A more common occurrence of this process is when we perspire on a hot, dry day. A breeze will feel cool to us because the sweat on our skin is being evaporated by taking the heat needed from our skin and the air. This quantity of heat needed is known as the heat of vaporization. If however the air was hot and humid, the rate of vaporization would be much slower due to the already present moisture content.

In Fig. 13, a conceptual design is shown that would take advantage of the adiabatic saturation process. It would also allow for the excess water to be collected in its entirety.

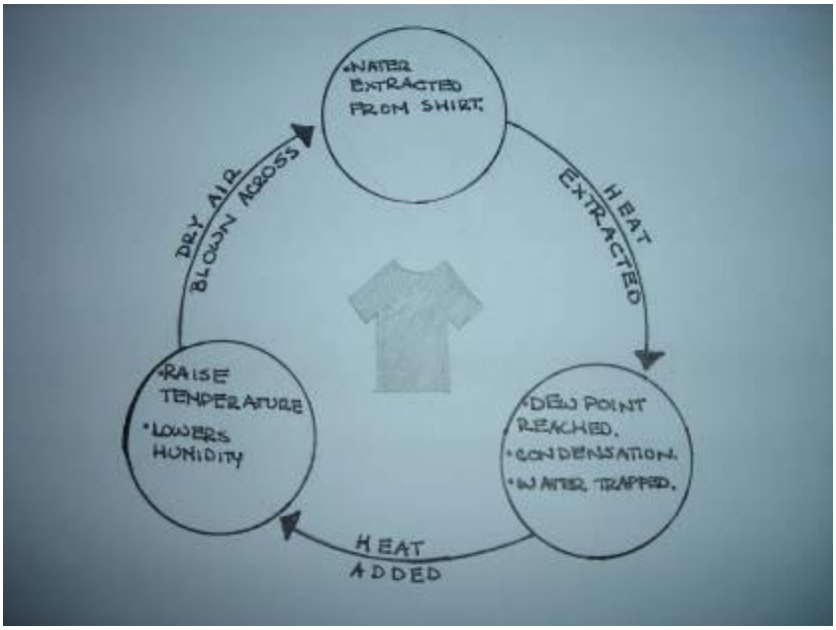


Figure 13. Coneptual Design of New approach
Process that takes adiabtic process into consideration..

D. Effective Solvent and Surfactant

The chemical engineer members of the group decided to look into using substitutes for water as a solvent. The options available were to use the current drying cleaning solvent known as PERC and liquid carbon dioxide. Because of the health risks of perchloroethylene (PERC), a new technique is being implicated in the process of dry cleaning based on the idea of using liquid carbon dioxide as a solvent, eliminating the need for toxic cleaning chemicals. This new technique is not widely used; however, its cleaning performance has been tested to be as effective as PERC. Liquid carbon dioxide is non-toxic, non-flammable, and an effective solvent, making it environmentally friendly. These characteristics make it an ideal solvent to investigate for future generations.

Research is also being conducted in order to isolate an effective, yet non-toxic surfactant to incorporate into our system. Currently, a few candidates are being considered. One surfactant being looked into is No Rinse®, a product presently used by NASA to disinfect and clean. No Rinse® is alcohol free and does not contain any toxins. In addition to No Rinse®, Soapopular® is another similar product containing no alcohol and no threat of flammability. Another surfactant being researched is referred to as soap nuts. Soap nuts are the dried fruit of the Chinese Soapberry tree. They contain saponin, a natural cleaner. Soap nuts are non-toxic, all natural, biodegradable, and recyclable. Continuous research will still be conducted in isolating a valid surfactant.

E. Presentation Notes

The SEI team was recently able to travel to San Antonio for an AIAA conference and to Johnson Space Center in Houston for an SEI conference. The Laundry In Space project was presented at both conferences. The AIAA conference gave the team a chance to finish their presentation and practice their responses during the question and answer sections of the presentations. The team learned certain things from the NASA conference, such as the need to compute an Equivalent System Mass to compare cost versus benefit of the system. The idea of “no-rinse” soap was also mentioned based on the alcohol free shampoo that astronauts already employ. This type of soap kills 99.9% of germs and is not alcohol based. The team plans to research this possible solution. During the NASA question and answer section the team was unable to answer why the temperature of the oven was set at 170°F. After research the team found that the oven was set there because it was the hottest temperature possible that would not damage the bag or garment. We were advised to look at the quantity of heat that would be required to evaporate the water out of the garment. This could be done by calculations based on how much water would remain within the textile after being washed. Another question involved the level of cleanliness that would be acceptable. To this we were given an idea of taking surveys of students at the college and ask to compare several pieces of clothing that would vary in “cleanliness” and to rate it on a scale of 1 to 5. It is believed that there is no method residentially used on Earth to detect dirt or oil left over with current washing machines. Therefore it may be assumed that it will require one wash cycle with the proper surfactant and the textile will come out free of contaminants, or in other words “clean”. This matter will be looked at more intensively once the drying component of the system is effective.

IX. Conclusion

After five generations of testing, it can be concluded that the project is progressing. As the drying efficiency of the system continues to increase, the goal of removing eighty to ninety percent of water becomes more tangible. With the purchase of a new vacuum pump and other system components it is plausible that the results will be far more successful. Expectations for water removal this semester are somewhere between forty and fifty percent, being that over thirty percent was removed last semester. This is still short of the goal of eighty to ninety percent; and for several reasons. One reason being; that even with component upgrades, pinhole leaks in the garment bag prove to be a prominent weak point. It is because of these pinhole leaks that the system is unable to utilize the full power of the vacuum, leaving room for improvement. In addition, the fittings which connect components of the system have also proved to be loose ends, which need to be improved. Another reason why the goal will probably not be met this semester is due to the fabric choice of N.A.S.A Astronauts. According to N.A.S.A mentors, Mr. Jim Broyan and Ms. Melissa Borrego, the main choice of clothing for N.A.S.A Astronauts is 100% cotton. Since this fabric is prone to consuming and retaining water, the drying process proves to be more difficult. This could be an avenue of exploration for the project in future tests. Overall the project is moving towards the final generations in the drying process and will soon be entering the washing and disinfecting stages.

X. Future Work

A. Mass Balance

Future plans for the project will include looking at where the water is actually going within the system. It is highly probable that there is water being transported through the system and is being unaccounted for. To accomplish this task, a weighing of the system's compartments, both before and after trial runs, will be taken to determine if water is escaping or being absorbed where not intended. This will assist in fine tuning future generations.

B. Different Fabrics

The behavior of the system with different types of fabrics (cotton vs. nylon, polyester, spandex, etc.) is something that should be implemented in testing. It is plausible that the permeability of cotton, which has been the material choice until now, has a lower permeability than of other fabrics. This characteristic could be very helpful with future testing to acquire the desired dryness of the garments.

C. Improve Garment Chamber

It may be possible to considerably lower leaks from pinholes with the implementation of a semi-rigid compartment. This of course could possibly replace the vacuum bag as the main chamber for the garment altogether. It has been in our team's experience that the vacuum bags have a risk of being torn easily or worn out rather quickly creating pinholes.

XI. Acknowledgments

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