Thermal Vacuum Integration for Cal Poly's Space Environments Laboratory

A Senior Project
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Bachelor of Science

by
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Thermal Vacuum Integration for Cal Poly's Space Environments Laboratory

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The purpose of the senior project is to construct a thermal vacuum by utilizing a pre-existing vacuum chamber in the Space Environments Lab, and a donated Advanced Thermal Sciences (ATS) chiller. While a thermal vacuum is already available on campus, building one for the Space Environments Lab would grant undergraduates access to the equipment, allowing a much better understanding of testing methods and procedures in use by the aerospace industry. This paper explains the design and analysis of the thermal vacuum (T-VAC) project as well as the operation and procedures required for the ATS chiller and fill/drain tank. The thermal vacuum consists of a vacuum chamber, the ATS chiller and fill/drain tank, Galden HT-110 (a heat transfer fluid), a hot/cold plate, and stainless steel tubing. Patran was utilized to analyze the design of the hot/cold plate and was then verified in a complete run of the T-VAC system. Overall, the system performed close to or better than expected, with the plate reaching a temperature as low as -18°C, and over 100°C in a short period of time, though a leak issue does still need to be resolved.

Nomenclature

A = area (m^2)
C_p = specific heat (W-hr/kg°C)
D = inner tube diameter (cm)
h = convection coefficient (W/m^2K)
k = conductivity (W/cm°C)
Q = heat (W)
T = temperature (K)
t = time (hours)
ε = emissivity
σ = Stefan Boltzmann constant (W/m^2K^4)
ρ = density (kg/cm^3)

I. Introduction

THERMAL vacuums are widely used throughout the aerospace industry, and are made up of essentially three parts; the vacuum chamber, the heating element, and the cooling element. The heating element is generally made up of multi-kilowatt lamps or heaters to provide radiative heat while the cooling element is generally a chiller/pump system that utilizes heat transfer fluid and thermodynamic processes to provide the low temperatures required to simulate the space environment. Thermal vacuum testing is not only performed on spacecraft as a whole, tests are also used on specific components. Because T-VAC (thermal vacuum) tests are able to demonstrate the performance of materials, components, subsystems, and spacecraft in realistic thermal environments, thermal vacuums are essential to the integration and testing of spacecraft, and the verification of thermal math models.

The tests that are performed in the thermal vacuum chamber help verify that thermal control design on a spacecraft works. These tests include: thermal balancing and thermal cycling. Thermal cycle tests subject the test component to a number of cycles of hot and cold temperatures in a vacuum environment while thermal balancing tests verify the thermal control of a subsystem/spacecraft as well as correlate to thermal analytical models. By constructing this thermal vacuum, undergraduates at California Polytechnic State University-San Luis Obispo will

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have the ability to perform the exact same set of tests that the aerospace industry, further increasing the school's "learn-by-doing" capabilities that are so unique to the school.

II. Project Components

All of the components required for the assembly of the chiller interface (excluding the vacuum chamber) can be seen in Table 1. Design was largely based around what was capable of accommodating a vacuum interface and would offer the smallest possibility of leaks (as Galden fluid is very expensive), as well as what would fit within the budget. According to contacts at ATS, the chiller should have tubing of diameter no smaller than a ½" (this would still be a step down from the 1" supply lines). The smallest size of a half inch was chosen due to the availability of fittings in this size (vacuum feedthroughs greater than 5/8" could not be found). Thus, pipe reducers were needed to convert from the 1" supply lines to ½" tool lines. Such adapters were only available as NPT to NPT fittings, so additional adapters from NPT to tube compression fitting were needed, and compression to compression fittings were needed to interface between the vacuum feedthroughs.

Table 1. Vacuum interface assembly component list

Component	Quantity
Stainless Steel Pipe Reducers 1" to ½"	4
Stainless Steel ½" Male NPT to ½" Tube Fitting (Swagelok)	4
Stainless Steel ½" – ½" Tube Fitting (Swagelok)	4
Stainless Steel ½" – ½" Tube Fitting 90° Elbow (Swagelok)	1
Vacuum Feedthrough – ½" Stainless Steel Tube	2
Stainless Steel Tubing ½" OD	30 ft
Copper Plate 12" x 12" x ¼"	1
Strip Heater 3" x 10" – 300 Watt	1

A. The Vacuum Chamber

The vacuum chamber utilized in this experiment is the Space Environment Lab's large green bell chamber referred to as the Dynamic Application Vacuum Experimentation chamber or "DAVE". Figure 1 contains the schematic of DAVE including a breakdown of the components within it.

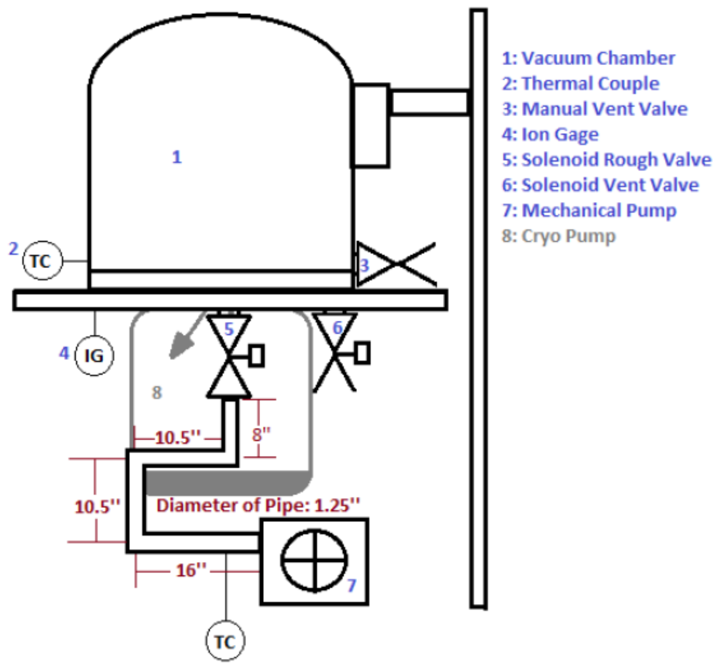

Figure 1. A Schematic of the DAVE Chamber[1].

The roughing valve, which is solenoid instead of manual, controls the flow rate of the gas leaving the chamber which then controls the pressure within it. DAVE also has two vent valves, one solenoid and one manual. There are thermocouples and an ion gage to measure the performance of the vacuum chamber during operations. Finally, two pumps, one mechanical and the other cryo, are utilized. For the purposes of the thermal vacuum, the chamber's feedthroughs are used to attach the chiller system to the vacuum chamber. During a dry run of the thermal vacuum system it was discovered that DAVE already has a cold shroud within the walls of the bell jar itself. Further investigation showed that it was impractical to use the shroud for our purposes (a chiller system instead of liquid nitrogen) so it was removed from the vacuum chamber.

Figure 2. The ATS-1231-CCN Chiller.

B. The Chiller System

Typical large T-VAC chambers used in the aerospace industry operate using liquid nitrogen, which is pumped through the vacuum chamber shroud in order to reach cryogenic temperatures that can simulate deep space.[2,3,4] However, using liquid nitrogen in such a fashion would be prohibitively expensive for Cal Poly, a fluid cooling chiller already in Cal Poly's possession is used. The ATS 1231-CCN-GL-004 chiller is a rather complicated, expensive piece of machinery that was donated to Cal Poly by Advanced Thermal Sciences (ATS), and can be seen in Figure 2. It is capable of providing two independently controlled cooling loops down to -40° C within +/- 1° C, up to 75 feet away from the chiller.[5]

One drawback to the chiller is that it does not go cold enough to perform testing up to Mil-Std-1540, which requires -44 C for acceptance testing (and even lower for proto-qual. and qual. testing).[6] While the chiller documentation specifies the use of Galden HT-70, contacts at ATS (the manufacturer of the chiller) have verified that other inert fluids will also work, such as HT-110, HT-135, FC3283, FC77 and FC84. Because reclaimed HT-110 was found for a significantly lower cost (over 2000$ in savings) and has a similar minimum operating temperature below -40° C, it will be used in place of HT-70.[7] In fact, the

higher boiling point is also desirable when the heating element is being used.

The chiller operates by sending refrigerant through a refrigeration compressor, then through a condenser where it is cooled by water supplied by the facility. The refrigerant then passes through a controllable expansion valve, and as it boils off, it cools the fluid passing through the cooling loop (through an evaporator heat exchanger). The refrigerant then loops back through the compressor and the cycle continues. A mechanical pump drives fluid in the cooling loop, and after it passes through the evaporator heat exchanger, it passes through an electrical heater, which is used to control the temperature of the fluid going into the tool (the tool is the interface between the cooling loop and component that must be cooled). This cycle is demonstrated in Figure 3.[5]

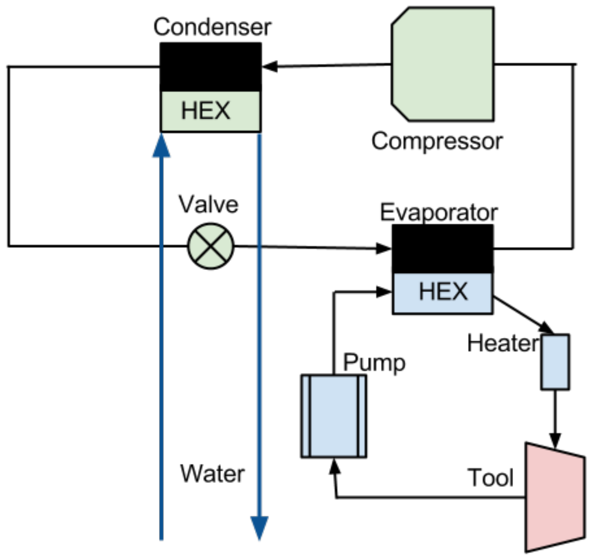

Figure 3. Representation of the thermodynamic cycle performed by chiller.

The chiller has several requirements regarding operation. It requires a 10 gallon per minute water flow into the condenser (previously described) with 100 micron filtration. The flow must be 100 psi and 20° C max, and also must be non-corrosive. Water facility connections are ½” face seal connections, and the tubing for these connections (as well as a filter) have already been provided. Directly after running water through the lines, it should be air dried using pressurized air. For power, the chiller requires a 3-phase delta (balanced load), 4 wire (3 phases & earth ground), 200 to 208 VAC electrical connection running at 50/60 Hz with 60 amps of current. Cal Poly’s Space Environments Lab has both water and electrical connections available for use[5]. The cooling loop fluid-in and fluid-out ports are 1” NPT male connectors, though according to contacts at ATS, using at least ½” OD piping is acceptable. It is desirable for use ½” as opposed to a full 1”, as 1” vacuum feedthroughs are more expensive and difficult to find. Stainless steel tube reducers (Figure 4) had to be found to be able to convert from the chiller supply and return to ½” OD piping, and steel piping will be used to interface with the vacuum chamber.

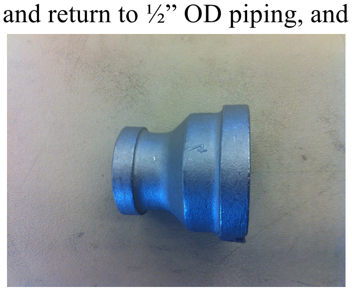

Figure 4. 1” NPT to ½” NPT adapter.

Thankfully, the chiller only produces 75 dB(a) of sound, which is well below OSHA’s standards of requiring hearing protection.[8] Filling, draining, and operation of the chiller are rather complicated, and somewhat confusing, as there are some conflicting instructions among the documentation. A rough overview of procedures may be found in Appendix A. Only one channel running the cooling fluid is desired of the chiller however, both channels must be filled in order to properly run the machine. In order to fill or drain the chiller of heat transfer fluid, a special Fill/Drain Tank is required, and has been purchased. Pressurized nitrogen and/or dry air is required to perform several tasks related to chiller operations (this is discussed further in Appendix A), and the operator must be very careful to ensure that air is always purged from the system. This means that if the tool is detached and reattached, special procedures must be followed. For more information about operating theory, see Appendix A.

C. Cold/Hot Plate

Copper was an excellent material to use for the cold/hot plate, as it has a very high conductivity, and an extra copper plate was available at no cost from past experiments. Pipe bends could only be made with a radius of 1 ½”, which meant that the tubing would not have a very large contact surface area with the plate – this can be seen in Figure 5. Tubing was braised onto the plate in order to attempt to mitigate this effect.

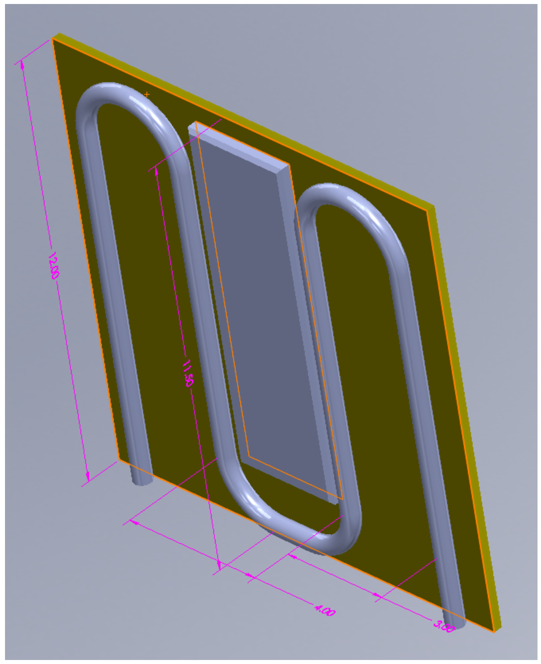

Figure 5. CAD model of copper plate assembly (dimensions shown are in inches).

A single strip heater is placed in the center of the plate – a wider heater was chosen both for a reduced cost and a larger contact area. The heater is to be fastened to the plate with two bolts. It should be noted that the location of the heater is less than ideal, as the Galden fluid should not be allowed to reach greater than 100°C, as it boils at 110°C. The temperature differential through the heater interface should be large enough to prevent this from happen as long as temperature is carefully monitored. Despite this, the higher wattage available the better, as this allows temperature to be ramped up more rapidly.

The cold/hot plate was constructed based on the design stated above using a 12x12” copper plate, a strip heater, and steel pipe. See Figure 6 below for the component breakdown.

Figure 6. The Cold/Hot Plate Component Breakdown.

The copper plate was used in an older senior project for the thermal vacuum chamber. There originally was ¼'' copper pipe braised on and had to be taken off. The leftover solder also had to be removed and the surface of the plate scrubbed of any oxidation.

To braise the steel tubing to the copper plate, a braising station was constructed utilizing a propane fueled grill, a steel plate, and brackets. Figure 7 below shows the basic braising station.

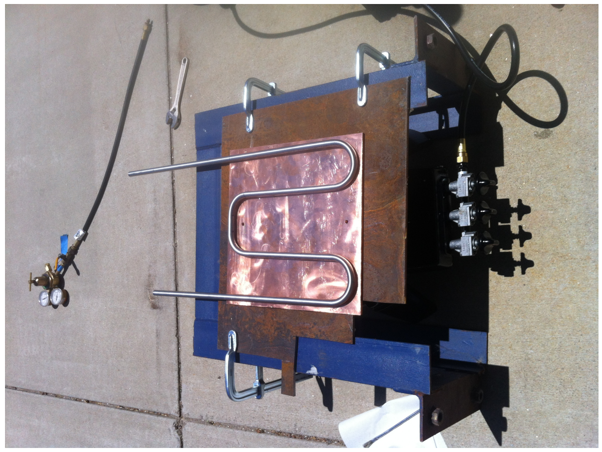

Figure 7. The Braising Station.

The propane fueled grill was stationed underneath the steel plate in order to supply a constant heat. The steel plate is then used to keep the copper plate from warping under the heat. The steel plate is then bolted down to a blue steel frame. Weights were also used to keep the steel tubing from bending under the heat stress. A propane torch was applied to the area of interest in order to control the soldering along the steel tubing. Afterwards the steel tubes were bent to fit into the adapters to connect to the chiller through the vacuum chamber feedthroughs. Then, using a drill press, ¼" holes were drilled in order to attach the heater.

D. Heater

The strip heater utilized in the thermal vacuum chamber was purchased from McMaster-Carr. It is 3/16" thick and 3x10" in dimension. The strip heater is mica-insulated and uses single phase power source. It can output about 300 W of heat.

III. Cold/Hot Plate Thermal Analysis

Thermal analysis was performed on the hot/cold plate in order determine expected temperatures as the plate either heats up or cools down. While the fluid can get as low as -40°C, the plate will never reach this temperature, as there will be a temperature differential across the conduction path through the pipe, solder, and into the plate. Analysis provides insight into what a more reasonable expected temperature may be, and how long it will take to achieve such temperatures. Because the vacuum chamber was not able to pull vacuum upon time of this writing, two cases for both either heating or cooling have been examined: a case where convective heat transfer to ambient air occurs, and a case where radiation heat transfer to the vacuum walls occurs. Room temperature inside the lab can vary from about 20°C to 30°C, and this must be taken into account. Because testing was done during the summertime, room temperature was often found to be as high as 29°C, which was used as ambient temperature for all of the analysis.
For the convective case, a reasonable convection coefficient for free convection of air can be assumed to be about 5 W/m^2K,[11] then Eqn.1,

$$Q_{in} = Ah\left(T_{amb} - T_{plate}\right) \tag{1}$$

where A is the convective area, h is the convection coefficient, T_{amb} is the ambient temperature, Q_{in} is the heat going into the system, and T_{plate} is the plate temperature , can be used to calculate heat transfer to the surroundings. For the radiation case, an emissivity of copper is needed, and the plate will be assumed to be in a large enclosure – this type of heat transfer is governed by Eqn. 2,

$$Q_{in} = \sigma \varepsilon A\left(T_{amb}^4 - T_{plate}^4\right) \quad (2)$$

where σ is the Stefan Boltzmann constant and ε is the emissivity.[12] Emissivity for a polished copper plate is about 0.052, while stainless steel has an emissivity of 0.14.[14] Thus, heat transfer between the plate and its surroundings can be calculated in either of these two ways. Because experimental data can be obtained for the convective case, it may be used to verify or determine the accuracy of the thermal math models created to represent the plate. These parameters, along with other material properties used, can be seen in Table 2.

Table 2. Material Properties List

Material	**Conductivity, *k* (W/cm°C)**	**Specific Heat, C_p (W-hr/kg°C)**	**Density, ρ (kg/cm^3)**	**Emissivity, ε**	**Convection Coefficient, *h* (W/m^2°C)**
Copper	3.912	0.107	0.00886	0.052	-
Stainless Steel 304	0.163	0.140	0.00803	0.14	-
Air	-	-	-	-	5
Galden HT-110	6.5×10^{-4}	0.270	0.00171	-	26

In order to calculate the convection coefficient for Galden HT-110 fluid traveling through the pipes, Eqn.3,

$$h = 4.36\frac{k}{D} \quad (3)$$

may be used to approximate the convection coefficient for laminar internal flow in circular tubes, where *k* is the conductivity of liquid, *D* is the inner diameter of the tube (in this case, 0.43").

Finite differencing models, as well as simpler lumped capacitance simulations, were created for all four cases (both methods were used to ensure that the computational simulation was producing a reasonable result). MSC Patran was used to create heat transfer models, and acted as a pre and post processor, while SINDA/G was used as a finite difference conduction network solver. MSC Patran is a finite element modeler, so it must translate the finite element model into a finite differencing network for SINDA/G to solve. The finite elements model created in MSC Patran can be seen in Fig. 8.

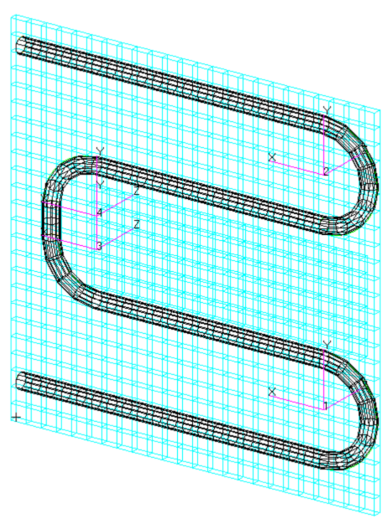

Figure 8. Finite Elements Model of the Cold/Hot Plate.

In order to perform a lumped capacitance analysis, Eqn.4 is used,

$$\rho V C_p \frac{dT}{dt} = Q_{in} - Q_{out} \tag{4}$$

where ρ is the density, V is the volume, and C_p is the specific heat capacity.[11] Solving the differential equation yields temperature over all time – one must simply determine amount of heat going in and out of the system. In this particular case, the thermal mass considered was the copper plate, and heat from the heater was added directly into the copper plate, while other energy balance terms were calculated using Eq. 1 and 2 above.

A. Cold Case:

The plate after being chilled for two hours can be seen in Fig. 9 below, with the assumption that the Galden fluid can be cooled immediately to -40°C. It should be noted that the pipe bends are a different temperature than the rest of the pipe – this is because the method for calculating conduction through the pipe included setting node equivalence, and some parts of the mesh did not connect in these bends (this should have a minimal effect on overall heat transfer). Because of the high conductivity of copper, the plate stays mostly isothermal.

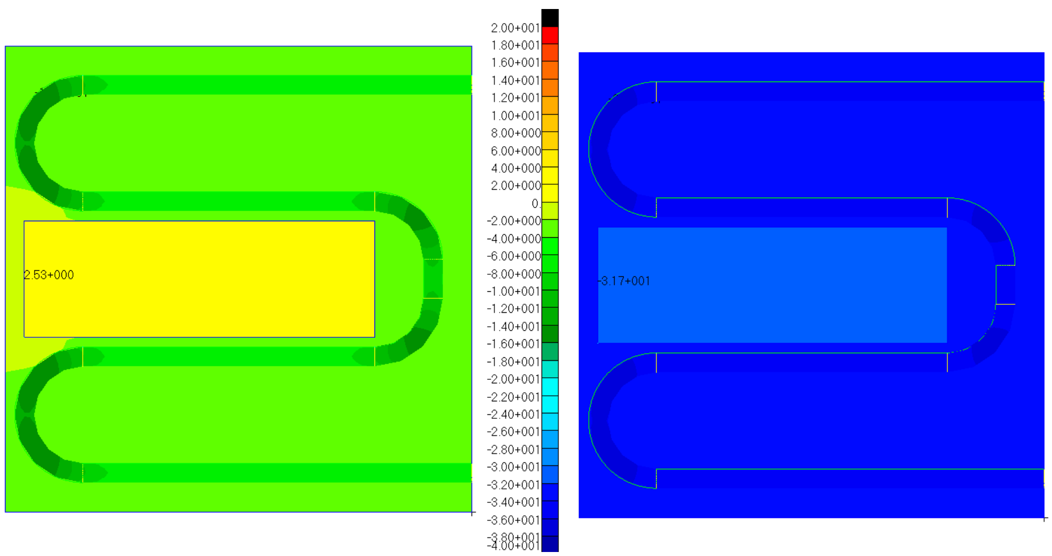

Figure 9. Finite Element results for cold case (right: vacuum, left: Convection), units are in °C.

When inside a vacuum, the plate would be capable of reaching significantly lower temperatures, as convective heating would be eliminated. In Fig. 10, this becomes very apparent as simulations show the plate reaching a temperature nearly 30°C below that of the plate when convection is accounted for. The differences between the two analysis methods in this case is also quite minor (of about +/- 4° difference). Steady state is reached after about one hour with convection, and just over two hours with radiation, with a minimum expected temperature of -34°C after two hours when the plate is in a vacuum. This temperature is adequate, though it would not be low enough in all cases to test components to qualification levels.

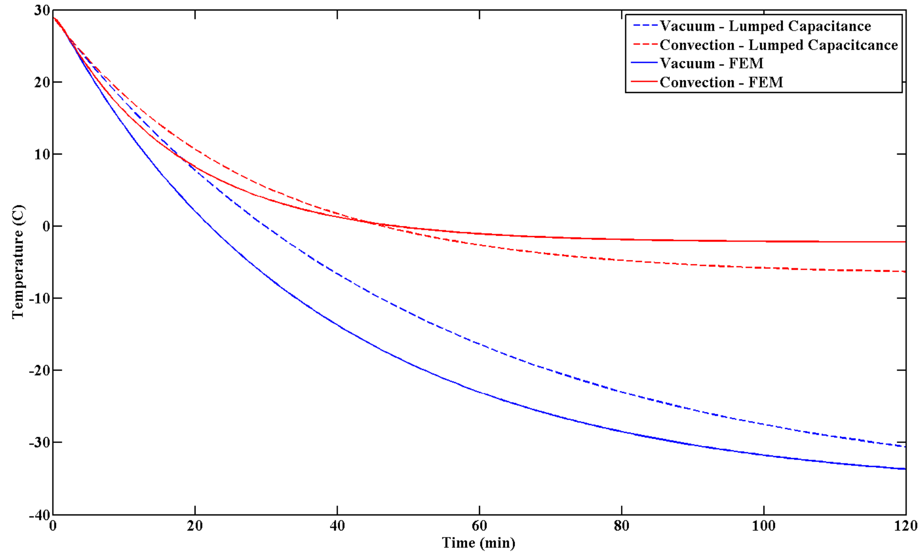

Figure 10. Transient results for cold case.

B. Hot Case:

Temperature results after being heated for two hours can be seen in Fig. 11 below with either convective or radiative heat transfer. Once again, the plate is mostly isothermal, with the region on top of the heater being slightly warmer than the rest of the copper plate. Because the plate exceeds the boiling point of Galden HT-110, care must be taken to ensure that the plate never actually reaches this temperature.

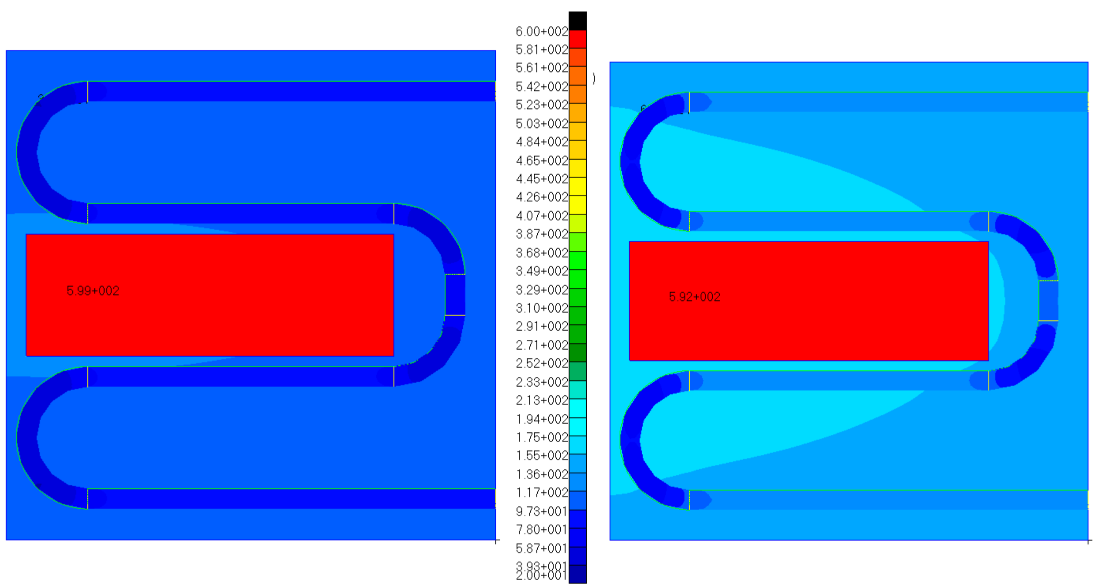

Figure 11. Finite Element results for hot case (right: vacuum, left: convection), units in °C.

The differences between the lumped capacitance and finite element models may be seen in Fig. 12, along with the transient response of the system. It is much easier to increase the temperature of the plate than it is to lower it, as the heater can operate much hotter than the fluid can operate cold. The high operating temperature of the heater means that temperature can be ramped up to about 100°C from room temperature in about an hour.

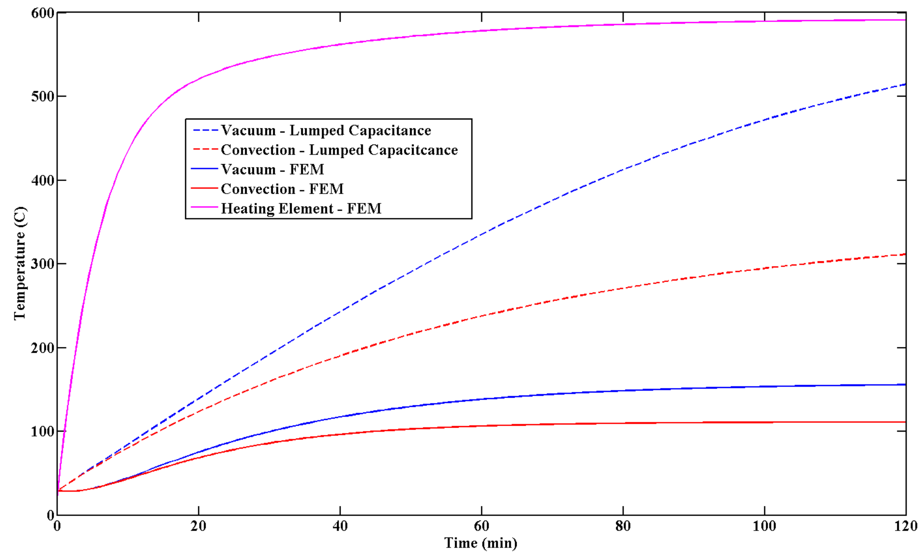

Figure 12. Transient results for hot case.

IV. Verification

A. Thermal Vacuum Set Up

Figure 13 below shows the basic schematic of the thermal vacuum chamber. The first step to put the thermal vacuum chamber together was to bend and cut the steel tubing to the size needed. This was done using a pipe bender purchased from McMaster-Carr and a pipe cutter supplied by the Space Environments Lab.

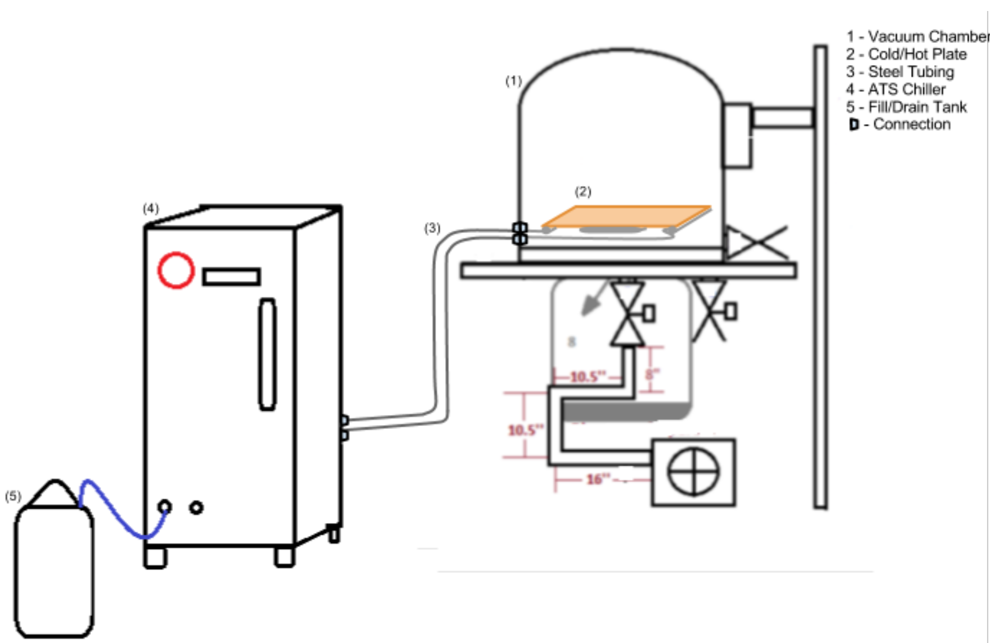

Figure 13. The thermal vacuum set up.

The steel tubes are attached at the inlet and outlet for Channel 1 and 2 on the ATS chiller using the tube reducer fitting shown in Figure 4 and a ½" compression tube fitting shown in the figure below. Another ½" compression tube fitting (Fig. 14) is used to connect the steel tubing to the Swagelok ½" vacuum feedthroughs, also shown in the

figure below. A final set of ½" compression fittings are then used to connect the tubing on the cold/hot plate to the vacuum feedthroughs.

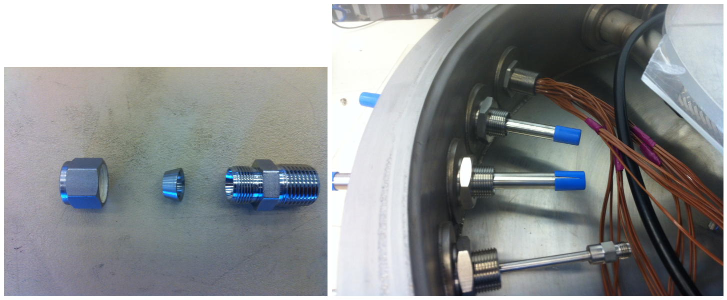

Figure 14. The ½" compression fitting and feedthroughs.

Next the fill/drain tank is attached to the front of the chiller on the fill/drain ports using hose provided by the manufacturer. For a more detailed instruction of this step, see Appendix A. The fill/drain tank is then filled with Galden HT-110 and pressurized using the air supply from the Space Environments Lab.

Figure 15. Fill/drain tank side and top view.

Once all the steel tubing and fill/drain tank connections are made, the chiller is ready to operate. For detailed instructions on ATS chiller operation, see Appendix A or the operating manual.

B. Experimental Results

The operation of the thermal vacuum is separated into two parts, cold testing and hot testing. The hot experimental test utilizes the heater on the copper plate while the cold experimental test utilizes the chiller as a source of heat transfer. The heater system was tested first and compared to the analytical results from the simulation performed in Patran, followed by the chiller. Unfortunately due to vacuum chamber repairs, no data for either the hot case or cold case could be taken while the cold/hot plate was within a vacuum, so at this time there is no experimental data for the vacuum case to compare to the thermal analysis.

Figure 15 below compares the data from the experiment to the thermal analysis done in Patran for both vacuum and non-vacuum. As can be seen in the Fig. 15, the trend is very similar between the three different scenarios. The experimental data shows that the copper plate reaches higher temperature than the convection case. This may be due to differences in the resistivity of the conductive path between the heater between the model and reality. However, performance of the hot plate is satisfactory, and caution should be erred to not exceed the 110°C boiling point of the Galden fluid (a margin of safety should be used, especially as it is difficult to control such heaters manually).

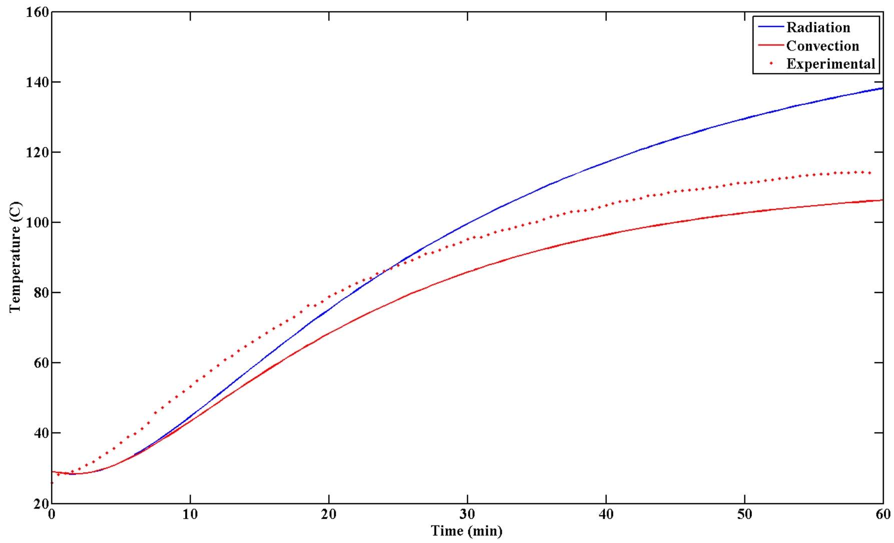

Figure 15. Experimental results employing the strip heater as heat transfer mechanism.

For the cold case, the experimental results do not match the analysis as closely as they do in the hot case. This can be seen in Fig. 16, which compares both analytical methods to the experimental results of running the chiller. A couple things to note are that the experiment reached equilibrium much faster than expected, and reached significantly lower temperatures than predicted – both of these are beneficial to the operation of a thermal vacuum system. About ten minutes from when the chiller was stopped, the plate quickly returned to near room temperature.

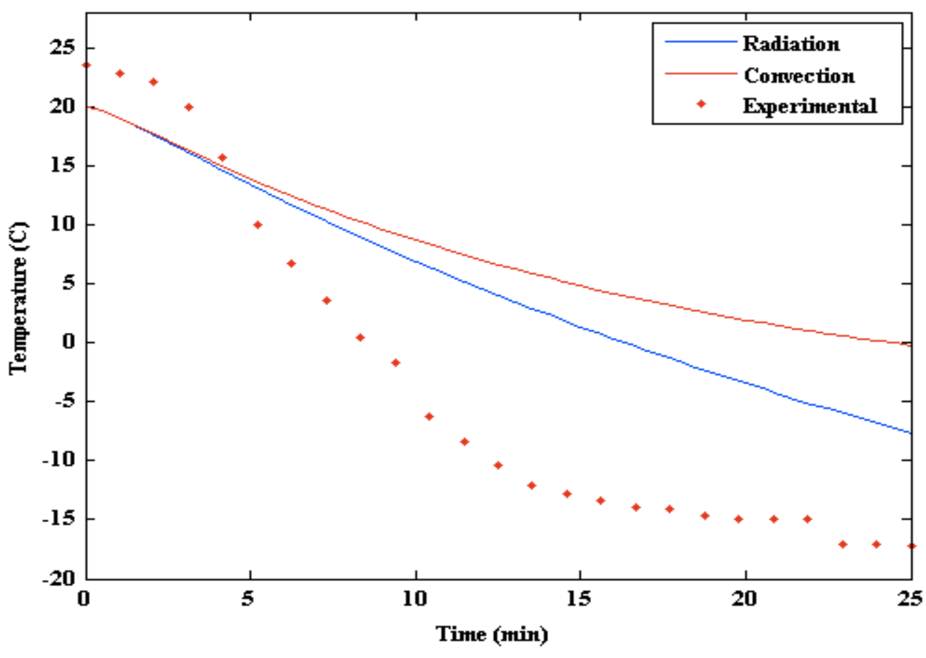

Figure 16. Experimental results employing the chiller as heat transfer mechanism.

The relatively high performance of the experimental results is likely due to over-conservative models being employed in the theoretical case. For example, in the Patran simulation, only a single line of nodes is allowed to communicate between the pipe and the plate (these nodes are "equivalenced," meaning that at that point of the plate where the pipe meets, the temperatures are fixed). In reality, the solder applied to join the pipe was not consistent throughout the joint, and difficult to accurately model. The area of the conductive path was perhaps larger than what

was accounted for in the simulation, demonstrating how difficult it is to account for things such as solder in a finite element model.

V. Conclusion

The successful completion of this senior project hinged on the correct implementation of the thermal vacuum and the chiller system which includes the ATS chiller and fill/drain tank, Galden HT-110 (a heat transfer fluid), a hot/cold plate, and stainless steel tubing. Patran was utilized to analyze the design of the system and compare to the actual test results for both the hot and cold cases. The Patran results for the hot case conclude that it would take about an hour to reach 100°C from room temperature with not real difference between conductive or radiative heat transfer. When comparing the experimental data to the convective data from Patran it was found that the copper plate reaches higher temperature in the experimental case, exceeding predicted results. This can be attributed to the fact that the Patran model used a more resistive conduction path between the heater and the plate was assumed more resistive then in actuality.

The chiller was successfully run and able to reach its minimum operating temperature of -40°C, with the plate reaching an average temperature of about -18°C in 25 minutes, exceeding expectations from model predictions. A slight leak exists at the ¾" NPT to ½" NPT adapter which should be addressed. Fluid can be recovered by catching it, however, there exists a problem when operating the chiller: frost builds up due to the low temperature, and then when it defrosts it can potentially mix with the fluid (water must *not* enter the chiller lines). While funding is low, in the future it may be beneficial to replace the adapters with higher quality fittings (other solutions, such as epoxies have been attempted with only slight signs of success). However, the system overall performs better than expected, and the solder joint between the copper plate and the pipe provides a satisfactory heat transfer path.

VI. Acknowledgments

The authors would like to extend their heartfelt thanks to Max Glicklin, for help in troubleshooting and much needed guidance, without whose support this project could not have been completed. The authors would also like to thank their advisor, Dr. Kira Abercromby for allowing this project to become a possibility, and keeping us on track (or at least as close as possible). Special thanks also goes to Cody Thompson, for offering expertise and advice on handling equipment.

VII. References

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Appendix A: Chiller Operational Procedures

Note: The instructions presented here are a summary of those given in the 1231-CCN-GL-004 Operating Manual, and their purpose is to touch on the key steps of chiller operation, and demonstrate some of the difficulty associated with chiller operation. For more detailed instructions, the Operating Manual should be consulted.

A. Filling the fill/drain tank:

1. Depressurize the fill/drain tank. Fill it with Galden heat transfer fluid through the cap opening on the top.
2. Pressurize the fill/drain tank to 80 psi by connecting the drain port on the tank to an 80 psi N_2 source.

B. Filling the hoses between the chiller and tool:

1. Close the supply valve for channel being filled. Connect the fill/drain tank fill port to the connection at the front of the chiller.
2. Hold the hose valve open until liquid is seen filling the sight glass without any bubbles. Pressure in the reservoir should be maintained near zero during this phase.

C. Filling the internal cooling loops of the chiller:

1. Open the supply valve for the internal loops of the channel being filled. Connect the fill/drain tank fill port to the connection at the front of the chiller.
2. Open the hose valve while maintaining pressure in the reservoir at zero.
3. For channel 1, observe the sight glass and continue filling the chiller until bubbles stop appear.
4. For channel 2, continue filling the chiller with the Ch.2 purge valve open for 2 minutes, then close the Ch.2 purge valve.
5. Disconnect the fill/drain tank.

D. Filling the reservoir:

1. Connect the fill port of the fill/drain tank to the reservoir drain connection.
2. Open the hose valve and maintain the pressure in the reservoir at zero. Continue filling the reservoir until the tank is full or bubbles are appearing in the sight glass (this indicates that the fill/drain tank is empty). Because air can be vented from the reservoir, introducing it at this point is not harmful to the chiller.
3. Disconnect the fill/drain tank from the reservoir and connect an 80psi N_2 source. Introduce N_2 into the system until 20 psi in the reservoir is reached. Channel 1 and 2 pressure gauges should also signify this temperature.

E. Chiller Operation:

1. Start pumps for the channel being purged, and check for flow. If flow is not established within 5 seconds, turn the pump off.
2. Repeat step 1 until flow is established (note the "Low Flow" indicating LED). Pressure should jump to 60-100 psi greater than reservoir pressure. If flow does not start, repeat the steps: "Filling the internal cooling loops of the chiller."
3. Open the purge valve for that channel for 3 minutes to remove remaining air in the chiller loop.
4. Turn on the compressor and heat/chill processing unit.

F. Draining a Tool Channel

1. Stop the pump for the channel to be drained, and close the supply valve.
2. Connect an N_2 source to the fill/drain line, and open the fill/drain valve to allow N_2 into the line. Connect a tank hose from the pressure valve at the top of the sight glass to the fill/drain tank drain port.
3. Continue the process until bubbles appear in the sight glass. Continue introducing N_2 through the fill/drain valve for approximately 30 seconds per 25 feet hose to be drained.

4. Close the return valve for the channel being serviced. The tool or lines are now ready to be disconnected.

G. Operating Theory

1. Once the chiller is installed, steps A, B, C, and D should be initially performed, then steps E should be performed when operating the chiller is desired.
2. If the chiller needs to be removed from the vacuum chamber system, steps F should be performed.
3. If the chiller is to be reintegrated in the vacuum system, steps B and C need to be performed again, then G may be performed. The process would repeat until it is desirable to completely remove the heat transfer fluid from the chiller.