Siemens Snowgun

Design Specifications

Team Siemens – Senior Design

12/12/2009
University of Delaware
Jacob Sherry
Andrew Phillips
Jason Landesberg
Eric Evers
Sarah Shovestul
# Contents

Project Introduction .................................................................................................................. 3

Problem Identification ............................................................................................................. 3

Project Scope .......................................................................................................................... 3

Defining Wants ........................................................................................................................ 4

Ranking Metrics ....................................................................................................................... 4

Benchmarking .......................................................................................................................... 5

Data Collection ......................................................................................................................... 7

Temperature Distribution ......................................................................................................... 7

Evaluation of the Tray Jams ..................................................................................................... 7

Concept Selection ...................................................................................................................... 10

Comparing the Concepts to the Target Values ......................................................................... 11

Design Specifics: ...................................................................................................................... 13

  Cartridge Heaters: .................................................................................................................. 13

  Controllers .............................................................................................................................. 16

Design Integration ...................................................................................................................... 18

Validation of Performance Goals ............................................................................................ 18

Design Synthesis ....................................................................................................................... 21

  Explanation of Experiments ................................................................................................. 21

  Experimental Results ........................................................................................................... 23

  Data Analysis ......................................................................................................................... 25

Resource Effectiveness ............................................................................................................ 26

Appendix .................................................................................................................................. 29

  Defining Wants ..................................................................................................................... 29

  Other Concepts ..................................................................................................................... 29
**Project Introduction**

**Problem Identification**

The Snow Gun is a cryogenic manufacturing device that atomizes a liquid reagent to be used in medical diagnostic equipment. The collection trays are suspended below the guide rails and separated by a sheet of plexi glass. The rail are exposed to the ambient conditions causing frost to form of the rail due to the combination of the humidity in the air and the subfreezing temperatures.

**Project Scope**

The scope of our project is to analyze and improve the Snowgun environmental conditions around the rails. The goal is to prevent tray jams within the snowgun due to frost buildup and construct a working prototype. From our initial investigation of the problem, we have come up with a few preliminary ideas on how to remedy the situation. They include integrating a dehumidifier into the system and isolating the room, heater strips along the linear slides, a lubrication, deicing, water/air jets, modifying the current HVAC system, or a combination of any of the aforementioned ideas. We will also run tests to determine the cause of the tray jamming within the input chamber and suggest ways to eliminate this issue.

Our contacts include the two manufacturing engineers who we are in contact with, a technician that operates the machinery, and the Siemens Consumables department. We aimed at keeping our design simple to reduce the chance of failure, durable to ensure the design is long-lasting and reliable, and low maintenance to ease the workload of the technician. The design must also be safe, not exceed our budget, and not interfere or alter the current reagent manufacturing process. In addition, it must be designed for wash downs and it must be removable for maintenance.
**Defining Wants**

In order to achieve an effective design, wants from the engineers, technicians and staff were collected and then ranked based on importance to the individual. UDesign was used to manage and organize this data which can be seen in Table 1 and defined more specifically in the Appendix.

<table>
<thead>
<tr>
<th>Final Ranking</th>
<th>Wants</th>
<th>Rate of Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>effectiveness</td>
<td>37</td>
</tr>
<tr>
<td>2</td>
<td>simplicity</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>ease of removability</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>low maintenance</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>high efficiency</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>ease of use</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>inexpensive</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 1**

**Ranking Metrics**

Metrics quantify how well the wants are satisfied. By ranking the metrics we are able to organize them based on relevancy to solving the problem. Metrics are ranked based on the priority of each want in correlation to the measurable quantity. These metrics provide us with a mathematical reasoning of choosing one concept over another. In order to achieve an effective deliverable/concept we are going minimize the mean time to failure (MTBF). Based on our sponsor’s preference to alter the environmental conditions, versus modifying the framework of the machine, we decided that controlling the humidity and temperature of the chamber is the best initial course of action. The remaining metrics and associated target values can be seen in Table 2.
### Table 2

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Target value</th>
<th>Ranked Order of Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature</td>
<td>-165 C</td>
<td>1</td>
</tr>
<tr>
<td>humidity</td>
<td>0%</td>
<td>2</td>
</tr>
<tr>
<td>cost</td>
<td>$5000</td>
<td>3</td>
</tr>
<tr>
<td>dimensions</td>
<td>5'x2'x2'</td>
<td>4</td>
</tr>
<tr>
<td>weight</td>
<td>&lt;50lbs</td>
<td>5</td>
</tr>
<tr>
<td>power required</td>
<td>&lt;20% more than current value</td>
<td>6</td>
</tr>
<tr>
<td>mass flow rate</td>
<td>N/A</td>
<td>7</td>
</tr>
<tr>
<td>number of moving parts</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>noise</td>
<td>&lt;15% more than current value</td>
<td>9</td>
</tr>
<tr>
<td>MTBF</td>
<td>2 hrs</td>
<td>10</td>
</tr>
</tbody>
</table>

**Benchmarking**

We have initiated benchmarking in order to conjure up basic ideas on how to solve the problem at hand. These might include the integration of pre-existing products/systems or researching existing technology used in competing companies or systems. We came across a low temperature bearing grease that could be applied to the linear actuators to keep them running smoothly at very low temperatures. The grease would be effective as it is rated at a temperature significantly lower than what we are dealing with (-165 C). Industrial dehumidifiers were part of our benchmarking as well since many of them, including the Scannar models, can provide levels as low as 1% relative humidity. Similarly, there are desiccant systems that have the same effect as dehumidifiers but are more economical at lower temperatures and lower moisture levels. We also researched ice protection systems on aircraft that could be modified and integrated into the Snowgun. These systems include the pneumatic boot, the bleed air system, the electro-mechanical expulsion deicing system, and the weeping wing system, which all prevent ice buildup either by mechanical or chemical means. Furthermore, we found a patented condensation and frost control system for cooler and freezer door entries that incorporates design aspects applicable to our problem. Lastly, we found that strip heaters,
which are implemented on a surface and are commonly used for moisture protection, could provide a very inexpensive solution that is easy to install.
Data Collection

Temperature Distribution

Data collection consisted of attaching eight thermocouples to the inside of the snow gun chamber. The test was completed with a water trial and the data was plotted versus time to be easily comparable. A smoothing function was used to convey the general trend in the temperature variation and eliminate small variations. The plot containing the smoothed functions is on the following page. The lowest temperature in the chamber was reached closest to the precipitate cylinder and reached a steady state temperature of about -65 degrees Celsius. Areas on the rail closer to room temperature air reached approximately -20 degrees Celsius. The dew point inside the chamber was taken to be 4 degrees Celsius and the relative humidity in the chamber was 40.2%.

Using this data, target values were assigned to the metrics. This data shows the temperature distribution between in the input and output chambers and on the rails. See Graph 1 for the temperature distribution as a function of time.

Evaluation of the Tray Jams

One problem pertaining to the Snowgun machine is the tray jams occurring in the input chamber. These jams do not occur very often, but always occur when there is a significant amount of frost accumulation on the rails. We aim to assess the problem and suggest measures to fix it.

We determined that the tray jams would be caused by one of two ways. First, the trays could be angularly offset somehow during the run. Second, the linear slide blocks may have been unable to obtain the proper position within its narrow tolerances. First, while the Snowgun machine was not running, one tray, located under the chamber where the snow would fall, is angularly offset as much as is allowed. When the second tray was loaded into the chamber, the first tray was realigned by the second, incoming tray, and no tray jams resulted from this angular misalignment. Next, the linear slide blocks offset to one side. When the next
tray was being loaded, the first tray could not properly move into the holding chamber and a jam occurred.

Having the linear slide blocks not in proper position was the only way to cause the tray jams. As nothing else sits on the rails, the frost accumulation is the only logical cause for the linear blocks to not reach the appropriate location and therefore causing the tray jams. We believe that solving the problem of the frost accumulation on the rails will also solve the problem of the tray jams.
Graph 1

Smoothed Chamber Temperature

Temperature (°C)

Time (s)
Concept Selection

Over the course of this semester, we plan to design and fabricate an environmental change, local to the rails, to address the frost build up on the rails of the Snowgun Machine. Our design will include a modification to the current rail system. We plan to have a new set of rails machined that can accommodate an electrical heating element that will be inserted into the center of the cylindrical portion of the rails. By heating the rails above the dew point temperature, we are able to control the local environment such that frost will not accumulate.

This concept is effective because heating the rails above the dew point temperature will inhibit ice buildup resulting in a tray jam. Complimentary to our wants, it is simple in nature because there are no moving parts, and very little operator intervention is required. The operator will be able to set the temperature control and will require little to no maintenance. The concept rails are easily installed for a prototype trial and will not interfere with the current system. If our concept is validated and implemented, removability will not be an issue, as the design is meant to be a permanent fixture.

This design meets all of the metrics and the associated target values, shown in table on the next page. Mean time before failure will be eliminated as long as the controller is functioning properly. Local humidity is less of a concern because the dew point will never be higher than room temperature. A cost estimate of this design is outlined in Table 1 and will be
within our defined budget of $5000. No noise is associated with the controllers or heating elements and the overall weight is well below 50lbs.

We plan to design and conduct experiments to diagnose and evaluate the tray jams involving the actuator. Preliminary observations suggest the problem may be interrelated with the rail jams and the accumulation ice. Further testing will help us to understand the problem and suggest solutions for the future.

Comparing the Concepts to the Target Values
We assigned each of the metrics a target value that would be appropriate for the project. Many of these metrics were determined based on the data collection previously mentioned. Each metric had a multiplier from 1 to 10, 10 being the most important. For each concept, if the target value was satisfied, it was given a 1, if it did not satisfy the target value, it was given a 0. Using this process, we were able to give each concept a score based on the importance of all of the target values it satisfied. The scored can be seen below, with the highest scoring concept as the cartridge heater.
<table>
<thead>
<tr>
<th></th>
<th>Dessicant</th>
<th>Cartridge Heater</th>
<th>Modify HVAC</th>
<th>Snow Plow</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTBF</td>
<td>&gt; 2 hours</td>
<td>&gt; 2 hours</td>
<td>&lt; 2 hours</td>
<td>&lt; 2 hours</td>
<td>&gt; 2 hrs</td>
</tr>
<tr>
<td>Humidity Output (% RH)</td>
<td>10</td>
<td>unsatisfied</td>
<td>7</td>
<td>unsatisfied</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Minimum Operating</td>
<td>-18</td>
<td>satisfied</td>
<td>4.5</td>
<td>satisfied</td>
<td>&lt; -62</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of moving parts</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Noise (dB)</td>
<td>40</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>&lt;115% current value</td>
</tr>
<tr>
<td>Cost</td>
<td>$3,000</td>
<td>$4,900</td>
<td>$1500</td>
<td>$2000</td>
<td>&lt;$5000</td>
</tr>
<tr>
<td>Dimensions</td>
<td>17&quot; x 25&quot; x 16&quot;</td>
<td>6&quot; x 4&quot; x 3&quot;</td>
<td>satisfied</td>
<td>2&quot; x 3&quot; x 2&quot;</td>
<td>&lt; 1 cubic ft</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>37</td>
<td>5 (controller)</td>
<td>0</td>
<td>~ 1.5 x 4</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Power Required</td>
<td>2000 W</td>
<td>200 W</td>
<td>120 V, 15 amps</td>
<td>0 W</td>
<td>0 W</td>
</tr>
<tr>
<td>Mass Flow Rate</td>
<td>100 SCFM</td>
<td>satisfied</td>
<td>90 SCFM</td>
<td>satisfied</td>
<td>0 SCFM</td>
</tr>
<tr>
<td>Score</td>
<td>24</td>
<td>44</td>
<td>25</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>
**Design Specifics:**

**Cartridge Heaters:**

Each hollow cylindrical rail will have two (2) 36” long cartridge heaters, running back to back through the center, and will have a diameter of 3/8”. Each heater will be running at 100W with a 120 volt power source. We want to maintain each rail as an individual system so we will have one controller monitoring rail temperature via J-type connection thermocouples at the rail midpoint. J-type connections are more sensitive than the standard K-type and temperature sensitivity was deemed important.

All of the equations were derived for a radial system, starting with the convection off of the cylinder wall. The total heat transfer is “q” and is considered to be constant throughout thickness of the cylinder wall. Using the dew point and room temperature as the lower and upper limits, a range of power required to heat the rails was determined.

To calculate the heat lost from the surface of the rail the following equation was used

\[ q_{\text{conv}} = 2\pi r L h_{\text{air}} \times (T_{\infty} - T_{s}) \]

Using an appropriate value for the convection coefficient (h) of air, we needed to measure the flow of air locally over the surface of the rails. This allowed us to calculate the Reynolds number of the flow, which we can confidently say is laminar, and from that, along with the associated Prandtl number, we were able to find the Nusselt number. The convection coefficient can then be found from the equation below:

\[ Nu = \frac{hL}{k} \]

In radial systems heat transfer rate is constant so

\[ q_{\text{conv}} = q_{n} \]

Use this to solve for the inner surface temperature
Then solve for the watt density

\[ T_{s,1} = \frac{q_h}{\ln \left( \frac{V_2}{V_1} \right)} + T_{s,2} \]

See Graph 2 for a plot detailing the heat needed versus a variable air speed. At a maximum of 1 m/s, 100W were needed to maintain the rail surface temperature at 23 degrees C. Since the air speed is significantly lower than 1 m/s around the rails, we decided 50W/cartridge heater will be more than sufficient to prevent frost build up. Since the cartridge heaters will have minor inconsistencies in manufacturing and a margin of error, we chose to purchase 100W heater cartridges.
Graph 2

Required Heater Power vs. Air Velocity

- Blue line: Dewpoint Temperature
- Red line: Room Temperature

Air Flow Velocity [m/s]

Q [W]

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Controllers

In choosing the proper controller for our heater cartridge design, we must take into account several aspects of our design. Since there are 2 rails to be heated with a total of 4 heaters, the controller must have at least 4 inputs. Monitoring the temperature along the rest of the rail will be unnecessary because the temperature is the lowest in the middle near the reaction chamber. The control algorithm should be a PID (Proportional plus Integral plus Derivative) or Proportional to allow for an accurate feedback loop. As opposed to Proportional control or On/Off control, PID offers the most accurate and stable control over the temperature of the object. It effectively minimizes the undershoot and overshoot of temperatures which greatly reduces the chance of the rail ever falling below the dew point. This is extremely important because if the surface temperature of the rail happens to fall below the dew point and condensation occurs, the condensate could drop off the rail and contaminate the reagent below it, a situation that our design is constrained to prevent.

It is also possible to use a Proportional control algorithm and set the temperature of the rail several degrees higher to compensate for the potential effect of increased undershoot or overshoot. On/Off control is used where precise control is not necessary, thus is not a good fit for our controller. Our chosen controller contains pre-installed software to maintain the rail temperature between operator-determined limits. No additional algorithm will need to be written to ensure proper operation. Since safety is an important constraint to our system, we must integrate a safety or limit sensor into our controller. Mechanical relays are commonly used and are very reliable for this application. A solid state relay should be used to control the process of maintaining the set temperature again due to its reliability and prevalence in these types of systems. Thermocouples will most likely be utilized as our temperature sensor as they are the most common for our type of application and we are also technically familiar with them.

We picked out a 120V, 16A controller with multiple inputs to control all four heaters at once. The thermocouple will be located in the middle of the rail, next to the reaction chamber with the coldest temperatures were recorded. With the same wattage fluxing through the rest of the rail, the temperature on the rest of the rail will surely stay at or above the set
temperature. The control algorithm is a PID (Proportional plus Integral plus Derivative) to offer the most accurate and stable control over the temperature of the rail. Our chosen controller contains pre-installed software to maintain the rail temperature between operator-determined limits. No additional algorithm will need to be written to ensure proper operation.
Design Integration

There will be several steps required for successful integration of our subassemblies. First, install the four (4) bushings inside the four (4) pillow blocks. The pillow blocks will be secured with a small set screw - torque hand tight. Next, insert the cartridge heaters into both of the Thomson shafts. There should be two standoffs in the center followed by a pillow block added to either side. Loosely, install the remaining 2 standoff supports at the ends of the shaft. Install standoffs onto the combination of the standoff spacers and L-Beam support using the 7/32” diameter, 1” length screws. Next, secure the pillow blocks onto the pillow block spacers and through to the new traverse using the ¼” diameter, ¾” length screws. Attach traverse to frame walls and then install the carriage using ¼” diameter and ¾” length screws, and the L beam support to the Snowgun.

For Phase 4, we plan to validate our concept after assembly and installation. We will perform a full run cycle using deionized water to prove that frost buildup on the rails will be prevented. Rail temperature will be recorded at specific time intervals to maintain the surface temperature above the dew point. After repeated cycles, the tray jamming within the input chamber can be monitored and assessed. Due to the infrequent nature of this occurrence, it may take many trials under various seasonal conditions to prove that this was a direct result of the frost buildup.

Validation of Performance Goals

In choosing the final parts for our design, it was necessary to make some informed decisions based on sound engineering practice. To aid in these decisions, it is common to use at least one or various analytical or experimental methods. For sufficient confidence in our design, we felt it necessary to implement both methods. The first experiment we ran on the Snowgun was used to gather temperature data for various specified locations within the environmental process chamber. From this, we were able to show that the temperatures were coldest around the rail. Using the lowest recorded temperature of -60 °C (during a typical two-hour run with de-ionized water), we were able to set a minimum operating temperature for our solution.
After using this, along with several other criteria, to compare and justify our chosen concept, it was then time to specify important characteristics of a final design.

For the rail heater, we wanted to change as little of the existing infrastructure as possible to ensure maximum compatibility and seamless integration. Our idea was to just hollow out a replica of the current rail and insert cartridge heaters inside the rails to distribute heat evenly along the surface. However, due to a limited selection of standard rail sizes manufactured by suppliers, and our inability to machine such a long part given the provisions of our machine shop, we were forced to bore the dimensions of the outer rail diameter to ¾ inches in order to accommodate a 7/16-inch cartridge heater. Having these new parameters, we were then able to determine the necessary power output of the cartridge heaters through calculations and analysis of heat transfer. It is important to note that, though we previously determined the dew point temperature to be 4 °C, we have targeted a temperature range of 10-23 °C to provide a buffer that will compensate for any error in the controller’s precision. The results of the calculations indicated that each cartridge heater would need an output of approximately 100 watts to keep the temperature of the rail within the desired temperature range. Needing to satisfy this criteria in choosing the cartridge heater for our final design, the most efficient choice we could find from any supplier was PMI’s 1000W, 3/8-inch diameter, 36-inch long cartridge heater, of which 2 would go into each rail. This also relates to our decision to use one controller instead of two; a single controller can easily meet this power requirement and some high end models often have multiple inputs for thermocouples. High feature content follows in that our desired controller must be PID and have a compatible kill switch that can be integrated into Siemens’ existing infrastructure to ensure that Snowgun operation will cease under unsuitable conditions.

Aside from applications of heat transfer, we also conducted an analysis of deflections on the key components of our design. The results of such an analysis helped us determine how much support was needed in installing our subassemblies. From this, we made decisions on the dimensions and placement of everything from screws to the standoffs used to mount the rail. Having a new set of dimensional constraints led us to change the amount of material required
and we were able to reconsider our production method. Using this information, we can now finalize our cost list for the project.

At this time, we are confident our design will solve the problem of tray jamming within the Snowgun. All of our experimentation and analysis strongly indicates that eliminating the frost buildup on the rails will prevent tray jamming in the environmental process chamber and any subsequent problem that may occur as a result. We are certain that our design satisfies the needs and wants of our customers and will perform with such expectation.
Design Synthesis

Explanation of Experiments

In order to validate our design, several things must occur. First, we must use available test data to show that the design effectively prevents the frost from accumulating on the rail. Second, we must be able to link the results to say with a certain confidence that our design will prevent tray jams. We will show this with two different test procedures, each test providing different information. We chose to validate our design before all of parts arrived, so we scaled down the experiments to use an available 6” long heater cartridge, similar to the one we chose for the implemented solution. This also simplifies the experiment and we were able to look closely at a small portion of the rail instead over the whole rail.

Although some specifications of our proof-of-concept prototype do not exactly mirror those of our final integrated solution, the differences are scaled to deliver the same results. The controller used for the testing was a single thermocouple input PID. For our integrated assembly however, we sought a single PID controller with four thermocouple inputs so that we could operate both heaters per rail individually. A controller with multiple inputs allows for independent shut-off of a single, or multiple, cartridge heater in the loop if there is a malfunction.

The experiment was setup so that we could obtain the most useful results in the most efficient way. By placing a single rail in the Snowgun as close to the existing rail (the one closest to the output storage chamber) as possible, without interfering with tray actuation, we were able to ensure that the heated rail would be able to cope with the minimum operating temperature in the chamber (~61 degrees Celsius). This, in turn, showed that the same setup would be more than capable of handling the conditions closest to the input storage chamber. Performing a series of runs where the heater cartridge was either in the middle or at one ends allowed us to get a more accurate reading of the heat distribution along the rail. Placing thermocouples in the centers of these heater cartridge segments along the rail, as in the area between the input and output chambers, monitor the temperature distribution in a large space.
The first test conducted shows that frost does not accumulate on the rails using a similar cartridge heater to the one chosen. Visual evidence was recorded over the 2 hour test to show that no frost accumulated. These pictures focused on the ends of the rails where the frost seemed to accumulate the most and ultimately were the most likely location for the cause of the tray jams. For this test, a 6” heater was placed at one end of the rail and remained on for the duration of the run. Since no frost formed, we know that the engineering principles were fully supported. The next step is to determine if the cartridge heaters will provide an adequate power supply to keep the surface of the rails above dew point.

The second test will determine if the correct amount of power was chosen for the cartridge heaters. A 6” heater will be placed in the center of one rail next to the chamber where the coldest temperatures were recorded. In order to measure the affected temperature of the rail at various locations over cartridge heaters, we needed thermocouples to be placed at various locations inside the chamber. As arranged once before, Siemens provided us with a specialist in temperature measurement to aid in the setup and collection of data. In order to use Siemens’ facilities to conduct this experiment, we had arranged with them to set aside a couple of days when the machine did not have to be in production. Thermocouples will be placed along the rail, with one directly over the heater, and the others around the chamber to record the temperature throughout the run. By monitoring the thermocouples directly over the heaters, we can show that the cartridge heaters can maintain the surface temperature above the dew point.
Experimental Results
Experiment 2 - Graph of Thermocouples Trial #1

![Graph of Thermocouples](image_url)
Experiment 2 - Graph of thermocouples test #2
Data Analysis

Based on the results from both of the experiments, we gathered that our solution would work. There were two experiments that we used thermocouples. For the first one, we wanted to see the effects on the ambient conditions to ensure that reagent in the trays or the chamber below wouldn't be affected by the heat radiating out of the rail. Since primarily the reagent produced by each trial can be valued in the thousands, there can be no effect on the conditions that it experiences during the runs. To monitor this we had thermocouples stationed throughout the rail section that took readings and showed data consistent with no effect on the environment. From there we ran a secondary experiment where we stationed thermocouples attached to the surface of the rail itself to see if the controller-heater setup was capable of maintaining the surface at its designated temperature of 40 degrees Celsius. The data we compiled showed that while the surface of the rail stayed consistently above 40 degrees the ambient temperatures through the chamber were again, not affected. With no change in the environment and a temperature of 40 degrees the results show that our solution is not only plausible, but also appears to be an effective one when it comes to maintaining no frost buildup on the rail surface.
**Resource Effectiveness**

As far as implementing the project results into the sponsor’s business, there will not be much added cost to the operation of the overall machine. There is additional power required for the controller in order to distribute power to the cartridge heaters, but this is minimal in comparison to the total power required for the machine to operate. The associated cost can be calculated from the operating time, the cost of electricity, and the known power requirement for the controller. We were also helped greatly by a Temperature Acquisition Specialist with our validation procedures. The results would have been for less useful and very tedious to collect without his knowledge and expertise of the equipment. An outside machinist was also contracted to fabricate some of the more complicated parts. Due to our available resources, we did not have the capability to machine these parts.

The total cost to build the assembly was under budget, as seen in the table below. This was an important target value to satisfy. Although, the cost of the design was in fact under budget, the use of some other resources to obtain data is not reflected in this cost. For each deionized water trial, 200 gallons of nitrogen are needed to maintain the temperatures of the input and output chambers as well as the reaction chamber. Also, the use of the Temperature Acquisition Specialist was very expensive. We required his knowledge and expertise for three separate cycles. The results of our design can be implemented immediately upon approval and completion of proper testing protocols. Our design is not only a prototype but a fully functional unit that can be used permanently within the machine. We expect the testing to begin in mid-January and complete, ready for permanent installation, two months later.
<table>
<thead>
<tr>
<th>Part</th>
<th>Quantity</th>
<th>Cost per Unit</th>
<th>Estimated Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>2</td>
<td>$393.00</td>
<td>$786.00</td>
</tr>
<tr>
<td>Heating element</td>
<td>4</td>
<td>$350.00</td>
<td>$1400.00</td>
</tr>
<tr>
<td>Temperature Controller</td>
<td>1</td>
<td>$300.00</td>
<td>$300.00</td>
</tr>
<tr>
<td>Integration Material</td>
<td>various</td>
<td>$555.00</td>
<td>$555.00</td>
</tr>
<tr>
<td>Raw Material</td>
<td>various</td>
<td>$875.00</td>
<td>$875.00</td>
</tr>
<tr>
<td>Machining</td>
<td>N/A</td>
<td>$1000.00</td>
<td>$1000.00</td>
</tr>
<tr>
<td>Team Budget</td>
<td></td>
<td>$5000.00</td>
<td></td>
</tr>
<tr>
<td>Amount Left in Budget</td>
<td></td>
<td>$84.00</td>
<td></td>
</tr>
</tbody>
</table>

The prototype for the Snow Gun project will be delivered to the Siemens reagent manufacturing group by December 18th. The deliverable will consist of the redesigned traverse and rail sub assembly; fully prepped for installation. Due to unexpected lead times and delayed orders, the intended prototype will not be delivered in full. Custom made heater cartridges took considerably longer to manufacture and ship than we had estimated; similarly with the controllers. The UD senior design team has full intentions to follow through with the project after the closure of the semester, assuming there is interest from Siemens to pursue the completion of the prototype.

Proof of concept testing has provided very good results with 3 dry run trials. The heaters were able to hold a constant external shaft temperature in the coldest area of the chamber; there was no formation of ice or condensation in the heated area. Further testing from Siemens will be needed in order to verify, and validate, that the prototype does not negatively impact the quality of the reagent manufactured in the machine. A seamless
integration is necessary in order to keep manufacturing costs to a minimum and not disturb the current working process.

Upon arrival of the heater cartridges and the controller, installation of the prototype is very straightforward. The current shafting supports, fully supported shafting, and all associated hardware will need to be removed. The prototype is designed with the intent to be “modular” and is a direct bolt on assembly, not requiring any mounting or fitment modifications. New traverses, hollow shafting, pillow blocks, bearings, standoff supports, and spacers can be assembled independently and then secured to the current mounting locations on the walls of the machine using ¼” x 20 screws (see the bill of materials for all other hardware specifications). Once installed the heater cartridges are to be inserted into the hollow shafting (2 per shaft, inserted end to end), and wiring is to be run and terminated to the controller. The controller is to be integrated into the existing control center to keep all functions of the Snow Gun machine accessible at one location; the integration into the existing system is the responsibility of Siemens. The heater cartridges need to be maintained at a temperature above the dew point so that no condensation accumulates on the new shafting; a quick reading from a hand held meter is sufficient.
Appendix

Defining Wants
Simplicity – minimize the number of moving parts & keep the overall complexity of our design within reason.

Effectiveness – how well our deliverable solves the problem and how long will our implemented design will last in terms of years or running hours.

High Efficiency – how our deliverable impacts the environment and how well we use energy to resolve the problem.

Low Maintenance – minimizing the mean time between interventions. Ultimately, this is how long you can let the system run without any interaction.

Ease of use – time it takes to train someone to use our deliverable.

Ease of Removability – time required to attach and detach our deliverable to the current machine.

Inexpensive – providing a deliverable that resolves the problem and stays within our given budget of $5,000.

Other Concepts
Desiccant Wheel – Again the desiccant wheel would have been able to prevent frost forming within the chamber, but some of the main faults that we came across with it were the cost and overall size of the system that would have had to been put in place. The cost was around ten times greater than that of the next most expensive concept and it would have been more than twice as large as our metrics allowed.

Modified HVAC System – This concept would have used the HVAC system that is already in place within the snow gun room and modifying it to adjust the environmental conditions within the chamber to try to keep ice from forming. It would re route some of the dry air being pumped into the precipitate cylinder through the chamber to drop the humidity and raise the
temperature. We chose not to go with this concept because it did not satisfy as many metrics as other designs as well as because it would not definitely solve the problem at hand.

Snow Plow – For this concept we would have attached a conical plow to either side of each bearing on the rails to remove frost as it built up along the rails. This design required the actuators to be strong enough to push the plow through the ice buildup as well as delicate machining to create the plows in the first place. We decided that this concept would not be chosen because it didn’t satisfy some of the metrics we listed. We also came to the conclusion that the snowplow would not necessarily solve the problem either. There would still be the possibility of frost build up to the point that it would slow down or stop production.