Red Feather - Team 20F02

Operation-Assembly Manual

Randall Holgate

Noah Kincheloe

Jessie Russell

Brittney Rogers

Wesley Garcia

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Project Sponsor: Red Feather Development Group

Faculty Advisor: Dr. Oman

Sponsor Mentor: Chuck Vallance

Contents

1. Overview

1.1. Specifications

The specifications for the main components of the system are shown below in *Table 1*.

Table 1: Specifications of Main Components

Description	**Area**	**Weight**	**Voltage/Power Input**	**Output**
Tank	70.5” height, 36” diameter	65 lbs.	N/A	N/A
Liquid-to-Liquid Heat Exchanger	600” pipe length, 3/8” inner diameter	10 lbs.	N/A	N/A
Liquid-to-Air Heat Exchanger	24” pipe length, 3/8” inner diameter	4 lbs.	N/A	N/A
Blower	10.6” width 12.3” depth 13” height	12.25 lbs.	120V, 480W	600 CFM (air flow)
Heating Tape (brand specs) Heating Tape (experimental specs)	96” length, 1” diameter	2 lbs.	240V 125V	1250W
Pump	13.58” width, 10.47” length, 7.44” height	4.59 lbs.	100V, 10W	16L/min
Battery	12.19” width 7.19” length 14.13” height	92 lbs.	N/A	6V
Solar Panel	26.18” width 24.4” length	10.58 lbs.	N/A	50W
Reservoir	7” width 14” height	N/A (5-gallon max capacity)	N/A	N/A
Platform	36” width 48” length	7 lbs.	N/A	N/A

2. Manufacturing

2.1. Heat Exchangers

There are two heat exchangers used in this design. The first is a liquid-to-liquid heat exchanger for the heating cycle and then the second one is liquid to air for the discharge cycle. In order to manufacture these heat exchangers, the soft copper piping needs to be coiled around with a 10-inch diameter. In order to do this, it was coiled around a bucket of this diameter. This bucket and the original coil can be seen below in *Figure 1*.

Figure 1: Heat exchanger coiling

Once the original coil is made around the bucket it needs to be smoothed out and ensure it has a constant diameter. Caution must be taken to ensure that the piping does not kink and therefore restrict flow.

2.2. Duct Work

The Duct work holds both heating loops. The only manufacturing that needs to be done with the tank includes drilling four holes in the side. Along with this, four twelve-inch pipes were slid through the holes in order to hold the air heat exchanger.

2.3. Soldering and Piping

In order to manufacture the piping two different kinds of copper piping is used. A soft copper coil of 3/8th inner diameter and straight copper piping of ½ in. inner diameter. The softer coiled piping was then coiled tighter to reach an average diameter of about 12 inches. To get all the sizing right some of the copper piping will need to be cut shorter and other piping will need to be lengthened using a straight coupling. When transitioning from the soft copper coil of the heat exchangers to the hard copper piping going outside of the tank to the pump and the other components, a Shark Bite 3/8" to ½" adapter fitting or a normal 3/8" to ½" adapter fitting that is soldered will be necessary. Along with this fitting eight 90-degree bends were fitted onto the pipes to facilitate the change in direction of liquid flow.

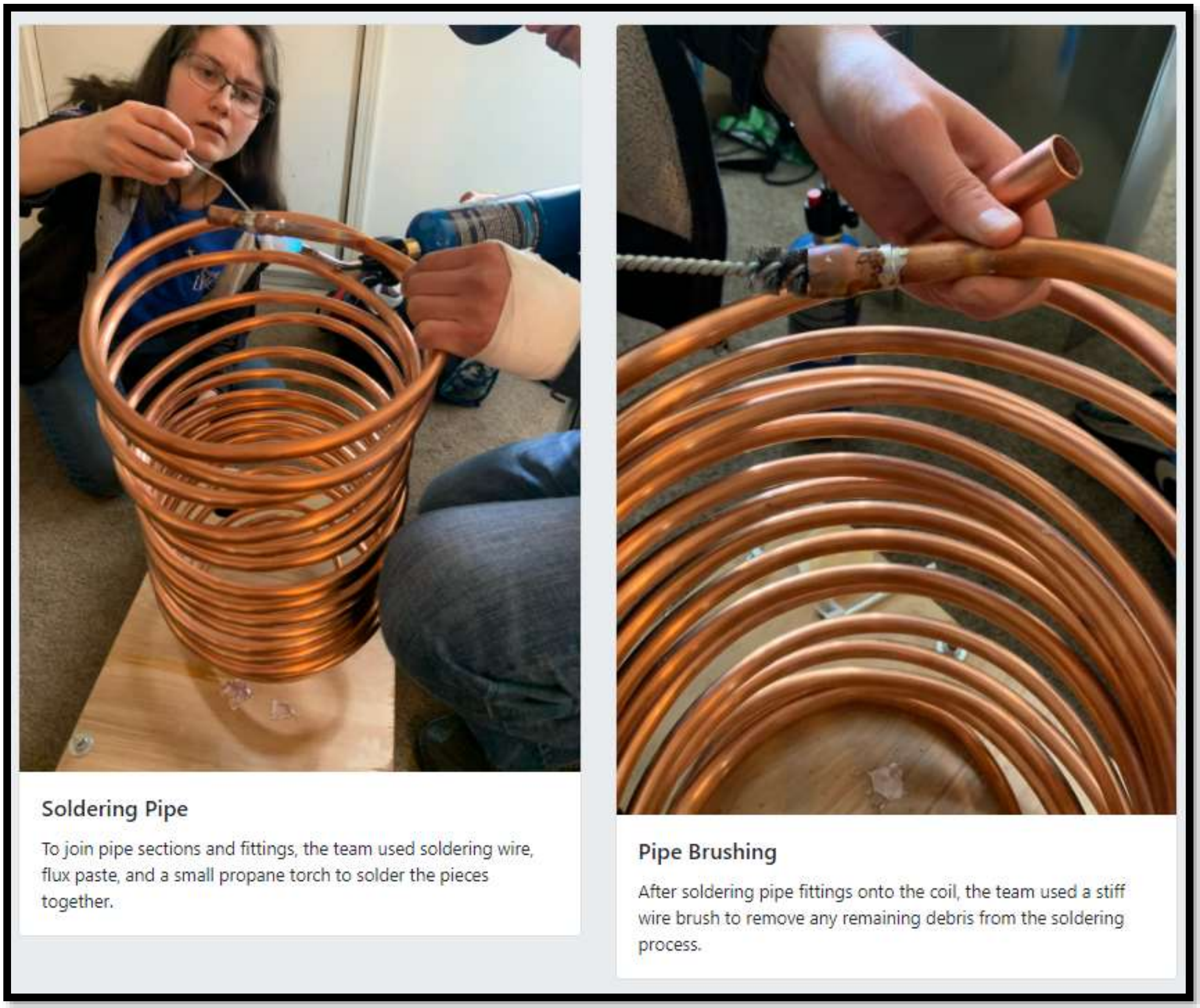

Figure 2: Soldering the heat exchangers.

The soldering process required three unique steps to securely connect the many copper parts. The first step required that the outside and inside of the piping be brushed by two special brushes. From there a special “Flex Paste” was coated around the piping that needed to be soldered. Finally, the fittings were placed on their respective spots and were soldered together using a blow torch and industrial grade solder.

2.4. Platform

The platform was constructed to hold the pump, blower, and reservoir. This platform can be seen in the *Figure 3* below.

Figure 3: Platform

This was constructed by using nails and mending plates to connect four 36” pieces of wood with a thickness of 1 and ½ inches. Then on the interior four planks of wood with a length of 30 inches, a width of 5 inches and a thickness of ½ inches were connected. There was an extra piece for a corner that was attached to add extra support.

2.5.Blower 3D printed Part

When testing the blower for the first time we found that the air outlet was too large for the piping, which created a lot of loss. Therefore, we 3D printed a connection for the blower to reduce the outlet diameter to connect it to the heat exchanger piping. This part was constructed by creating a CAD part and then drawing so that the 3D printer could create it. The CAD model for this part is shown below in *Figure 4*.

Figure 4: 3D printed part for blower

Then the part was attached to the blower with the use of gorilla tape.

2.6. Reservoir

To properly prime and run the pump/liquid-to-liquid heating loop a sperate reservoir was required. This reservoir, shown in *Figure 5* below, is made up of a plastic gas tank that can hold up to 2.5 gallons of liquid.

Figure 5: Gas can reservoir prior to drilled holes.

To integrate the reservoir with the heating loop two holes were cut into it. The first is near the bottom of the tank acting as an out flow to the pump. The next is on the side of the pump allowing water to flow into the reservoir from the heating loop. The hole in the side of the reservoir can go without a fitting and simply acts as an opening for the exit pipe. The hole near the bottom of the reservoir that can be seen in *Figure 6* below uses a fitting with a washer, was threaded into the tank, and uses a sealant to prevent leaks.

Figure 6: Reservoir pump fitting

2.7. Piping outside of the tank

The piping outside the tank is set up to connect the liquid-to-liquid heat exchanger to the reservoir and pump, and it also is set up to provide length for the heating tape to operate on without overlapping itself. This piping is all made of ½” hard copper piping. It starts with a 5” pipe going from the pump to a 16” pipe, connected by a 90-degree elbow copper fitting that is soldered on at both ends of the elbow. The 16” length leads to another soldered 90-degree elbow that connects to a 14” section of pipe that is again connected with solder to another 90-degree elbow which leads to a 90-degree elbow and more hard copper piping going into the bottom of the liquid-to-liquid heat exchanger, where it is connected by a ½” to 3/8” adapter fitting. Another part of the liquid-to-liquid heat exchanger is connected to the reservoir with 90-degree elbows as shown in *Figure 7* below. The piping heading to the reservoir from the 90-degree elbow and the liquid-to-liquid heat exchanger is pushed far into the elbow and then taped with electrical tape at the connection to reduce the chance of leaking while keeping disassembly easy.

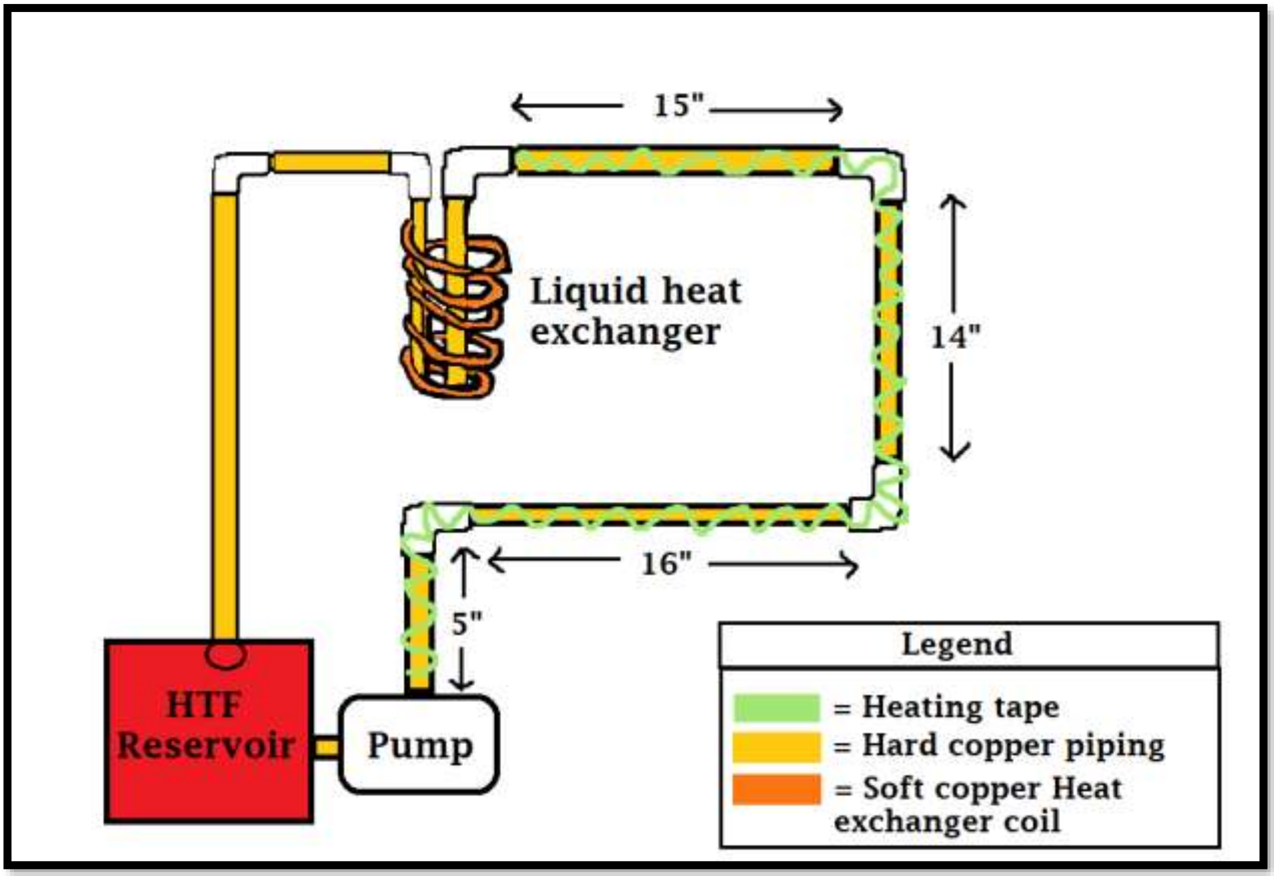

Figure 7: Piping outside of the tank schematic

3. Assembly

3.1. Duct Assembly

The duct should be stood upright and then the liquid-to-liquid heat exchanger should be placed onto the bottom of the duct. Then, the liquid-to-air heat exchanger should be placed into the duct, aligning it with the holes at the top of the duct. Holding the liquid-to-air heat exchanger up, place the 16" hard copper pipes into the duct holes. These copper pipes will hold up the liquid-to-air heat exchanger, so it is not suspended in the air. A picture of the duct and heat exchangers assembled together can be seen in *Figure 8* below.

Figure 8: Heat exchanger ducting

3.2. Lid Placement

The lid can be taken off and put onto the tank by putting the piping (leading to the liquid-to-liquid heat exchanger) outside of the tank through one of the holes in the lid. Then the lid can be moved over the piping until it reaches the tank. At this point, the lid can place the liquid-to-air heat exchanger piping through the other hole in the lid. Now, one can tighten the lid and twist the heat exchangers into a preferable position.

3.3. Platform Component Placement

The platform has a designated area for the pump and reservoir to be placed, designated by an “X” underneath the platform. This is because some parts of the platform are studier than others, and the setup of the components on top of the platform balances most effectively in a particular setup. A plank of wood should be placed underneath the pump to give it height to fit into the reservoir. Another piece of wood should be placed underneath the blower, placed to the left of the reservoir. Next, a counterweight of 15 lbs. should be placed on the side opposite of the blower, to counter the weight of the blower. This concludes the placement of the components onto the platform. Now, one can place the hard copper piping indicated “HX to Gas Can” from the reservoir to the liquid-to-liquid heat exchanger. The blower’s small copper piping can be pushed into the liquid-to-air heat exchanger, coming out of the tank.

Figure 9: Component placement on platform with Arduino and heating tape

Figure 10 displays a side view of the piping network connected to the shark bite female street elbow adapter threaded onto the pump. The 20-pound dumbbell and stone are placed across the blower and reservoir to act as a counterweight keeping the platform balanced.

Figure 10: Platform component placement with counterweights

3.4. Pump

The pump needs to have Teflon tape wrapped clockwise around the inlet and outlet threading to prevent leaking. Next, a ½” male-to-female adapter fitting is tightly placed onto the inlet thread. This part will thread into the ½” female fitting leading to the reservoir. An image of the pump can be seen below in *Figure 11* to see where the inlet and outlet are. The pump’s connection to the reservoir can be seen below in *Figure 11*.

Figure 11: Pump

In figure 12 a 5/8” rubber O ring is placed onto a ½" male to ¾” hose thread female adapter. The adapter is then threaded into the gas can, tight enough so the O ring does not become disoriented. Silicone is place around the O ring and adapter to ensure no leakage occurs. A ¾" hose thread male to ½" male adapter is threaded into the ¾" hose thread female end of the adapter from the gas can. The ½" male end is threaded into the ½" galvanized iron coupling. The coupling was then threaded to the pump and PTFE tape was applied to all threaded components.

Figure 12: Pump connection to reservoir

3.5. Heat Exchanger to Pump

A 90-degree street elbow should be placed onto the outlet threading. A ½” Shark Bite fitting is placed onto the end of this 90-degree elbow fitting. This Shark Bite connects to the 5” hard copper piping that connects in a network of hard copper piping that leads to the liquid-to-liquid heat exchanger. To disconnect the shark bite from the copper piping a ½" disconnect tool will be needed and is listed in the bill of materials.

Figure 13: Pump fitting to heat exchanger

3.6. Setting up Heating Tape

The heating tape is wrapped around the surface area of the piping going out of the pump and moving into the tank. While the tape is wrapped around closely it is important to make sure that one of its parts overlaps. Along with this it will need to be close to a plug in and will be restrained by two strings on either end or, if needed, electrical tape to further secure it.

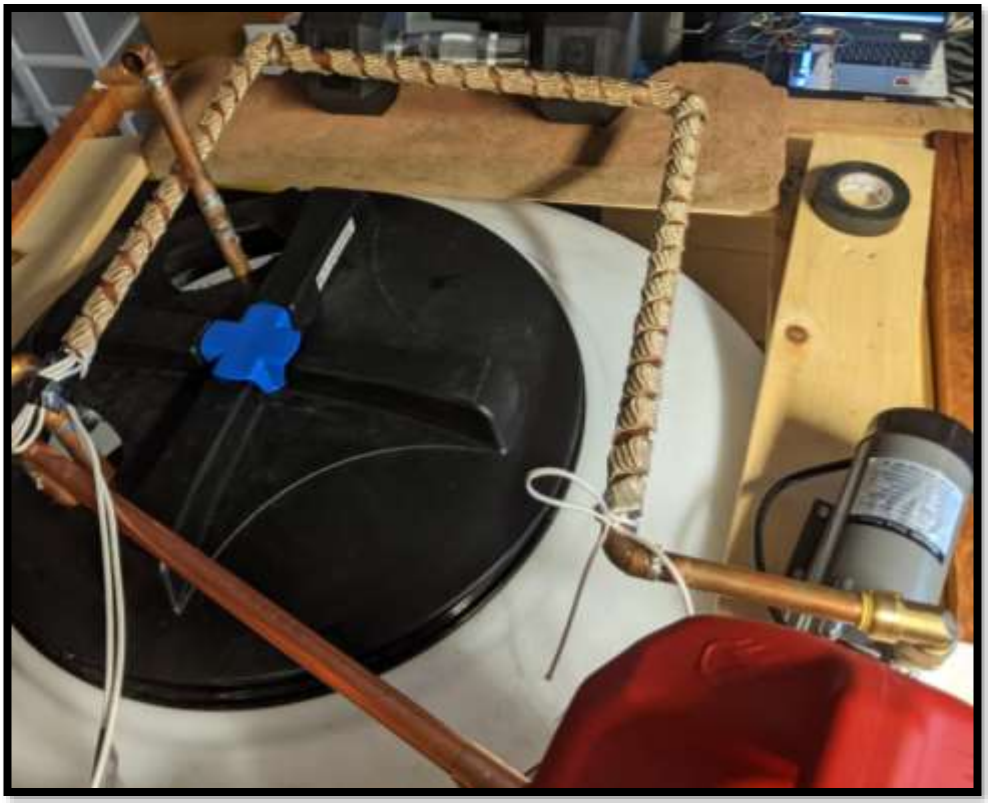

Figure 14: Heating tape wrapped around copper piping.

3.7.Solar PV Set up

There are three 50W solar panels to be set up in parallel, as seen below in *Figure 15* and *Figure 16*. These require three MC4 connectors to connect each panel to each other to be connected to the battery. There also needs to be an MC4 to Bare Conversion cable set, called a GS-MC4-CC. This will connect these solar panel wires to the battery. Finally, there is a solar panel controller which these solar panel wires also plug into. The battery also connects to the solar panel controller. This allows the battery to store energy collected by the solar panels. Finally, an inverter is used to take power from the battery. This inverter can be plugged into to power the components in the thermal storage device, including the pump, blower, and heating tape (or alternative heating source).

Figure 15: Solar PV Panels parallel setup

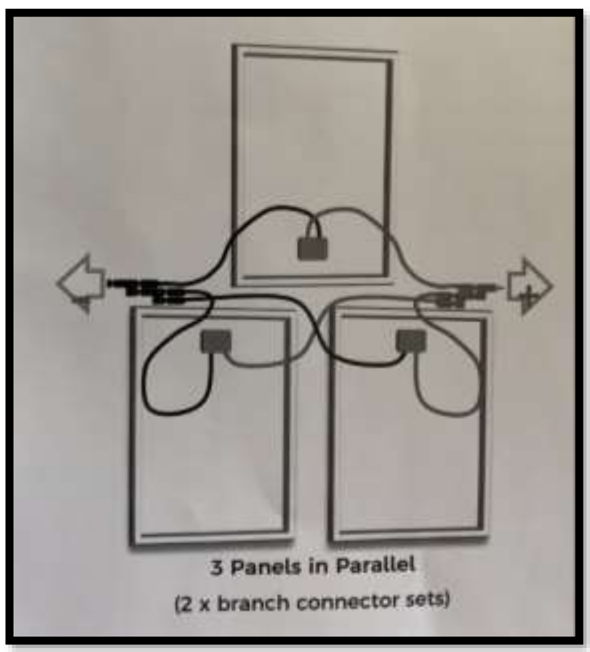

Figure 16: Instruction manual for Solar PV connection

4. Operation

4.1. Tank Location Selection

The first step in operating this system is to choose a location to place the tank. This is important for two reasons. First the tank will not move once it is filled so it should be placed in an area that is out of the way and allows it easy access to where it will be heating. Secondly, except for the case of burying the tank, it should be placed in a spot that allows it to be easily drained from the bottom port.

4.2. Filling the Tank with Water

The tank can hold a total of 200 gallons of water; however, it only needs to be filled to approximately 175 gallons. This can be done most efficiently by using a hose attached to a sufficient water source. Along with this it is important to understand how you intend to empty the vessel after you are done using it. Two useful methods are either syphoning the water out with a hose or unscrewing the bottom port and letting the water flow out.

4.3. Filling the Liquid-to-Liquid Heat Exchanger and Reservoir with Propylene Glycol

When filling up the heating loop with liquid it will need to be poured in two different shifts. The first will be the copper piping section of the loop. Once this loop is completely filled the reservoir can be filled with the Propylene Glycol Solution. In order to fill both of these sections a funnel is used to pour the solution into each. The funnel allows the easiest path for the liquid to fall into each section. Filling the piping will take more caution than the reservoir in order to avoid spills. It is important that before pouring the liquid into the Reservoir, that all the connections in and out of the Reservoir are secure.

Figure 17: Filling the liquid-to-liquid heat exchanger.

4.4. Plugging in the Heating Cycle Components

Two components need to be plugged into the outlet in order for the system to run. The heating tape and the pump will both need to be plugged into a power source so that the system starts. While the pump can be plugged into the blower, the heating tape will need to be plugged into a separate outlet.

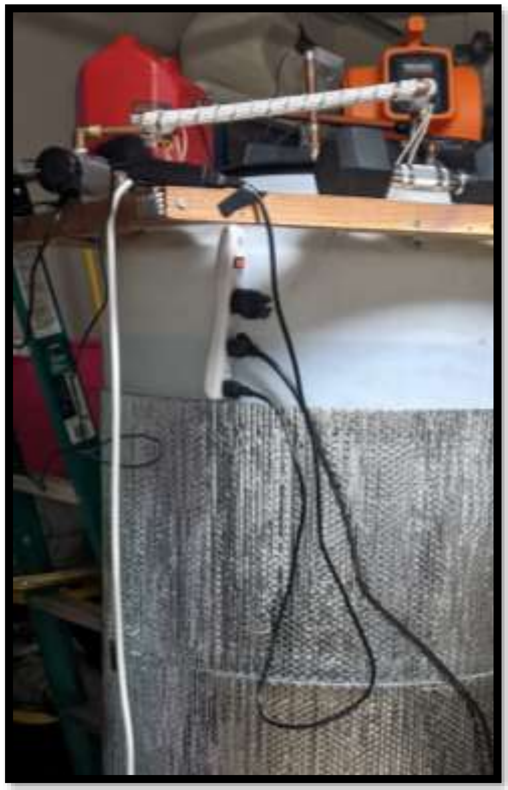

Figure 18: The electrical plugs for the heating cycle

4.5. Running the Heating Cycle

While the system is running the temperature of the pump, heating tape, and water inside the reservoir should be monitored. The heating tape has no temperature regulator and so should be monitored to ensure it does not reach a temperature over 200 degrees. Along with this the pump's temperature should be checked every two hours in order to prevent the pump from overheating. If any abnormal sounds begin coming from the pump it should be unplugged as this could be a sign that it was unproperly primed or may be overheating. Finally, the liquid in the reservoir should be monitored in order that it stays below boiling temperature.

4.6. Plugging in the Discharge Cycle Component (Blower)

The discharge component uses a blower in order to move the air through the piping. In order to get the blower working it needs to be plugged into the outlet.

5. Maintenance

5.1. Solar PV System

The maintenance required for solar panels is minimal but should be done in order to receive optimal performance. The panels will be requiring light cleaning two to four times a year so that they will have maximum energy production. The main times that this should happen is when there is not much rain and when there is heavy snowfall. The one thing when cleaning them is never use hot water due to the risk of cracking the panels. The battery also requires some light maintenance. The terminals of the battery need to be cleaned on a regular basis. The usual way of performing this is by using cleaner brush with baking soda and distilled water and then rinsing it with water afterwards. Another way it needs to be maintained is that the connection needs to be checked to ensure they are tight and secure. There needs to be a high temperature grease or sealant on all the metal connections to make sure it stays secure. Batteries have a shorter lifespan than solar panels so most likely the battery will have to be replaced at least once in the solar panel's lifespan. Solar panels usually last around 25 or 30 years. The charge controller and inverter also require some light maintenance. The connections need to be checked to make sure they are tight, clean, and secure, which prevents the chance of failure in the system due to heat or resistance. This needs to be performed at least once a year. The controller and inverter have a chance of needing to be replaced at least once in the solar panel's lifespan.

5.2. Heat Exchangers (Leak Test, Cleaning)

The heat exchangers should be taken out of the tank once per year. They should have water poured through them and tilted to see if there are any leaks. If there are leaks, the area where there is a leak should be noted. If the leak is at a soldering connection, someone trained with soldering should dry the area and then solder the connection again to seal any leaks. Repeat the leak test to see if the leak persists. If it does, the spot needs further inspection before resoldering. Make sure it is the correct area being soldered. After these leak tests are done, the heat exchangers should be inspected for any buildup from outside contaminants, such as sediment. Wipe down any contaminated areas with a cloth.

5.3.Replace Pump

The pump should be observed on a weekly basis to ensure that it is running normally and that there are not any problems with the motor or other components. The pump should be checked for noise, alarmingly hot temperatures when touched with one's back hand, and leaks. If a spot is noisy compared to usual, then the motor should be checked, or the propylene glycol level should be checked to ensure its not running dry. If the pump is hot, then it could be a tell that the load is too large or that the pump is going bad and may need maintenance or replaced. Lastly if there is a leak then the fittings may need to be tightened. The pump will most likely last 10 years, after which it will need to be replaced and it may go bad sooner or be replaced to improve efficiency.

5.4. Replace Blower

The blower will require regular maintenance. It is going to need to be cleaned every 6 months. The blower will most likely last 6 years with regular use.

5.6. Water Tank

The water tank needs some light maintenance. The tank needs to be checked to make sure there is not any damage, leaks, or deterioration yearly. Another thing is that the tank itself could be required to be replaced around every ten years. The tank should be cleaned every three years to ensure that there is no growth or problems. The water in the tank needs to be checked every year to ensure that it is fresh and not creating any problems. The water could create growth or other problems that could create a smell. The water should be replaced or treated at the time that the tank is cleaned.

6. Troubleshooting

While operating the device, a variety of problems may eventually arise as a result of general wear and tear on the system. This section attempts to address as many of these as possible, in order to provide users advice on how to mitigate them.

6.1. Case 1: Outlet Air Not Heated

If the air delivered through the output of the discharge loop exhibits the same temperature as the ambient air, there are a variety of possible reasons. The first thing to check is the temperature of the tank fluid. If the tank fluid is not heated appropriately, refer to Case 2. If the tank fluid is at the appropriate temperature, check whether there is enough fluid in the tank to fully cover the liquid-to-air heat exchanger and fill the tank almost entirely. If tank fluid is below the 200-gallon mark, adjust it and mark the new waterline. If the water level decreases noticeably in less than a day's time, it is possible that the tank is leaking. If this is the case, the leak must be found by thoroughly examining the surface of the tank. It can then be repaired with the application of Teflon tape. If the water does not noticeably decrease, it is possible that the loss was simply the result of evaporation; if this is the case, the tank should be refilled to the 200-gallon mark and checked later for any leaks.

6.2. Case 2: Storage Fluid Not Heated

There are several reasons why the storage fluid may not be heating properly during the application of the device. The first step in diagnosing this problem is to check the charge loop reservoir; if the fluid in this reservoir is heated but not moving, refer to Case 3, which diagnoses pump failures. If the fluid is moving but not heated, refer to Case 4, which diagnoses heating tape failures. Finally, if neither the fluid is neither moving nor heated, first check to see if they are properly connected to the power source. If so, refer to Case 5, which attempts to address electrical failures.

6.3. Case 3: Pump Circulation Failure

If the pump has ceased to circulate fluid, there are several explanations. The first is that it became too hot, and thermal fail-safes shut down the pump to prevent it from burning out. If this is the case, the pump can be fixed by simply unplugging it and the heating tape and allowing it to cool for at least 15 minutes. If this is insufficient, the other explanation is that the pump may be burned out; this can be a result of overheating, or of running the pump dry for too long. If this happens, the pump must be replaced for the device to continue functioning. Finally, the third potential case is that the pump has been jammed by some foreign object. If this is the case, then reservoir should be drained, and the pump disconnected. From there, it is possible to remove the front panel of the pump in order to access the machinery within and clear any blockages. If there are any, the pump should return to functioning normally so long as it is carefully reassembled to reflect the prior configuration.

6.4. Case 4: Heating Tape Failure

Heating tape failure can be caused by a variety of sources, some of which can be more easily addressed by the user than others. If the tape has ceased to heat, the first step is always to unplug it. Once this has been done, check the outlet with a different electrical device to verify that it is powered. The blower or pump can both be used for this purpose. If the outlet fails to power other devices, refer to Case 5 for electrical failure help. If other devices function as expected, the next step is to check the wiring itself; this can be done by disassembling the electrical plug itself, and visually checking to see whether both wires for the heating tape are properly wrapped around the appropriate terminals. If either is disconnected, the user can attempt to re-wrap the wire, at which point the plug can be reassembled and re-tested. If this fails, it is possible that there is some sort of short or breakage within the tape itself. If this is the case, then it will likely be necessary to replace the heating tape in its entirely, to prevent electrical or thermal hazards to the user of the tank.

6.5. Case 5: Electrical Failures

There are several different issues that may cause electrical failure, and varied approaches to dealing with them, depending on the power source in question. For the current iteration of the design, only the blower is designed to use battery power, while the pump and heating tape are expected to rely on grid power delivered by the testing facility. If the failure involves either of these latter two, the testing facility likely has some form of power or connection issues. If this is the case, the team recommends contacting a qualified, licensed electrician. If the failure instead involves the battery, there are certain steps that can be taken to troubleshoot. The first is to check whether the battery has charged; if the battery has charged, check to see if both it and the device in question are properly connected to the inverter. If it has not charged, first attempt to do so with the solar panels provided. If this fails, check the connection between the panels and the battery. Next, check whether the battery can be charged using conventional means; if it can, the issue is with the solar panels, which can be replaced. If it cannot be charged via conventional means, the battery should be regarded as faulty and replaced.

6.6. Case 6: Blower Circulation Failure

If the blower has ceased to move air through the liquid-to-air heat exchanger there are a few possible solutions. The first check is to determine whether the blower is running; if it is, and the velocity out of the tube is still 0, there is likely a leak in the heat exchanger or a stoppage in the pipe preventing airflow. Refer to Case 7 for information on dealing with this. If the blower itself has ceased to function, begin by checking for electrical failure. To do this, unplug the blower and repeat the procedure from Case 4 where a different device is plugged into the same outlet to check for functionality. If the issue is with the outlet, refer to Case 5 for instructions on addressing electrical failures. If the outlet functions properly, check the blower cable for any breakages or potential causes of electrical disruption. If none are found, it is possible that the blower motor has burned out, or that some other internal component has failed. If this is the case, the blower should be replaced.

6.7. Case 7: Heat Exchanger Stoppages

The final set of problems can be caused by blockages in the liquid-to-liquid or liquid-to-air heat exchangers. The former is much harder to diagnose than the former, however if the pump appears to be functioning normally but the flow rate still seems reduced, this is an indicator that the heat exchanger may have a blockage. For the liquid-to-air heat exchanger, blockages are apparent if the exit airflow is significantly reduced, or zero. To solve this, the liquid-to-air heat exchanger must be extract from the tank and checked for any fluid inside the bends. If the interior of the loop is dry and air still does not flow, it is likely there is a blockage within the heat exchanger. The only suggestion here is to attempt to clear the blockage with water, or a similar liquid mixture depending on the suspected nature of the blockage. If it cannot be cleared, the coil must be replaced. On the other hand, if there is fluid in the coil, it is possible that a fluid leak has formed a plug, causing the blockage. In this case, the leak can be found by adding additional water to the extracted heat exchanger and evaluating the seams at which the water is most likely to be escaping. If there is a leak, it can be fixed with the careful application of heat, flux paste, and soldering wire (once the coil has been given abundant time to dry).

Stoppages in the liquid-to-liquid loop are more difficult to deal with than these fluid plugs because they generally suggest that a foreign object has become jammed in the coil. If this happens, and the blockage cannot be eventually cleared by the normal circulation of heated fluid through the exchanger, then it is unlikely that the blockage can be removed, and as such the liquid-to-liquid heat exchanger should then be replaced.

7. CAD Drawing

Included in this section are CAD drawing images generated to provide additional visual reference for the key components of the design, as well as to provide some clarity on their configuration within the device. This includes both a standard exploded view image of the design with added bill of materials, and a more compartmentalized system view intended to demonstrate the major functions of the device.

7.1.Exploded View

Shown below in *Figure 19* is an exploded view image of the device, with attached numbers and a bill of materials.

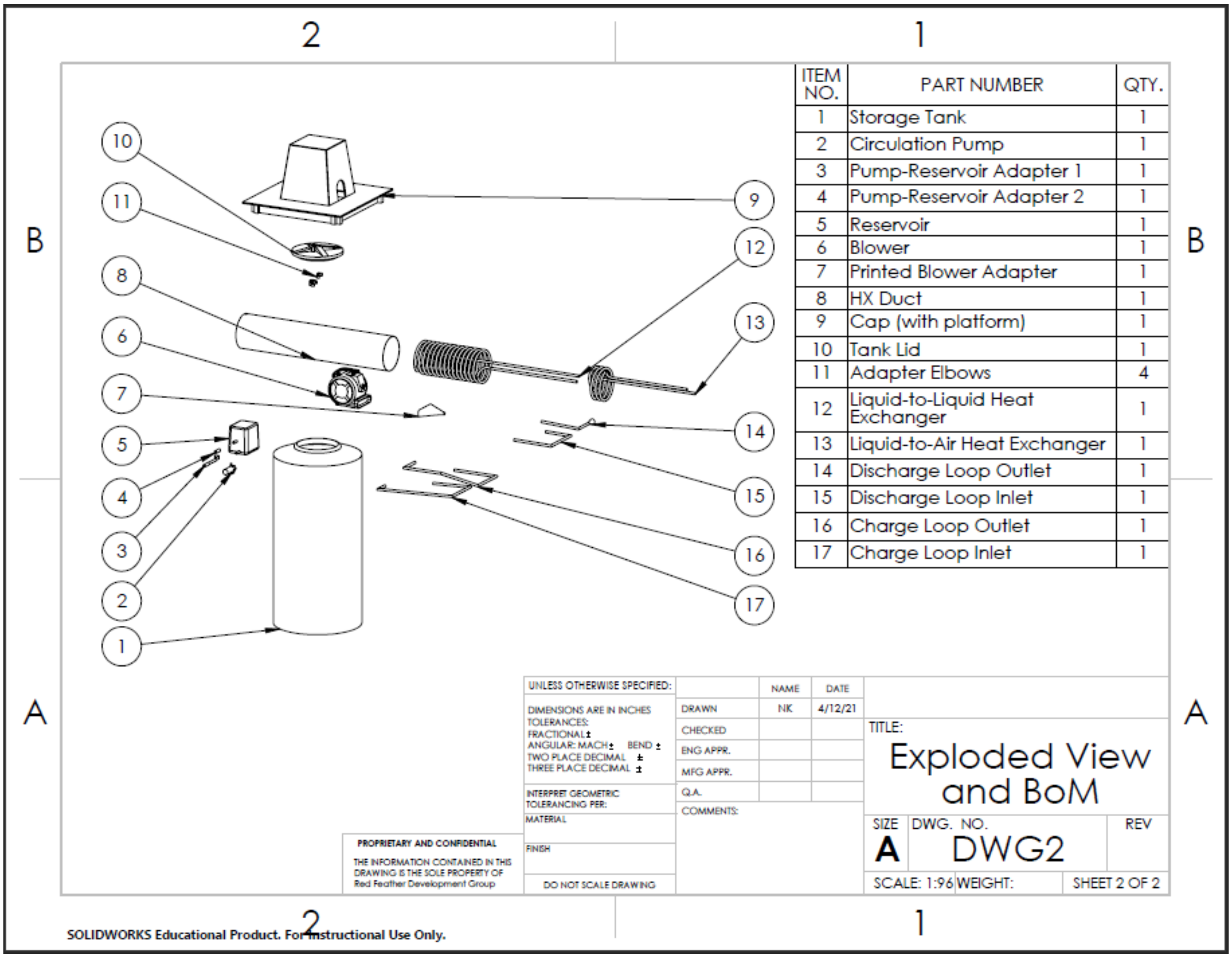

Figure 19: Exploded View Drawing

The above figure displays all components of the CAD drawing, for comparison with the created prototype. Note that there are several major differences between the bill of materials shown in the image, and the true bill of materials for the device; this is because the CAD model does not include the full number of fittings, nor does it include supports within the duct itself. The heating tape was also not included due to its relative size, though in the physical prototype it is wrapped around the section of pipe most like the one labeled as the Charge Loop Inlet (Item No.17). The other major difference exists with the presence of the closed cap (No.9). The closed cap is shown as an integral part of the platform, however in the constructed prototype it is not included. This is due to fitment issues; however, since the team did in fact construct the closed cap, it is included in the CAD model. A version of the CAD without this enclosed cap is depicted in the system view drawing. There are some other minor differences between the models, but these all related to minor details deemed irrelevant by the team.

7.2. System View Drawing

The other main CAD drawing created by the team is included in *Figure 20*, shown below.

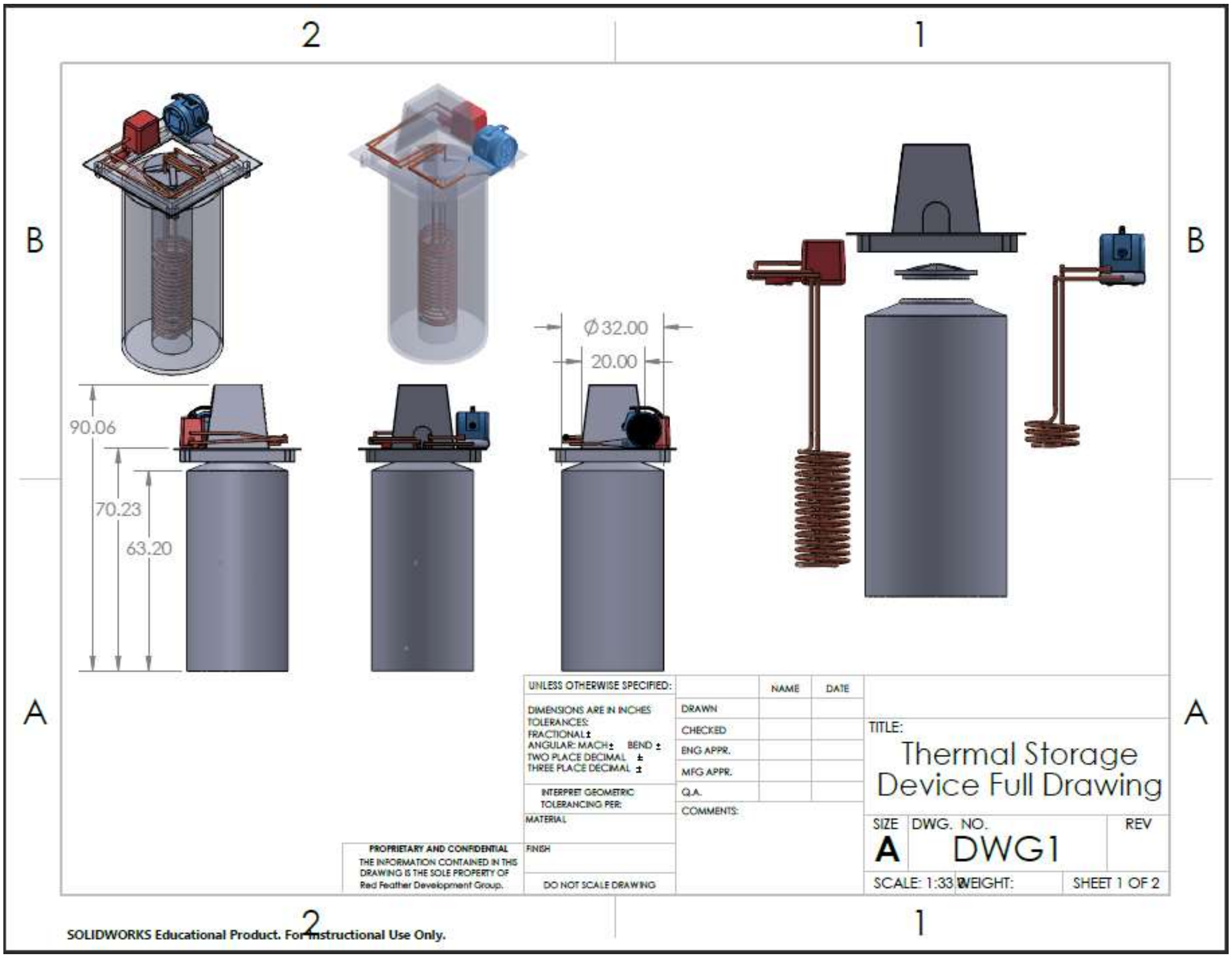

Figure 20: System View Drawing

The above image shows a more broad, full system overview of the thermal storage device. It includes an image of both configurations of the tank, with and without the closed cap, as well as the dimensions in inches. On the right side, it also shows the relative sizes and shapes of the charge and discharge loop, with the charge loop marked in red and the discharge loop blue. Both are connected to copper-colored piping, which nests together inside the duct as shown. While neither loop can be removed in a single piece as shown, the image above is still a useful comparison for the sizes of each heat exchanger, which contained the same number of loops prior to the reduction of the liquid-to-air heat exchanger. This drawing also shows one proposed pipe arrangements that would allow for the inclusion of the closed cap. This was not attempted with the constructed prototype for time reasons, however future iterations of the design could incorporate this configuration to allow for successful cap fitment.