Thermal Storage Solution for the Organic Rankine Cycle

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Team: # 17

Authors:

Belal Nabulsi

Bruce Orozco

Cory Nelson

Jhamal Holliday

Sponsor:

Verdicorp

Advisor:

Dr. Juan Ordonez

Submitted to:

Dr. Nikhil Gupta

Dr. Chiang Shih

Design of Experiment & Results

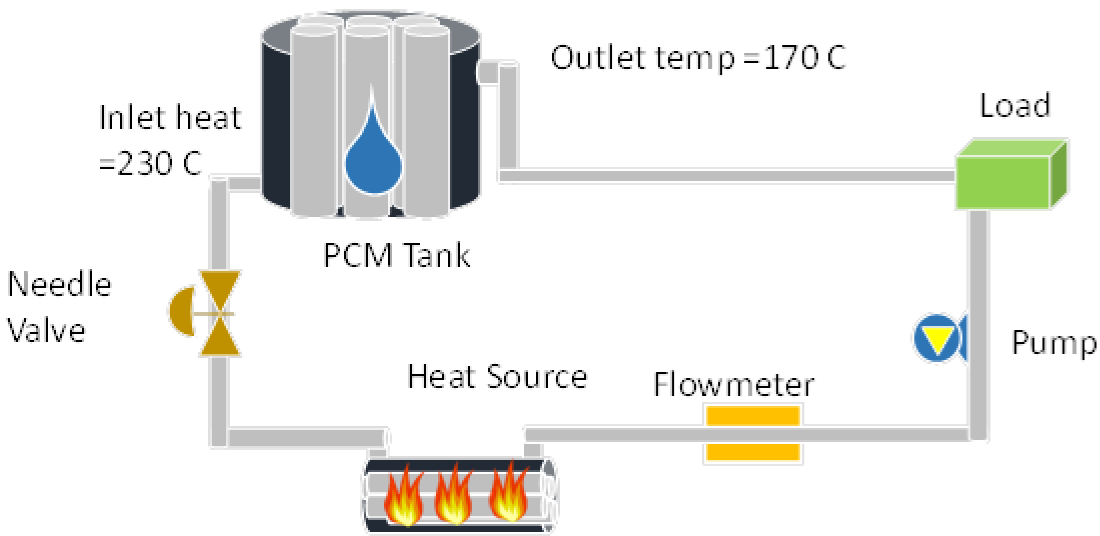

Figure 1 Final System Diagram

For the charging cycle the pump circulated fluid at a rate of 1.12 gallons per minute and the load was left off to decrease startup time. Temperature at the inlet and outlet of both the PCM tank and the heat source were recorded using calibrated thermocouples every 10 minutes. There also a thermocouple placed at the inlet of the load and recorded at the same time interval. Thermocouples were calibrated to the temperature of the environment which was reported to be 24 degrees Celsius. During the discharge cycle the load was switched on and the temperatures at the previously stated points were recorded at 2 minute intervals. Any changes in the environment our testing parameters were noted as they occurred.

Experimental results varied largely from the simulation results. This was probably due to several key factors that were not accounted for in the simulation. The major difference during the charging cycle was the flow rate. This parameter was increased to 1.12gpm, far above the suggested 0.27gpm of the simulation, in order to insure that the temperatures of the heat cartridges in the heat source were maintained at an acceptable level. This was a concern placed by the industry experts that were present during testing. Increasing the flow rate drastically increased the amount of startup time necessary to heat the transfer fluid to 240 degrees Celsius at the tank inlet, as it was assumed to be in the simulation. It was estimated to be a 45 minute startup time at 0.27gpm but once the flow rate was increased it took 4 hours before reaching the ideal inlet temperature. The time was also increased by the leak of heat from the heat source during operation. Although the load was not on the load was still exposed to the environment allowing heat to leak from the system this was minimized by covering the load with insulation.

At the 150 degrees Celsius mark it was discovered that the flow meter was beginning to fail due to the high temperatures. This was later discovered to be caused by a mix up in parts. Although a proper flow meter was specified the wrong flow meter was purchased due to a mix up in part numbers.

Another factor that may have caused the data collected to deviate from the simulation was the gap between the Aluminum baffles and the PCM Tank's inner wall. A tolerance was given for the baffles due to expected thermal expansion and as a result some of the transfer fluid was allowed to bypass the desired flow route across the circular area of the capsules. That being said it was observed that the system was well insulated. Temperature drops across long sections of pipe were 1 degree Celsius, which was in the error of the thermocouple readings. It was also observed that over 48 hours after the start of the test, the transfer fluid at the outlet of the tank was at 48 degrees Celsius.

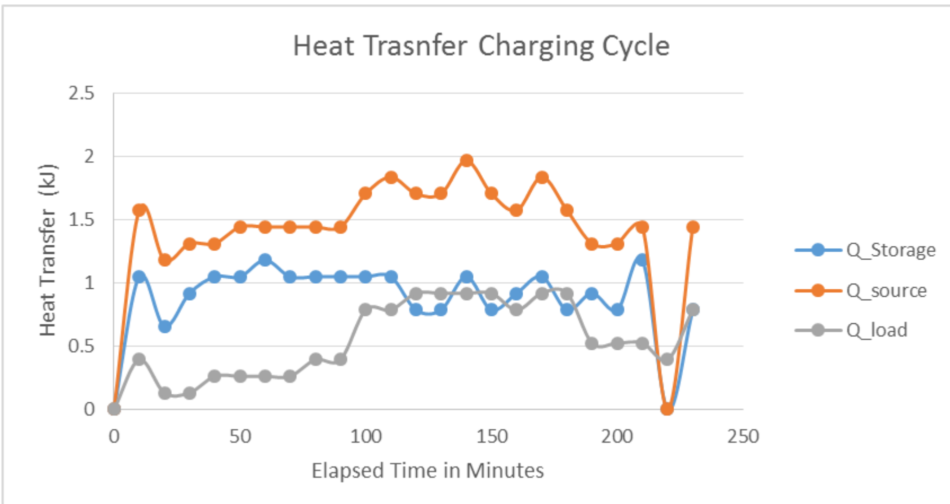

Figure 2 Charging Cycle Heat Transfer

Figure 2 compares the heat transfer across the major subsystems of the experimental rig, including the heat source, the load representing the ORC, and the thermal storage tank. After approximately 175 minutes into the test it was observed that load was having adverse effect on the source's ability to increase the temperature of the transfer fluid. Although the load was off during the charging cycle its ability to transfer heat increased dramatically at 100 minutes due to an increase in the temperature gradient from ambient to average bulk temperature of the fluid. The drop in heat transfer seen at 175 minutes occurred when the load was covered with insulation to decrease this heat loss from the system. The difference in heat transfer through storage tank and heat source remained fairly constant throughout charging cycle. This was not predicted in the simulation that predicted that the heat transfer would decrease with time due to a decrease in temperature gradient as capsules were heated. This discrepancy was most likely caused by the fact that the temperature at the inlet of tank was always increasing at proportional rate to the change in temperature if the capsule. The sharp decline in temperature at 230 minutes occurred when the heat cartridges reached a maximum temperature of 230 degrees Celsius and were cut off by their controller.

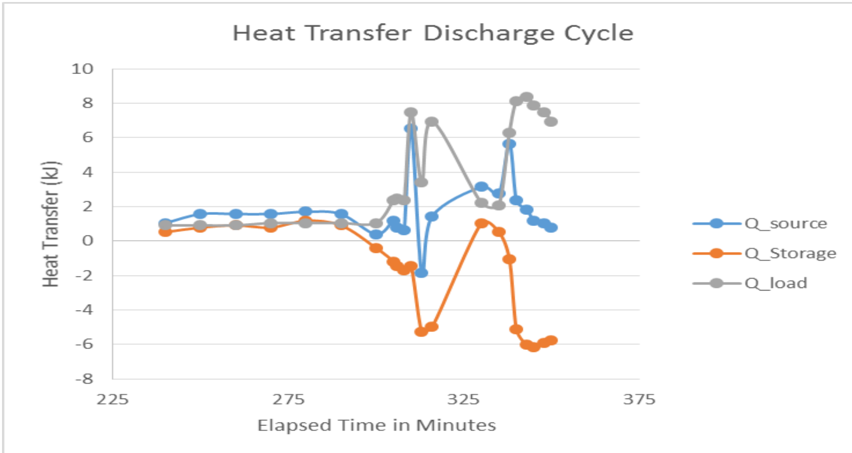

Figure 3 Discharging Heat Transfer of Major Subsystems

Heat Transfer during the discharging cycle was also recorded and the results were reported in Figure 3. From 235minutes to 285 minutes the load remained off due to the original load fans overheating from exposure to high temperatures. Once the fans were replaced it was observed heat was being lost to the source due mixing of fluid at different temperatures. As expected the heat transfer through the load was dramatically increased, but an unexpected result was found in the behavior of the storage tank. Although operation was at a much higher flow rate than prescribed a considerable amount of heat transfer occurred in the tank. This is even more obvious when the change in temperature across the tank was plotted in Figure 4. After the heat source was turned and the applied load dropped the inlet temperature of the tank to 160 degrees Celsius the tank was able to raise the temperature by up to 50 degrees. This may be due to several factors including the presence of a temperature gradient in the tank. As the cold fluid entered the tank it would mix with hotter fluid that had not yet been removed from the tank meaning that outlet was pulling from a warmer reservoir that had yet to leave the tank. This also provided an explanation for the sharp decline in temperature difference at the 325 minutes mark in Figure 4. Another reason for the sharp decline may have been due to the solidification of the phase change materials within the tank itself. Pulling energy out of the capsules too fast would have caused the temperature of Dynalene closest to the capsule wall to fall below the melting point and thus impede heat transfer. Since the temperature at the outlet of the tank never truly stabilized it can be hypothesized the Dynalene capsule never underwent a full phase change. Nor did the tank become fully charged. Team 17 has provided Veridcorp with flexible testing ground for future testing to occur.

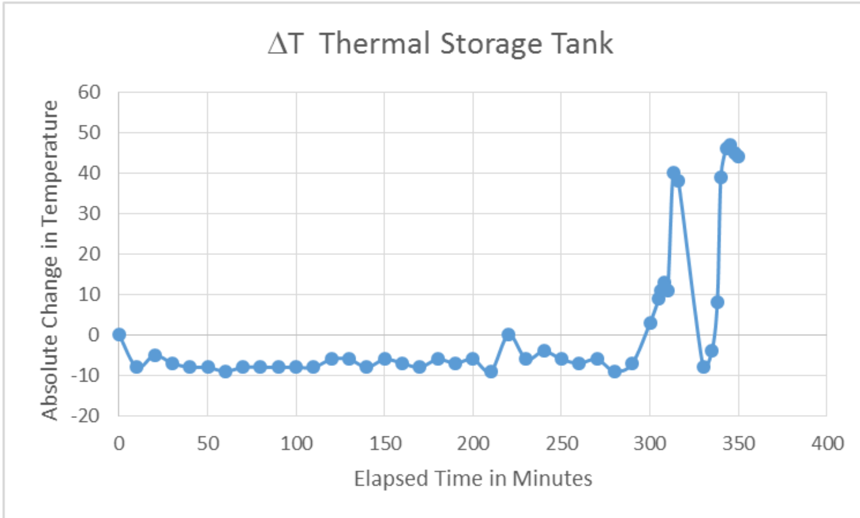

Figure 4 Temperature Change From inlet to outlet of PCM Tank

Restated Conclusion

Team 17 was tasked with developing a design for a Thermal Storage System. During the design process many things changed including the scope and direction of the project. Originally we were tasked with developing a design that applicable specifically in Birdsville, Australia. Taking the remote location and impact on environment into account the team decided to pursue a sensible heat storage design, but when Verdicorp acquired a new patent for encapsulating phase change materials our objective was changed to designing a system that would specifically take advantage of the part geometry of this innovative product. The team developed and shell and tube heat exchanger to take advantage of the cylindrical shape of the capsules. Transient thermal analysis was performed on the system and results showed that if the inlet temperature of the tank was held to 240 degrees Celsius it would take 2 hours and 15 minutes to fully charge the storage device. During actual testing it was evident that reaching this inlet condition took substantial amount of time. Future testing should account for this by heating the transfer fluid until it has reached this condition separately from the rest of the system. Once the load was turned off the tank was able to achieve a 50 degree raise in temperature at the outlet. Future testing should be conducted. For more telling results it is advised that thermocouples be placed with the capsules themselves.