# Thermal Storage Solution for the Organic Rankine Cycle

**Deliverable:**

Operation Manual

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# Abstract

Verdicorp, the sponsor of this thermal storage project, is a company that produces and sells Organic Rankine Cycle power systems. After Verdicorp acquired a new patent on phase change material encapsulation Team 17 has endeavored to design and manufacture an efficient storage design that would take advantage of the geometry of the encapsulations and thermal properties of the phase change material. The following is document that outlines the operation and design specifications of our chosen design including the dimensions and other pertinent data on crucial components, Instructions on operations, and maintenance concerns.

# I. Introduction

Presented In this report is our current understanding of the Thermal Storage Solution project. This report documents. To achieve our goal to:

*"produce a commercially viable thermal energy storage solution for Verdicorp's Organic Rankine Cycle using their patented PCM, environmentally friendly materials, and cost effective manufacturing."*

We have designed a thermal storage device that takes advantage of the encapsulation geometry. The following report was designed to give the end user insight in the daily operation and maintenance of the device. Including maximum allowable temperatures and flow rates. Finally this document also provides troubleshooting advice on problems that may occur during operation.

# II. Functional Analysis

A key to the success of the project will be the management of the various constraints that are inherent in the design, or that may arise during the design process. In order to optimize the productivity of the team these constraints must be constantly analyzed and reevaluated. The present constraints of the project are categorized by full and prototype scale:

For Thermal Storage Unit (prototype):

- Maximum operating pressure: 50 psi
- Construction material: 80-20 alloy
- Must be mobile
- Design must be marketable
- Maximum budget for parts and materials: $2000
- Must not heat the working fluid, R245, of the ORC to temperatures in excess of 170$^{o}$C
- Ability to deliver energy as demand dictates

The energy storage material is a key component to the design, and after careful consideration and talks with our sponsor, it has been decided to implement phase change material as our storage medium. This material must be contained in an insulated environment and be capable of transferring energy with minimal losses and maximum heat transfer. The heat exchanger configuration and piping must be designed to optimize the energy control to and from the system. An example of a possible design is presented in Figure 1. The type of material and heat transfer configuration selected will determine the amount of heat that can be stored and the duration. The device must be capable of storing the thermal energy for at least 14 hours and consistently deliver the heat needed to generate power in the ORC system.

### Prototype Sensors and Control

In order to determine if our system is working, thermocouple temperature sensors will be placed before and after the thermal storage tank. Based on the outcome temperatures, modifications to the flow can be made to pull the oil through the tank slower or faster using the circuit setter that doubles as an extra flow meter. Changing the flow of the oil will change the amount of time it is exposed or in contact with the PCM capsules. The circuit setter and flow meter components have a max temperature 200 $^{0}$C and therefore are placed behind the heat load. Another thermocouple will placed here to monitor the temperature entering these components. The typical flow in the system will be between 0.27 gallons per minute (gpm) and therefore a flow meter with these characteristics has been specified. A diagram of the system can be found in the appendix Figure 2.

# III. Project Specification

Our project requires many components to perform well but the most important comes from the materials that we use to transfer and store the energy. After all, that's what our project revolves around. After tirelessly researching and communicating with our sponsors we came to the conclusion of using Dynalyne MS-1 as our PCM material and Duratherm HF as our heat transfer fluid. Many advantages led us to this decision. Many PCM materials were available for us to choose from but it was important to our sponsor that the freezing point be as high and as safe as possible for us to test. That number was decided by our sponsors as around 200$^{o}$C. Dynalene was the easiest to have shipped since they were in the US and offered extensive data that other companies did not provide. Duratherm HF was another easy choice for our sponsors since they already had an account with the Duratherm Company and were satisfied with their products. Technical data for both are listed in Table 1 below.

Table 1. Material Properties Phase Change Material and Heat Transfer Fluid

| **Dynalyne MS-1 Properties** | **Values** | **Duratherm HF Properties** | **Values** |
|---|---|---|---|
| **Freezing Point** | 225$^{o}$C | Flash Point | 276$^{o}$C |
| **Max Operating Temp** | 565$^{o}$C | Max Bulk Temp | 338$^{o}$C |
| **Latent Heat** | 117 J/g | Auto ignition | 393$^{o}$C |
| **Thermal Conductivity** | 0.50 W/mK | Viscosity | 5.63 cSt (@208$^{o}$C) |
| **Specific Heat** | 1.40 J/gK | Density | 44.1 lb/ft$^{3}$ (@260$^{o}$C) |
| **Density** | 1.9 g/cm$^{3}$ | Thermal Expansion Coeff | 0.1101 %/$^{o}$C |
| **Viscosity** | 4.0 cP | Thermal Conductivity | 0.075 BTU/hr F ft (@260$^{o}$C) |
| **Freezing Contraction** | 3% | Heat Capacity | 2.587 kJ/kg K (@260$^{o}$C) |

Other important equipment include the pump, heat load, heat source, temperature sensors, valve and flowmeter whose important properties are listed below in Table 2. The pump is a refurbished one that Verdicorp worked on themselves offering 3/4 hp which would be able to handle the flow rate we expect for our system which is about 0.25 gpm. Tank has been leak tested to ensure nothing will leak during operation.

Table 2. Major Component Dimensions and Data

| **Hayden liquid to air heat exchanger (heat Load)** | **Values** |
|---|---|
| **Dimensions** | 24in x 12in x 1.5 in |
| | |
| **Fan (Mechatronics: Model UF25GCA12)** | |
| **Dimensions** | 10in Diameter 5in width |
| **Electrical Input Load** | 60/75 W |
| **Input Voltage** | 115V |
| | |
| **Flowmeter (Headland H601-001 HT) NPTF** | |
| **Flow range** | 0.1-1gpm |
| **Max temp** | 260$^{o}$C |
| **Dimensions** | 6.6in x 2.01in |
| | |
| **Valve (B&G Circuit Setter)** | |
| **Max Temp** | 121$^{o}$C |
| **Dimensions** | 3/8 in inlet and outlet diameters |
| | |
| **Thermocouples** | |
| **Type** | K |
| **Max Temp** | 1250$^{o}$C |
| | |
| **Tank** | |
| **Dimensions** | 17in x 16 in OD (15.25 in ID) |
| **Material** | A-36 low grade Hot rolled steel |
| | |
| **PCM Capsules** | |
| **Dimensions** | 12 in x 2.375 in OD (2in ID) Schedule 10 |
| **Pipe Material** | 304 Stainless steel |
| | |
| **Piping** | |
| **Dimensions** | 1/2in ID |
| **Material** | Standard low grade steel |
| | |
| **Pump** | |
| **Mechanical Power** | 3/4 hp |
| **Electric Input** | 230V |
| | |
| **Heat Cartridge** | |
| **Power Output** | 1500W |
| **Maximum Temperature** | 550 degrees Fahrenheit |
| **Dimensions** | 10in x 3/8in Diameter |

# IV. Project Assembly

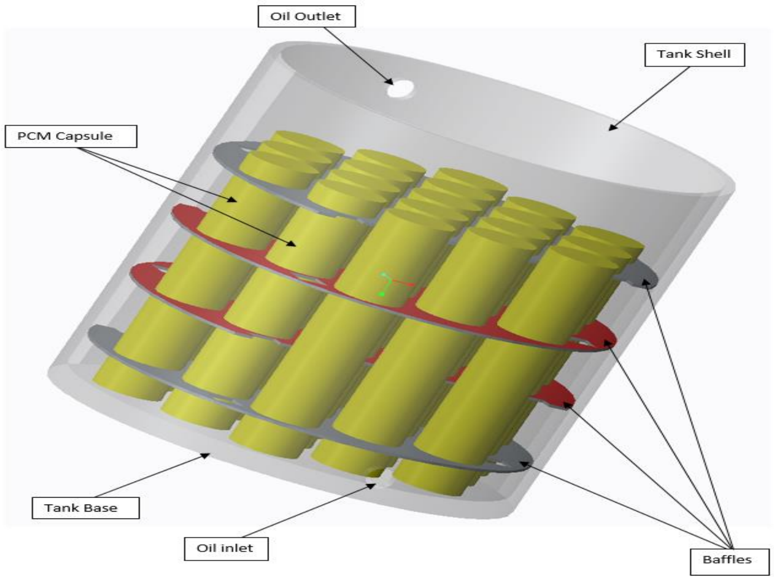


*Figure 1: Shell and Tube concept*

Inlet and outlet diameters for the pump is 3/8 in which is slightly smaller than the piping diameter of 0.25 in we need to achieve our flow rate. 1/2 to 3/8in couplings will be needed for that portion of the system. Same thing goes for our heat exchanger which is provided by Verdicorp as well. It has inlet and outlet diameters of 3/4 in so we will 3/4 to 1/2in reducers for that portion of the assembly. The heat load will simulate the ORC in its consumption of the heat. It resembles a radiator on a smaller scale and will have two fans blowing atmospheric air onto it fins and pipes to improve the cooling effect. To ensure that all the air powered by the fans reach the pipes and fins, a thin metal box will enclose the device and two holes will be cut out for the top for the fans to be mounted on. The other side of the device will be free to the atmosphere. The flowmeter and valve will be placed after the heat load to ensure that the equipment will stay within its operating temperature. The oil will be heated by resistance cartridges that will be placed in a wider pipe that will link in series with the rest of our system. As the oil flows through it, it will get heated to the desired temperature before entering the tank. These cartridges are rated at 1000 W and will be provided by Verdicorp. The cartridges are controlled via applied voltage and the amount of watts applied may be varied via controller. It is imperative that when the cartridges are on they have a constant flow over them or else they will burn up internally and become useless. A overall system can be found in the Appendix Figure 2.

# V. Operation Instruction

Before beginning the operation, one must insure that all components are tightly connected to ensure no leaks during operation. After ensuring that components are tight sealed the power should be turned on. Since it is crucial to determine that the pump, heat cartridges, and heat load are all receiving power the operator must witness the illumination of the light indicators that signal the power delivery. One light will indicate the heat source cartridges being turned on. At this point the pump will begin to push Duratherm through the piping system. The operator must inspect the flow on the flowmeter and adjust the flow of the system using the circuit setter. The flow should be adjusted to a maximum of 0.27gpm. Before the charging cycle can begins the bulk transfer fluid must be heated to 230 $^{o}$C. This operation takes up to 1 hour. During the start of any charging cycle the heat load should be adjusted so that no temperature leaving the load exceeds 200$^{o}$C. The operator must continually monitor the three thermocouples over 15 minute intervals to ensure this. After 2.5 hours the system will be fully charged and the testing can begin. Next the heat source is turned off. Then the circuit setter will once again be used to adjust the flow rate until the thermocouple directly after the tank maintains a steady temperature output of 170 $^{o}$C. Once the flow rate is set the temperature reading across all thermocouples will be recorded at a maximum of 5 minute intervals for the following 40 minutes.

# VI. Troubleshooting

The heat cartridges need a steady flow to dissipate heat or else they will burn up internally rendering them useless. We will have inlet and outlet temperature sensors before and after the heat source that monitor the temperature of these components. If the output temperature exceeds the 230 $^{o}$C power to the system should be cut and allowed to cool. Once cooled to room temperature the cartridges should be inspected for damage. If the cartridges are undamaged, the pump only should be turned on and the operator should monitor the flowmeter and ensure that it reads the expected value. If the flow is not as expected there may be some impedance in the piping network that must be cleared before operation can resume. Another problem we may encounter is having the temperature coming out too hot from the load. The circuit setter Verdicorp has chosen has a relatively lower operating temp so if allowed to exit at too high a temp it may ruin the circuit setter. To avoid we will turn down the heat source or add a regular house fan to blow air on the device to further convective heat transfer. We may encounter the problem of not vacuum sealing the PCM capsules due to lack of knowledge and time on Verdicorp's part since they are the ones manufacturing it. If that is the case we will drill holes into the caps of the capsules and lead copper pipe from the top of the capsule to the top of the tank to act as a vent so that we do not see pressure build up within the capsules.

# VII. Regular Maintenance

To prevent sludge from building up in the tank, the Duratherm transfer fluid should be removed from drained from the system at least once a month and the tank should be cleaned of any built up debris. This will insure that an impeded flow will be maintained during operation. The circuit setter should be replaced every 6 months as well since it will likely be running near max temperature for almost every test at a $50 cost per part to the end user. As mentioned previously, the heat cartridges are prone to burn out. Therefore they should be inspected once a month for full functionality to ensure that the heat transfer fluid achieves the melting temperature of the phase change material in the expected time frame.

# VIII. Spare Parts

The parts listed below are components ant the recommended quantities of those components that should be kept in stock to ensure reliable operation.

- (1) Heat Cartridge in case of early burn out
- (2) Thermocouples
- (1) ½” NPT B&G Circuit Setter

# X. Conclusion

Utilizing all resources available to us, our group has designed and manufactured a thermal storage testing bed for our customer. The materials used in this scaled down model will be chosen with three things in mind, cost, effectiveness, and accessibility. This manual describes the daily operation and maintenance of the overall system, spare parts that should be kept in stock during testing, and pertinent data on major components of the system. This includes dimensions for the tank itself of 18” diameter and 2’-1/4” height. The operator should be wary of exceeding maximum allowable temperatures and any flow impedances during operation. Excessive rusting in the piping should continuously monitored for this may be a sign that the storage medium is leaking from their encapsulation. This problem may quickly cause the entire system to become inoperable.

# XI. References

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# XII. Appendix

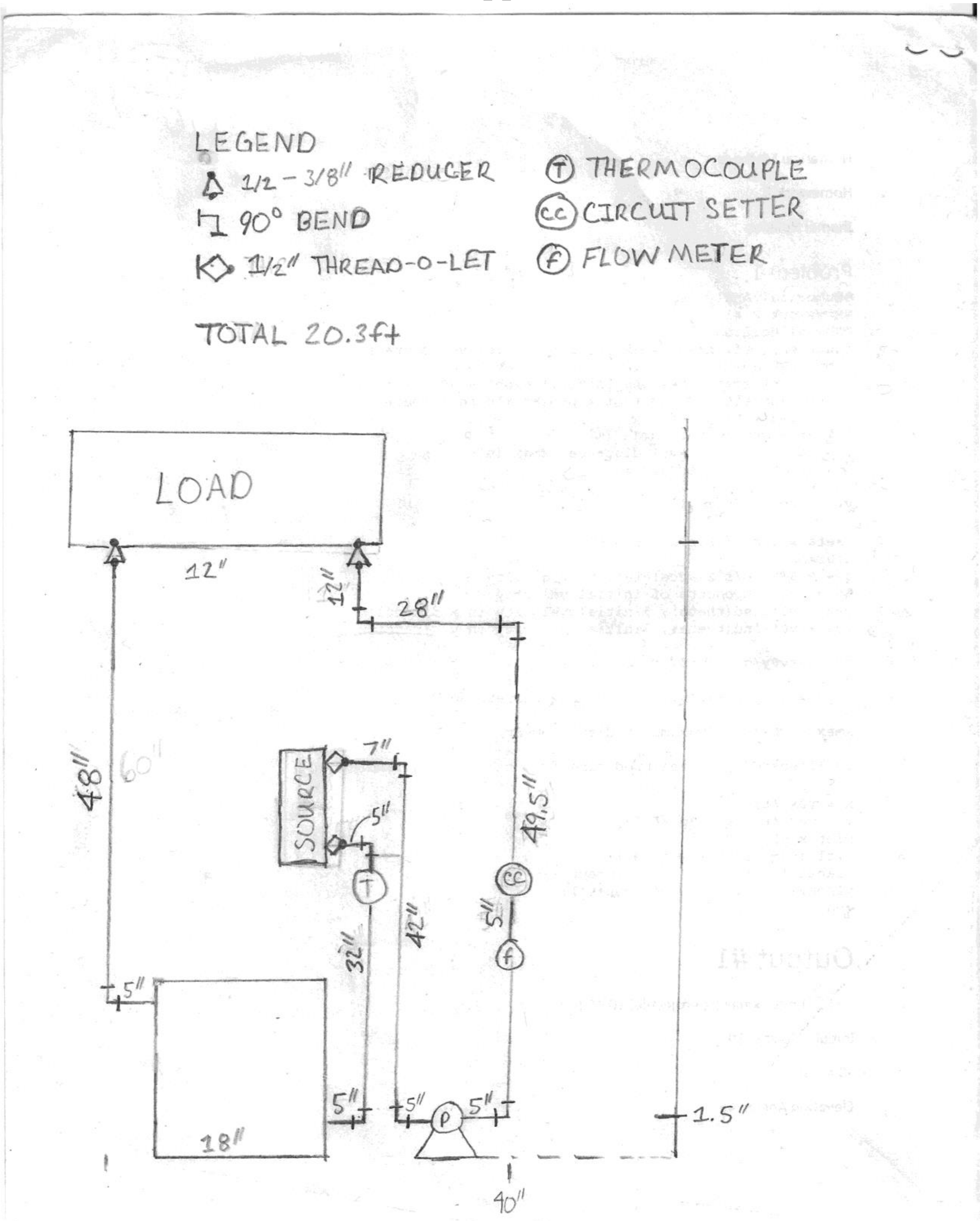


*Figure 2. Piping and Sensor Layout*