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The Effect of Laminar and Turbulent Flow on Phase Change Materials for Energy Recovery

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ABSTRACT

Phase change materials (PCMs) can be used for energy storage and recovery, and it is interesting to see what effect laminar and turbulent flows would have on them. a phase change material is a substance with a high heat of fusion, melting, and solidifying at a certain temperature, which is capable of storing and releasing large amounts of energy. laminar flow is a slower and smoother flow where the flow is parallel and there is no disruption between layers. turbulent flow is more chaotic, and its flow pattern cannot be predicted. paraffin wax was used as the PCM, and water was used for turbulent flow while mineral oil was used for laminar flow. the goal of this research is to improve the efficiency of a system by performing experiments with corrugated plates and paraffin wax as the PCM within the recovery unit. corrugated plates were used as an advanced material and channels of media which carry the thermal fluid (water or mineral oil) to the back plate of the unit which was occupied with the PCM. the experiment measured the temperature in and out from the unit to estimate how much watts (power) that the unit can save in the molten wax and, monitor the temperature inside the PCM using implanted thermocouples. the approach of this work is to collect temperature as a function of time to find how much energy units are used to reach the charging point and reverse the flow to retrieve energy from the unit.

1- Introduction

The idea is to create energy storage devices is just as important as developing new energy sources. Although energy can traditionally be converted into another form, there are still many challenges that some scientists and technologists face today with this new development. Energy storage not only reduces the mismatch between supply and demand, but also improves the performance and reliability of energy systems and plays an important role in conserving the energy. It promotes a cost-effective system by alleviating the loss of energy and capital cost. For example, storage would improve the performance of a power generation plant by load leveling and higher efficiency would lead to energy conservation and lesser generation cost. Thermal energy storage and phase change materials in particular have been a major topic in research for the last two decades. One of the most efficient methods to store thermal energy is latent heat storage using phase change materials (PCMs). Using PCMs provide higher heat storage capacity and more isothermal behavior during charging and discharging compared to sensible heat storage. To ensure good performance in many industrial processes, thermal energy storage systems are requisite for both heat and cold. High energy storage density and high-power capacity for charging and discharging are desirable properties of any storage system. These storage systems have been studied for many years addressing different problems of the used materials such as low thermal conductivity and segregation of the PCM.

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2- Procedure

1. Fill the JULABO with fluid of choice (Turbulent or Laminar)
2. Connect the PVC Pipping from the JULABO to the Power Recovery System (Outlet connects to "IN" on JULABO and Inlet connects to "OUT" on JULABO)
3. Set the desired temperature on the JULABO Control Station
4. Close Flow Value until the desired fluid temperature has been met
5. Record the initial Thermocouple temperatures for the inside of the Power Recovery System
6. Release the fluid into the Power Recovery System and record both the flow rate and inlet/outlet pressures
7. Record Thermocouple temperatures, pressures, and flow rate every five minutes
8. Once the PCM is fully melted into its liquid (sensible heat) phase, turn off and disconnect the PVC connected to the "IN" "OUT" port on the JULABO.
9. Connect the "IN" PVC to a source of Tap Water and leave the "OUT" PVC in a water waste sink or waste container
10. Record initial temperatures of the Thermocouples then release the tap water through the system
11. Record the Thermocouple temperatures, pressures, and flow rate every one minute until the PCM is fully solidified (sensible heat) phase
12. Analyze data and compare results for both Laminar and Turbulent Flow Fluids

3- Equipment/Design

JULABO

- Pumps Fluids at 4 different Flow Rate Settings
- Maximum volume capacity: 4.5L
- Working Temperature Range: -28 °C to 200 °C
- Minimum Flow Rate: 2.3 GPM

Figure 1: Julabo

POWER RECOVERY SYSTEM

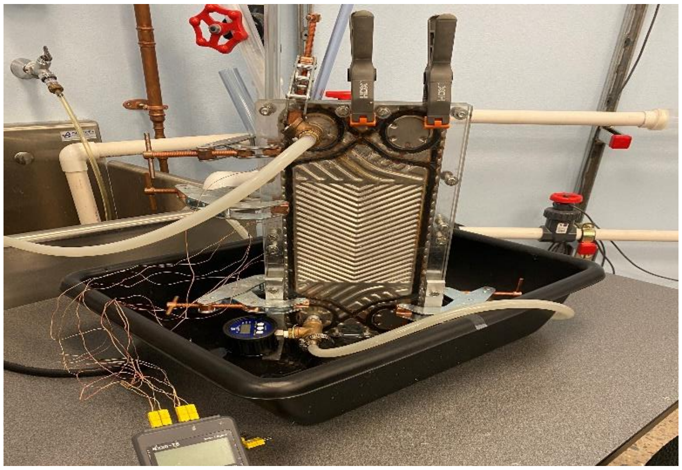

Figure 2: Power Recovery System

- Materials: Plexiglass, Gaskets, Heat Exchanger Plates, PCM (Paraffin Wax)
- Plexiglass properties
  - i. Poly methyl methacrylate
  - ii. 10in * 19in * 1in
  - iii. Chemical and Heat Resistance

- Gasket Properties
  - i. Chemical Resistant
  - ii. Glue Style and Clip Style Seals
  - iii. Directs Flow of Fluid

- Heat Exchanger Plates
  - i. Exchanger Plates
  - ii. Two Chevron Style Plates
  - iii. Increases turbulence
  - iv. Corrugation Achieved by Cold Forging Sheet Metal

- Data Acquisition Analysis
  - i. HUATO Temperature Input Module
  - ii. Temperature Evaluation between -200 °C to 1800 °C

- Paraffin Wax Properties
  - i. Melting Point: 58 °C
  - ii. Thermal Conductivity: 0.2-1.7 W/m*K

4 Results and Discussion

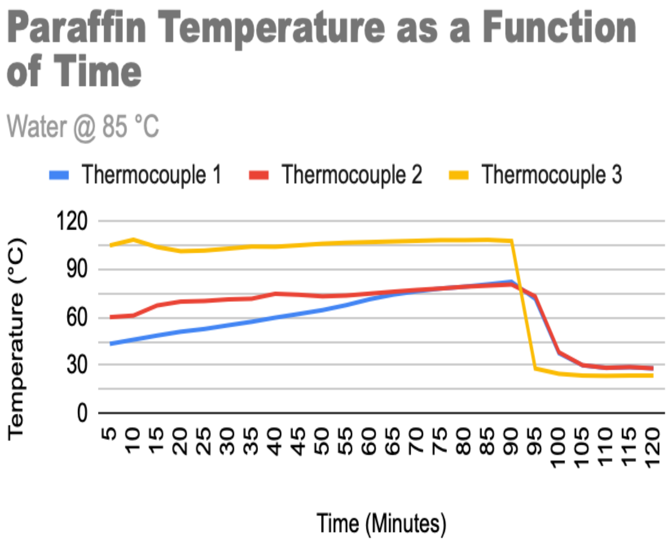

Figure 1: Water Fluid Source

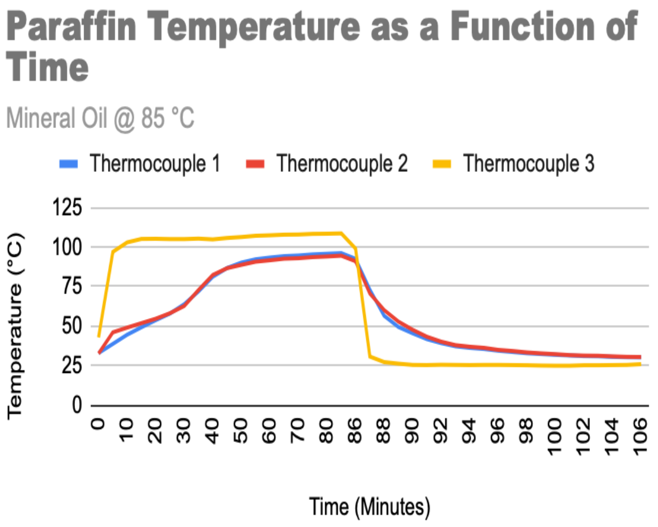

Figure 2: Mineral Oil Fluid Source

Figure 1 and Figure 2 yielded a maximum temperature of 108.5 degrees Celsius within the paraffin wax (PCM). The average flow rate of the water to the energy recovery system was 1.1 GPM while the mineral oil was supplied at 1.97 GPM at 85 degrees Celsius by the JULABO. While Figure 2 had a faster phase change and recovery time, max temperatures were the same regardless of the flow rate.

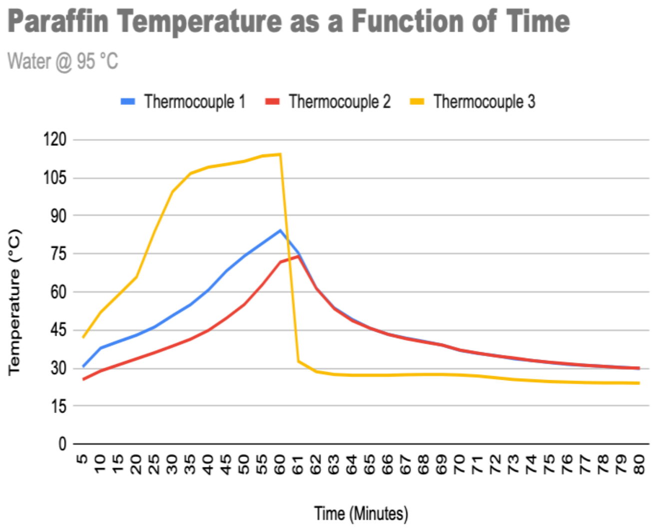

Figure 3: Water Fluid Source

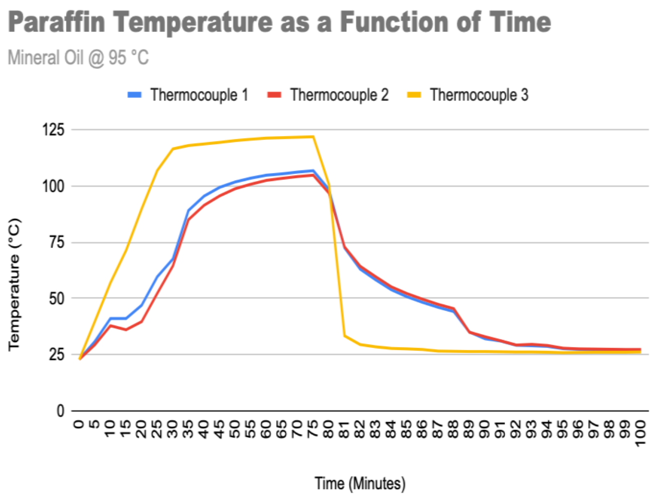

Figure 4: Mineral Oil Fluid Source

Figure 3 yielded a lower maximum temperature of 114.2 degrees Celsius within the paraffin wax than Figure 4 that was 122 degrees Celsius (PCM). The average flow rate of the mineral oil to the energy recovery system was 1.97 GPM which is greater than the water which was 0.7 GPM and supplied at 95 degrees Celsius by the JULABO. Figure 3 had a faster phase change time than Figure 4 even though the flow rate was more than doubled and had a higher maximum temperature.

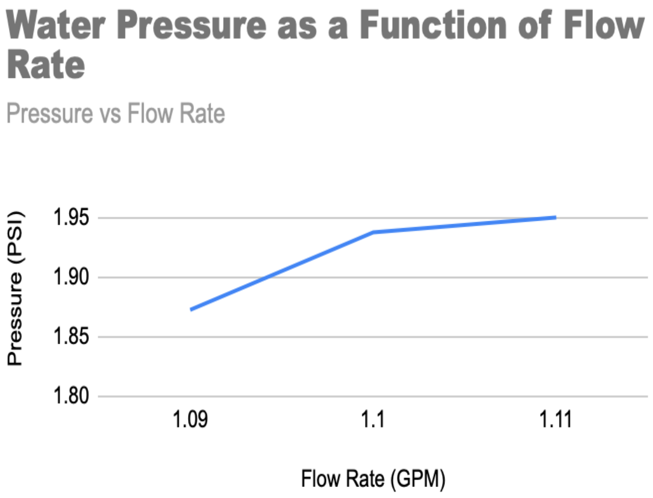

Figure 5: Water @ 85 °C

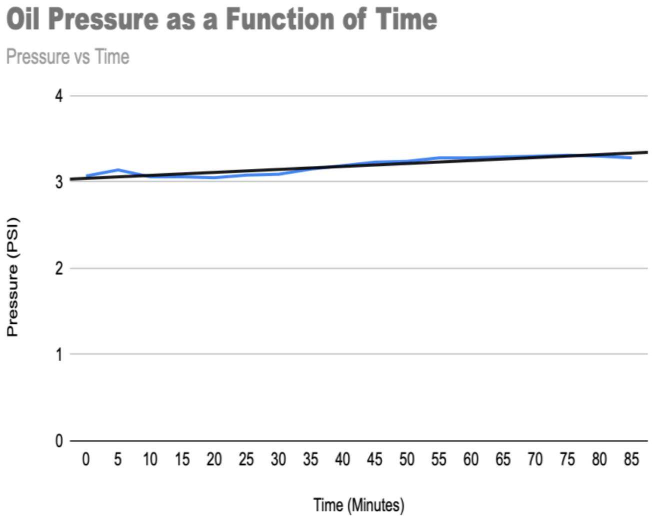

Figure 6: Mineral Oil @ 85 °C

Figure 5 revealed that water is identified as one with turbulent flow. The square root curve that is formed by the *water pressure vs flow rate* graph reveals the non-parallel form of flow. In contrast, Figure 6 revealed that mineral oil is identified as one with laminar flow. The linear slope that is formed by the *oil pressure vs time* graph reveals the parallel form of flow at a constant flow rate. A linear slope correlates to laminar flow while a square root curve represents turbulent flow.

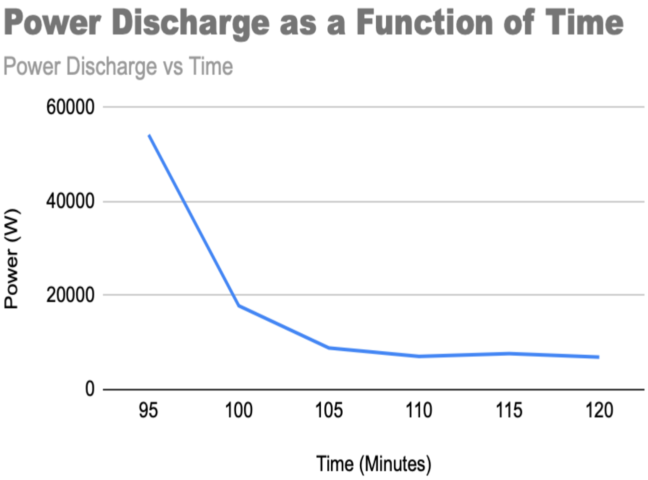

Figure 7: Water Fluid Initial Source @ 85 °C

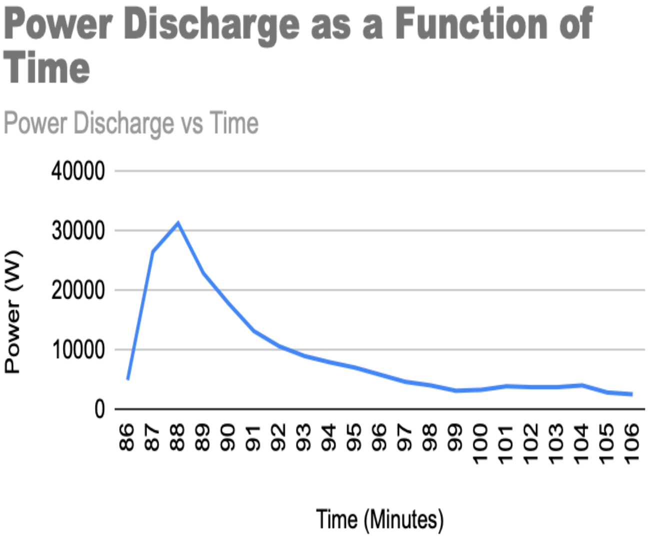

Figure 8: Mineral Oil Initial Source @ 85 °C

Both Figure 7 and Figure 8 reveal the power discharge from the phase change material (PCM) after it was melted to a liquid and room temperature water was then ran through the system. The maximum power discharge for Figure 7 (54,191.61677 W) was 73.21% higher than Figure 8 (31,287.42515 W) while both figures followed a exponential decay function as the room temperature water continued to run through the system.

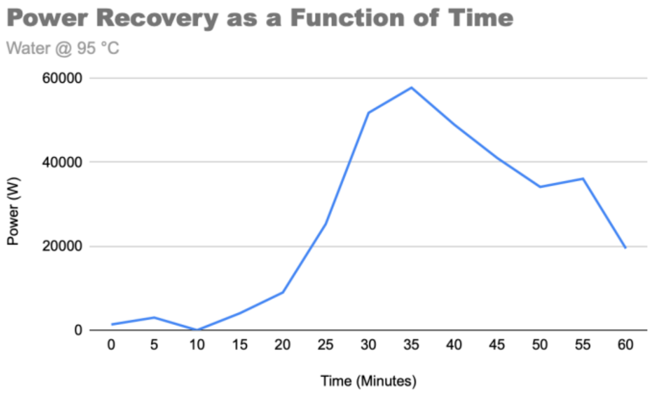

Figure 9: Water @ 95 °C

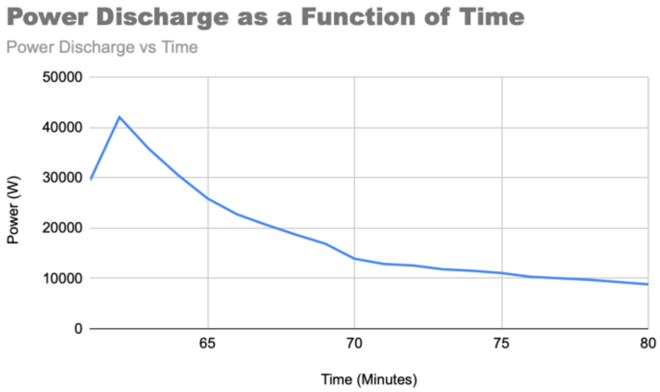

Figure 10: Water @ 95 °C

Figure 9 has a maximum power recovery of 57,784.43114 W while Figure 10 has a maximum power discharge of 42,065.86826 W. The maximum loss of thermal power to surroundings is 37.37 % for water at 95 degrees Celsius. The efficiency of the system is directly related to the loss of power through lack of insulation during the power recovery and discharge process.

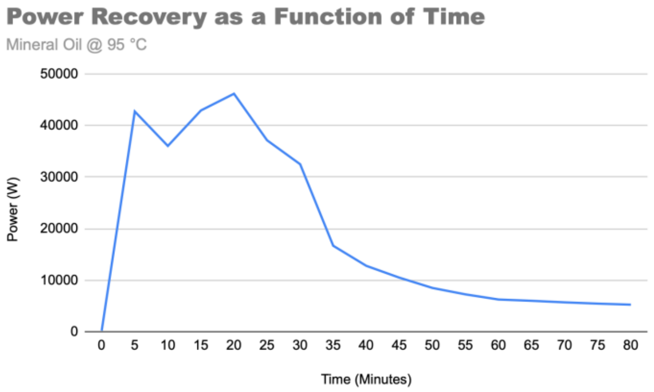

Figure 11: Mineral Oil @ 95 °C

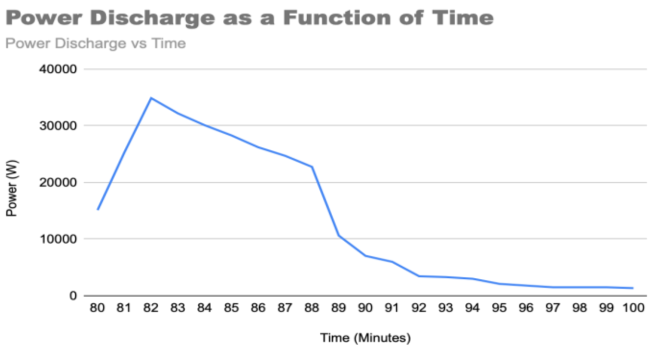

Figure 12: Mineral Oil @ 95 °C

Figure 11 has a maximum power recovery of 46,157.68463 W while Figure 10 has a maximum power discharge of 34,880.23952 W. The maximum loss of thermal power to surroundings is 32.33 % for water at 95 degrees Celsius. The efficiency of the system is directly related to the loss of power through lack of insulation during the power recovery and discharge process.

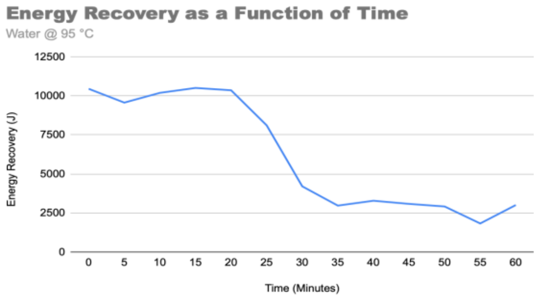

Figure 13: Water Fluid Source

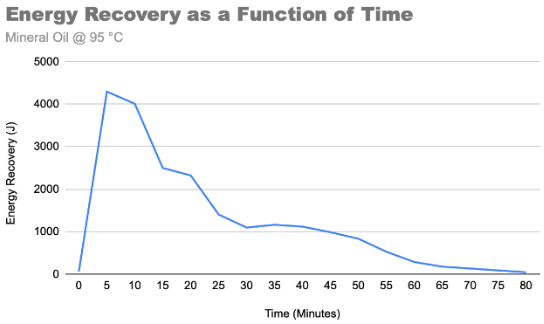

Figure 14: Mineral Oil Fluid Source

Both Figure 12 and 13 are utilized to reveal the energy recovery from the phase change material (PCM) after it was melted to a liquid. The maximum energy recovery for Figure 13 occurred at 4,291.072061 J while Figure 12 had a 244.71 % higher energy recovery (10,500.62664 J). Energy recovery decreased in a distorted fashion due to the fluctuation of pressure as the fluid continued to run through the system.

5 Conclusion

Within high temperature experimentation, water (due to its turbulent flow and specific heat) provides higher maximum efficiency than mineral oil and is thus a more sustainable fluid for Power/Energy Recovery as well as discharge. Lower Flow rates leads to higher accuracy within energy and power recovery. Laminar Flow provided by mineral oil is beneficial due to its minimal leakage within the Power Recovery System.
Total power and energy recovery is performed through synthesizing a 10th order polynomial and integrating it for the duration of the energy/power recovery cycle. In order to compare laminar flow fluid to a turbulent flow fluid, two major variables were kept constant: temperature and flow rate. Once these variables were kept constant, it was revealed that while water has a higher energy recovery, mineral oil had a higher power recovery. One might think that both energy and power recovery are the same idea; however, the calculations are different. Through the Reynolds number being used in the power recovery calculations, it is easy to see that power recovery is a more inclusive data set that represents the properties of the fluid and the system that is performing the power recovery cycle.

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