Thermal Lab Report

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Group 10
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1. Presentation of the lab setup

The main objective of this laboratory is to evaluate the performance and characterize a latent heat-based Mobile Thermal Energy Storage (M-TES) prototype.

The whole experimental system consists of oil bath, water cooling, coil heat exchanger (HX), heat transfer fluid (HTF) reservoir, pump, data logger, MTES and measurement system as shown in **Figure 1**.

Two thermostatic oil baths are used to regulate the temperature of the HTF, which is stored in a HTF reservoir. Heat transfer is facilitated by a coil HX, while a pump with a frequency controller circulates the HTF, maintaining the desired flow rate. Flow measurements are recorded using an omega flow meter. Temperature monitoring is performed using ten PT100 sensors placed at specific positions within the M-TES unit, complemented by a type-T thermocouple for tracking the HTF reservoir's temperature. The temperature data is logged via a Keithley data acquisition system connected to a computer, with pre-configured settings in Excel for data processing. Cooling is achieved using a cold water faucet when the buffer tank temperature falls below 100°C, allowing controlled heat discharge.

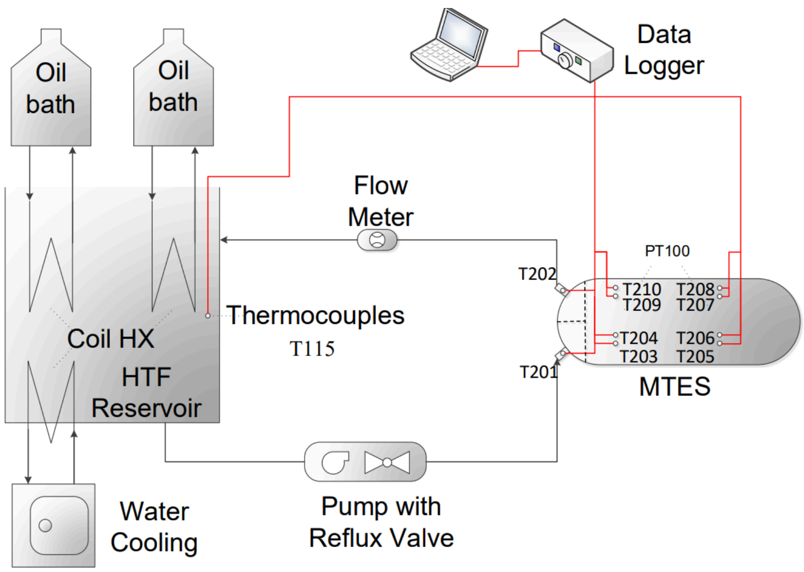


Figure 1 Experiment system patterns

2. Boundary conditions for the test

The boundary conditions for the test are established to simulate operational scenarios for the M-TES unit as shown in **Table 1**. Key parameters include the initial and final temperatures of the PCM and the HTF, along with controlled flow rates and ambient conditions to ensure consistent and reliable performance evaluation.

Additionally, the physical parameters of applied PCM and HTF are summarised and listed in **Table 2** and **Table 3**.

Table 1 Designed experimental set-up parameters

Parameter	Value
Empty shell weight (stainless steel)	150 kg
Ambient temperature	22.8 ℃
HTF flow rate	2 L/min
Total volume of PCM	44 L
Starting temperature of PCM	71.1 ℃
End temperature of PCM	40.1 ℃
HTF Temperature in	-
HTF Temperature out	-

Table 2 PCM physical parameters

The PCM used is “**RT60 HC**”.

Parameter	Value
Nominal phase change temperature	60 ℃
Density (liquid phase)	0.75 kg/L
Density (solid phase)	0.85 kg/L
Cp (specific heat capacity)	2 kJ/(kg*K)
Phase transition enthalpy	264.5 kJ/kg
Phase transition range solidification	62 ℃ → 51 ℃
Total volume PCM	44 L

Table 3 HTF physical parameters

The HTF oil used is “**RENOLIN THERM 300 X**”.

Parameter	Value
Density (at 15 ℃)	875 kg/m^3
Cp (at 50 ℃)	2 kJ/(kg*K)

3. Theoretical calculations

Equation 1-4 presents the calculation methods for the theoretical storage capacity. Based on these equations and **Table 1-3**, the theoretical results were calculated and presented in **Table 4**.

$$Q_{PCM_{sensible\ solid}} = c_{P_{PCM\ solid}} * m_{PCM} * \Delta T_1 \qquad \text{Eq.1}$$

$$Q_{PCM_{sensible\ liquid}} = c_{P_{PCM\ liquid}} * m_{PCM} * \Delta T_2 \qquad \text{Eq.2}$$

$$Q_{PCM_{latent}} = L * m_{PCM} \qquad \text{Eq.3}$$

$$Q_{storage} = Q_{PCM_{sensible\ solid}} + Q_{PCM_{sensible\ liquid}} + Q_{PCM_{latent}} \qquad \text{Eq.4}$$

Table 4 Theoretical calculation results

Metric	Value
m_{PCM}	33 kg
$Q_{PCM_{sensible\ solid}}$	719.4 kJ
$Q_{PCM_{sensible\ liquid}}$	601.3 kJ
$Q_{PCM_{latent}}$	8728.5 kJ
$Q_{storage}$	**10049.2 kJ**

4. Experimental results

In this section we use the experimental data to calculate the heat that is transferred from the PCM to the HTF (oil). The temperature data is logged for ten sensors in the MTES, Chn 201 to Chn 210. 201 is at the inlet, 210 is at the outlet, as can be seen in figure 1. Chn 115 logs the temperature of the oil reservoir, to monitor the buffer tank HTF temperature. In figure 2, the experimental results are shown for all sensor temperatures over time. The total test lasted about 8 hours, the data was logged every 10 seconds.

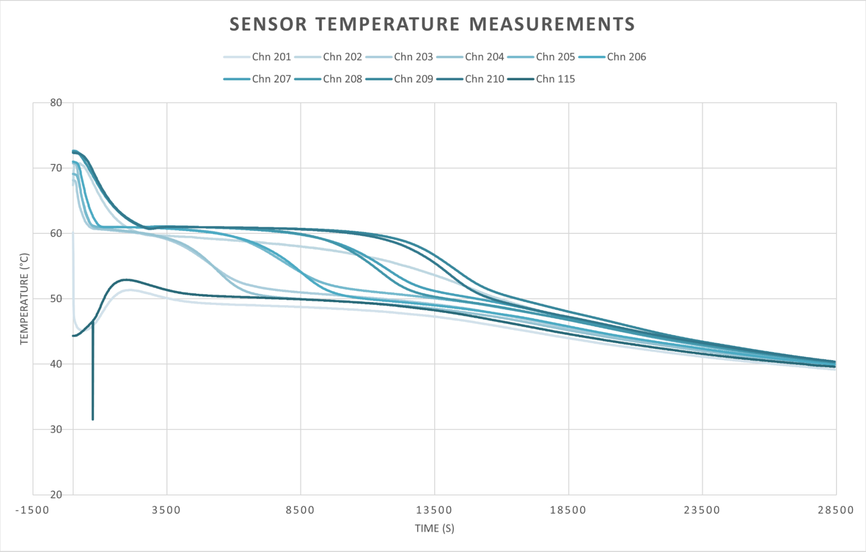


Figure 2 Sensor measurements vs Time

Analyzing this plot there are a few key observations:

- The inlet temperature at Chn 201 is the first to drastically decrease in temperature.
- The outlet temperature at Chn 202 follows a different type of course than the other sensors, it is steadily decreasing throughout the test.
- The pairs 203-204, 205-206, 207-208 and 209-210 follow a similar pattern, where the intermediate time between these consecutive drops is roughly 40 minutes.
- There is a sudden drop in the recorded temperature of the oil reservoir, which is most likely a measurement error.
- After 8 hours, all sensors log a temperature of 40 ℃, as expected. This is the temperature of the oil baths, at this point no heat is extracted from the PCM anymore.

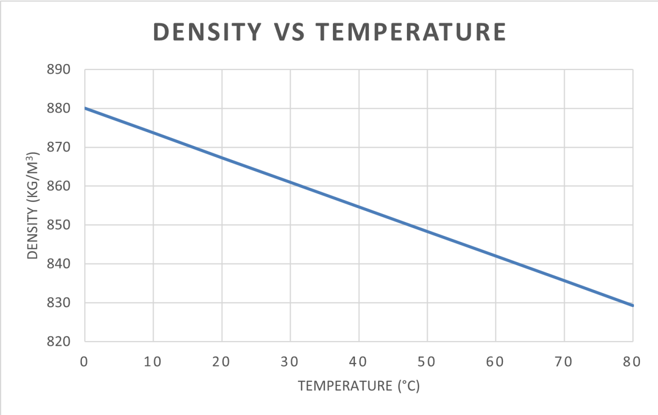
Method 1

To determine from the data the amount of heat transfer, we consider the difference between inlet and outlet temperatures (Chn 201 and Chn 202). The following formula is used to calculate Q_{HTF}, the experimental heat transfer.

$$Q_{HTF} = \sum_{t_1}^{t_{2850}} C_{P,HTF} \cdot \Delta T \cdot \dot{V} \cdot \rho \cdot \Delta t$$

where

- $\Delta T = T_{Chn202} - T_{Chn201}\ (K)$
- $\dot{V} = 2\ L/min = 2(L/min) \div 1000\ (L/m^3) \div 60\ (s/min) = 0.0000333\ m^3/s$
- ρ and $C_{P,HTF}$ are functions of temperature, as can be seen in figures 3 and 4. To create these figures, the plots of the datasheet for the HTF were used. $C_{P,HTF}$ starts at a value of 2.033 $kJ/kg\ K$, at the end of the experiment this value has dropped to 1.945 $kJ/kg\ K$. Density ρ starts at 839.6 kg/m^3 and increases to 854.9 kg/m^3 at the end of the experiment.
- $\Delta t = 10\ s$



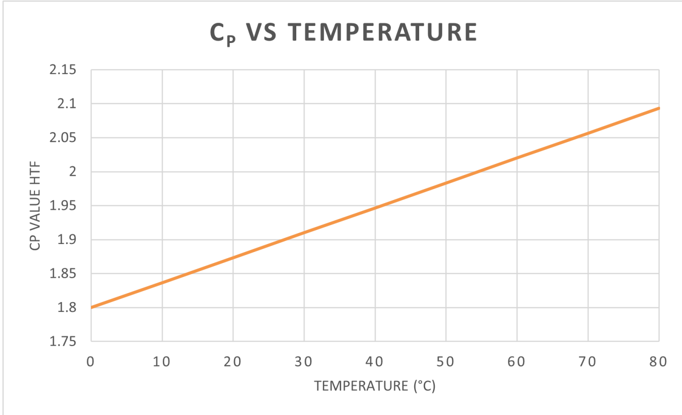


Figure 3: HTF density vs Temperature

Figure 4: HTF Cp vs Temperature

Summing for all timesteps, while taking into account that ρ and $C_{P,HTF}$ vary, we obtain Q_{HTF} = **10035.6 kJ**

Method 2
Another way to use this formula, is to take constant values for ρ and $C_{P,HTF}$. We take $\rho = 825\ kg/m^3$ and $C_{P,HTF} = 2\ kJ/kg\ K$. Now summing again for all timesteps, we obtain Q_{HTF} = **9814.6 kJ**

Method 3
Finally, we could also consider the fact that the heat from the PCM is not only transferred to the HTF, but also to the storage tank itself. For the tank we can assume $m = 150\ kg$, $C_p = 0.5\ kJ/kg\ K,\ \Delta T = 30\ K.$
The amount of heat taken up by the tank can thus be calculated as:
$Q_{Tank} = m \cdot C_p \cdot \Delta T$ = 2250 kJ.

Then, the total heat transfer can be calculated either as 10035.6 + 2250 = **12285.6 kJ** or as 9814.6 + 2250 = **12064.6 kJ**

5. Analysis and discussion

- Analysis and discussion on the outcome comparing the theoretical calculation against the experimental results.

"Actually, the heat is not only stored in PCM but also in the stainless shell and tube. The empty weight of the tank is 150 kg (you can find this info on its nameplate in the lab handout). Assume Cp 0.5, and Dt(70-40), it's already 1000+ kJ heat stored by half of the weight. I believe this is the main reason of QHTF is higher than QPCM."

From the theoretical and experimental results, it is notable that the experimental number is higher that the theoretical
(If $Q_{HTF} > Q_{PCM}$ then this could be because the shell takes up sensible heat as well.)

Write here more about why the theoretical values and experimental values differ. This piece is very important :)

6. Conclusion and future work (max 1 page)