Thermal Degradation of Erythritol

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ISEC Project

The Insulated Solar Electric Cooker (ISEC - see Figure 1) is a double walled Aluminum pot with a resistive heater directly connected to a solar panel. The goal is to harness the power of the sun to reliably cook food and to ultimately disseminate in areas in the world that still primarily rely on biomass—coal, wood, etc—cooking, such as rural India, sub-Saharan Africa, etc. It can be built for under $100, but requires insulation to better contain heat. The project was started to alleviate the environmental and health burdens arising from biomass cooking in rural areas, where it is estimated that around 3 billion people in the world use biomass for daily cooking, and 4 million die from health complications due to it annually.¹

![Diagram of ISEC with Phase Change Material](image)

Figure 1: Diagram of ISEC with Phase Change Material

The device, hooked to a 100 W solar panel, can boil 1 L of water per 1 hr of sunlight, and therefore can use the boil-and-simmer method, it can cook about 5 kg of food in a day.¹ In order

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for the ISEC to completely replace biomass cooking, it needs to produce power at night as well, which is achieved with Phase Change Materials

**Phase Change Materials and Erythritol**

Phase Change Materials (PCMs) are substances that can absorb or release energy when transition phases (melting absorbs energy, solidifying releases energy). The operating principle revolves around a PCM’s latent heat of fusion. As it approaches its melting point, the material will undergo an endothermic process, and the absorbed energy will remain in the liquid PCM until it begins cooling. The cooling process is exothermic, so when the PCM is changing phases from liquid to solid, it will release all the energy building in its system. PCMs are characterized by their high heats of fusion, so they can provide more heat than materials with lower heats of fusion. Since the ISEC solely relies on solar power to cook, it is only viable during daytime. Since most communities across the world have at least one meal towards sunset/nighttime, PCMs step in and allow the ISEC to harness the power of the sun even after it sets. Latent heat storage allows the ISEC to produce greater power and cook for longer periods.

Erythritol (ET), the focus of this paper, is a sugar alcohol with a Latent Heat of 315 J/g, and its melting temperature is around 121°C. Organic PCMs are great sources for thermal storage, but repeated use begins to degrade the material. As ET degrades, its melting temperature will drop, and there is a decrease in the heat of fusion and it will turn from clear/off white to dark brown/black, as shown in Figure 2. Once the melting point decreases below 100 °C, the PCM has limited value to cook food.

<table>
<thead>
<tr>
<th>Latent Heat</th>
<th>Melting Temperature</th>
<th>Heat Capacity</th>
<th>Thermal Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>315 J/g</td>
<td>121 °C</td>
<td>2.87 J/g*K</td>
<td>0.33 W/m*K</td>
</tr>
</tbody>
</table>

Table 1: Erythritol’s properties
Figure 2: (left) fresh sample of Erythritol, melted for the first time
(right) degraded sample of Erythritol after months of cycling

Initial Design

This project was largely conducted during the COVID-19 pandemic, where access to Cal Poly’s lab and its materials was restricted or prohibited due to the nationwide lockdown. Most of the materials and instruments used for the project were purchased from Amazon, and experiments were conducted in a garage.

The primary design involved using 4 glass beakers with nichrome wire wrapped around the length of it. Each beaker was filled with 200g of ET with thermal switches and fuses ranging from 120°C to 180°C in 20°C increments. A 12 V DC Power Supply was connected to each beaker, with the resistance of the nichrome wire measured around $3\Omega$. The goal of the experiment was to cycle the same amount of ET at different temperatures and observe its rate of degradation as it changes phase repeatedly.
The second design involved using 4 stainless steel beakers (to spread the heat more evenly) and ceramic resistors (three 1Ω resistors connected in series per beaker) with Four 12 V Power Supplies. The third design involved 4 stainless steel beakers and pieces of resistive heating coils, connected in parallel to a 240 W DC Power Supply set to 12.6 V and it was surrounded by thick layers of rockwool for insulation.

**Data**

Figure 3: Data recorded over 160 hrs shows phase change around 112°C

Figure 4: Same beaker from Fig 3, 1 month later, shows phase change around/lower than 110°C
Data collection proved quite difficult due a variety of complications. The goal was to keep the beakers heated between 3 days to one week with continuous heat and then observe how many times the ET achieved phase change, which was partially achieved in Figures 3 and 4. Figure 3 shows data collected from March 1 to March 8, 2022 from a beaker whose thermal switch was set at 160°C. Throughout the graph, around 112 °C, the graph hits a flat section where the blue line is bolder, indicating that the beaker stayed at that temperature for longer than others in the same range, which is a sign that the Erythritol is undergoing phase change. One month later, in Figure 4, data collected from April 1 to April 6, 2022 from the same beaker shows a slight drop in the melting temperature, as the phase change line is now at the bottom end of the temperature range, signifying that the since the melting point could have lowered or that the sensor did not register phase change and got shifted, the temperature switch range must also be lowered to more accurately capture the phase change temperature.

Due to the lockdown, the first 7 months of this experiment was conducted remotely. The first design, featuring glass beakers and nichrome wire, could not adequately spread heat evenly so some parts of the ET melted quickly while others remained solid, and since the temperature sensor was attached to the side of the beaker the thermal switch triggered too early. Since glass is a poor conductor of heat, when the nichrome wire’s temperature rapidly rose (peak temperature was around 250°C to 300°C), the glass began to crack due to prolonged exposure. After four out of eight beakers cracked and spilled hot ET onto the labstation, the second design was adopted.

The second design, featuring steel beakers and ceramic resistors, provided more promising results, but also exposed more problems. The power supplies were not intended to be used continuously for days on end, so they began to malfunction due to a rise in the power supply’s internal temperature. Eventually, they stopped conducting any current at all because the
circuits in the block had completely burnt and the plastic container housing the circuit had partially melted. In addition, the ceramic resistors were also cheap and of poor quality, so they too stopped conducting current after a few weeks.

Figure 5: A skewed data set where the thermocouple was sitting too close to the nichrome wire

Figure 6: Another example of skewed data

The third design, featuring a 240 W power supply and resistive heating coils, was by far the most effective design, although it still posed a lot of problems regarding data analysis. The heating coil was difficult to cut and shape, so any adjustments were difficult to make. The
thermocouple, now submerged into the beaker of ET, would read skewed data because of the way the coil wrapped partially around the beaker (one side was hotter than the other), as shown in Figure 5, where the upper temperature (which should be 160°C) climbs near 170°C and the lower temperature (which should fall to around 110°C) rests around 157°C. Figure 6 shows another example, where the maximum rests at 130°C and the minimum (the graph flattens, signifying phase change) rests at 100°C, but both bounds should be about 20°C higher.

Since most of the recorded data was unusable, towards the end of the project the apparatus was modified for an alternate approach to data collection: measure the current melting points of each beaker, after several months of temperature cycling (August 2021 to May 2022) and compare them to the initial melting point. However, the data collected showed extremely erratic spikes that couldn’t be explained by physical phenomena, as shown by Figures 7 and 8.

![Temperature (°C) vs. Time (hr)](image)

Figure 7: ET in three beakers was heated to 170°C on a hot plate and left to cool
Figure 8: ET in a beaker heated to 150°C and left to cool

Figure 7 shows three beakers (differentiated by red, blue, and green) whose temperature shows drastic rises and drops within seconds of each other, which leads to the conclusion that the data collection was flawed in some way. Possibly, the thermocouples were faulty and not viable for further use. Figure 8 shows a gradual temperature decrease with no phase change plateau, followed by a sharp rise in temperature and then a gradual decrease with no phase change plateau. Since the thermocouple was submerged into the melted ET, it likely shifted positions as the ET solidified, which could explain the sharp rise, but the cause remains unidentified.

Analysis

Over the course of 9 months, four steel beakers, each filled with 200g of previously unused Erythritol, was cycled at 120°C, 140°C, 160°C, and 180°C. Throughout the course of the experiment, the data collection was inconsistent and difficult to analyze. Through the limited
data that was usable, from Figures 3 and 4, the phase change plateau clearly shows a decrease in the melting temperature of ET, which indicates that its capacity for thermal storage dropped.

**Data from the Differential Scanning Calorimeter (DSC)**

Differential Scanning Calorimetry is a technique that measures the heat a sample takes in/gives off when it is heated, allowing the determination of things like recrystallization energy, latent heat, and specific heat. DSC is particularly useful in observing phase transitions; as a material begins transitioning to a different phase, more or less energy needs to go into the system to keep it at the same temperature to complete the transition. The amount of heat flow depends on whether the process is exothermic or endothermic.

![DSC results of Erythritol samples at varying degrees of degradation](image)

Figure 9: DSC results of Erythritol samples at varying degrees of degradation

Figure 9 shows the phase transitions of Erythritol samples of varying degrees of degradation as they are taken from a temperature range of 25°C to 180°C. The horizontal axis

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2 Data obtained from Daniel Nagy, a researcher on the ISEC team
displays data in °C, while the vertical axis shows data in Power/mass [W/g]. This metric describes the amount of energy spent in a given amount of time per gram of Erythritol. Erythritol’s cooling process is exothermic, as is visible in graphs blue, purple, and black. The melting point for the blue and purple samples seems to rest around 110°C, while the melting point for the black sample shows the melting point around 125°C. The blue and purple samples (much more degraded than the black sample) also release less energy (the integrated area under the curve) than the black sample in their solidifying process. Erythritol’s degradation, therefore, reduces its energy output.

**Conclusion**

Though temperature regulation and accurate data collection became significantly difficult, some data provided promising results. The data from Figures 3 and 4 suggest that from August 2021 to May 2022, ET’s melting point lowered from 121°C to 108°C (estimated). The two figures show consistent flat sections around roughly the same temperature, indicating that the sample went through phase transition or reached its melting point. Physically, it transformed from a clear to black solution, signifying that the sample physically degraded. Based on the observed rough rate of degradation, Erythritol is not a viable option for phase change in the ISEC.
References
