SOLAR HEAT SINK FOR BATCH DISTILLATION

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Project Background

Project Opportunity:

Whey is a waste product produced during cheese making processes. The lactose in whey can be fermented to produce 2-3% alcohol by volume (ABV). Alcohol concentrations this low require much larger energy input than traditional spirit distillation that starts around 8% ABV. Therefore, there is a need for a low energy cost distillation. One possible solution is to store thermal energy from the sun in molten salt by using a Fresnel lens.

Project Goals:

- Develop a prototype heat sink using lithium nitrate as a medium
- Complete a 4 L batch distillation using molten lithium nitrate as the heat source
- Heat lithium nitrate to 400 °C using a Fresnel lens
- Integrate the melting process powered by the Fresnel lens with the distillation

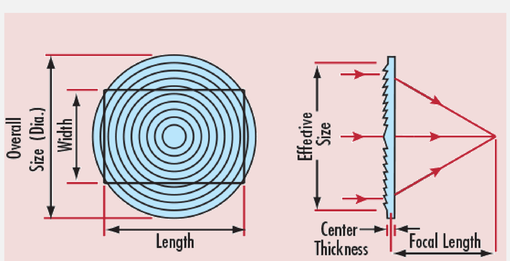
Lithium Nitrate Properties:

- Melting point- 255°C
- Latent Heat- 373 kJ/kg
- Thermal Conductivity- 0.59 W/(m·K)
- Heat Capacity- Solid: 0.93 kJ/(kg·K)
- Heat Capacity- Liquid: 1.8 kJ/(kg·K)

For a 4 L batch distillation from 8 to 23% ABV, 1.17 kWh of energy is needed. This can be obtained using 23 kg of $LiNO_3$ initially at 400 °C assuming 30% efficiency.

Fresnel Lenses:

Fresnel lenses consist of a series of concentric grooves etched into a lens (think tree rings). They can be used to concentrate solar energy for heating in solar cookers, solar forges, and solar collectors used to heat water for domestic use.



Edmund Optics, Inc "https://www.edmundoptics.com/resources/application-notes/optics/advantages-of-fresnel-lenses/"

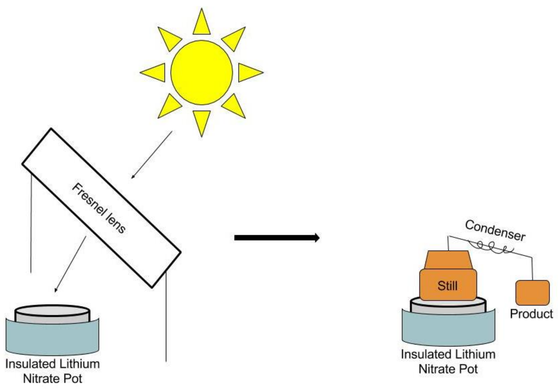


Figure 1: Process overview. A Fresnel lens melts lithium nitrate using solar energy, and that molten salt is used to power a batch distillation.

Lithium Nitrate Salt Testing:

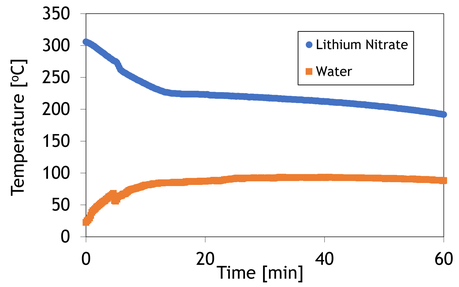


Figure 2: Heating of 25 mL of water over time using 280 g of lithium nitrate with a starting temperature of 310 °C. Experimental configuration below.

Figure 3: Experimental set-up for lithium nitrate salt testing. Lithium nitrate was placed in an insulated vessel, then water was placed on top to heat.

Lid Design:

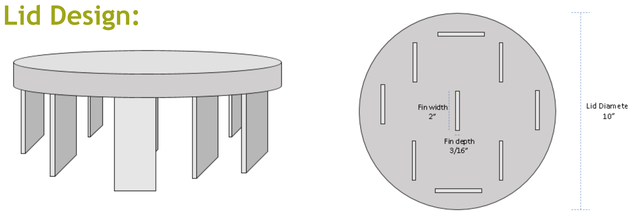


Figure 4: Lid design for the lithium nitrate container made from stainless steel due to its corrosion resistance. Fins extending into the salt increase heat transfer between the salt and the still.

General Equations:

Fresnel lens efficiency based on the sensible heat and temperature change of the aluminum block:

$$Eff = \frac{m_{block} C_p \Delta T}{I \cdot A \cdot \Delta t} \quad (1)$$

Energy Balance for lithium nitrate heating water with an assumed 30% efficiency:

$$30\% \cdot m_{salt}(\Delta H_{fusion} + C_{p,liquid}(T_f - T_{melt})) = m_{water}(C_p(T_{boil} - T_0) + \Delta H_{vap}) \quad (2)$$

Fresnel Lens Testing:

Figure 5. Experimental lens setup for heating aluminum block.

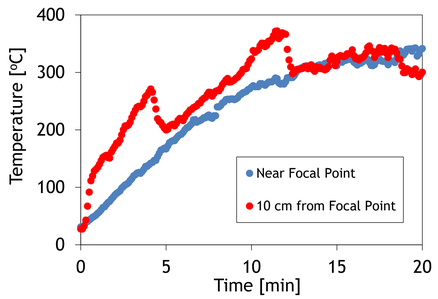


Figure 6: Temperature of a 437 g block of aluminum while being heated over 20 minutes using the Fresnel lens.

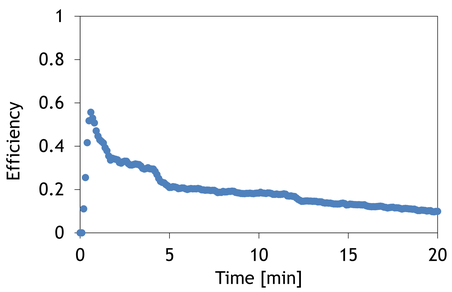


Figure 7: Efficiency of solar energy transferred to the aluminum block using the Fresnel lens. This was calculated using Equation 1. Based on the results of a single trial, the efficiency of the Fresnel lens is approximately 19% ± 9.4%.

Challenges and Future Work

Engineering Challenges:

- Storing the vessel between trials to reduce the environmental rehydration of the lithium nitrate salt
- Insulating the vessel containing lithium nitrate to reduce heat loss to the surroundings
- Molten lithium nitrate is highly corrosive and limits what materials can be used
- Higher temperatures result in greater heat loss to the surroundings and lower efficiency

Future Work:

- Run distillations with lithium nitrate
- Create barrier around the lens target to reduce convective heat transfer
- Heat water using new lid and container designs
- Melt lithium nitrate with Fresnel lens

Acknowledgments

Paul Hughes - Project Sponsor
Derrick Risner - Project Advisor
Sebastian Ramirez - Lab Technician
John Cochran - Material Supply
Andy Brickman - Material Supply
Greyson Termini - Machining Support
Darren Stehle - Machining Support
Philip Harding - Project Head

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