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# Prototype Design of a High Temperature Phase Change Material Storage System

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## Abstract

One of the promising technologies that could be implemented for energy generation that is renewable, dispatchable, and can add to system strength is concentrated solar power (CSP). However, if this technology is ever to deliver on its promise, the cost of the technology must be reduced. A potential solution to this is to operate at higher temperatures than conventional systems (>700°C) to take advantage of more efficient power blocks such as the $sCO_2$ brayton cycle. Unfortunately, traditional CSP plants are limited to temperatures around 600°C due to decomposition of the heat transfer fluid (HTF) and storage media, solar salt (60% $NaNO_3$: 40% $KNO_3$) [Bauer et al., 2013]. To overcome this, new materials and combinations are required. One such combination which has been proposed utilises liquid sodium as the HTF and high temperature phase change materials (PCMs) as the storage media. This combination combines the large temperature operating range and high thermal conductivity of sodium, with the low-cost and high energy density of the PCM. While numerical evaluation of this combination has proven promising [Liu et al., 2019], there does not currently exist a demonstratable system which transfers heat from liquid sodium at high temperatures (>600°C) to a PCM storage system. Therefore, to determine the effectiveness of such a system, a prototype system ($4kWh_t$) has been designed and constructed.

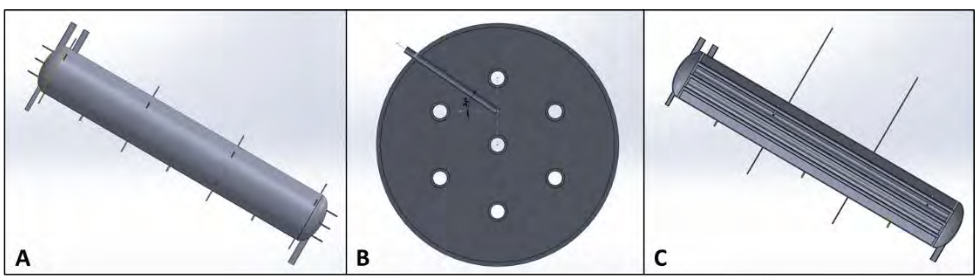


**Figure 1- Design of a High Temperature PCM Storage System for use with Liquid Sodium**

(A) Side view (B) Internal (C) Side view exposed

## PCM Storage Design

The design is intended to transfer heat from liquid sodium at 750°C to a PCM storage media (53% $K_2CO_3$: 47% $Na_2CO_3$) in a shell-and-tube design (*Figure 1*). Due to space limitations, the tank has been designed to operate at a 30° angle. Once the system is charged, heat can be retrieved by flowing liquid sodium at 650°C through the system to deliver an outlet temperature above 700°C for the duration of the test. The physical specifications of the constructed tank are given in , below.

**Table 1- PCM Storage Module Design Parameters**

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| *Shell Diameter (mm)* | 193.7 ID, 219.1 OD (DN 200, Sch 80S) | *Storage Media (wt%)* | PCM705 (53% $K_2CO_3$: 47% $Na_2CO_3$) |
| *Tank Length (mm)* | 1450 entire tank | *PCM Length (mm)* | 1200 For max length of PCM when fully melted. |
| *Tube Size (mm)* | 12.53 ID, 17.15 OD (DN10, Sch 40S) | *PCM Volume ($m^3$)* | 0.026 |
| *Number of Tubes* | 7 | *PCM Mass (kg)* | 64 |
| *Tube Spacing (mm)* | 60 | *Shell and Tube Material* | SS347H |

Using this design, the system was fabricated by Brittania Jahco and filled using a custom built system. This system was then instrumented, insulated, and an ullage tank added for testing with liquid sodium *(Figure 2)*.

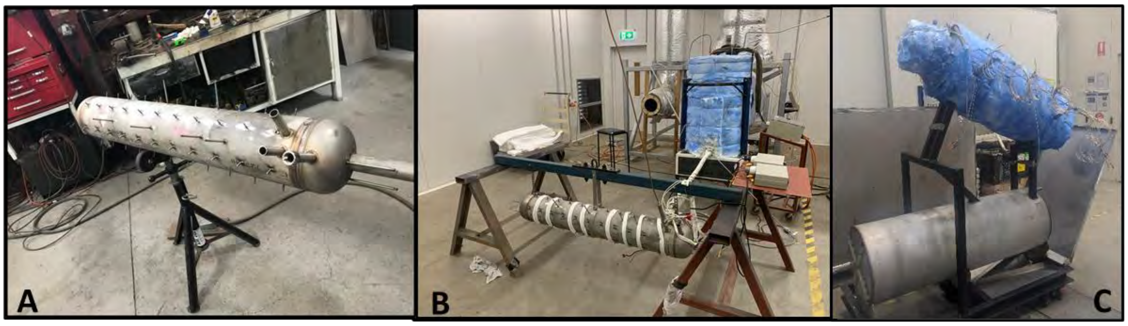


**Figure 2- PCM Storage System**

(A) Delivered PCM Storage Module (B) Filling System for Module (C) Insulated PCM Module and Ullage Tank

### PCM Storage Predicted Performance

Using validated PCM models [Liu et al., 2019], the thermal performance of the proposed system was evaluated Furthermore, a detailed thermomechanical study of the system was undertaken *(Figure 3)*.

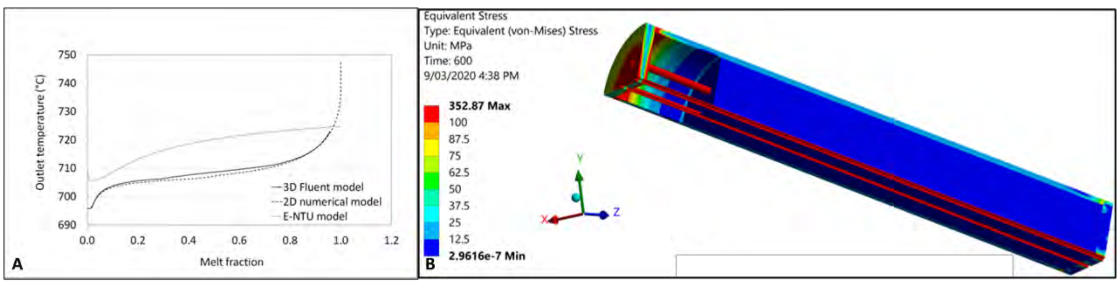


**Figure 3- Modelling Results**

(A) Comparison results of the thermal models (B) Thermally Induced Stresses during Charging

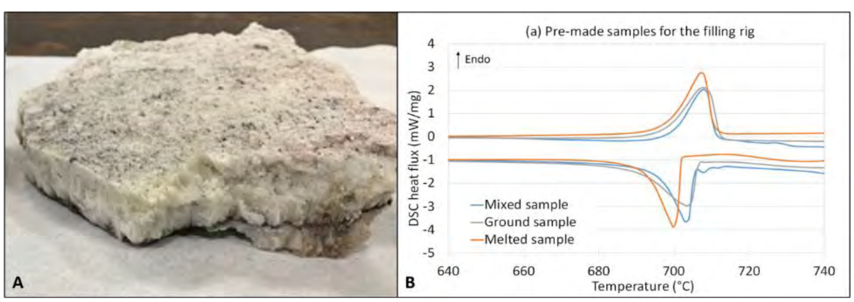


**Figure 4- Impact of the Filling System on PCM Properties**

(A) PCM sample taken from filling sump (B) Comparison of PCM properties

### As-filled PCM Storage Properties

The thermal properties of the PCM before and after filling were compared to evaluate the impact of the filling process (*Figure 4*).

### Preliminary Conclusions

A 4 $kWh_t$ prototype PCM thermal storage system has been fabricated and filled for testing with liquid sodium at up to 750°C.

Thermal modelling of the system suggests the system will be able to effectively charge and discharge while thermomechanical modelling suggests stresses at the tube-to-tubesheet connection are manageable. Lastly, comparison of the 'pure' PCM and PCM removed from the tank show minimal impact on the melting point or latent heat due to filling.

### References

Bauer T, Pfleger N, Laing D, Steinmann W-D, Eck M, Kaesche S. *High temperature molten salts for solar power application.* Chapter 20 in "Molten Salts Chemistry: From Lab to Applications", edited by Lantelme, F. and Groult, H., Elsevier, 2013. https://doi.org/10.1016/B978-0-12-398538-5.00020-2

Liu M, Riahi S, Jacob R, Belusko M, Bruno F. *Design of sensible and latent heat thermal energy storage systems for concentrated solar power plants: Thermal performance analysis*. Renewable Energy (2019); **151**: 1286-1297.