Compressed Expanded Natural Graphite (CENG) Processing for PCM Composites

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The National Renewable Energy Laboratory

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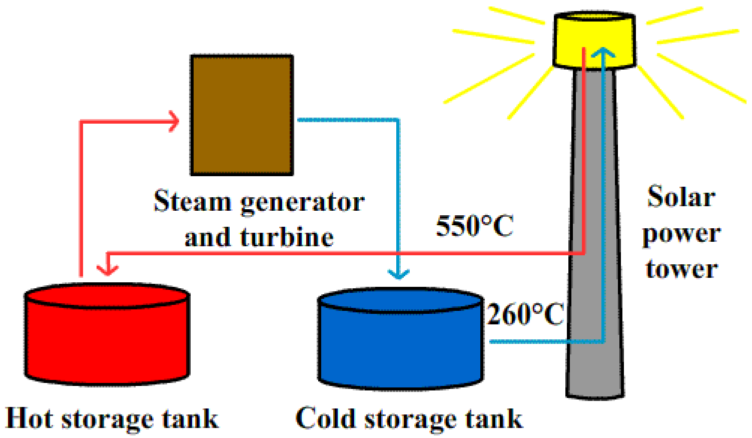
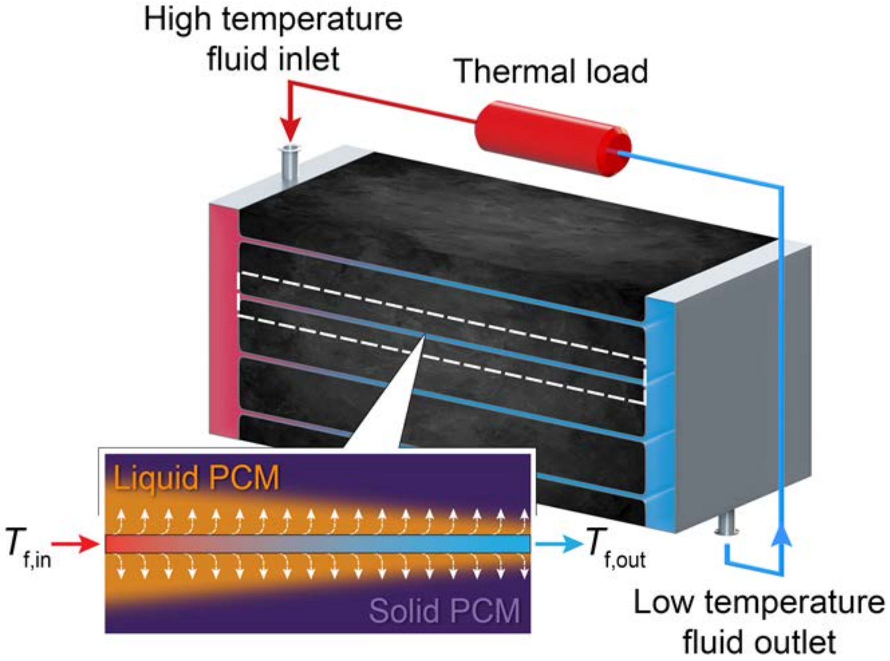
Applications for Thermal Energy Storage

Solar Energy Storage

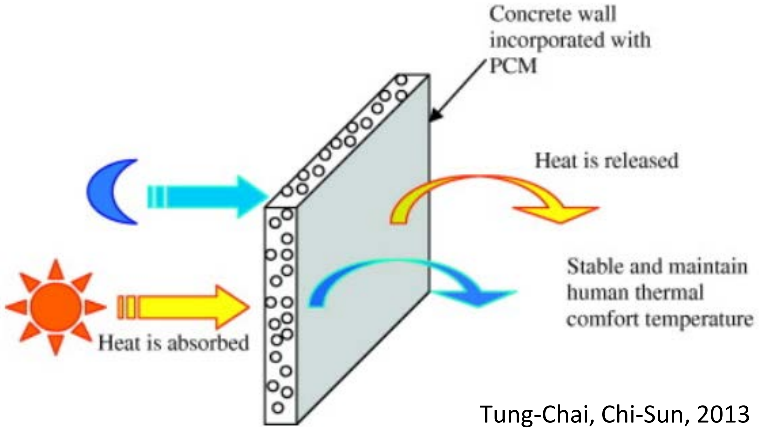


Stanford University, 2010

TES Batteries



Building Envelope Energy Storage



Tung-Chai, Chi-Sun, 2013

Compressed Expanded Natural Graphite (CENG)

Graphit

Benefits

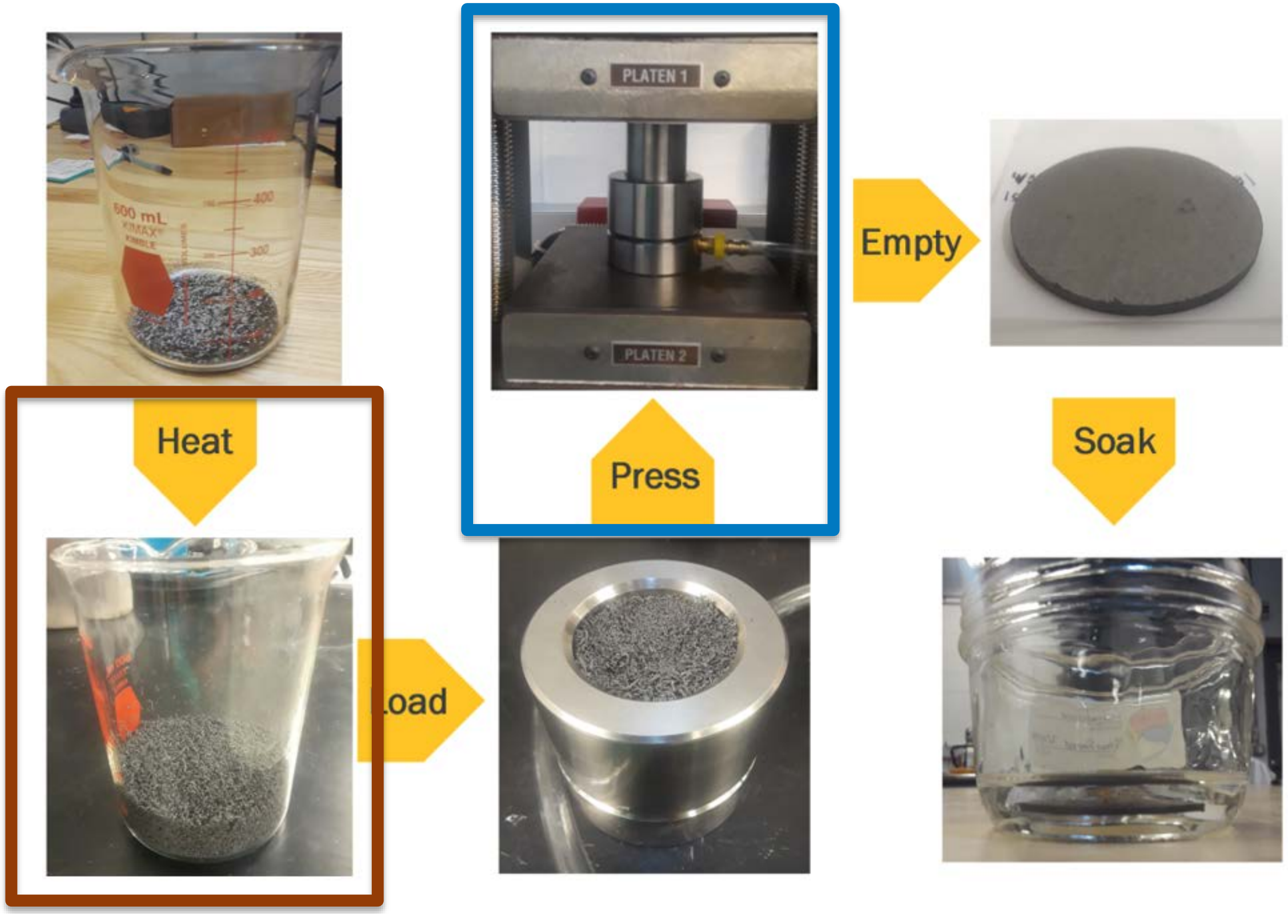
- High th
- Low co
- High p
- Low po nanom
- High p
- Ability geome

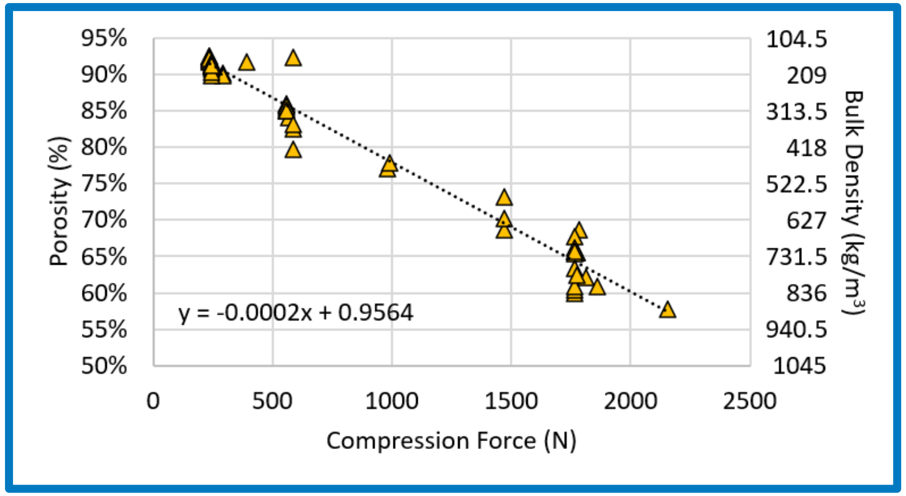
Compressed Expanded Natural Graphite

1. Graphite flakes are intercalated with acid
2. Thermal shock causes rapid expansion
3. Expanded graphite “worms” are compressed to form a CENG matrix

Mallow et al, 2018

CENG Processing:





Porosity: Well Characterized

Not Investigated:

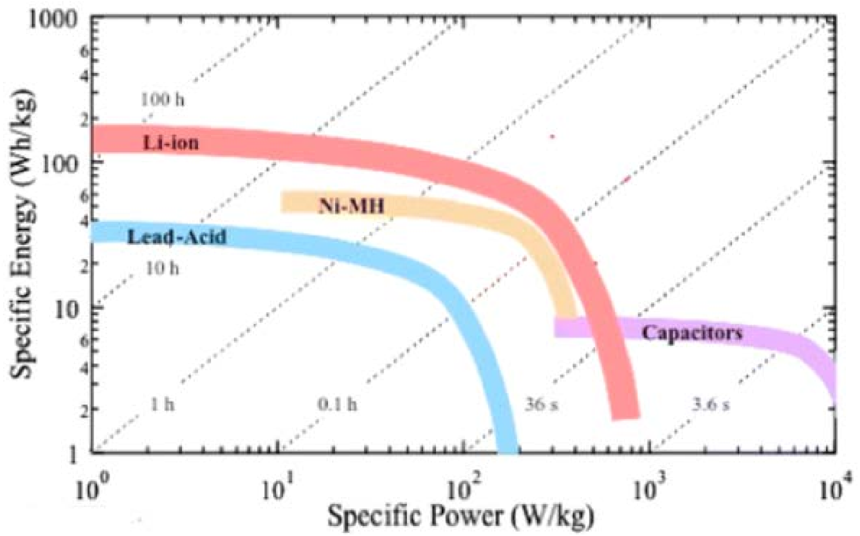
1. Thermal Shock Temperature
2. Thermal Shock Exposure Time

*We will soak in Tetradecane ($C_{14}H_{30}$)

CENG Performance Parameters

Objective: *Evaluate Effect of CENG Processing Parameters (Thermal Shock Temperature and Exposure) on CENG Performance Parameters*

Example Ragone Plot:



McCloskey, 2015

- **Energy Density:** Energy Stored per unit Volume – Improved by maximizing the **% Volume of PCM**
- **Power Density:** Rate of Energy Transfer per unit Volume – Improved by maximizing the **Thermal Conductivity**

doi: 10.1021/5b01813

Saturation Experimental Procedure

CENG Bulk Density: $$\delta = \frac{m_{CENG}}{V_{CENG}}$$

CENG Porosity: $$\varphi = 1 - \frac{\delta}{\rho_{CG}}$$

PCM Volume Fraction: $$V_f = \frac{m_{PCM}}{\rho_{PCM} \cdot V_{CENG}}$$

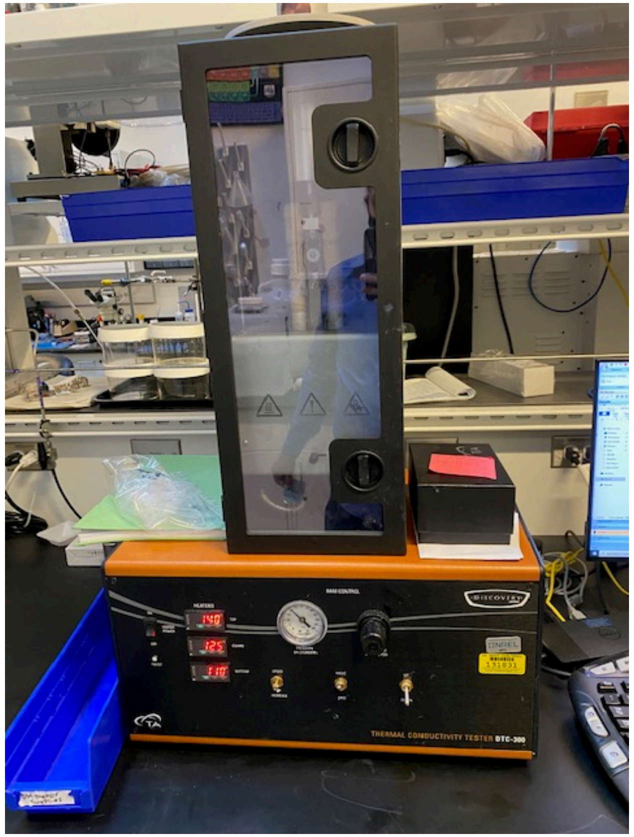
% PCM Pore Saturation: $$V_{f,PCM} = \frac{V_f}{\varphi}$$

Exposure Time (min)	Thermal shock temperatures (°C)			
	300	400	500	700
5	X	X	X	X
30	X	X	X	X
60	X	X	X	X
120	X	X	X	X

1. **Soak CENG in PCM**
2. **Remove at Time Interval**
3. **Dry and Weigh**
4. **Restart timer and soak to next interval: repeat**

*Manufacturer recommends min shock temp @ 290 C

Thermal Conductivity Experimental Procedure

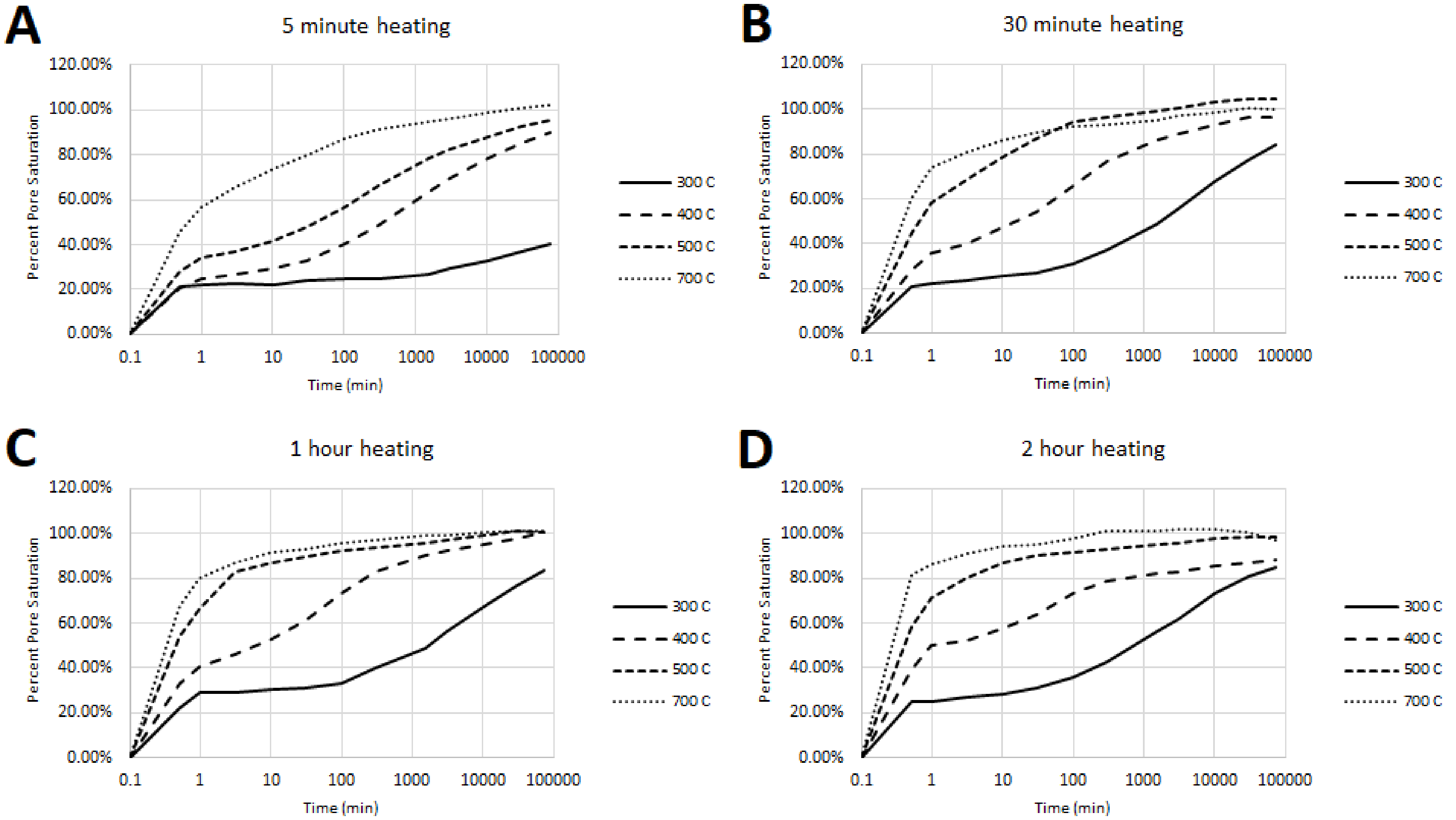


Porosity (%)	Thermal shock temperatures (°C)		
	300	500	700
65%	X	X	X
75%	X	X	X
83%	X	X	X
90%	X	X	X

1. Shock mass of CENG required to achieve desired volume and porosity
2. Compress CENG puck to required thickness based on instrument resistance range
3. Use guarded heat flow meter to measure conductivity

Thermal Shock Effect on PCM Saturation

95% Porous CENG



-Increased shock temperature and exposure yield:

- *Greater rate of saturation*
- *Greater max saturation*

-Shock exposure improves saturation, but has diminishing returns

*Cause of low shock temperature plateau starting at 30 s – 1 min is unclear

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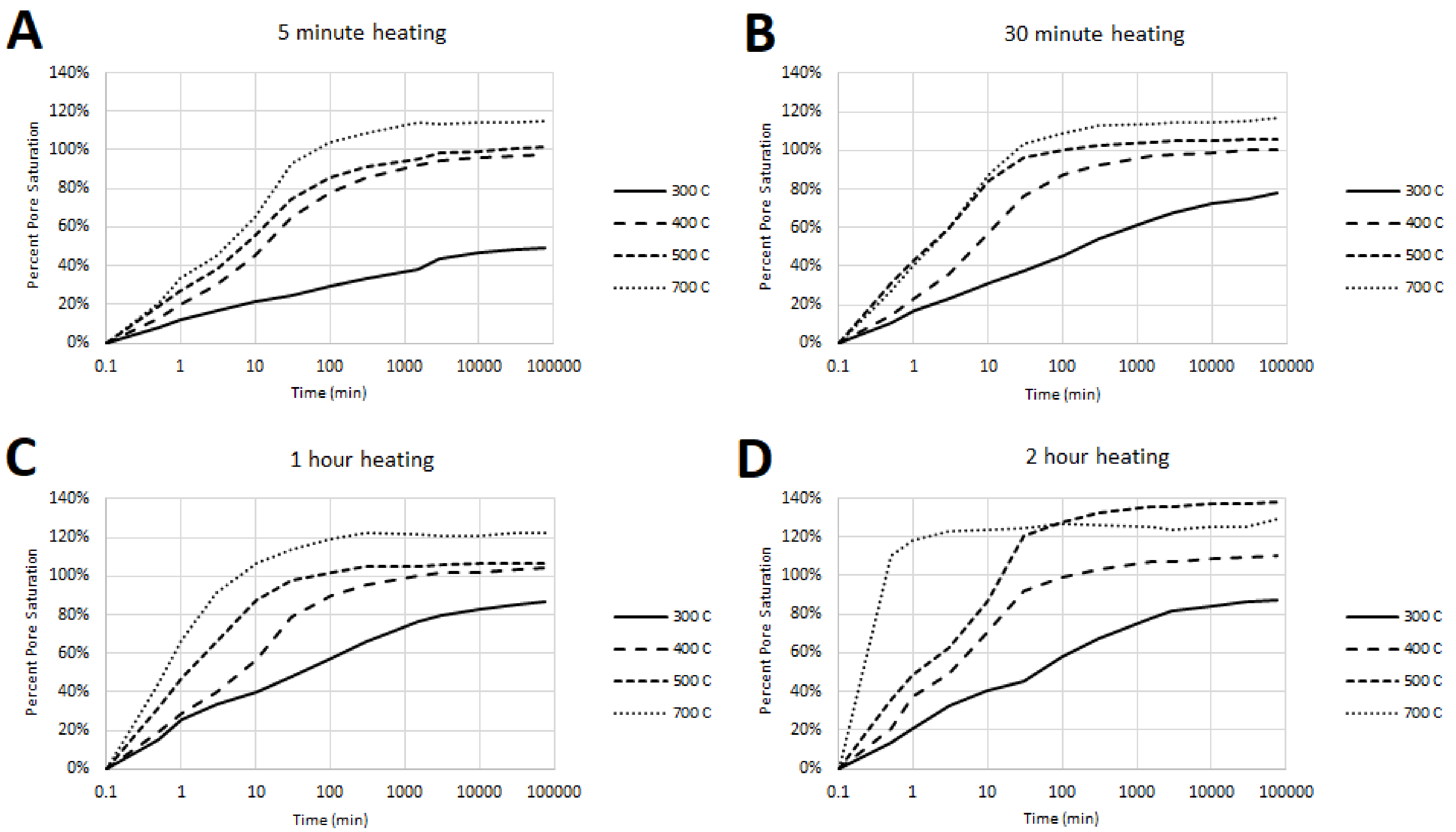
Thermal Shock Effect on PCM Saturation

65% Porous CENG



-Increased shock temperature and exposure yield:

- *Greater rate of saturation*
- *Greater max saturation*

-Shock exposure improves saturation, but has diminishing returns

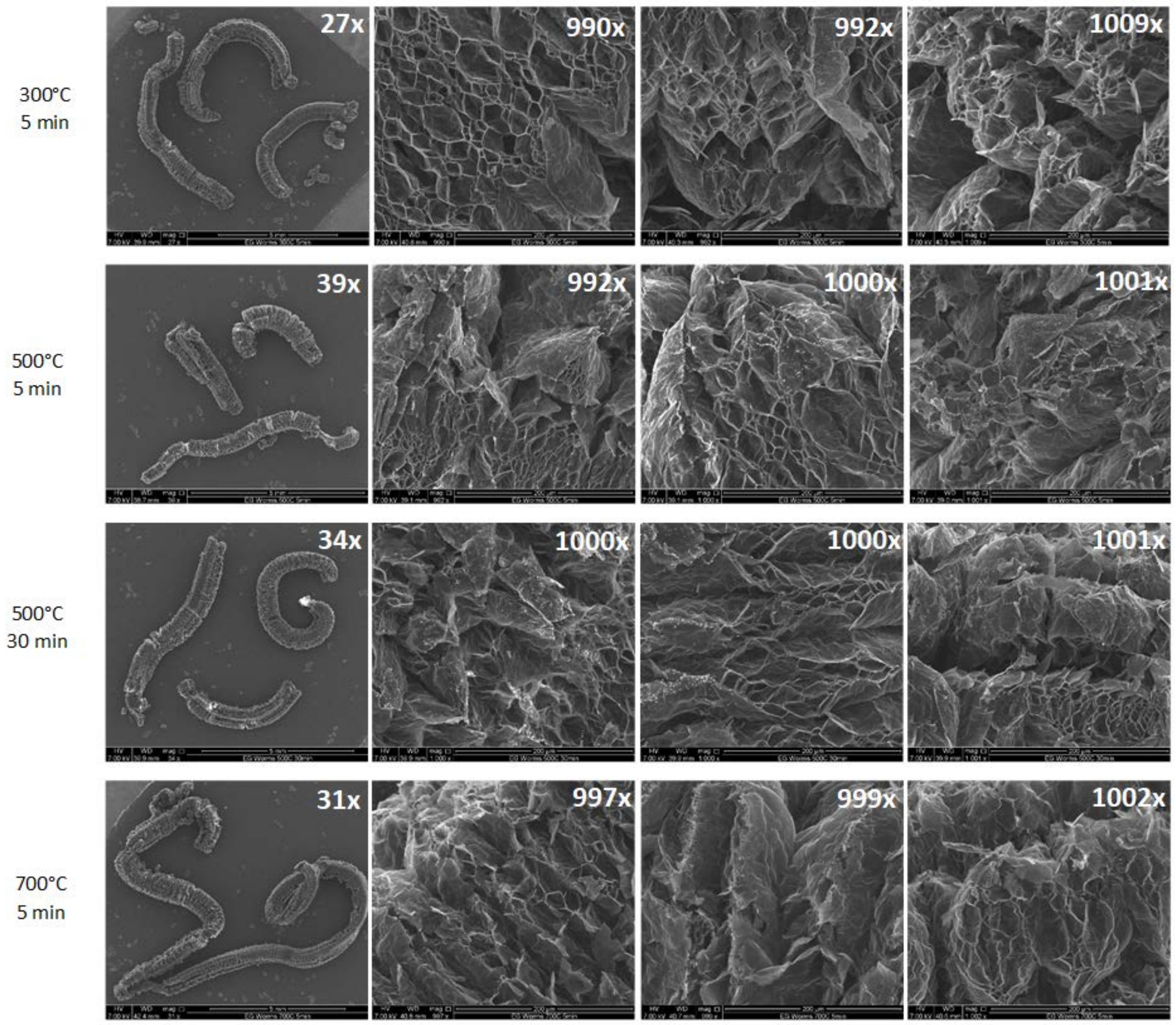
*Lower Saturation Rates at Lower Porosity

Thermal Shock Effect on Matrix Morphology

SEM Imaging of Expanded Graphite:

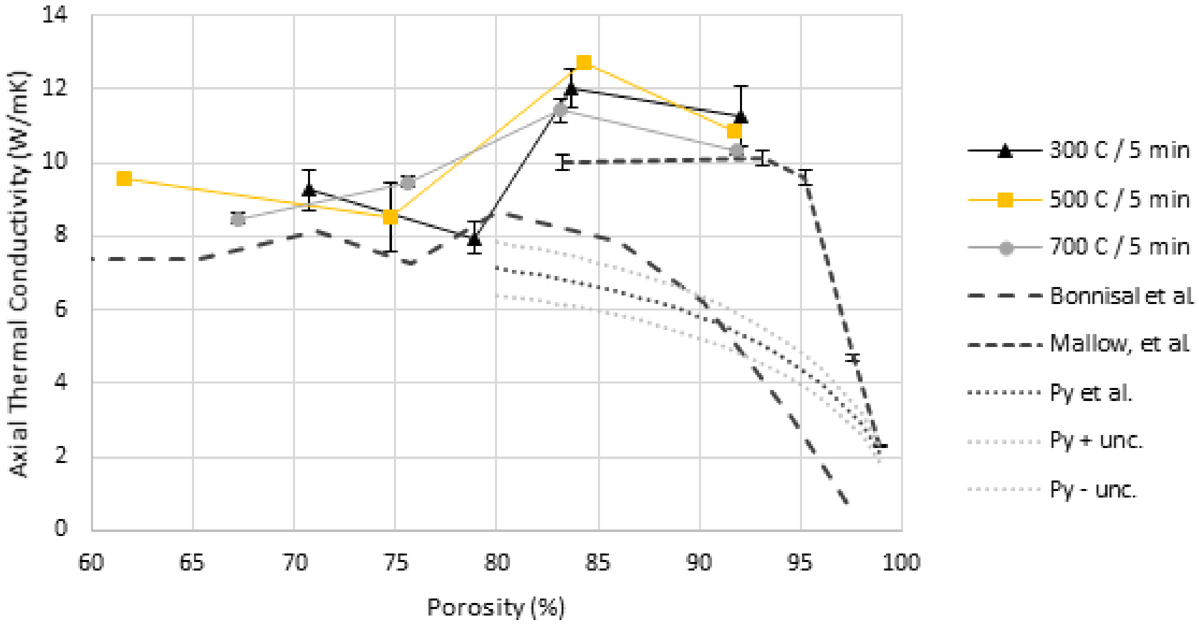
Greater Shock Temperature and Exposure Time Yield:

- *More pores per unit length*
- *Partial oxidation at 700 C associated with larger pores*
- *More accessible pores (pore walls broken)*



Effect of Thermal Shock and Porosity on Thermal Conductivity

Thermal Conductivity vs. Porosity Measured at 20 °C:



*Different Measurement Methods Between Studies

- *No significant effect of shock temperature*
- *Similar local maximum conductivity around 80- 83% porosity seen by Bonnisal et al.*
- *Higher pore density above 83% yields lowered conduction pathways*
- *Anisotropic layering under high compression at porosities below 83% increases resistance*

dois: 10.1016/S0017-9310(00)00309-4; 10.1016/S0008-6223(01)00032-X; 10.1115/IPACK2017-74244

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Summary

- Low thermal conductivity PCMs are impregnated in conductive CENG matrices to improve power density
- Past studies had only evaluated effect of CENG porosity and not thermal shock temperature or exposure time
- Greater shock temperature yields improved rate of PCM saturation and total saturation, as well as greater pore density
- Greater shock exposure improved saturation rates up to a day below 500 C
- Shock conditions did not affect conductivity but effect of porosity was consistent with literature

Thank you! Questions?

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