Dry Cooling Technologies for Enhanced Thermal Performance

Presenting Author: Sean H. Hoenig

Air Cooled Condenser Users Group Conference 2018

Acknowledgements

- This project is supported by DOE award number DE-SC-0011317
  - The program manager is Mr. Robie Lewis
- This project is supported by DOE award number DE-AR-0000582
  - The program manager is Dr. Michael Ohadi

- ACT contributors
  - Richard W. Bonner, Mohammad Reza Shaeri, Chien-Hua Chen, Fangyu Cao

U.S. DEPARTMENT OF ENERGY

arpa·e

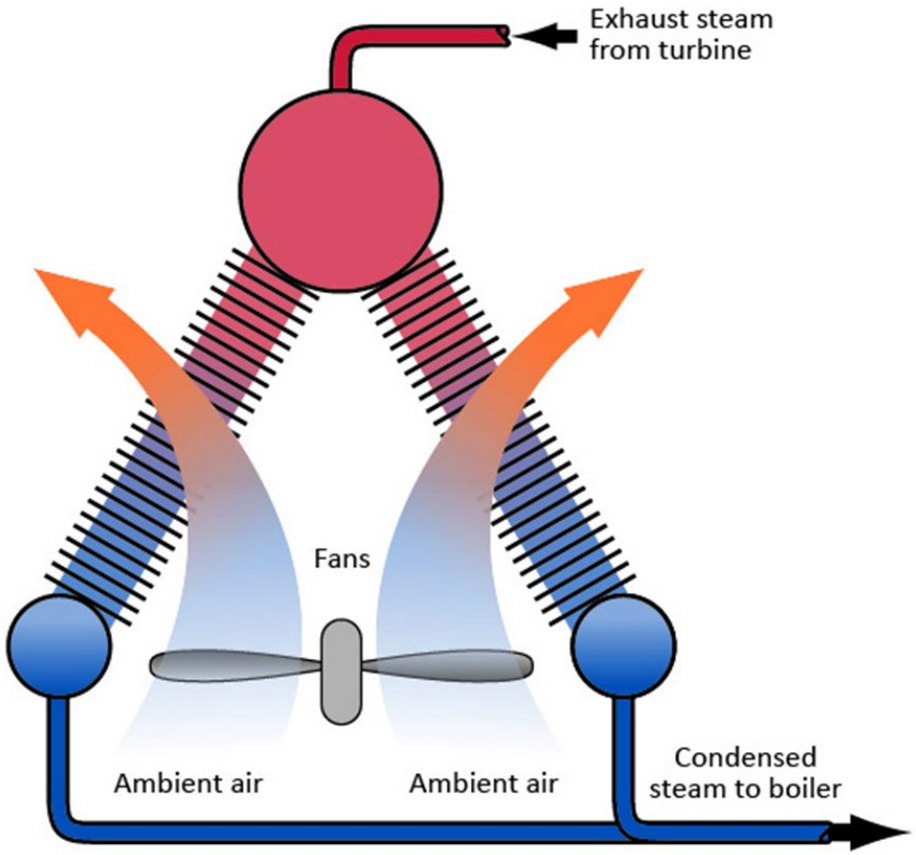
CHANGING WHAT'S POSSIBLE

R&D Motivation

- How can we shift the thermal performance of air-cooled condensers closer to that of wet cooling towers?

<u>Reasons</u>

- Poor air thermal properties
- High cost of operation during peak power demand
- Freshwater availability
- Market opportunity



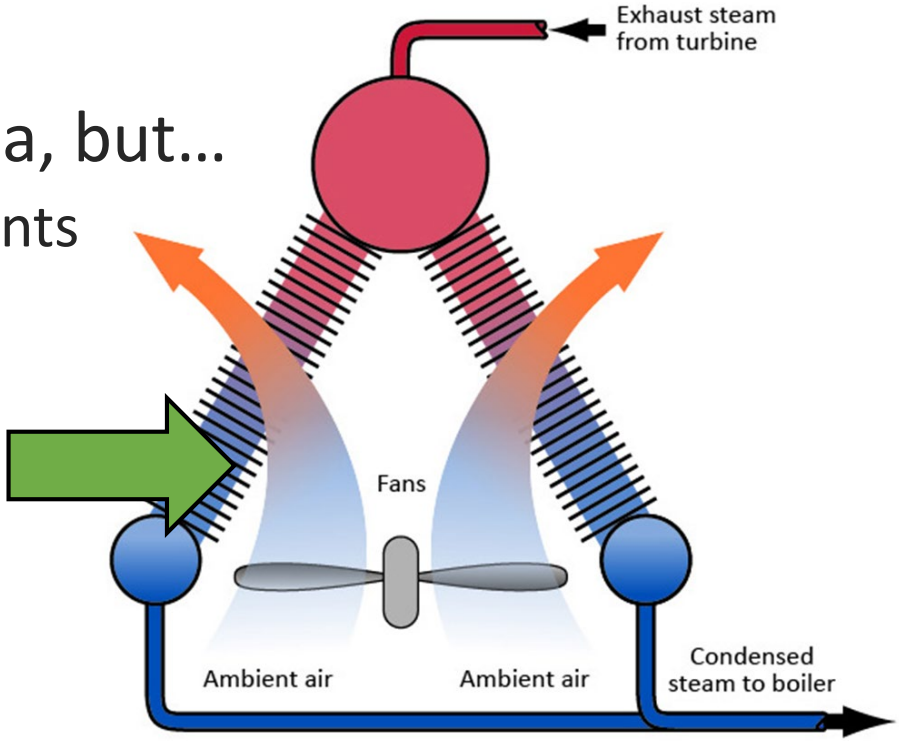
Agenda

- Reduce the thermal resistance on the…
  - Steam side – coatings to generate dropwise condensation
  - Air side – perforated-finned heat sinks

- Improve the thermodynamic cycle performance via…
  - Load shifting – supplemental thermal energy storage

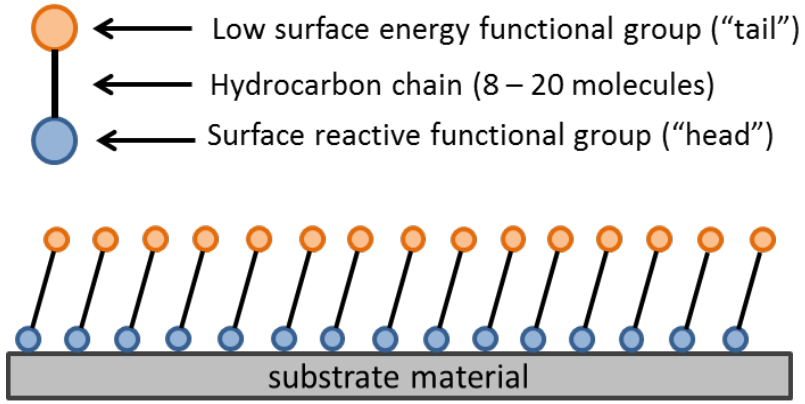
Steam Side Challenges

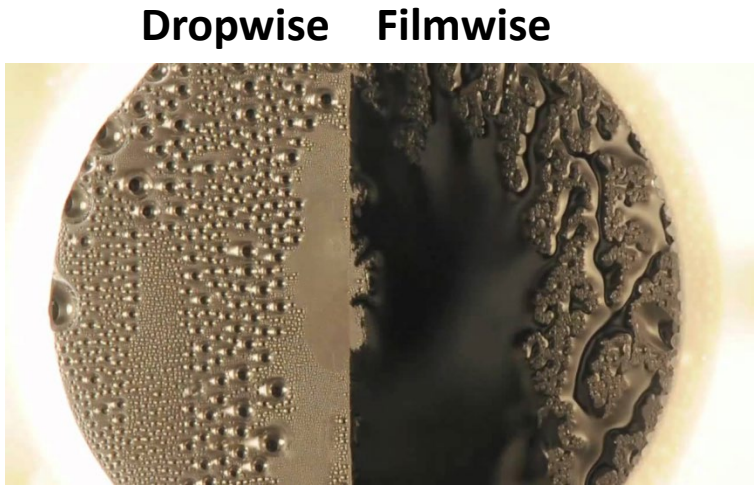
- Mainly due to condensation limitations
  - Filmwise condensation is self-limiting
  - Thicker film = higher thermal resistance
- Solution: more surface area, but…
  - Impractical area requirements
  - Higher capital cost
- Need another technique…



Dropwise Condensation (DWC)

- Use coatings to promote dropwise condensation
  - Low additional thermal resistance
  - Low surface energy of the coating generates droplets during condensation
- DWC can promote 10-20x higher steam side heat transfer coefficients than FWC

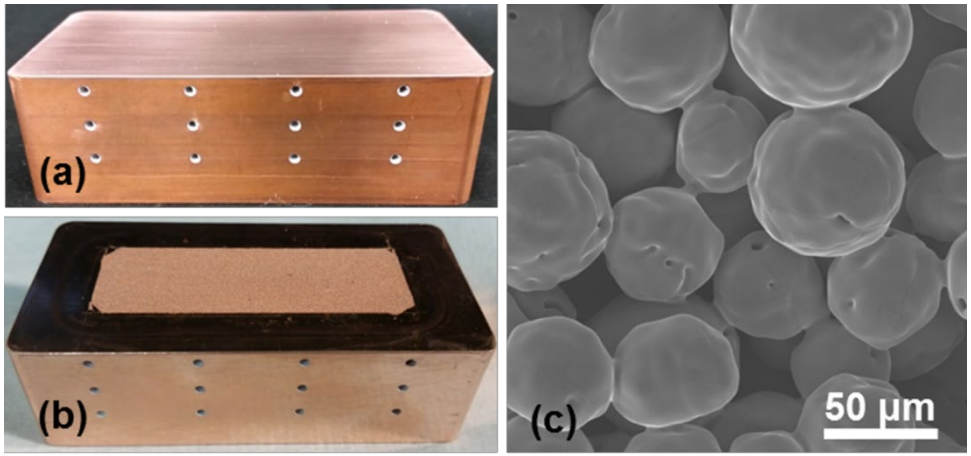


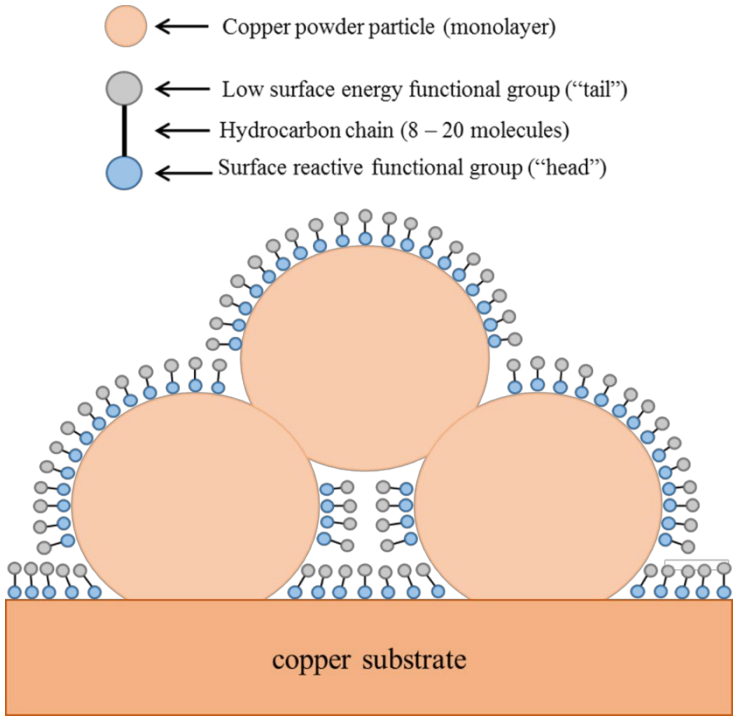


Varanasi Group image

Hydrophobic Microporous Wick

- Use microporous powder to create a microtextured surface for DWC
- Goal: remove small droplets quickly from the condenser surface
- Test substrates





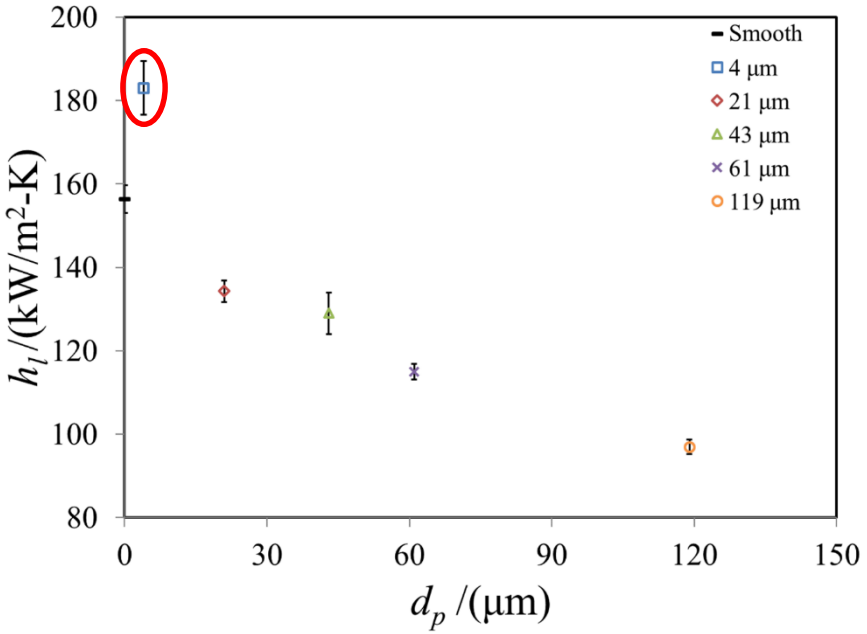
DWC Visualization

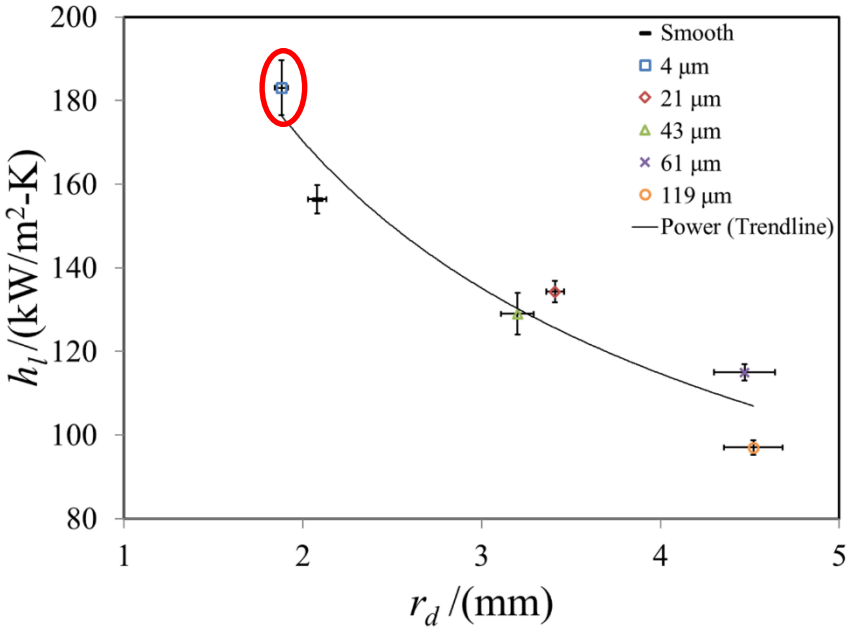
- Microporous surfaces that mimic a smooth surface have better thermal performance
- Small departing droplets can form on small diameter powder
- Large departing droplets form on large diameter powder

Video link to DWC

DWC Results

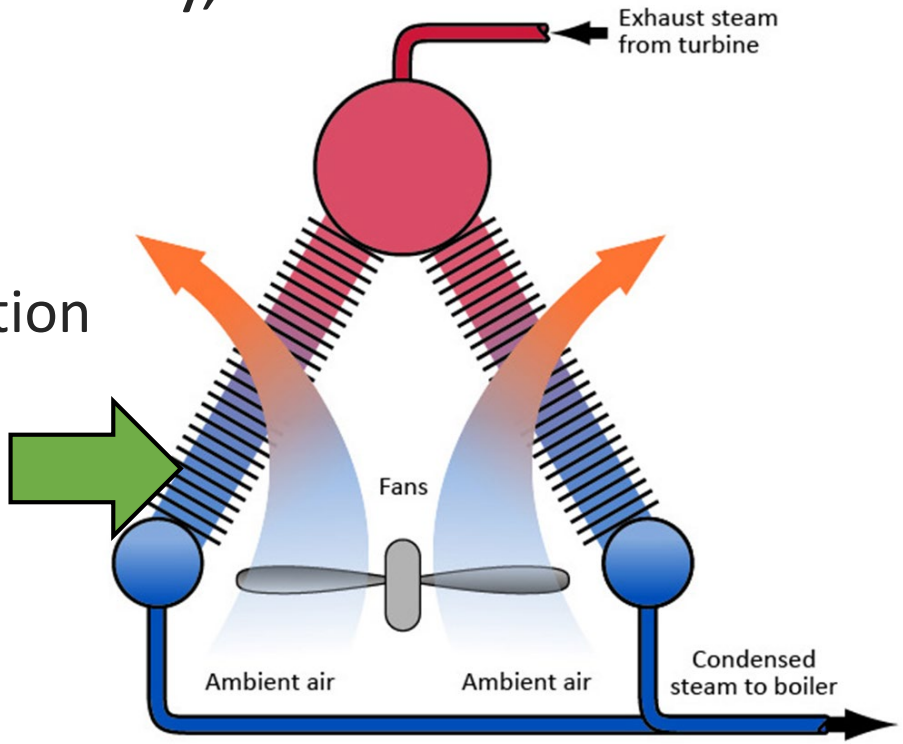
- 23% improvement compared to traditional DWC
- 1800% improvement compared to filmwise
- Need to establish long-life for continuous use
  - What else?





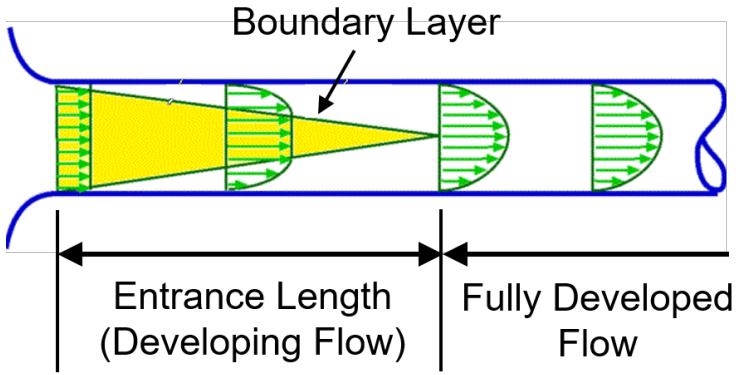
Air Side Challenges

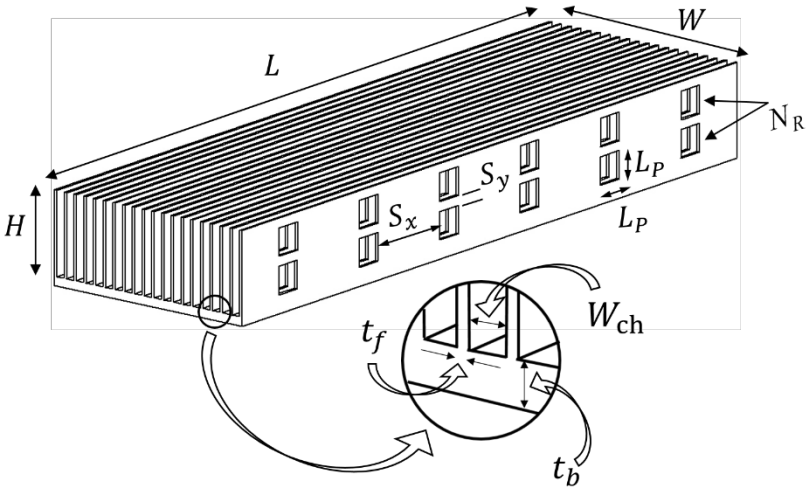
- Mainly due to poor air thermal properties
  - Dominant thermal resistance
- Solution: increase the air velocity, but…
  - Requires a larger fan
  - Larger pressure drop
  - More pumping power
  - Increase in noise and vibration
  - More space is required
- Need another technique…



Perforated-Finned Heat Sinks (PFHS)

- Thermo-fluid characteristics of air-cooled systems are dictated by the boundary layer thickness
  - "blanket of insulation"
- Interrupting the BL enhances thermal performance
- In PFHS, the BL terminates and reforms over perforations
- PFHS leads to light-weight systems and less material

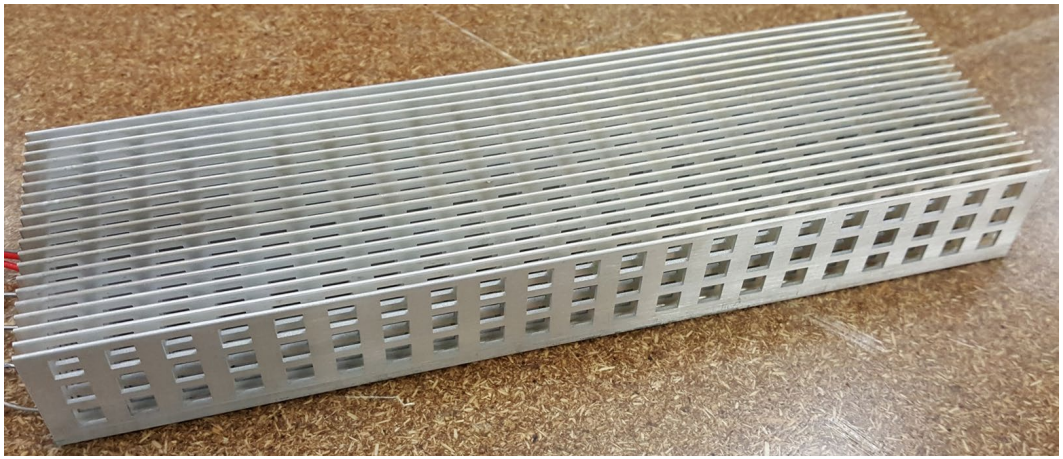




PFHS Optimization

- Applications that require colder & lighter heat sinks

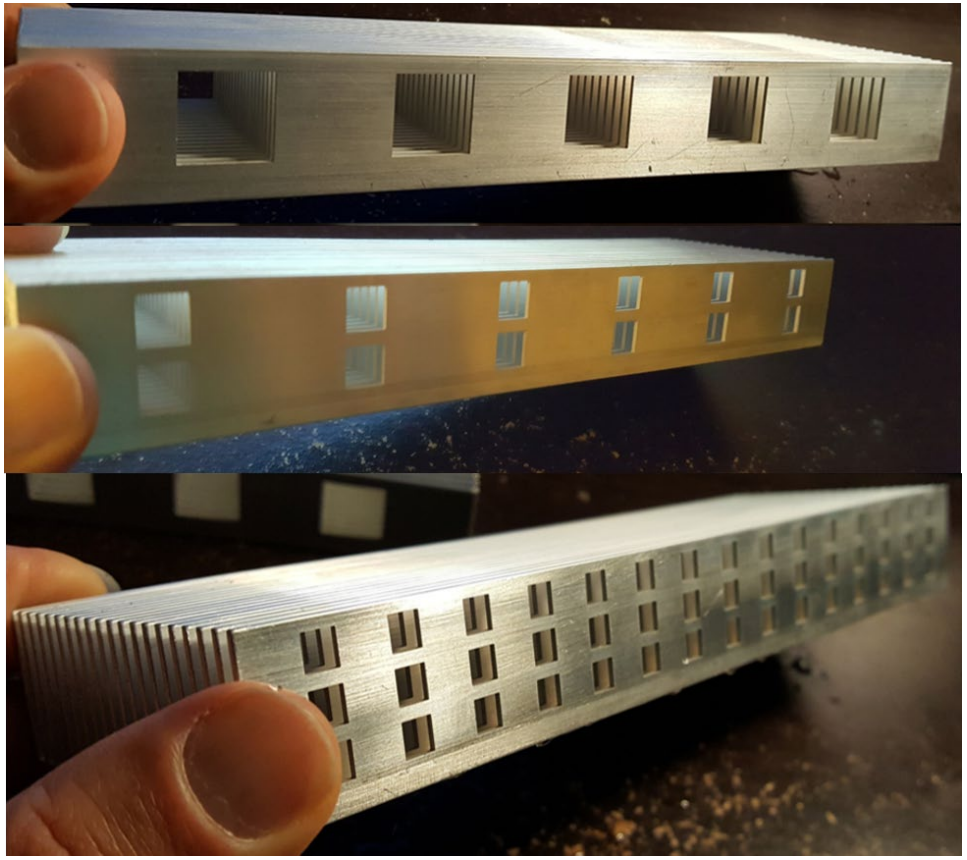
- Designing an efficient heat sink requires compromise between…
  - Thermal resistance
  - Pumping power
  - Volume



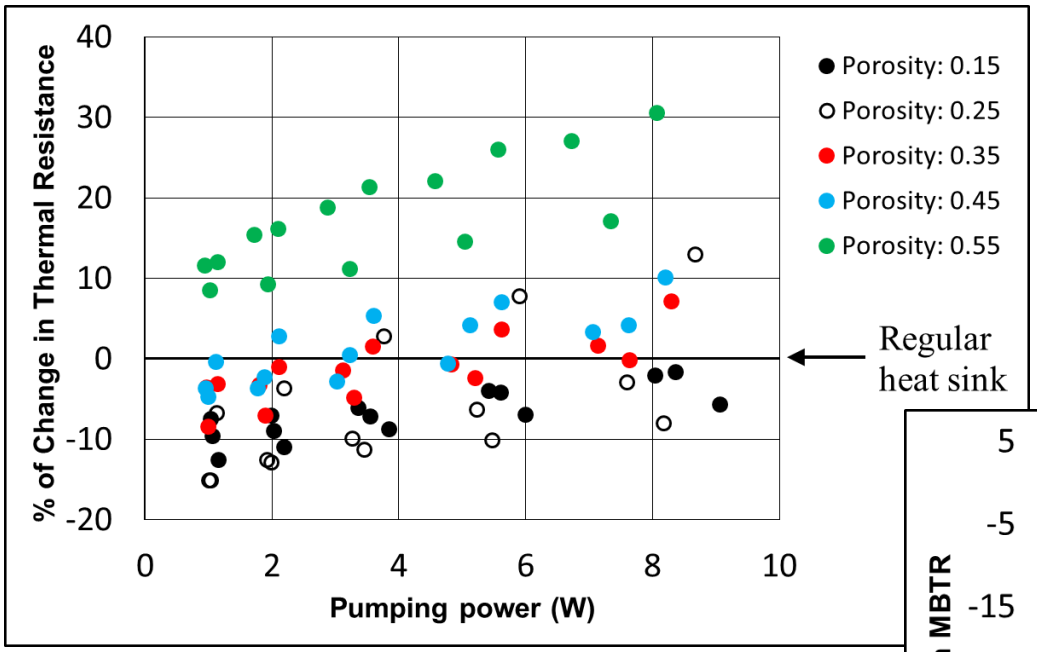
PFHS Images

- Fabricated differently sized perforations and porosities to determine optimal characteristics

Similar to current ACC fins

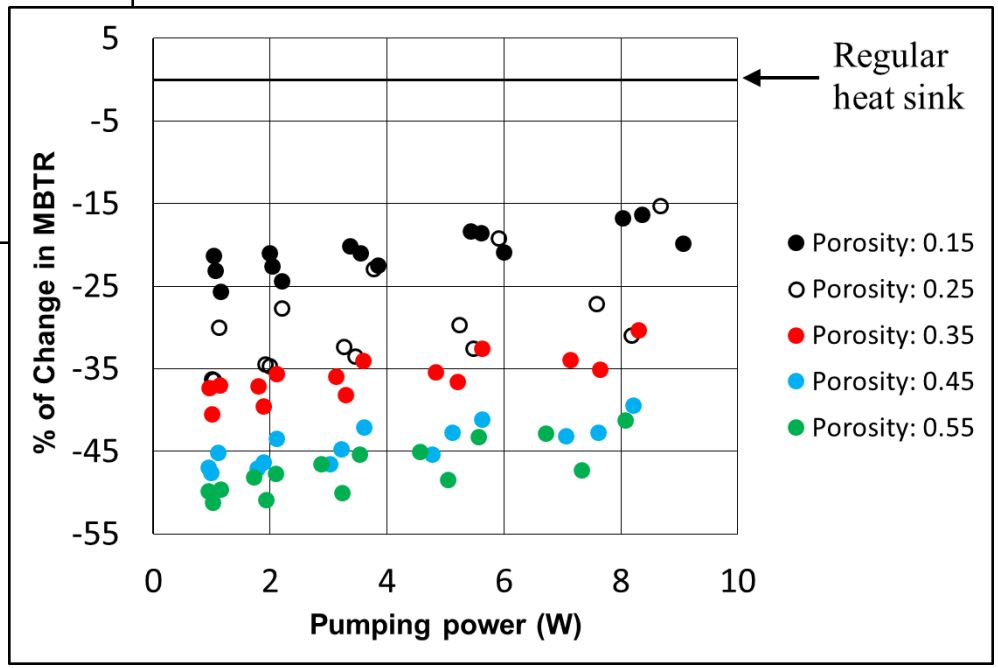


Fin Enhancement Results



For the same pumping power, there is up to a **15%** improvement in thermal resistance

For the same pumping power, there is up to a **50%** improvement in mass-based thermal resistance



Load Shifting Challenges

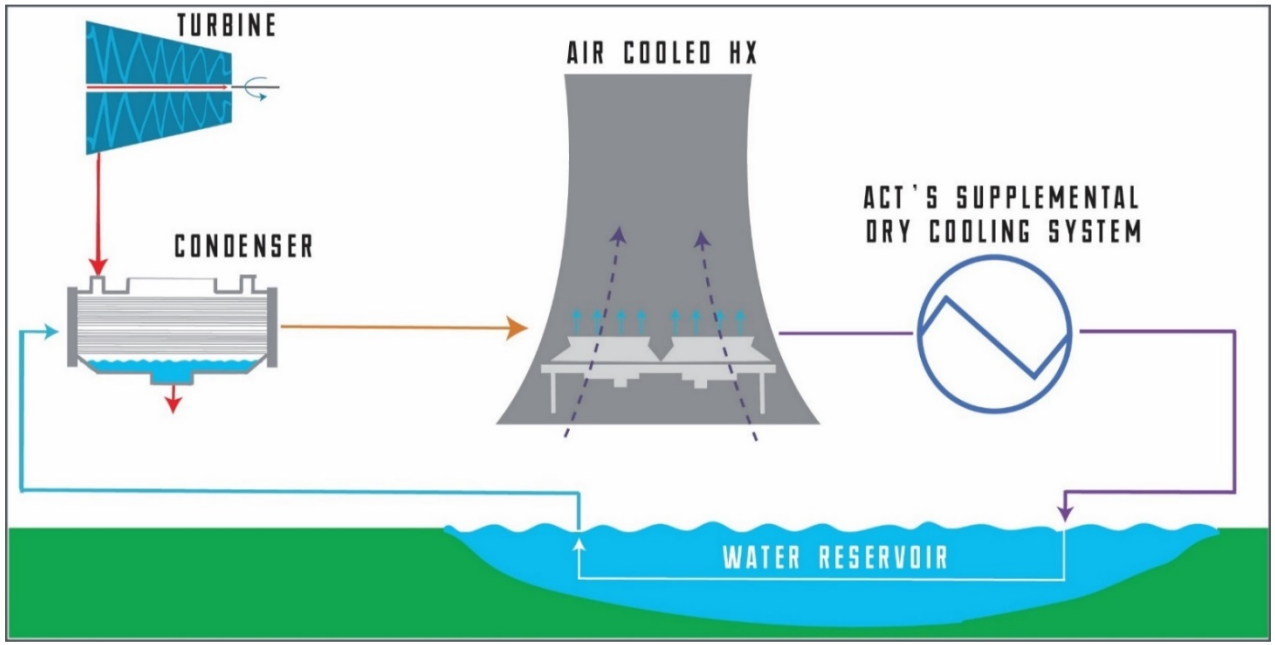
- Poor air-side heat transfer during peak power demand
  - High thermal resistance due to high ambient temperatures
  - Limits the cooling capacity and total power generation
- Need to reduce freshwater dependency by improving the system level performance of ACCs

- Need a new technique…

Thermal storage video link

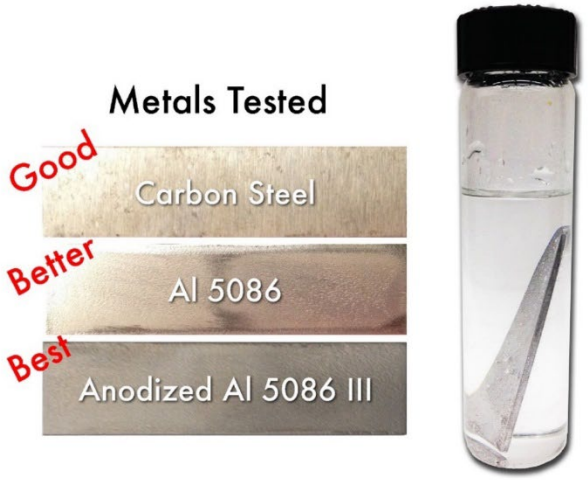
Thermal Energy Storage (TES)

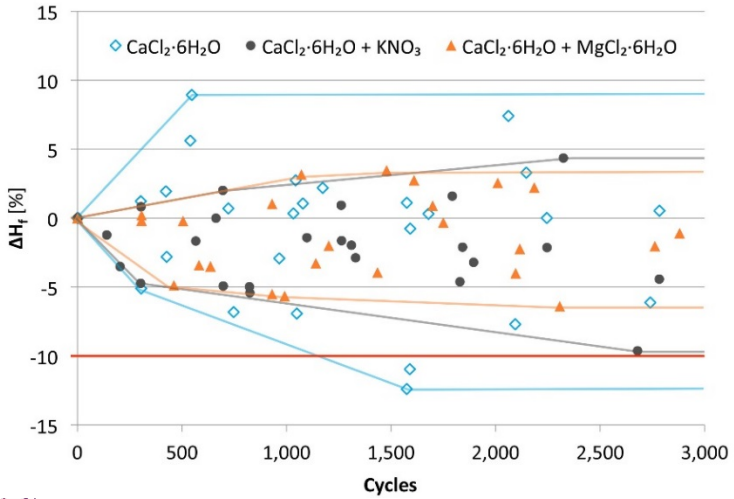
- Supplemental TES system dissipates waste heat with no net water consumption
- Reduces dependency on water cooling for electricity generation
- Uses low-cost salt hydrate phase change materials (PCM)

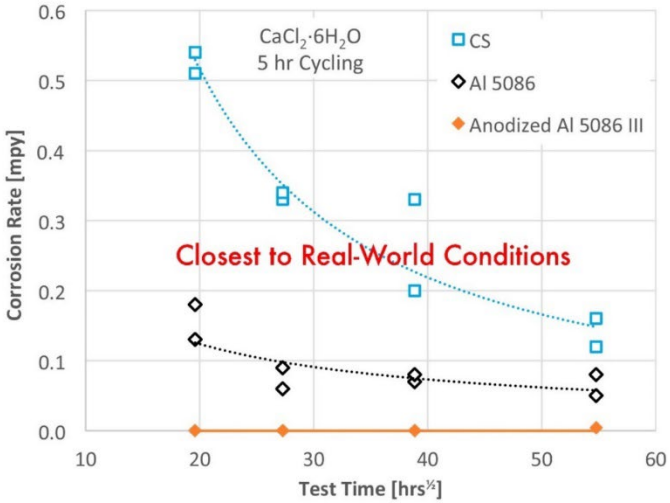


Salt Hydrate PCM & Properties

- 25x cheaper than paraffin waxes
- Validated the PCM's…
  - Latent heat capacity
  - Corrosion rate on different metals
- Data is validated for long-term use via thermal cycling

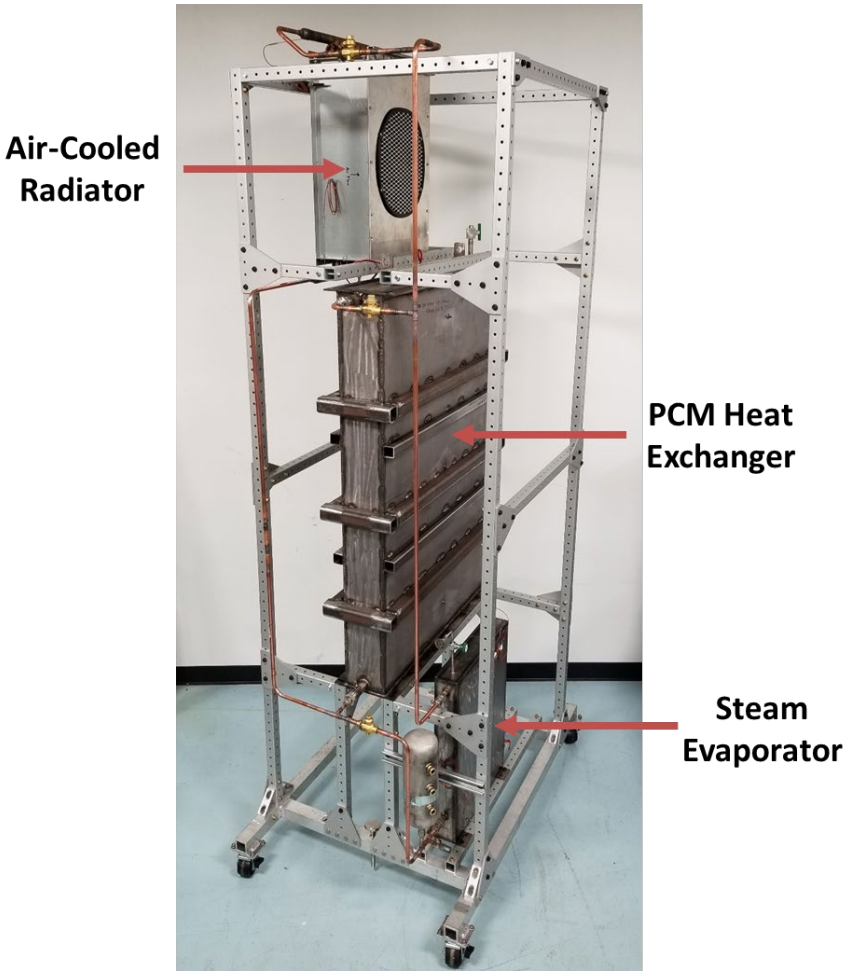




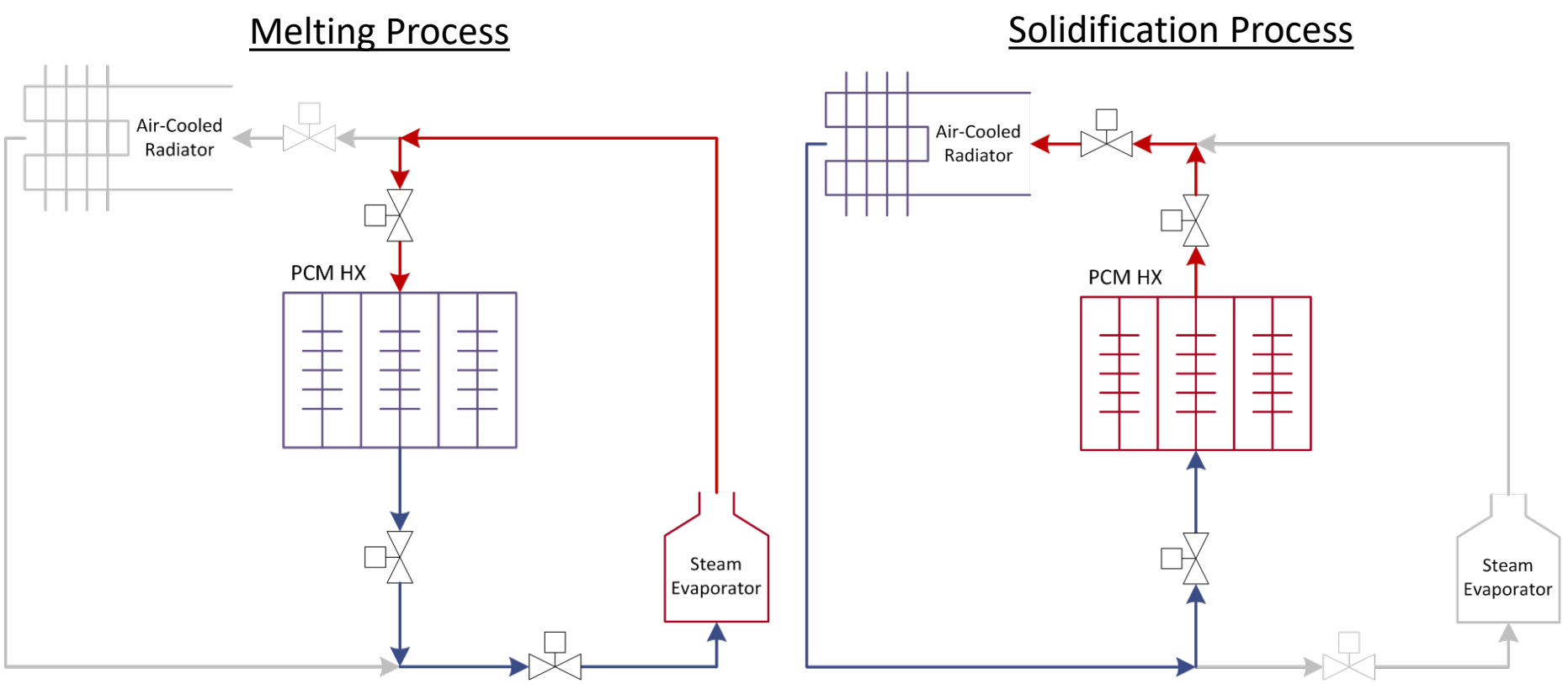


10kWh Prototype

- Uses passive, high thermal performance loop thermosyphons to transfer heat in and out
- Simulates ACC conditions to determine system thermal performance
- Cycle the PCM between liquid and solid phase for continuous testing

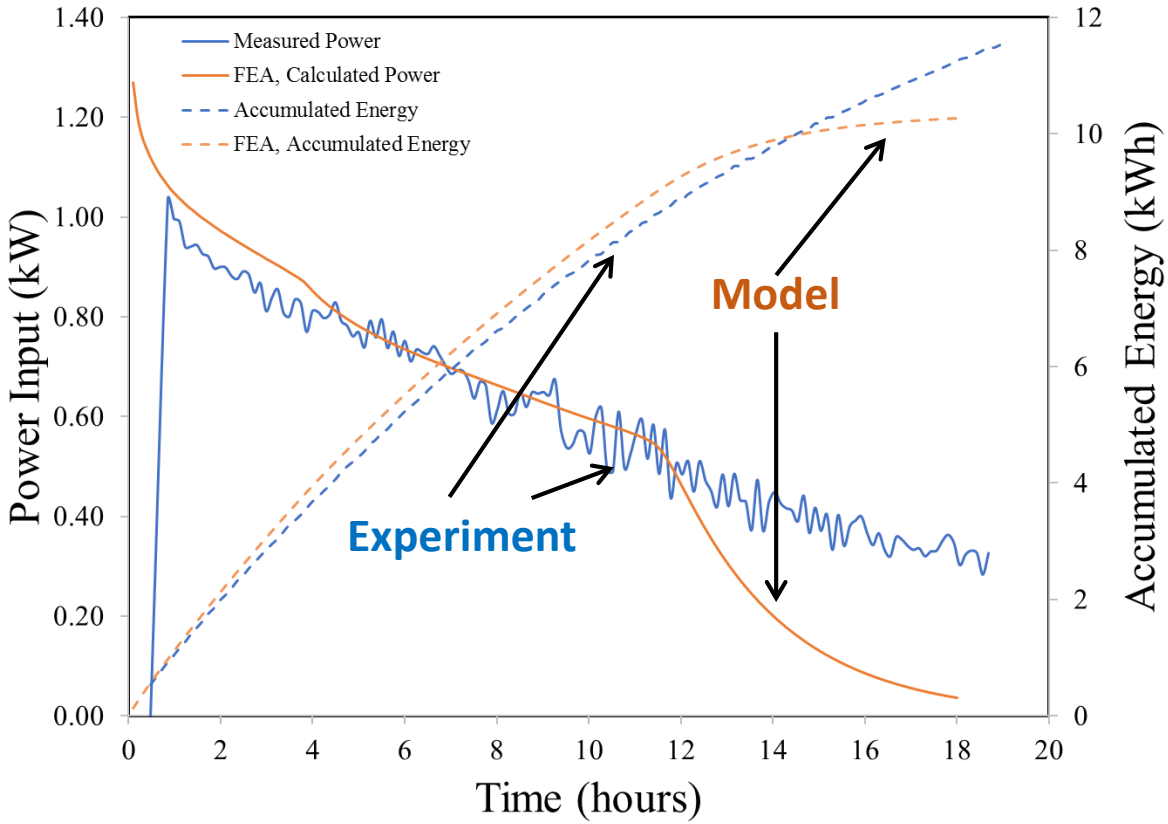


Process Operation



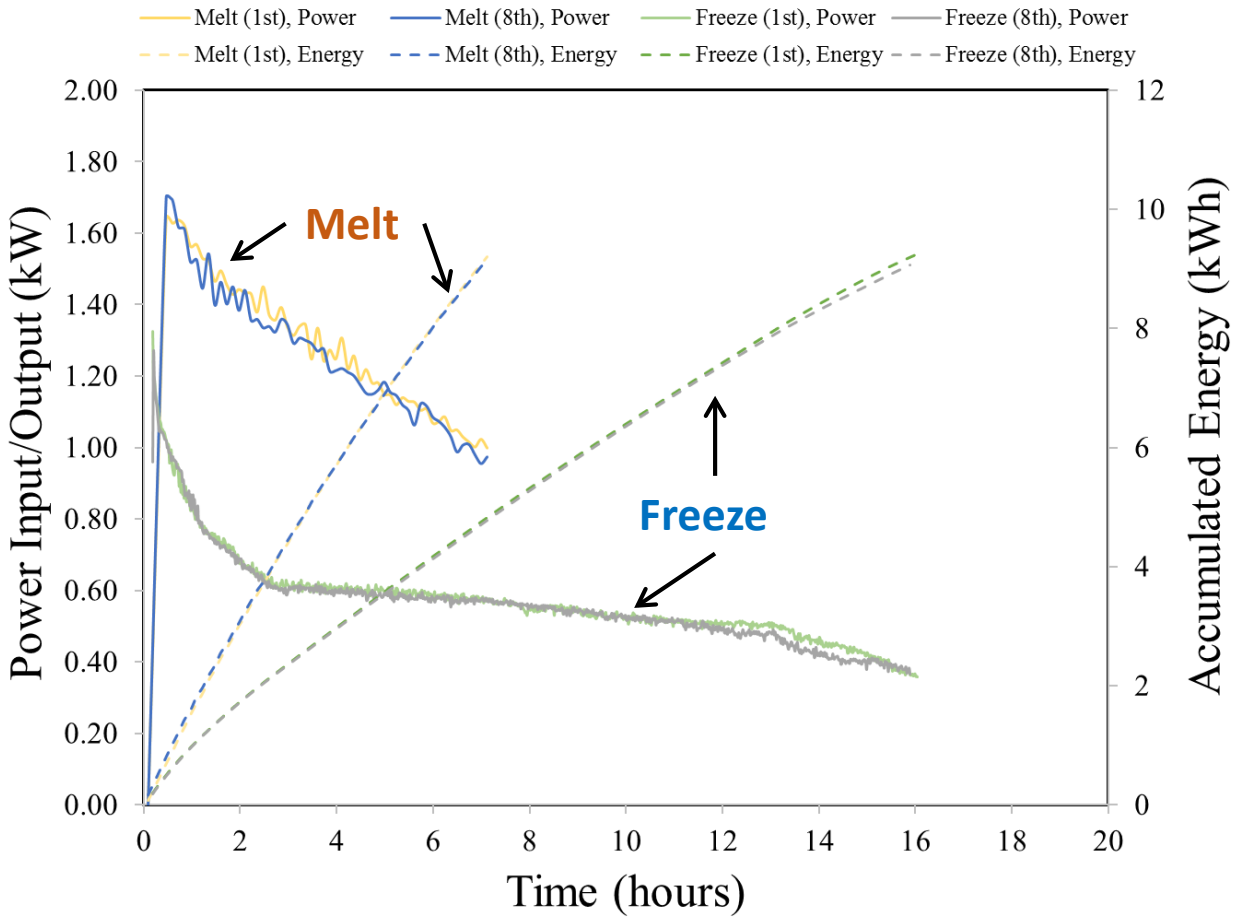
Thermal Performance Results

- Experimental results match modeling results within 10% for thermal performance



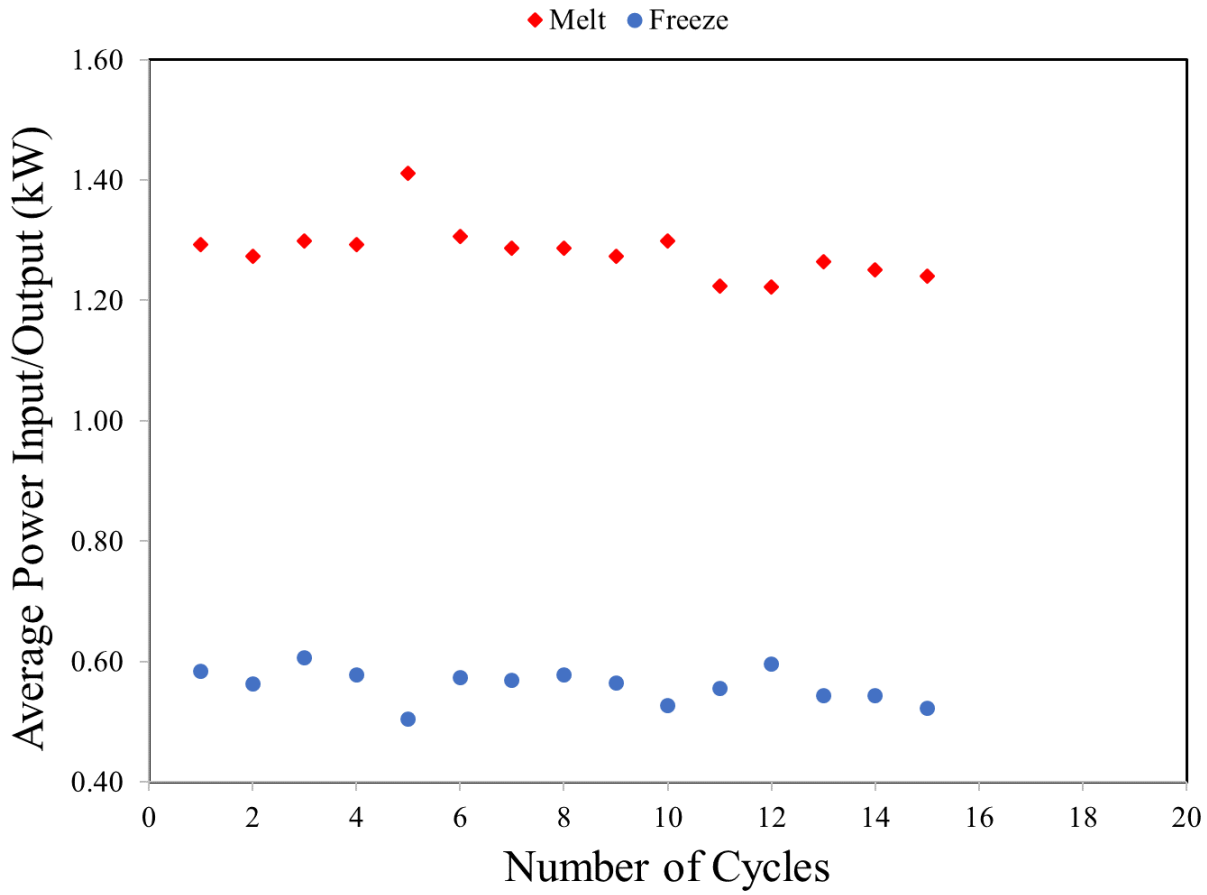
Thermal Performance Results

- Cycling results have performed consistently



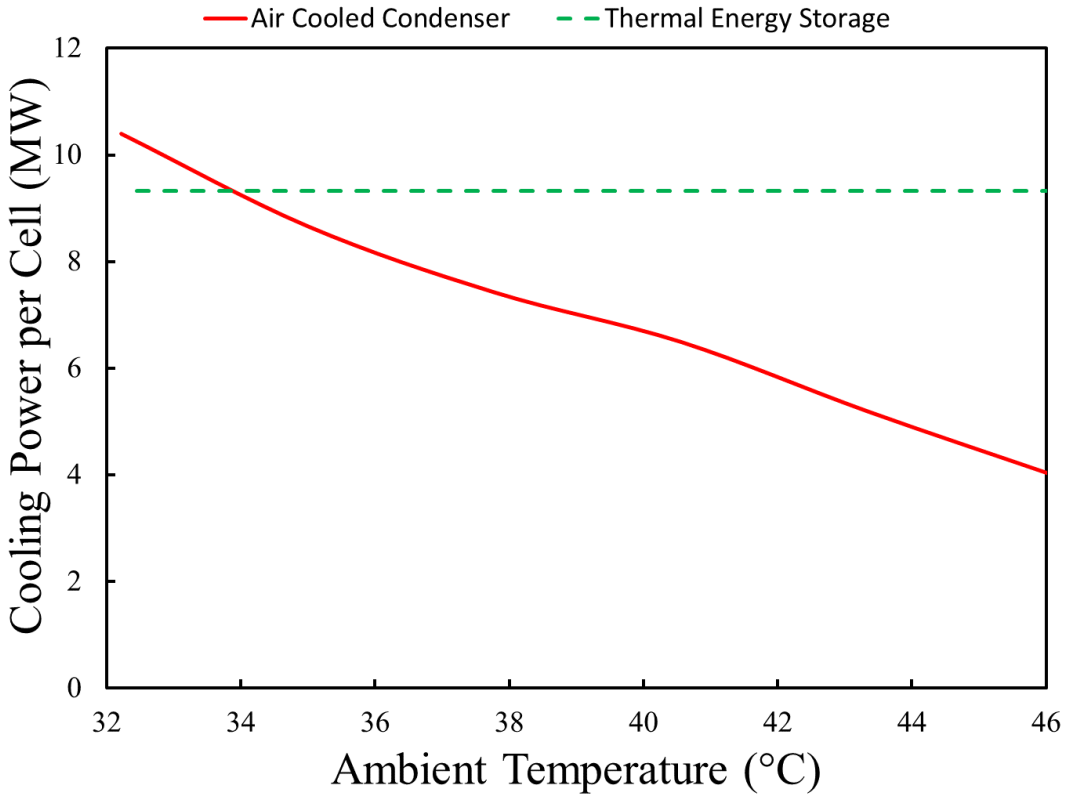
Thermal Cycling Life Test

- Average power has been maintained for many cycles



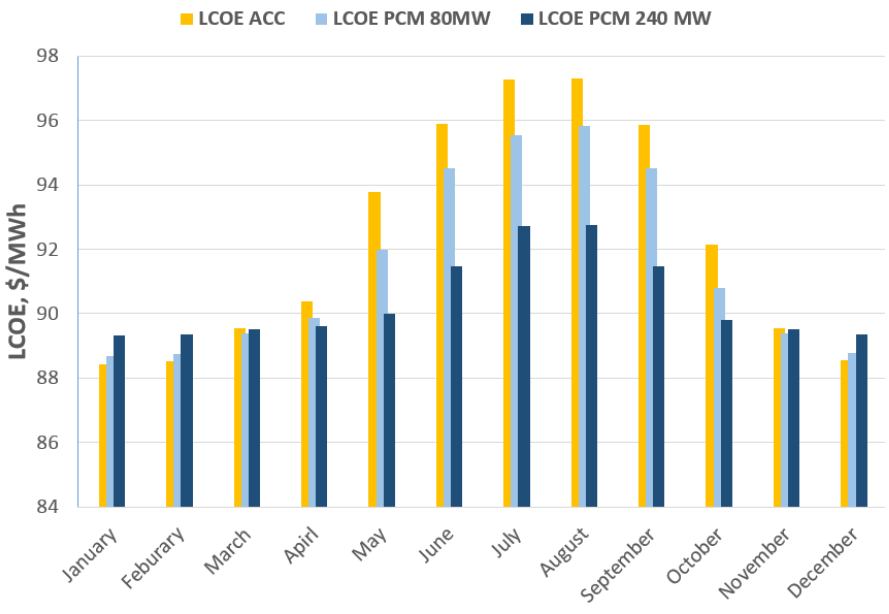
ACC vs. Thermal Storage

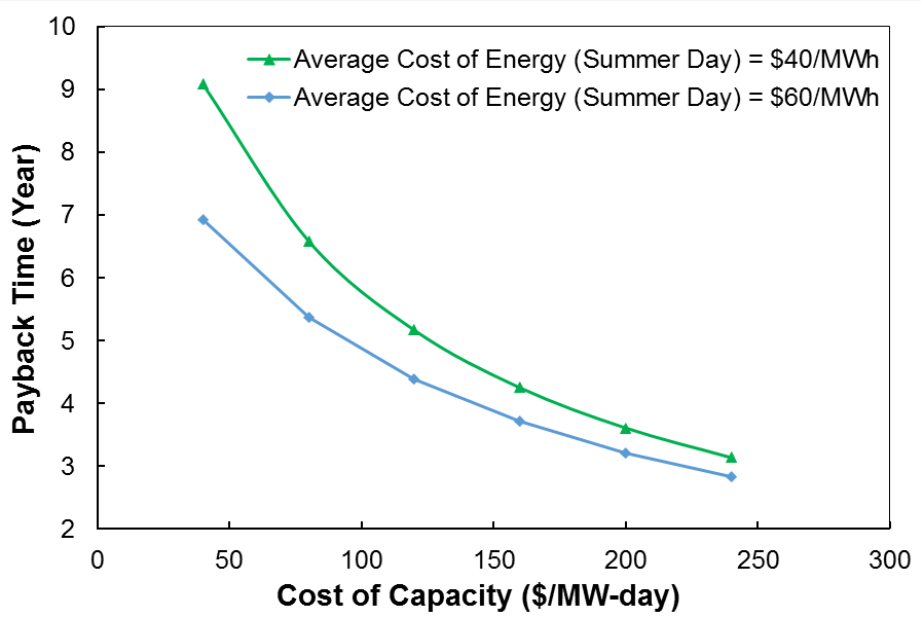
- ACC cooling power decreases with increase in ambient temperature
- The cooling power of thermal storage is independent from ambient temperature fluctuations (constant heat sink temperature)



Cost Analysis

- Additional electricity generation & fan power reduction decreases LCOE for ACC systems
- Payback time is ~4 years
  - Supplement peak demand during extremely hot days





Conclusions

- Steam side
  - Performance benefits over filmwise condensation warrant additional research
  - Need long-life coatings on industrial steel surface condensers
- Air side
  - PFHSs provide between 15-50% thermal resistance reduction compared to traditional flat plate fins at the same pumping power
  - This benefit correlates to capital & operational cost savings
- Load shifting
  - Low-cost salt hydrate PCM is a viable TES medium for ACCs
  - Supplemental thermal storage would boost electricity generation without a large capital investment

ADVANCED COOLING TECHNOLOGIES

The Thermal Management Experts | www.1-ACT.com

Thank you for your time.

1046 NEW HOLLAND AVENUE, LANCASTER, PENNSYLVANIA 17601, USA
PHONE: (717) 295-6061
EMAIL: INFO@1-ACT.COM VISIT: WWW.1-ACT.COM