Light-weight, single-phase, liquid-cooled cold plate

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05/15/2012

2012 Vehicle Technologies Program (VTP)
Annual Merit Review (AMR)
Washington, DC

NREL/PR-5400-54423

APE039

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Overview

Timeline

Project Start Date: FY11

Project End Date: FY12

Percent Complete: 65%

Budget

Total Project Funding: $1.1M

DOE Share: $1.1M

Funding Received in FY11: $700K

Funding for FY12: $400K

Barriers

- Cost
- Weight
- Performance

Targets Addressed

- Cost
- Specific power
- Power density

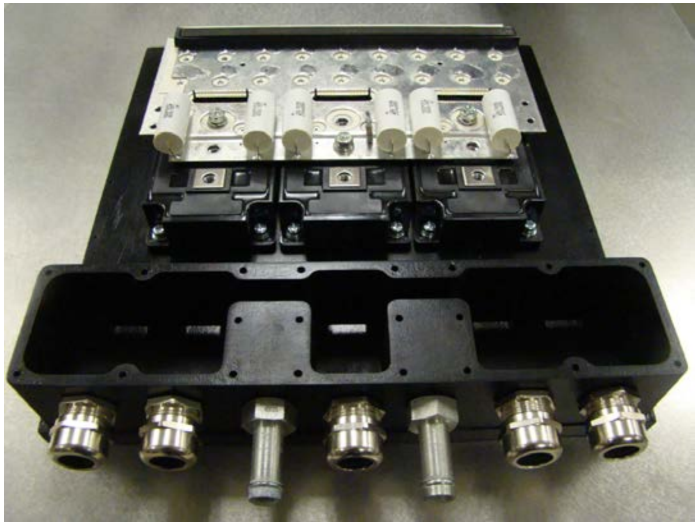
Partners

- Interactions/ collaborations
  - UQM Technologies, Inc. and Wolverine Tube, Inc.
- Project lead: National Renewable Energy Laboratory

Relevance/Objective(s)

- Advanced thermal control technologies are critical to enabling higher power densities
  - Resulting in lower weight, size and cost.

- Objectives
  - Design and develop light-weight, single-phase liquid-cooled, automotive inverter-scale heat exchanger based on impinging jets and enhanced surfaces.
  - Through thermal management, directly contribute towards the 2015 power electronics power density (12 kW/liter), specific power (12 kW/kg), and cost ($5/kW) targets.
  - Enable use of high-temperature water-ethylene glycol (WEG) coolant for power electronics cooling.



Credit: Mark Mihalic, NREL

Milestones

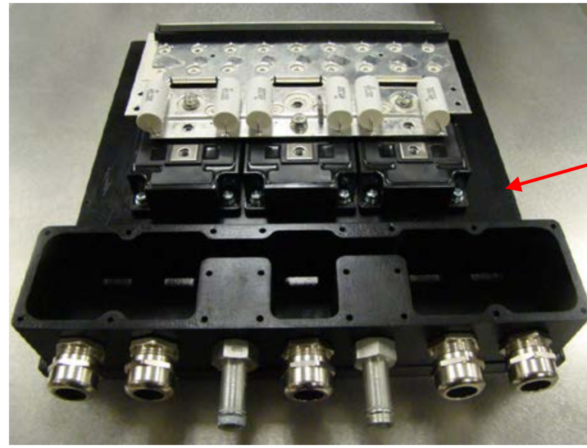
Date	Milestone or Go/No-Go Decision
January 2011	Acquired inverter from UQM Technologies, Inc. – provided platform for demonstrating new heat exchanger based on jets. Initiated finite element analysis (FEA) and computational fluid dynamics (CFD) modeling for design of heat exchanger.
July 2011	Initiated investigation of long-term reliability of impinging jets on enhanced/microfinned surfaces.
September 2011	Completed FEA and CFD modeling to design the first prototype heat exchanger. **Go/No-Go Decision**: Modeling results showed significant promise for the new design as compared to the baseline channel flow case; decision was made to proceed with hardware fabrication.
February 2012	Fabricated first jet-based plastic heat exchanger prototype; initiated experimental testing for pressure drop and thermal performance.
April 2012	Complete experimental thermal characterization of first prototype heat exchanger. Go/No-Go Decision: If promising results are obtained, begin fabrication of second prototype based on jets in conjunction with enhanced surfaces.
September 2012	Complete characterization of both prototypes and the study on reliability of the impinging jet configuration.

Approach/Strategy

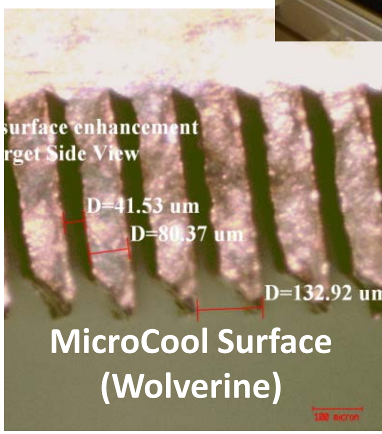
Baseline heat exchanger

Credit: Sreekant Narumanchi, NREL

New heat exchanger



Credit: Mark Mihalic, NREL



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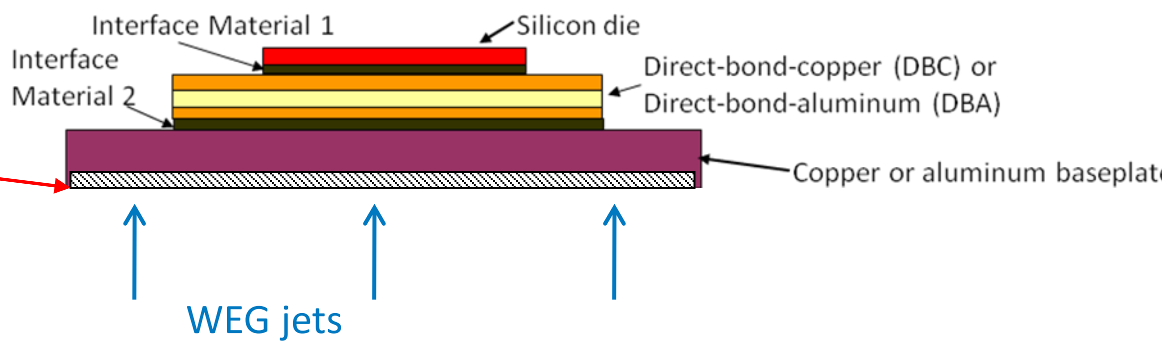
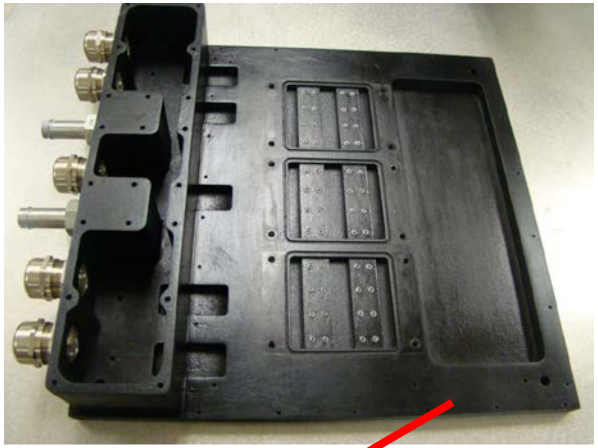


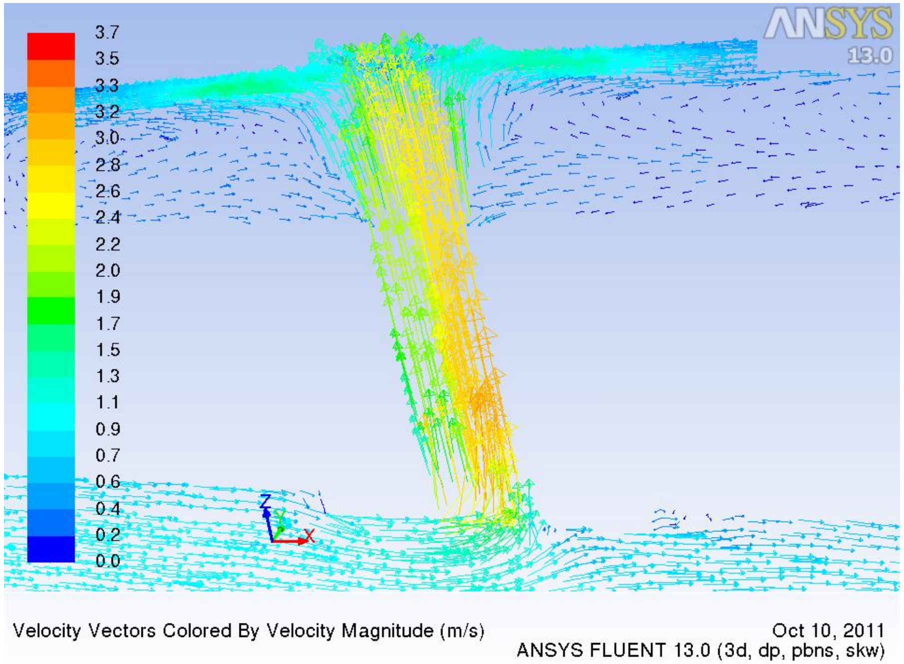
- Reduce thermal resistance, increase heat transfer rates through WEG jet impingement on enhanced surfaces, and use light-weight material.
- Characterize thermal performance based on steady-state and transient/realistic loading conditions.

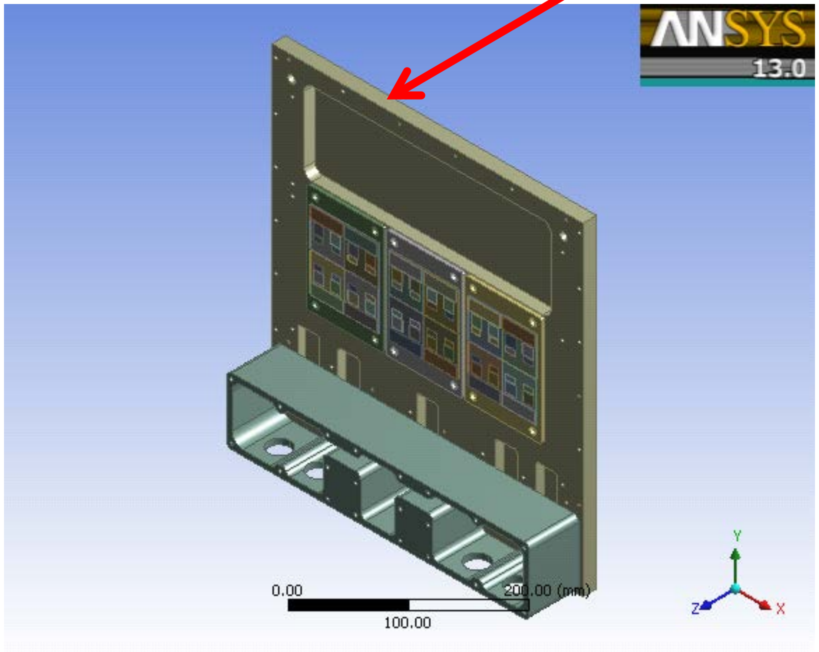
Heat Exchanger Design

- A jet plate/manifold designed using CFD modeling.
- A glass-fiber reinforced nylon plastic material used for the bulk of the fluid manifold (replacing aluminum).
- WEG jet impingement on the copper base plate with and without microfinned surfaces.

Credit: Mark Mihalic, NREL



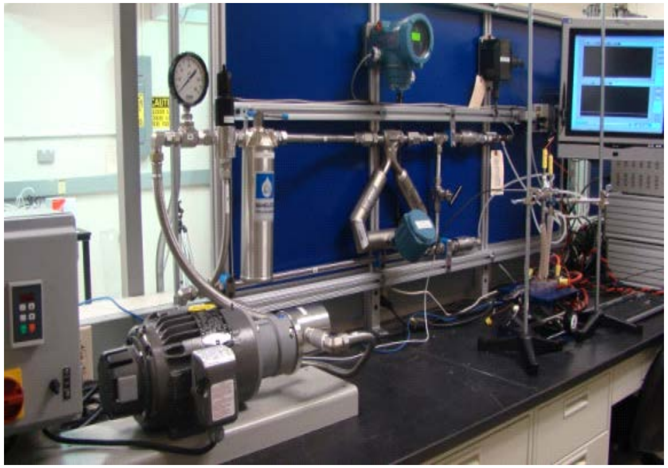




Validation of CFD Modeling for Baseline Heat Exchanger

Flow rate, m^3/s (liters/minute)	Pressure drop (Pa)		Average temperature in diodes (^oC)	
	Experiment	CFD	Experiment	CFD
0.336e-04 (2)	1,076	1,079	84.9	84.0
1.667e-04 (10)	19,374	16,988	82.8	82.9

- 105.3 W dissipated in four diodes in the center power module.
- WEG mixture (50%–50% by volume) at 70°C used as coolant.
- Junction temperature in the four diodes measured using the transient thermal tester during the steady-state heating.
- Reasonable match between modeling and experimental results.



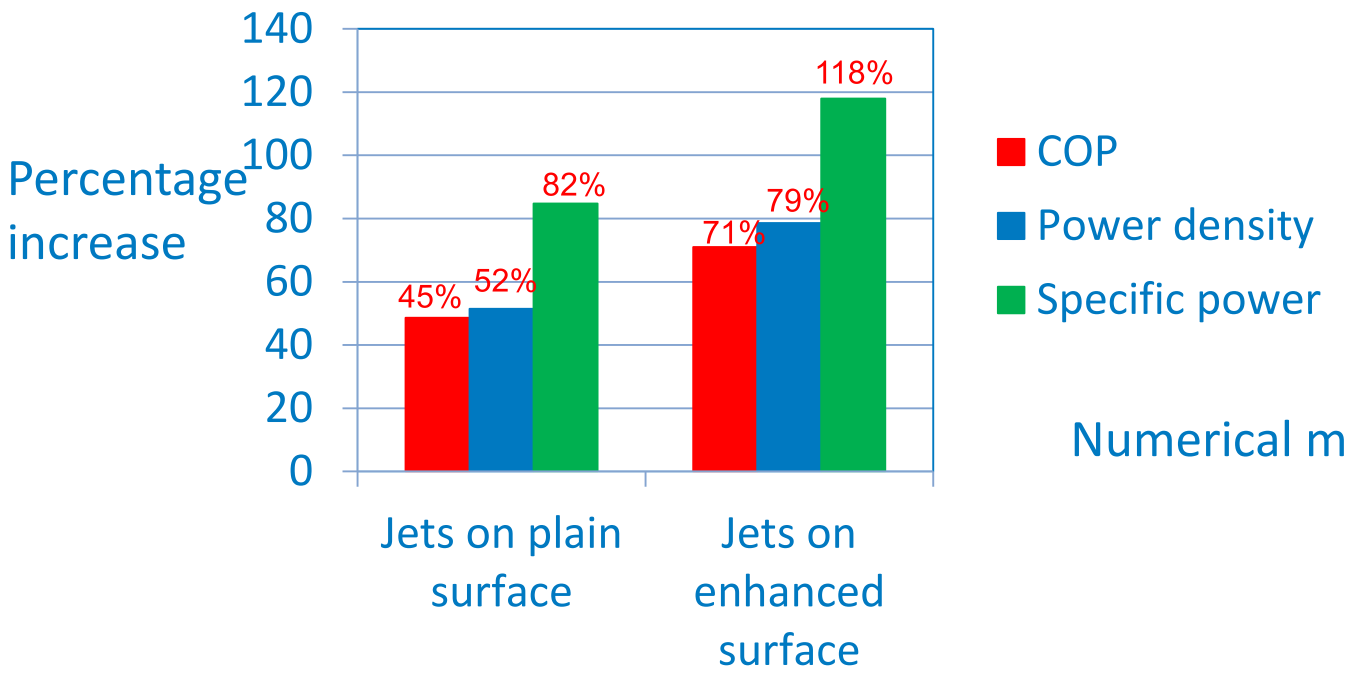
Credit: Sreekant Narumanchi, NREL

CFD Modeling Results for New Heat Exchanger

Parameter	Baseline (channel flow)	Jets impinging on plain surface	Jets impinging on microfinned surface
ΔP (Pa)	16,858	17,458	17,458
$R_{th, ja}$ (K/W)	0.294	0.191 (34% lower)	0.166 (44% lower)
Temperature uniformity (^{0}C)	2.7	0.3	0.15

- Design case with 2.5-kW heat dissipation spread over 24 insulated gate bipolar transistors (IGBTs) (72 W in each IGBT) and 24 diodes (33 W in each diode)
- WEG at 70°C as coolant at 1.667e-04 m^3/s (10 liters/minute) flow rate , thermal resistance based on four diodes in the center module: $R_{th, ja} = (T_{4diodes, avg} - T_{coolant})/q_{4diodes}$

Impacts on Coefficient of Performance (COP), Power Density, Specific Power and Cost

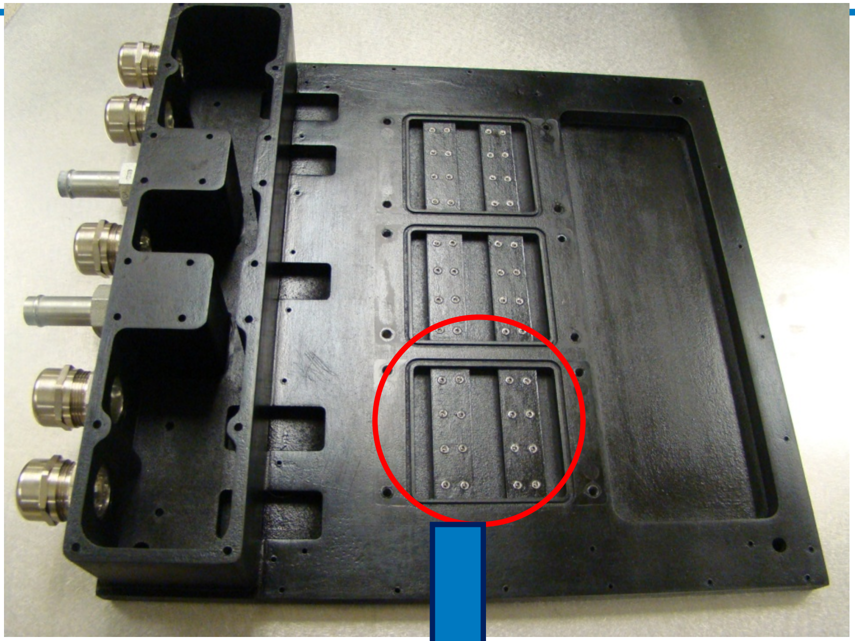


Numerical modeling results

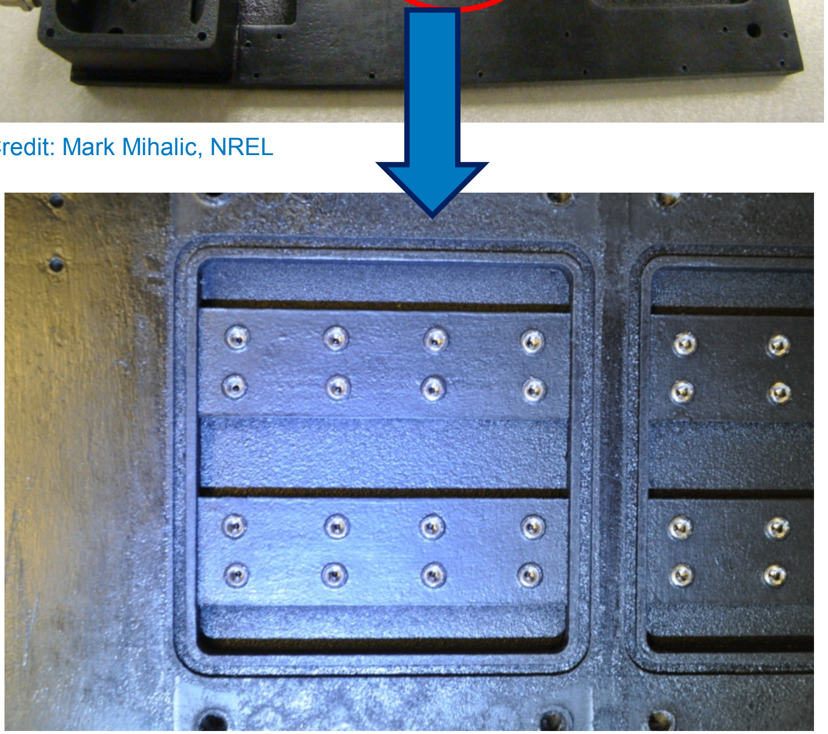
- Using plastic instead of aluminum results in approximately 2.9 kg (6.3 lb) or 50% weight reduction of the heat exchanger
  - results in up to 118% increase in specific power
- Cost likely to be cheaper with respect to aluminum baseline heat exchanger

Fabrication of Heat Exchanger Prototype

- Fabrication of first automotive inverter-scale heat exchanger prototype based on jet-impingement complete
- Glass-fiber reinforced nylon used as the material for the heat exchanger
- A selective laser sintering process was used
- Flow/pressure drop and thermal characterization underway



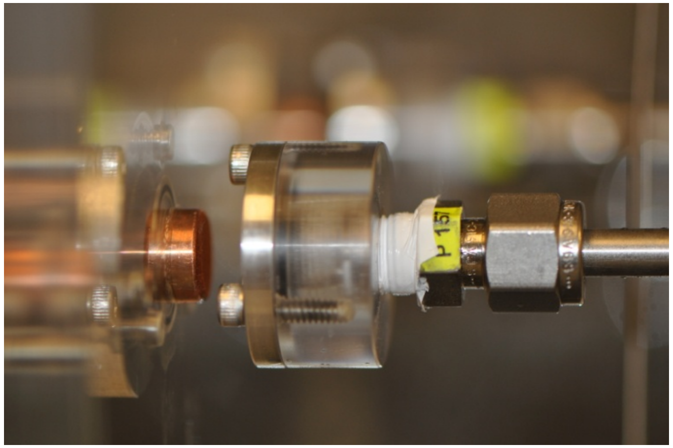
Credit: Mark Mihalic, NREL



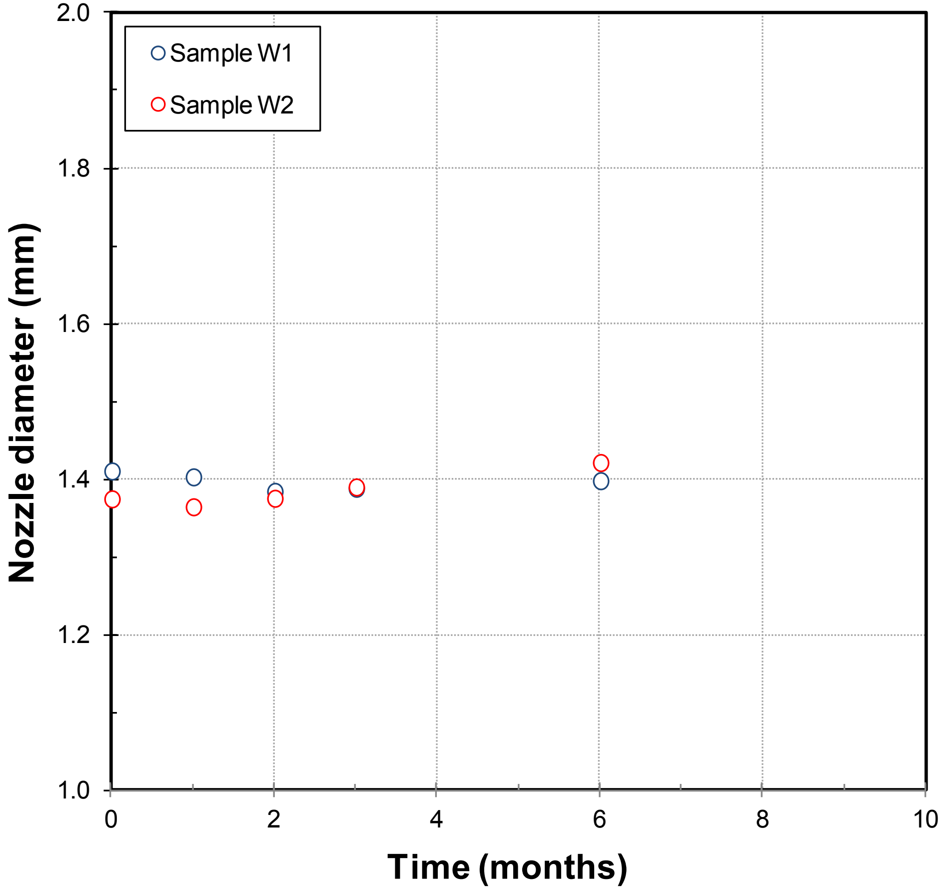
Credit: Doug DeVoto, NREL

Experimental Reliability Assessment of Jet Impingement (1)

- Tests initiated with WEG jet impinging on microfinned surface (on 12.5-mm-diameter copper target surface).
- Negligible change in jet nozzle diameter after 180 days of nearly continuous impingement.



Credit: Gilbert Moreno, NREL

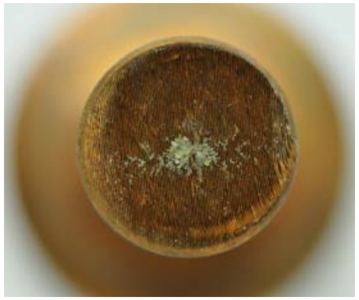


Experimental Reliability Assessment of Jet Impingement (2)

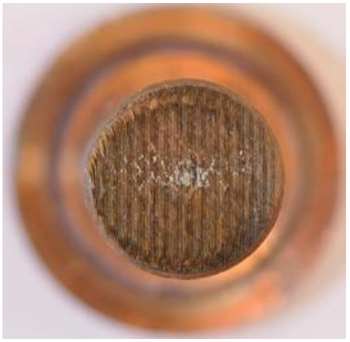
- Evidence of oxidation on surfaces (no initial coating/plating on the surface).

Sample W1 (7 m/s jet velocity)

t=0

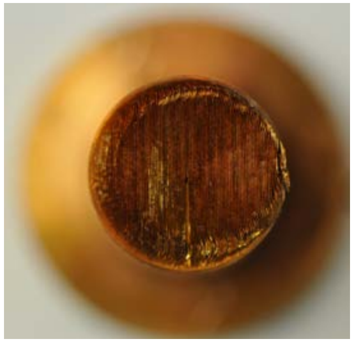


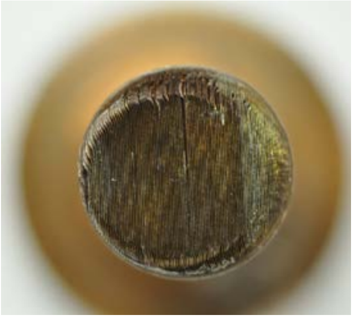
t=90 days



t= 180 days

Sample W2 (2 m/s jet velocity)



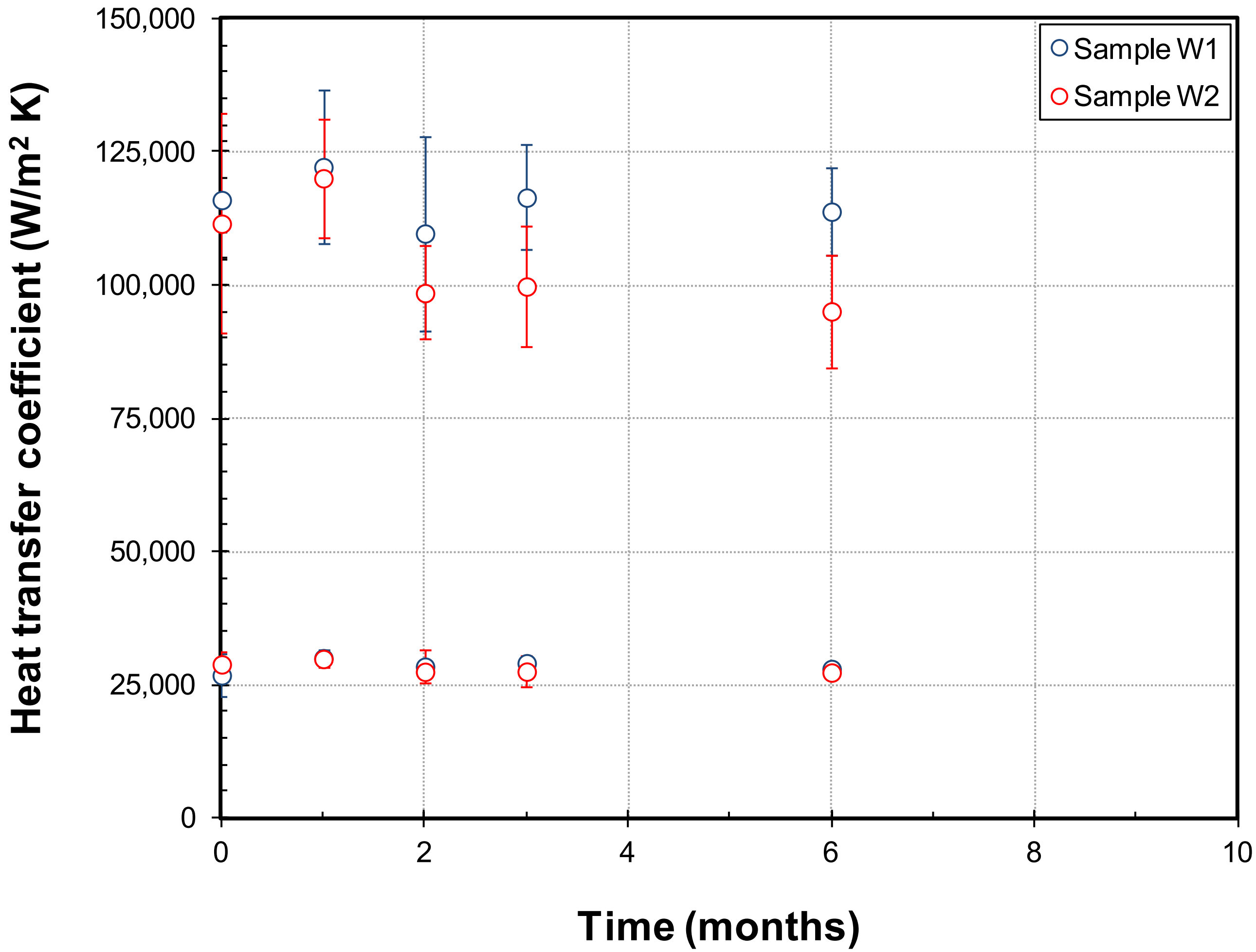


Credit: Gilbert Moreno, NREL (all photos)

Experimental Reliability Assessment of Jet Impingement (3)

- Change in thermal performance of the surfaces over time (180 days of impingement) within the 95% confidence intervals (CI).

Error bars: ± t s / √n
t = Student's t-distribution (95% CI)
s = sample standard deviation
n = number of tests (3-4 typical)



Collaboration and Coordination

Collaborator	Type of Interaction/Collaboration
UQM Technologies Inc. (Industry)	• Source for inverter and power modules • Source for dynamometer testing of the inverter
Wolverine Tube, Inc. (Industry)	• Provided microfinned enhanced surface on copper base plate and blocks

Proposed Future Work

Remainder of FY12

- Continue tests on the heat exchanger
  - Power module tests using a transient thermal tester
  - Dynamometer testing for performance under realistic loading conditions

- If experimental results follow trends predicted by modeling, fabricate second prototype heat exchanger incorporating jet impingement on microfinned surface

- Continue long-term reliability testing of impinging jets on different types of surfaces (enhanced surface, surface with coatings)

- Project in the current form ends in FY12

Summary

DOE Mission Support

- Through thermal management, enable 2015 power electronics goals of power density (12 kW/liter), specific power (12 kW/kg) and cost ($5/kW)
- Enable use of high-temperature WEG coolant

Approach

- Jet impingement on base plate with and without microfinned surface
- Light-weight, low-cost plastic for rest of the heat exchanger
- Demonstration of reliability

Accomplishments

- Completed FEA and CFD analyses and designed first prototype heat exchanger
  - Modeling predicted significant performance improvements with respect to baseline channel flow case (up to 71% higher COP, 79% higher power density and 118% higher specific power)
- Fabricated first prototype and initiated testing
- Results after 6 months of near-continuous jet impingement on enhanced surfaces showed no degradation in heat transfer performance

Summary

Future work

- Complete flow and thermal characterization on first prototype.
- Pending favorable results, fabricate second heat exchanger prototype based on jets in conjunction with microfinned surfaces.
- Complete characterizations on both prototypes.
- Complete reliability assessment/testing of impinging jet on surface.

Collaborations

- UQM Technologies Inc.
- Wolverine Tube Inc.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Acknowledgment:

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U.S. Department of Energy

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