Integrated Traction Drive Thermal Management

Keystone Project 3

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June 11, 2019

DOE Vehicle Technologies Program
2019 Annual Merit Review and Peer Evaluation Meeting

Project ID # elt217

Overview

Timeline

- Project start date: 10/01/2018
- Project end date: 09/30/2021
- Percent complete: 15%

Barriers

- Barriers addressed
  - Cost
  - Power density of a traction drive/system
  - Reliability and lifetime

Budget

- Total project funding: $250K
  - U.S. Department of Energy (DOE) share: $250K
- Funding for FY 2019: $250K

Partners

- Industry
  - Automotive original equipment manufacturers (OEM)
  - Driveline fluid manufacturers
- Research institutions
  - Oak Ridge National Laboratory (ORNL)

Relevance

Objectives:

- Research and evaluate motor-integrated power electronics packaging technologies and thermal management approaches
- For selected driveline fluids, measure convective cooling and electrical properties

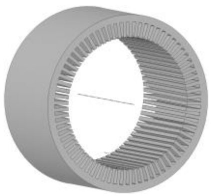
Project Impact:

- Identify pathways enabling high-performance, compact and reliable integrated electric drives:
  - Help achieve DOE 2025 target of 33kW/L system power density for an electric traction drive

Milestones

Description	End Date	Status
Go/No-Go • Traction drive fluid thermal and electrical evaluation (literature review). Determine if thermal, electrical, and mechanical fluid properties align with driveline fluid performance requirements for the integration methods proposed for the electric motor and power electronics.	06/30/2019	On Track
Milestone • Perform jet impingement heat transfer coefficient characterization for one automatic transmission fluid (ATF) type based on already identified parameters.	09/30/2019	On Track
Milestone • Submit manuscript based on jet impingement heat transfer coefficient characterization results for ATF.	09/30/2019	On Track
Milestone • Perform thermal management simulations for up to two integration approaches.	12/31/2019	On Track

Approach: Thermal Modeling and Experimental Heat Transfer Characterization

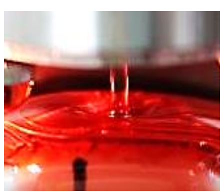


Geometries of state-of-the-art components

- Bar (hairpin) winding electric machines
- Wide bandgap (WBG) power electronics (PE) / inverters

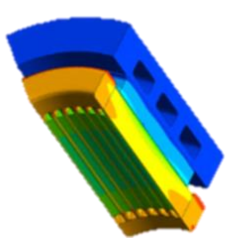
Motor + PE integration approaches

- Separate motor and PE enclosures
- PE distributed/mounted radially on the motor casing
- PE integrated axially in the motor front/back plate



Experimental heat transfer characterization

- ATF currently used in automotive transmissions
- Select dielectric driveline fluids suitable for direct electric motor and PE cooling



Evaluate cooling solutions with numerical modeling

- Water-ethylene glycol (WEG) cooling both motor and PE
- Split approach: ATF cooling motor and WEG cooling PE
- ATF cooling both motor and PE

Clarification of terms:

PE – power electronics: used for control of electric traction drives
WBG – wide bandgap electronics: emerging semiconductor technology in power electronics
WEG – water ethylene glycol solution: used in automotive cooling applications
ATF – automatic transmission fluid: used for lubrication and cooling in vehicle transmissions

Motor figures credit: Shajjad Chowdhury, ORNL
Photo credit: Bidzina Kekelia, NREL
Simulations figure credit: Emily Cousineau, NREL

Approach: Resources for Modeling and Experimental Heat Transfer Characterization

- Access to commercial finite element analysis (FEA) and computational fluid dynamics (CFD) numerical modeling software tools for thermal modeling

- Large fluid loop test bench for measuring convective heat transfer coefficients (jet impingement cooling)

- Small fluid loop test bench is being built and expected to be operational by mid-2019

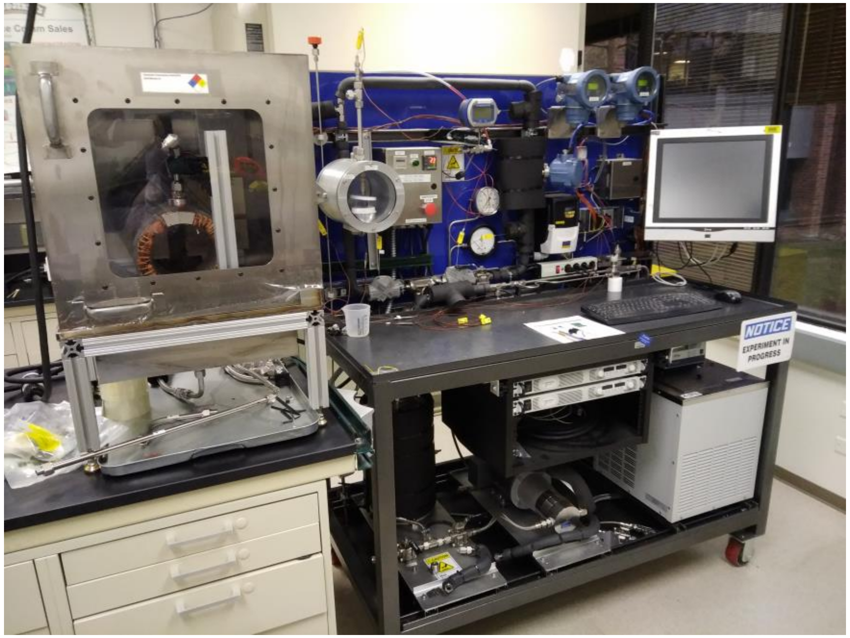


Photo credit: Bidzina Kekelia, NREL

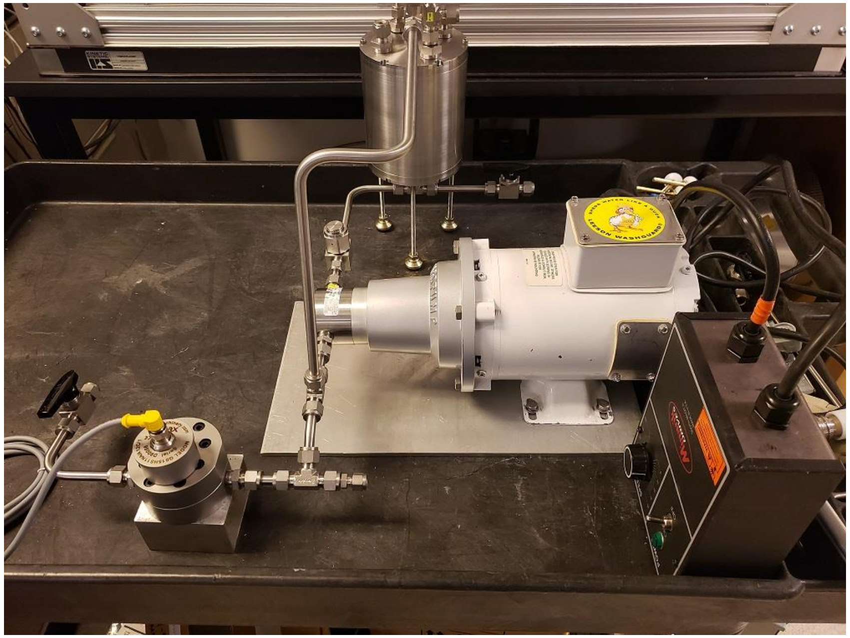
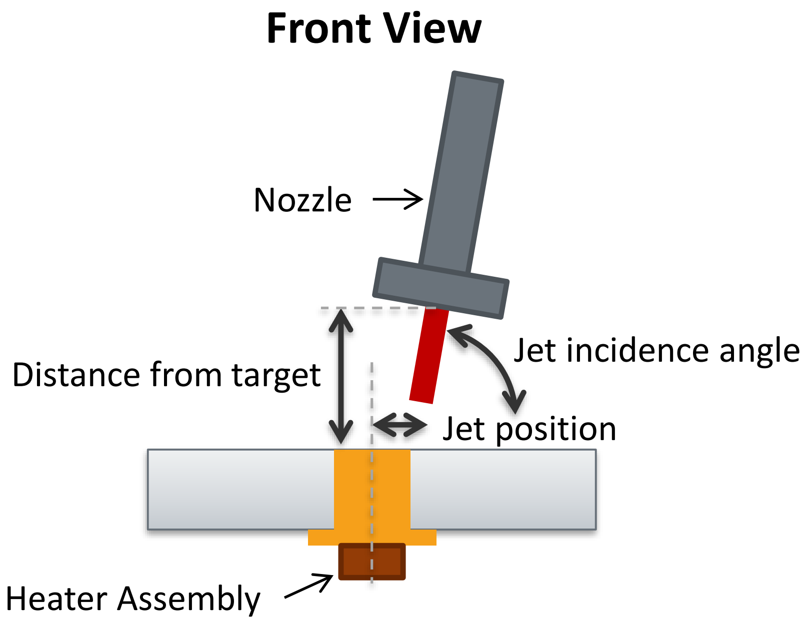


Photo credit: Gilbert Moreno, NREL

Approach: Experimental Heat Transfer Coefficient Measurements



$$h = \frac{q_s}{A_s(T_s - T_l)}$$

$h = heat\ transfer\ coefficient$

$q_s = heat\ removed\ from\ target\ surface$

$A_s = Area\ of\ target\ surface$

$T_s = Target\ surface\ temperature$

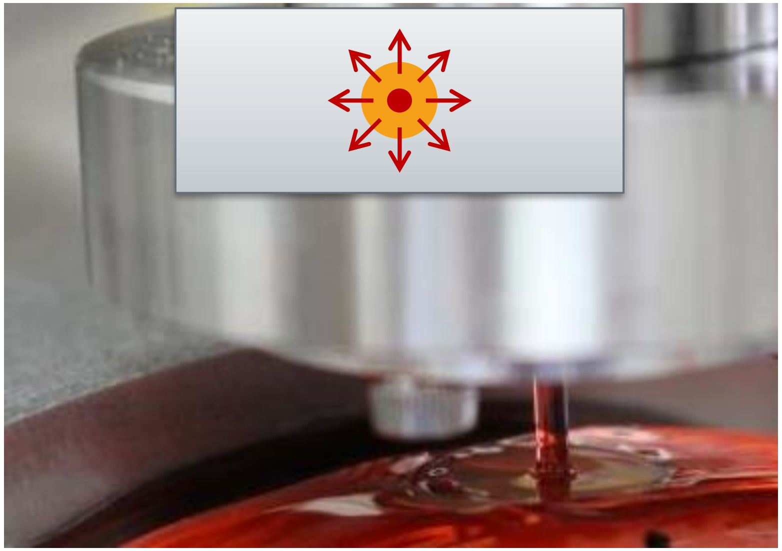
$T_l = Fluid\ or\ liquid\ temperature$

Parameter	Values
Fluid temperature (T_{fluid})	50°C, 70°C, 90°C
Surface temperature ($T_{surface}$)	90°C, 100°C, 110°C, 120°C
Jet incidence location	center, edge, 5mm away from edge
Jet incidence angle	90°, 60°, 45°
Nozzle distance from target	5mm, 10mm, 15mm

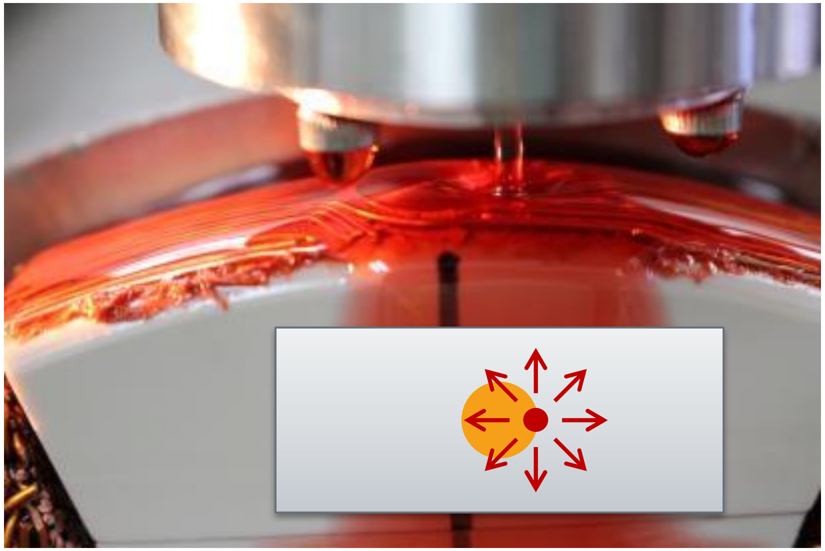
Figure credit: Kevin Bennion, NREL

Technical Accomplishments and Progress: Orifice Jet Impingement

- Experimental measurements of heat transfer coefficients (HTC) for jet impingement cooling
  - Ford MERCON® LV automatic transmission fluid (ATF) – ongoing
    - 50°C fluid temperature – complete for 90° jet incidence angle
    - 70°C fluid temperature – ongoing
    - 90°C fluid temperature – ongoing
  - Other driveline fluids (to be identified) – planned



Orifice jet center impingement



Orifice jet edge impingement

Photo credits: Bidzina Kekelia, NREL

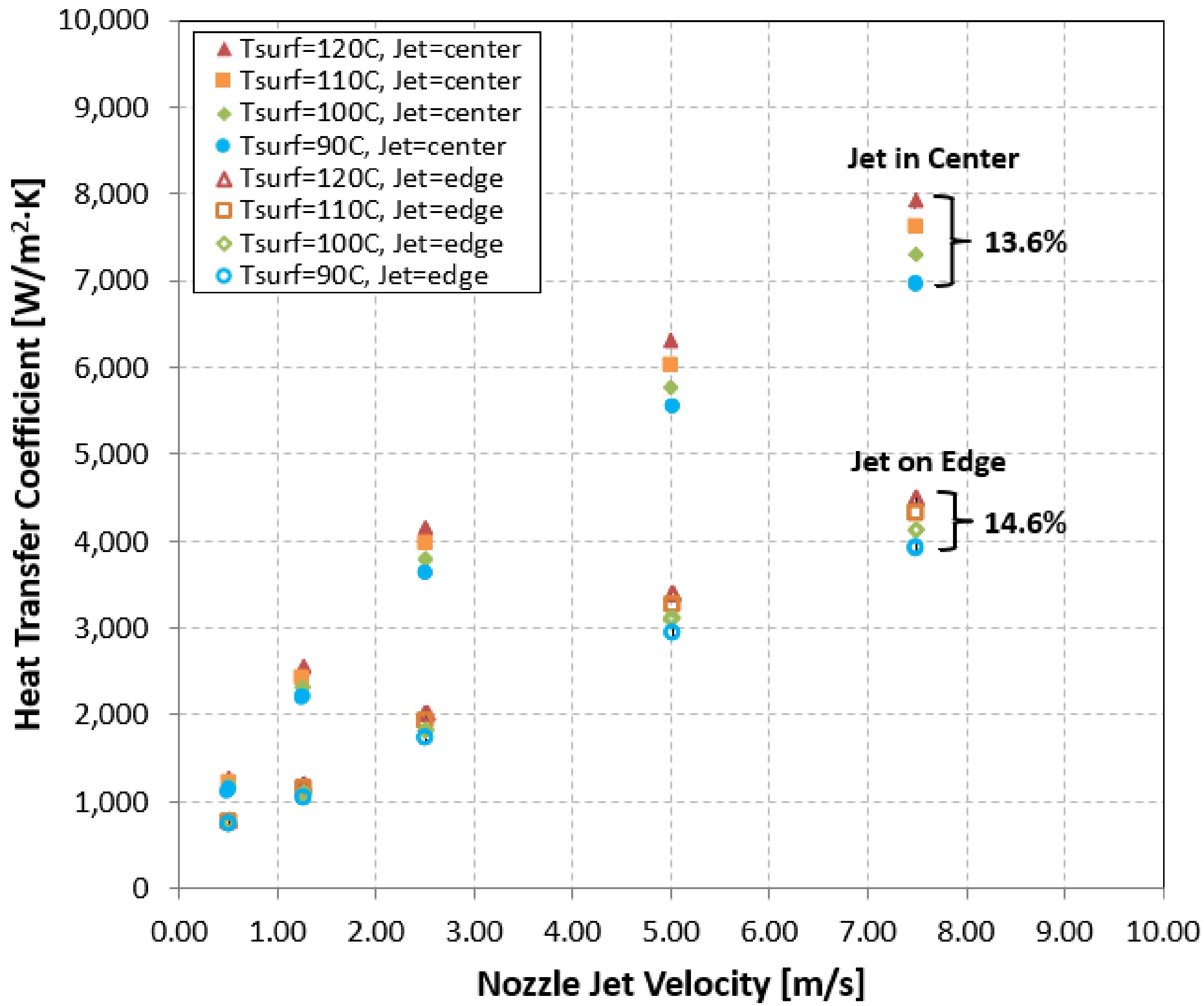
Technical Accomplishments and Progress: Orifice Jet Impingement

Heat transfer coefficients for ATF at T_{fluid} = 50°C

- Data useful for design and development of thermal management solutions of electric machines
- Temperature (T) of the cooled surface affects HTC values:

  $T_{surface} \uparrow \Rightarrow h \uparrow$

- The observed phenomenon is likely due to increased fluid film temperature near heated surface => resulting in reduced viscosity (strongly temperature-dependent for ATF) => increasing fluid flow => enhancing heat transfer



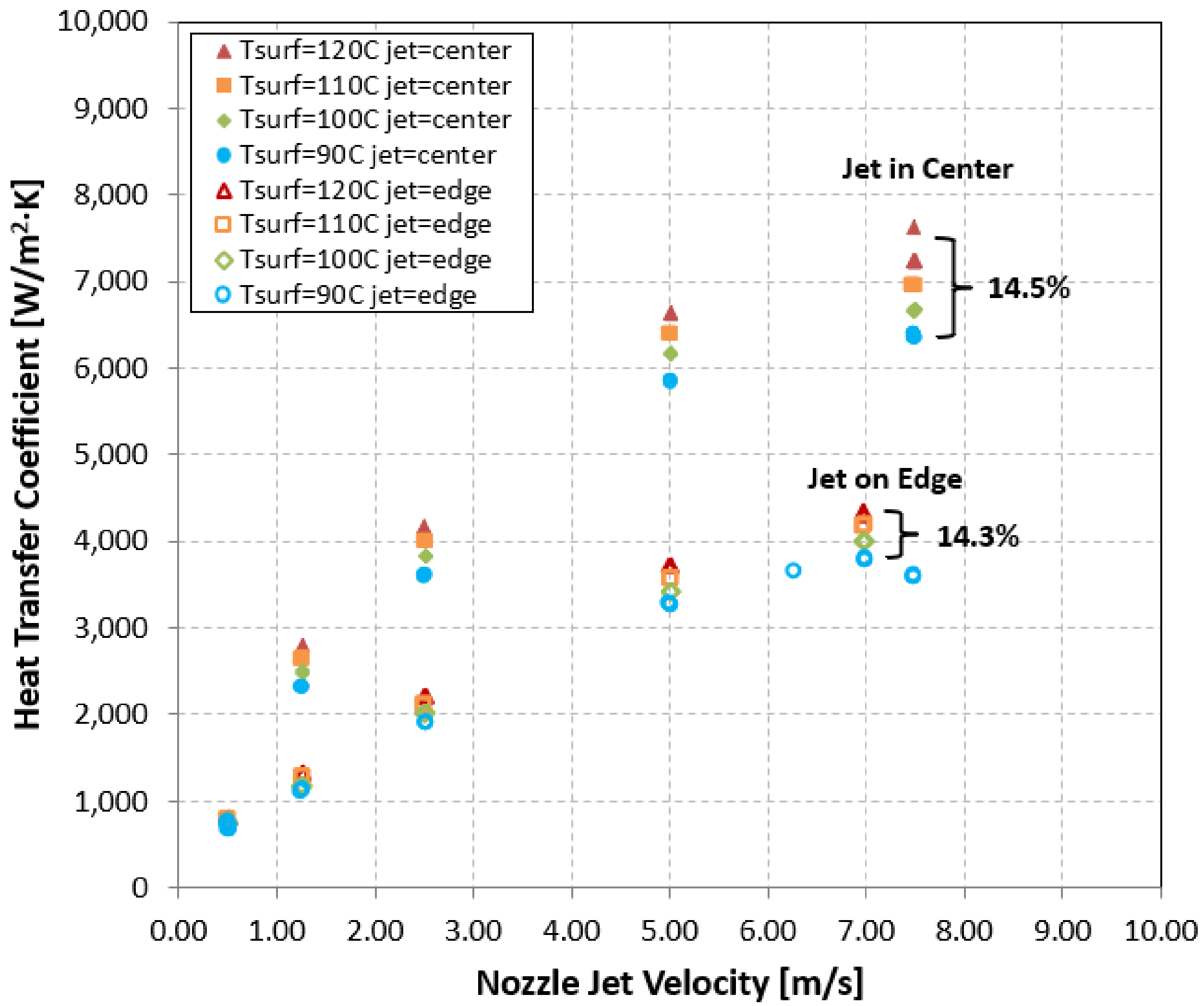
Technical Accomplishments and Progress: Orifice Jet Impingement

- Temperature of the cooled surface affects HTC values:

  $T_{surface} \uparrow \Rightarrow h \uparrow$

- Experiments ongoing to evaluate HTC varying other parameters:
  - incidence angle
  - nozzle distance from target surface

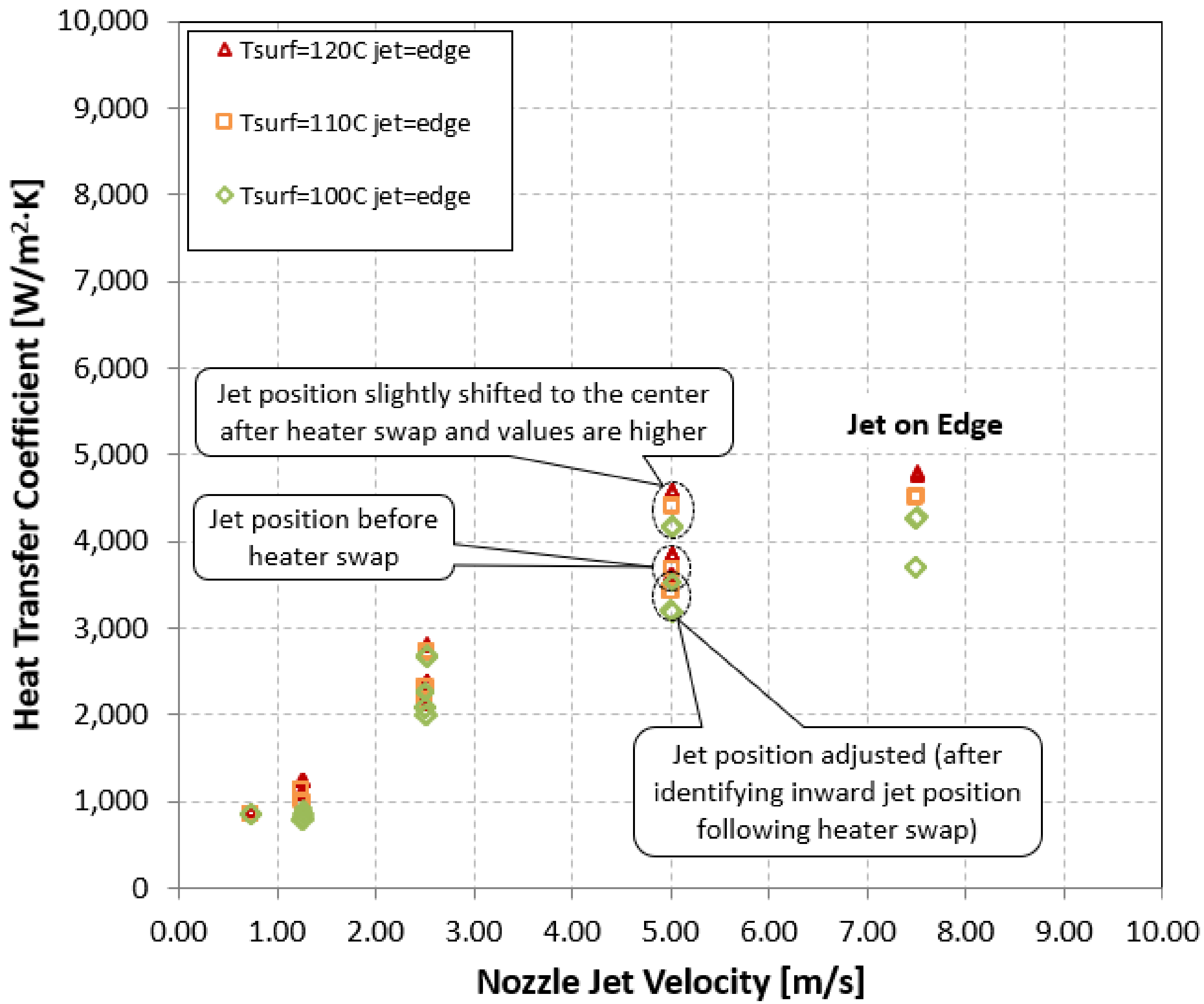
Heat transfer coefficients for ATF at T_{fluid} = 70°C



Technical Accomplishments and Progress: Orifice Jet Impingement

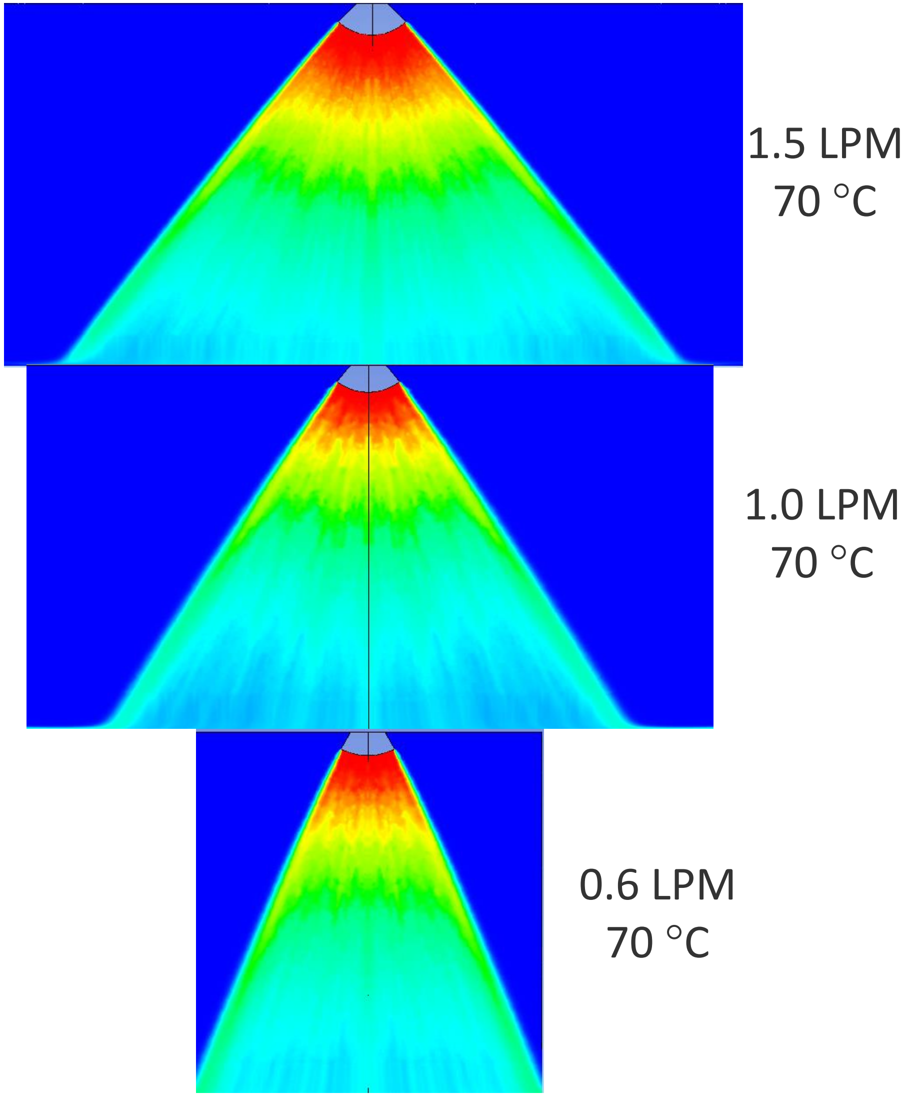
Heat transfer coefficients for ATF at T_{fluid} = 90°C

- Small variation in jet position affects HTC values.
- Precise mechanism for jet position control to be devised
- Experiments ongoing to evaluate HTC varying other parameters:
  - jet position
  - incidence angle
  - nozzle distance from target surface



Technical Accomplishments and Progress: CFD Simulations of Fan-shaped Jet Impingement

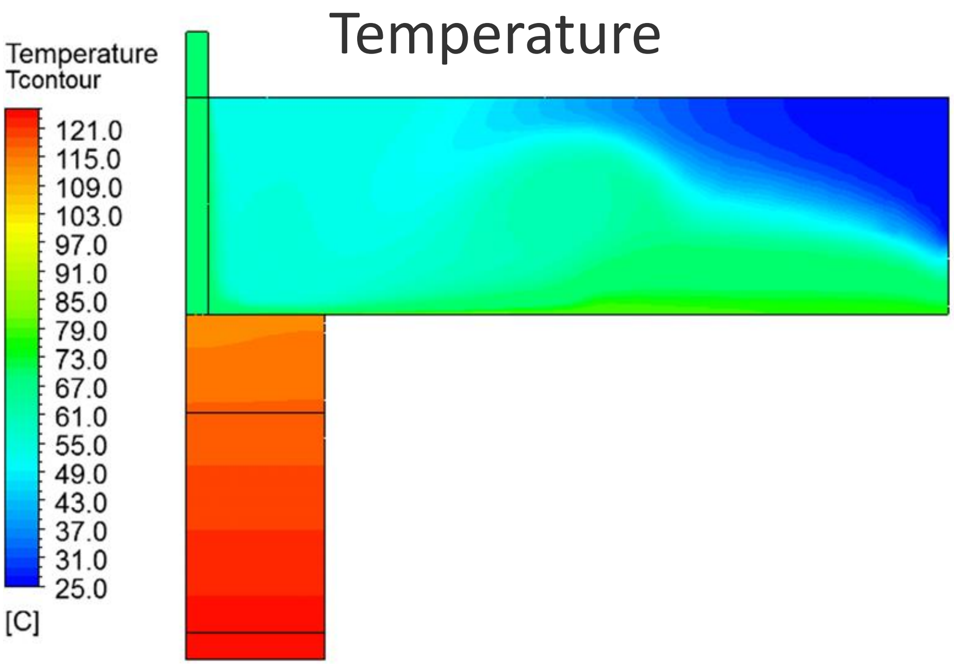
- Conducted CFD simulations on fan-shaped ATF jet impingement on heated copper target surface
- Implemented volume of fraction (VOF) model
- Observed span angle to vary with mass flow rate
- Studied different flow temperatures (50°, 70°, 90°C) and flow rates (0.6, 1.0, 1.5 and 2.0 LPM) using CFD modeling
- Further work to refine the inlet boundary condition is in progress

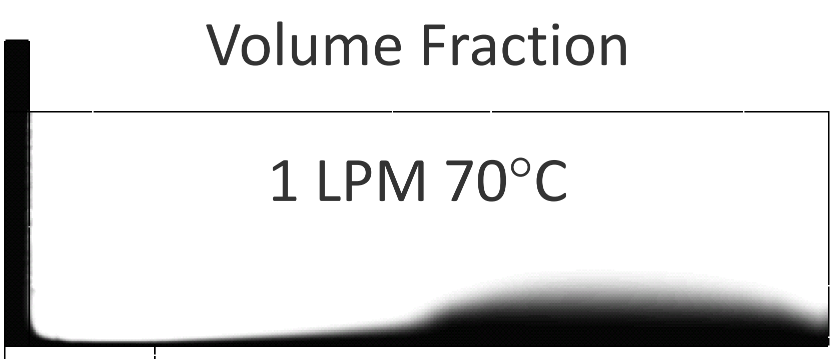


Figures credit: Xuhui Feng, NREL

Technical Accomplishments and Progress: CFD Simulations of Orifice Jet Impingement

- Conducted CFD simulation on orifice ATF jet impingement on heated copper target surface
- Studied different flow temperatures (50°, 70°, 90°C) and flow rates (0.6, 1.0 and 1.5 LPM) using CFD modeling
- Derived heat transfer coefficients from modeling show excellent agreement with experimental results





Figures credit: Xuhui Feng, NREL

Responses to Previous Year Reviewers' Comments

- Current project was initiated in FY 2019 and has not been reviewed in 2018

Collaboration and Coordination

- **Industry**
  - Automotive original equipment manufacturers (OEM)
    - Defining priorities and focus areas
  - Driveline fluid manufacturers and suppliers
    - Automatic transmission and driveline fluid properties

- **Research institutions**
  - Oak Ridge National Laboratory, Integrated Electric Drive System Lead Shajjad Chowdhury
    - Collaborating on identifying state-of-the-art OEMs, component geometries, their integration and thermal management approaches and general aspects of thermal modeling

Remaining Challenges and Barriers

- Gathering information on proprietary motor-integrated power electronics and thermal management solutions (not readily available or open source) for evaluation and comparison
- Identifying driveline fluids suitable for direct cooling of high-voltage (400V-1,200V) power electronics
- Potential need for quantifying electrical (dielectric) properties at high voltages for selected candidate fluids => requiring development of additional in-house fluid characterization capabilities or identifying external providers of similar services

Proposed Future Research

FY 2019

- Perform ATF jet impingement experiments according to the identified matrix of parameters (see Table in the Approach: Experimental Heat Transfer Coefficient Measurements section)
- Identify candidate dielectric driveline fluids suitable for direct cooling of high-voltage components and power electronics
- Devise integrated traction drive packaging geometries and cooling concepts based on researched solutions and start numerical thermal modeling. Perform thermal management simulations for one or two integration approaches (see Approach: Thermal Modeling and Experimental Heat Transfer Characterization section for details)

Beyond FY 2019

- Extend effort of characterizing jet impingement cooling with ATF to other driveline fluids for various configurations (similar to previously defined matrix of parameters)
- If needed, quantify thermal and/or electrical (dielectric) properties of identified driveline fluids (building a test bench in house or via commercial testing service providers)
- Identify promising fluid jet delivery arrangements to motor windings (external jets: top, side; internal jets: upwards, side, bottom)
- Carry out FEA and CFD thermal modeling for comparison of different integrated thermal management approaches (see Approach: Thermal Modeling and Experimental Heat Transfer Characterization section for details)

Any proposed future work is subject to change based on funding levels.

Summary

Relevance

- Effective thermal management is essential for high-performance, compact (power dense) and reliable integrated electric traction drives to achieve the 2025 DOE system power density target of 33 kW/L

Approach/Strategy

- Research state-of-the-art thermal management solutions for integrated electric traction drives
- Identify component geometries based on publicly accessible scientific literature, published OEM materials, interactions with automotive industry and collaboration with research labs
- Experimentally quantify heat transfer coefficients for direct jet impingement cooling with ATF and other driveline fluids
- Apply measured heat transfer coefficients in finite element analysis thermal modeling for comparison of various integrated thermal management approaches

Technical Accomplishments

- Conducted series of experiments and CFD modeling for ATF jet impingement cooling for 50°C, 70°C and 90°C fluid temperature at 90° jet incidence angle
- Established target surface temperature impact on heat transfer: increasing target surface temperature increases heat transfer coefficient
- Conference paper publication is underway

Collaborations

- Industry: Automotive OEMs, driveline fluid manufacturers
- Research institutions: Oak Ridge National Laboratory

Acknowledgments

Susan Rogers, U.S. Department of Energy

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Thank You

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PO-5400-73549

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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