Nanofluids for Thermal Conditions – Underhood Heat Transfer

Wenhua Yu

Energy Systems Division

May 19, 2009

Coworkers:

D. France, D. Smith, J. Routbort, E. Timofeeva, D. Singh, and R. Smith

Project ID # VSSP_22_Yu

Vehicle Technologies – Annual Review – May 18-22, 2009

*Sponsored by **Systems Optimization**, and **Propulsion Systems Materials**, & partial support from Michelin, Saint Gobain, Tardec, and the Industrial Technology Program, CRADA with PACCAR*

Argonne NATIONAL LABORATORY

... for a brighter future

U.S. Department of Energy

UChicago Argonne LLC

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Project Organization

Nanofluid Development for Engine Cooling Systems

FWP 49424/**<u>49386</u>** Agreement # 16822

Erosion of Materials

FWP 49113/49381

Agreements

#9416/15529

Nucleated Boiling

FWP 49425

Agreement # 14758

Overview

Timeline

- Project start FY06
- Project end FY12
- 40% complete

Budget

- Total project -
  see Project ID #
  VSS_13_Routbort
- Heat Transfer
  - FY08 = 250k (DOE)
  - FY09 = 400k (DOE)

Barriers

Reduction of radiator weight, aerodynamic drag, and parasitic energy losses by engineering stable nanofluids having

-High thermal conductivities
-High heat transfer
-Low viscosity
-Environmentally friendly
-Result in no damage to radiator materials

Partners

- TARDEC/WFO
- Saint Gobain-cost share
- Michelin WFO/cost-share
- PACCAR (CRADA in progress)
- Industrial Technologies Program (DOE)

Thermal Management

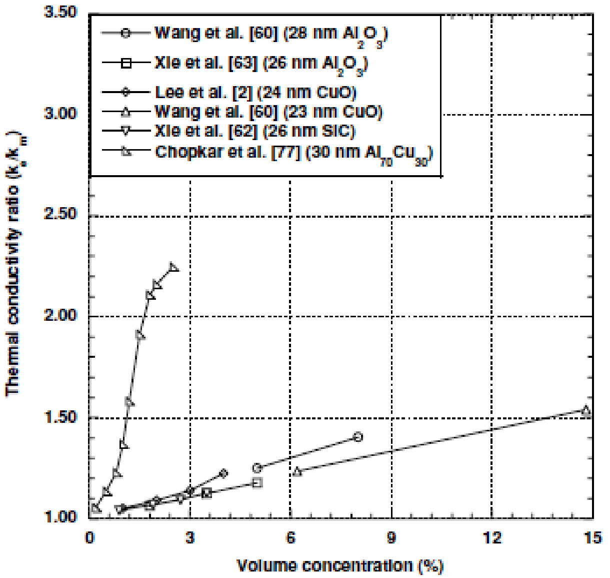
- Efficient heat transfer is critical to thermal management of heavy vehicle engines and support systems. The technology addresses reduction in energy usage through improvements in engine thermal efficiency and reductions in parasitic energy uses and losses.

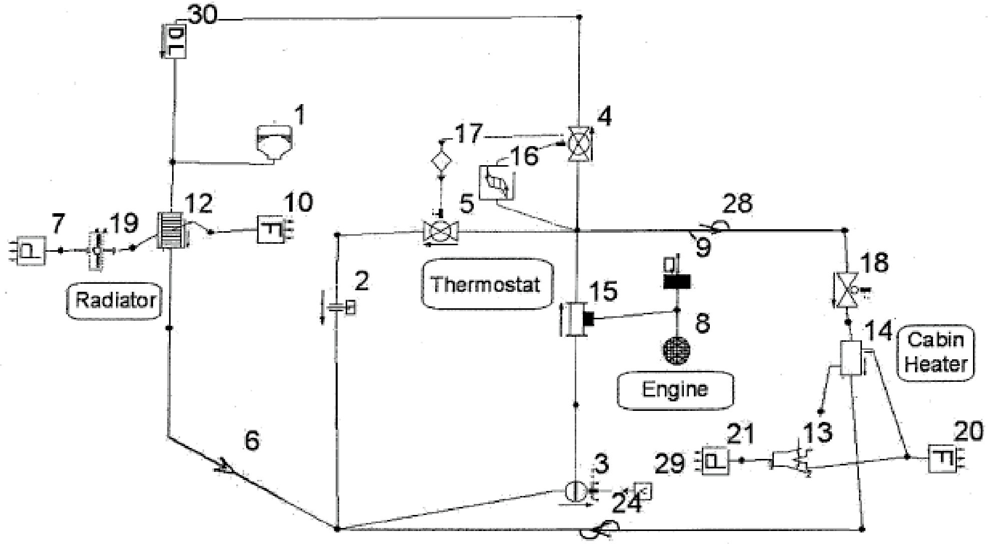
Dr. Sid Diamond, Mid-America Truck Show, photo by Routbort

With permission from PACCAR

Why Nanofluids?

- Enhanced thermal conductivity
- Enhanced heat transfer coefficient $h \geq C\,k^{0.6}$
- CFD of a Cummins 500 hp engine using an "ideal" nanofluid indicated a 5% reduction in radiator size (SAE-2007-01-2141)





Objectives

- This work addresses the possibilities of using nanofluids or other cooling schemes to increase the heat rejection in cooling applications thereby reducing the heat exchanger size, weight, and possibly shape.
- Components of this interrelated program are:
  - Development and characterization of nanofluids (Poster)
  - **Experimental measurements and theoretical analysis of heat transfer characteristics of nanofluids (This Poster)**
  - Investigation of the erosion effects of nanofluids (Poster)
  - Nucleate boiling of ethylene glycol/water (Poster only).

Milestones

- FY08 *(all completed)*
  - Identify critical barriers
  - Initiate collaborations
  - Thermal and viscosity characterization some potential promising nanofluids produced by industry and ANL
  - **Heat transfer measurements of nanofluids**
    - ***SiC / water***
    - ***SiC / ethylene glycol and water***
  - Comparison of theory and experiments
- FY09
  - Nanofluid viscosity modification without changing thermal properties
  - Explore nanoparticles with higher thermal conductivities
  - **Measure heat transfer rates in latest developed nanofluids**
  - Further develop collaborations with industry
    - *Heat transfer of nanofluids*
    - *Evaporative cooling for high heat loads*

Potential Barriers

- High thermal conductivity enhancement with low viscosity to remove heat more efficiently without increasing pumping power.

Laminar flow:

$$\frac{\eta_{eff}}{\eta_0} \approx 1 + C_\eta \phi \qquad \frac{k_{eff}}{k_0} = 1 + C_k \phi \quad \Longrightarrow \quad C_\eta / C_k < 4$$

Turbulent flow (Mouromtseff number):

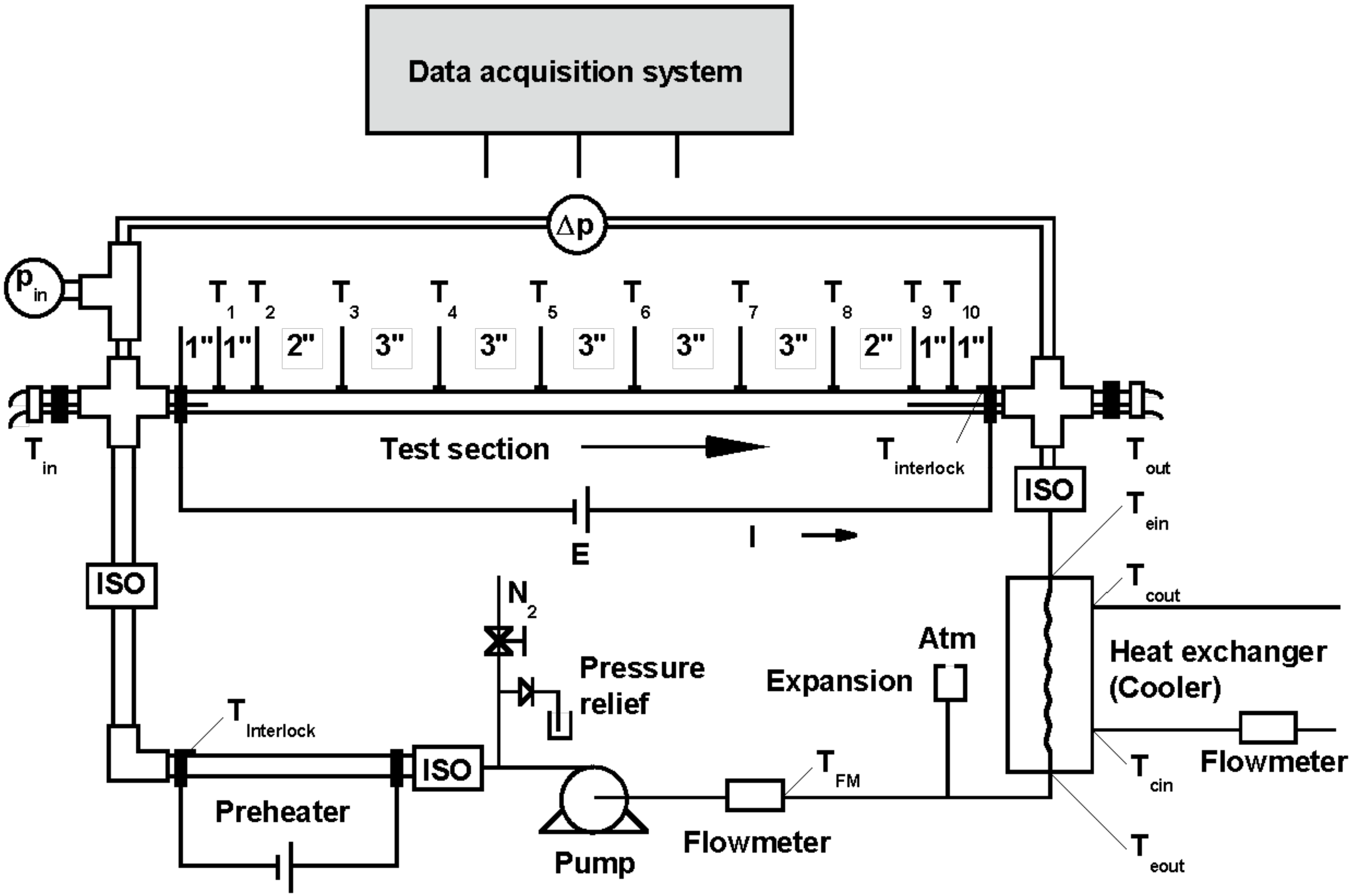
$$Mo = \frac{\rho^{0.8} k^{0.67} c_p^{0.33}}{\eta^{0.47}} \quad \Longrightarrow \quad Mo_{nanofluid} / Mo_{base\ fluid} > 1$$

Argonne NATIONAL LABORATORY

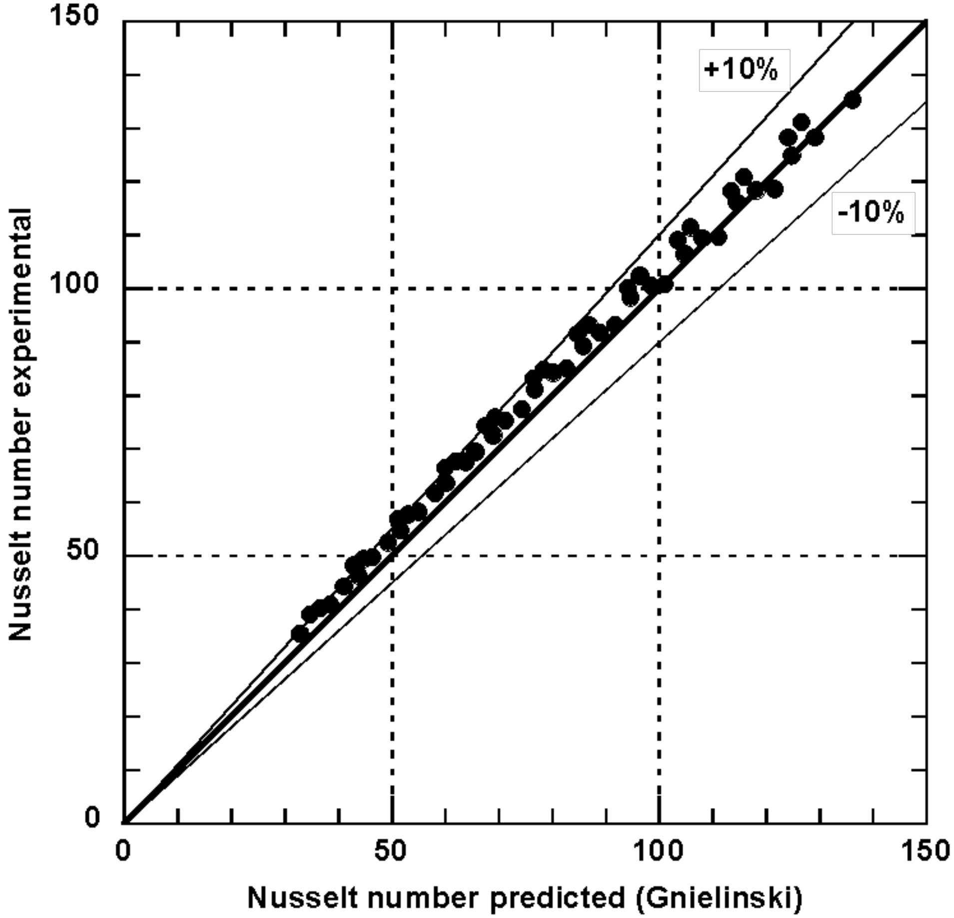
Approach

- Use existing theories and extensive experimental results to select nanoparticles that when dispersed in ethylene glycol/water mixtures might have the best cooling performance with little or no penalty on pumping
- Perform experiments & compare results of thermal conductivity, viscosity, and heat transfer to theory. Modify theory, if required
  - **Perform heat transfer tests in ANL test facility**
  - **Analyze results and compare to the few others available in literature**
- Continue to improve thermal properties while using chemistry to reduce viscosity
- CFD on diesel engines using ANL nanofluids to calculate size, weight reduction of radiator
- Collaborate with industry to demonstrate efficiency of nanofluids

ANL – Nanofluid Heat Transfer Test Facility

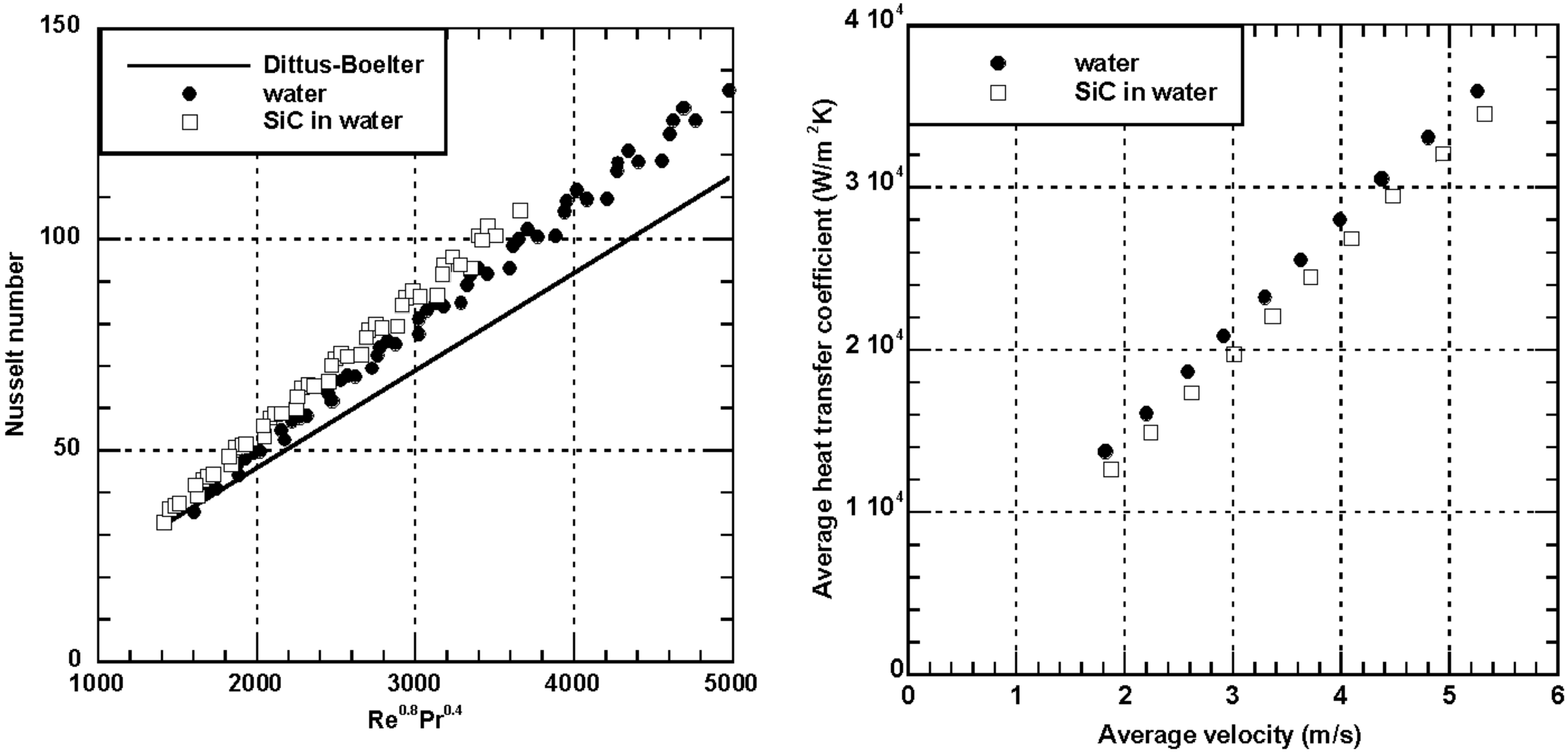


Heat Transfer of Water Base Fluid
facility validation



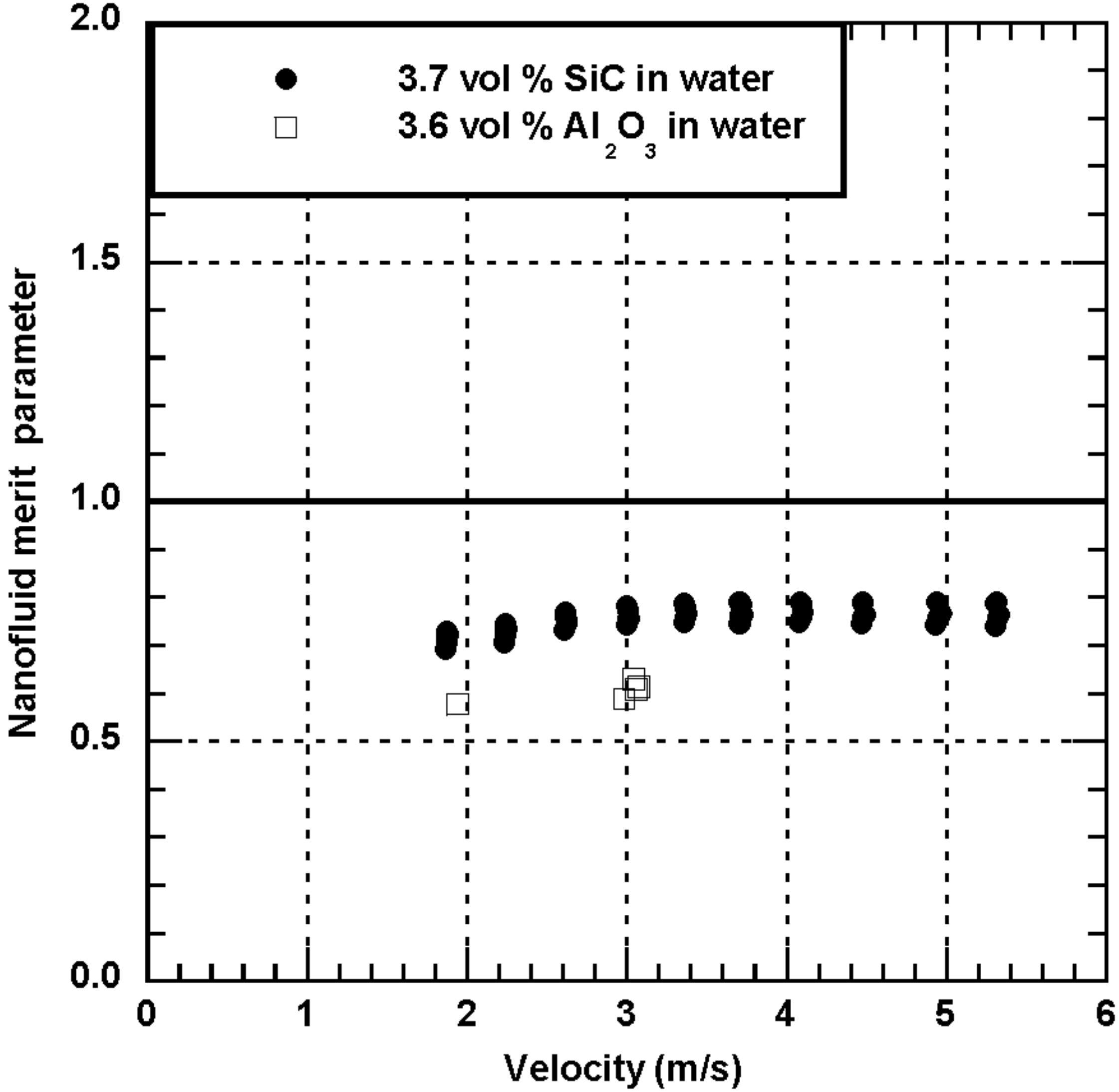
Good comparison serves as an end-to-end validation of the system, sensors, electronics, & data reduction

Heat Transfer to SiC/Water Nanofluid



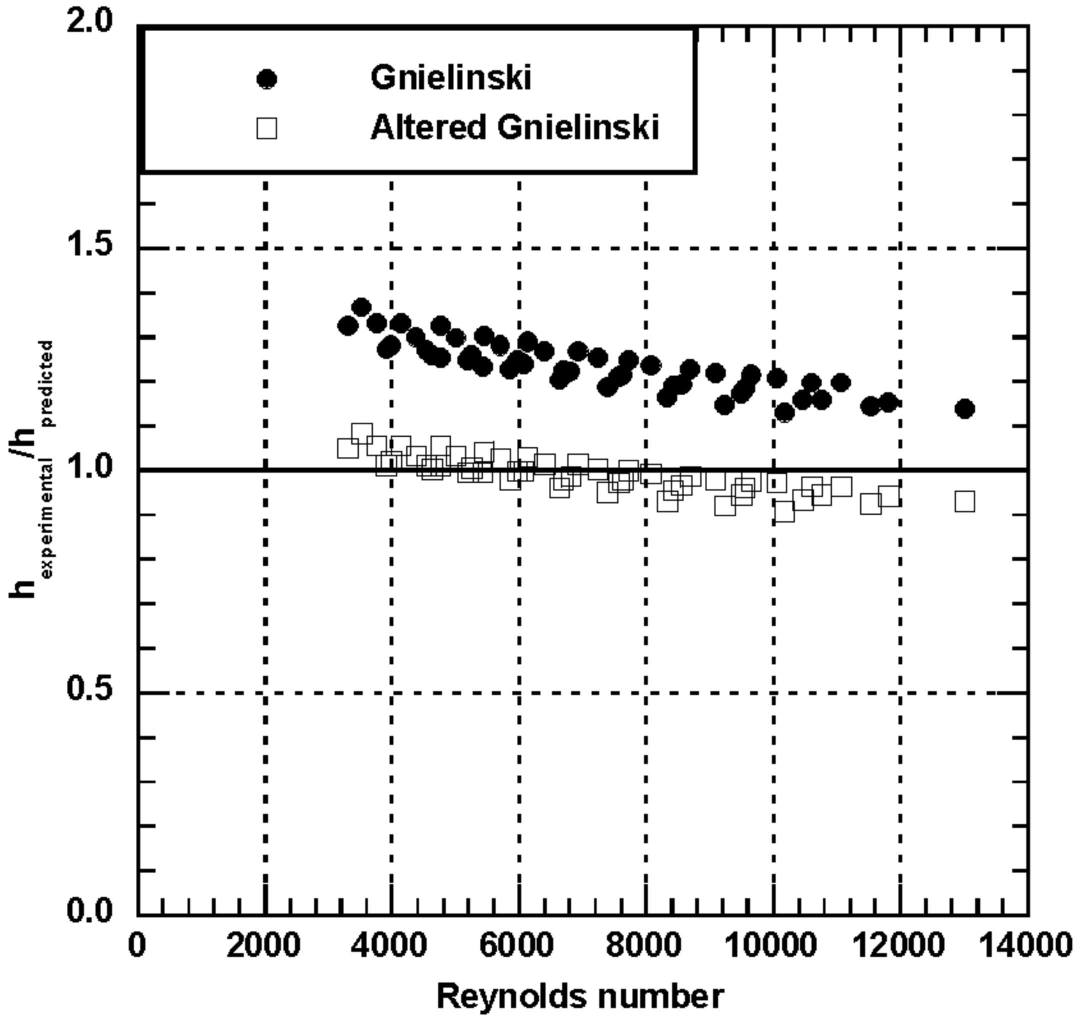
SiC/water nanofluid heat transfer above base fluid, but not when compared on average velocity

Heat Transfer/Pumping Power Merit Parameter



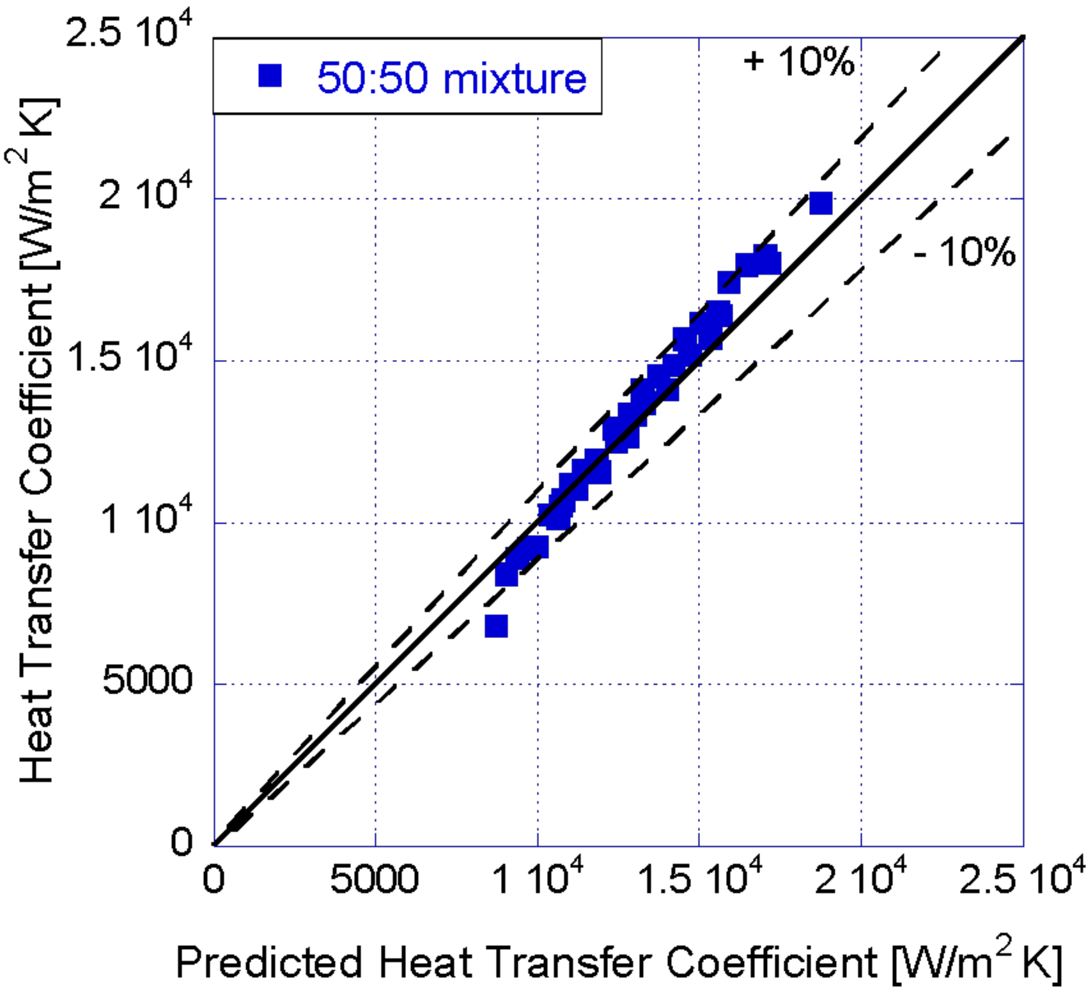
SiC improvement over alumina, but nanofluid with lower viscosity is required

Heat Transfer Enhancement Above Prediction

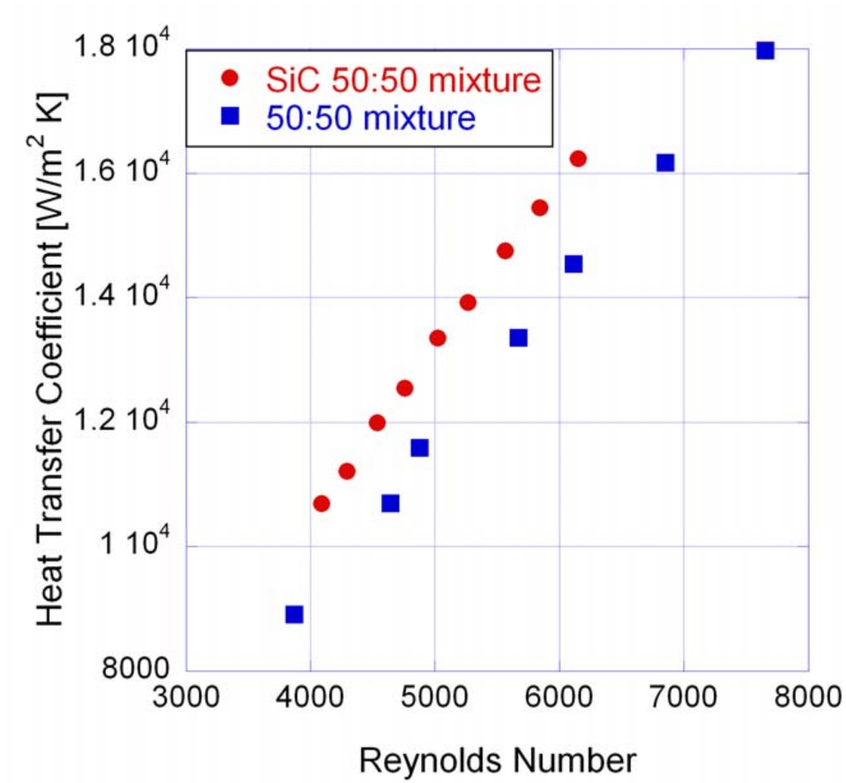


SiC/Water nanofluid heat transfer enhancement is beyond what is expected from suspension properties alone.

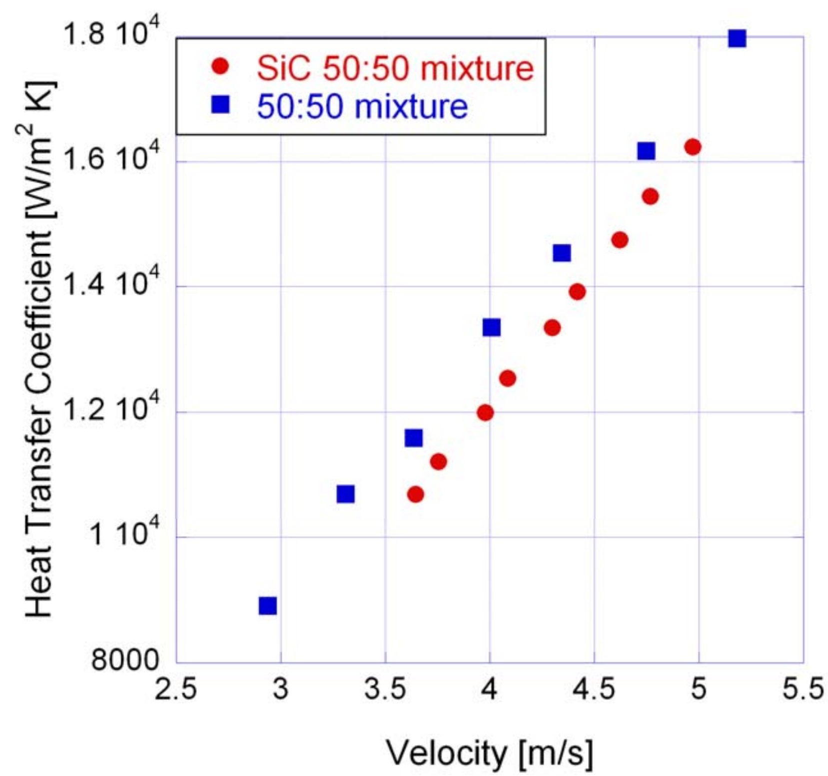
Heat transfer coefficient 50% EG/50%H_2O



Heat transfer enhancement of SiC in 50/50 mixture of ethylene glycol & water

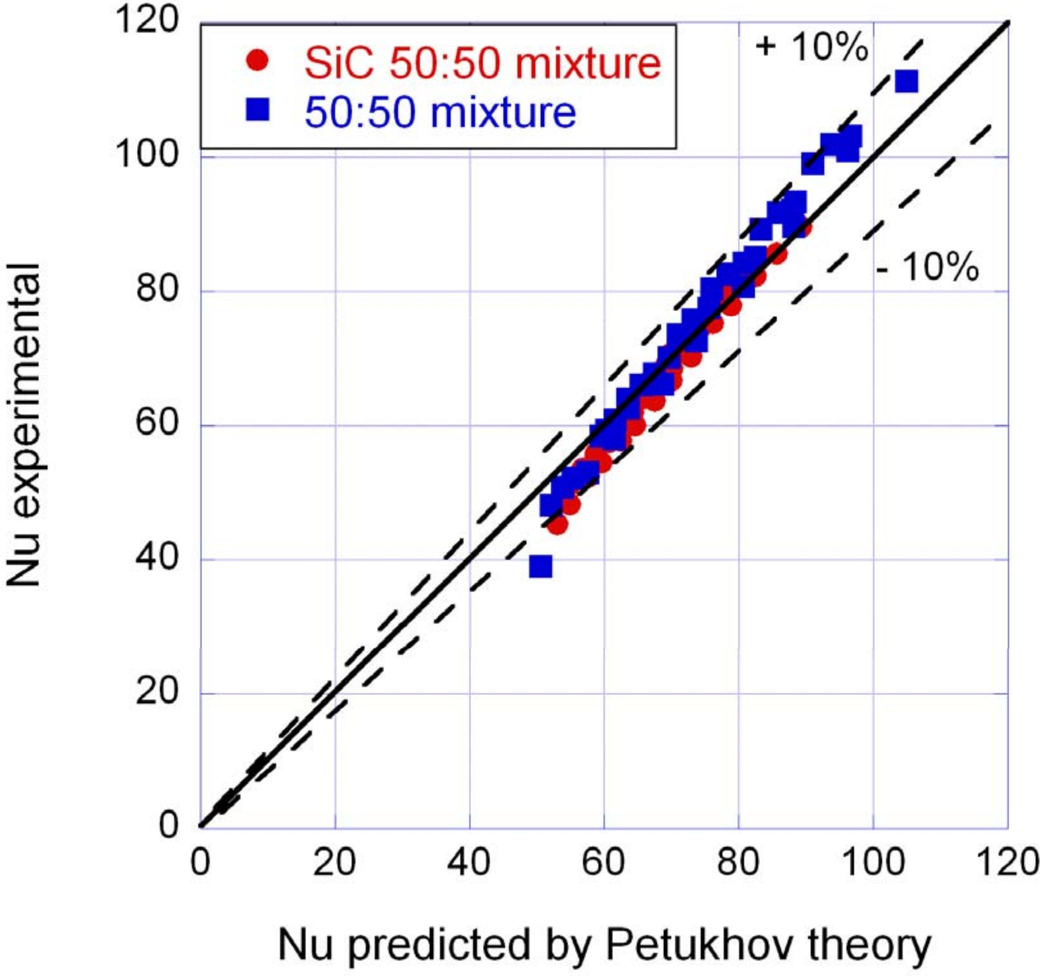


Constant Re



Constant velocity

Heat Transfer Predictions for SiC 50/50 Mixture & for Base Fluid



SiC Nanofluid Heat Transfer Enhancement

- Both water and ethylene glycol/water base fluids
  - Heat transfer is enhanced over base fluid when compared on the basis of constant Reynolds number
  - Heat transfer is slightly below base fluid when compared on the basis of constant velocity
- Nanofluid heat transfer compared to liquid predictive models
  - Nanofluid heat transfer higher than predicted for water base fluid
  - Nanofluid heat transfer well predicted for ethylene glycol/water base fluid
  - Prediction is required for application and fundamental understanding but commercial viability is related to enhancement independent of predictability

Path Forward

- Nanoparticles with higher TC → higher heat transfer
  - Metals
  - Intermetallics
- Viscosity modification to reduce pumping power (≈ velocity)
  - Particle shape/size
  - Surface chemistry
- **Heat transfer coefficient measurements on reduced viscosity nanofluids**
- **CFD simulations**
- Comparison of base fluid to nanofluid using small scale heat exchanger
- Full scale cooling application with industrial partner

Conclusions

- SiC nanofluids show good potential for commercial applications
- SiC nanofluids heat transfer is better than widely studied Alumina nanofluids
- We have identified the critical barriers for the use of nanofluids for cooling applications
- Using lessons learned, we have identified a viable path forward