Nanofluids for HEV Cooling Applications

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November 3, 2011

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FY12 Kickoff Meeting for Advanced Power Electronics and Electric Motors R&D

Sponsored by ***DOE Vehicle Technologies: Vehicle Systems, Propulsion Systems Materials, and Advance Power Electronics***

Objectives

- Analysis of coolant requirements for APE
- Develop cost-effective nanofluids for cooling of APE having:
  - High thermal conductivities
  - High heat transfer
  - Low viscosities
  - No erosion or clogging
- Demonstrate on commercial system

Approach

Work with Valvoline to develop graphite-based nanoparticles in mixture of EG/H_2O while developing ANL nanoparticles

Overview

Timeline

- FY13 – Demo

Budget

- FY11 – $150K (from Propulsion Systems Materials)
- FY12 – $375K (from PEEM, Vehicle Systems, & Materials)

Barriers

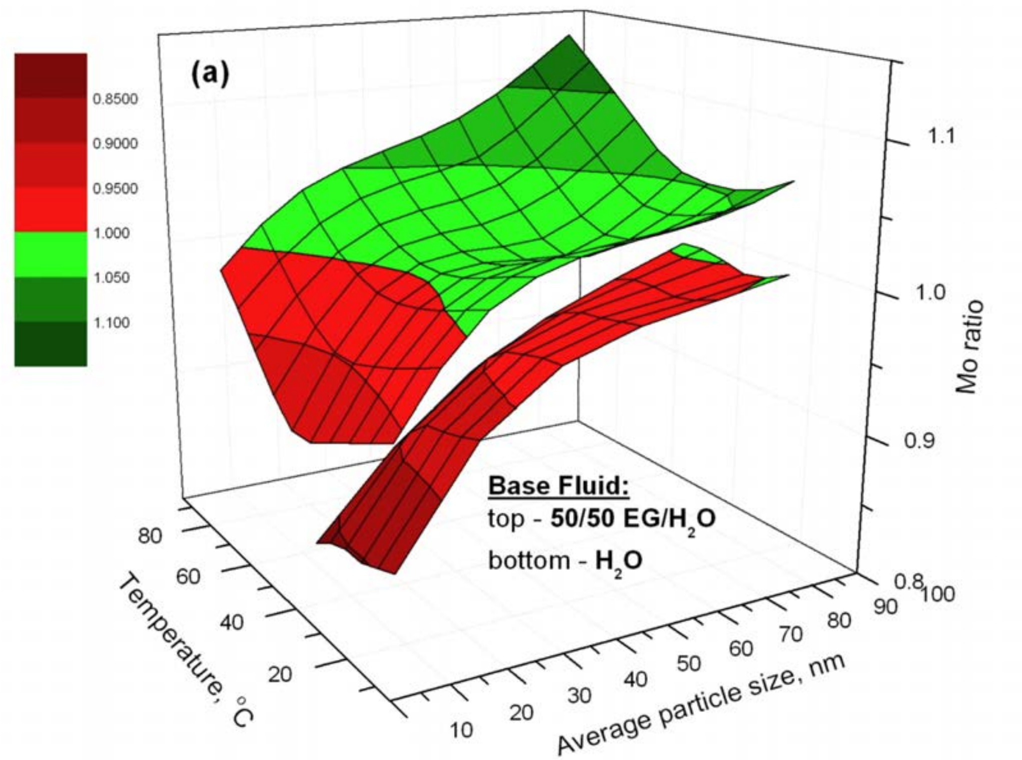
- Potential applications of nanofluids for thermal management in power electronics for HEV not established?

⇒ development of effective, affordable nanofluid
⇒ industrial acceptance
⇒ manufacturability
⇒ needs demonstration

This project complements the overall effort in the area of nanofluids for thermal management with emphasis on cooling for power electronics

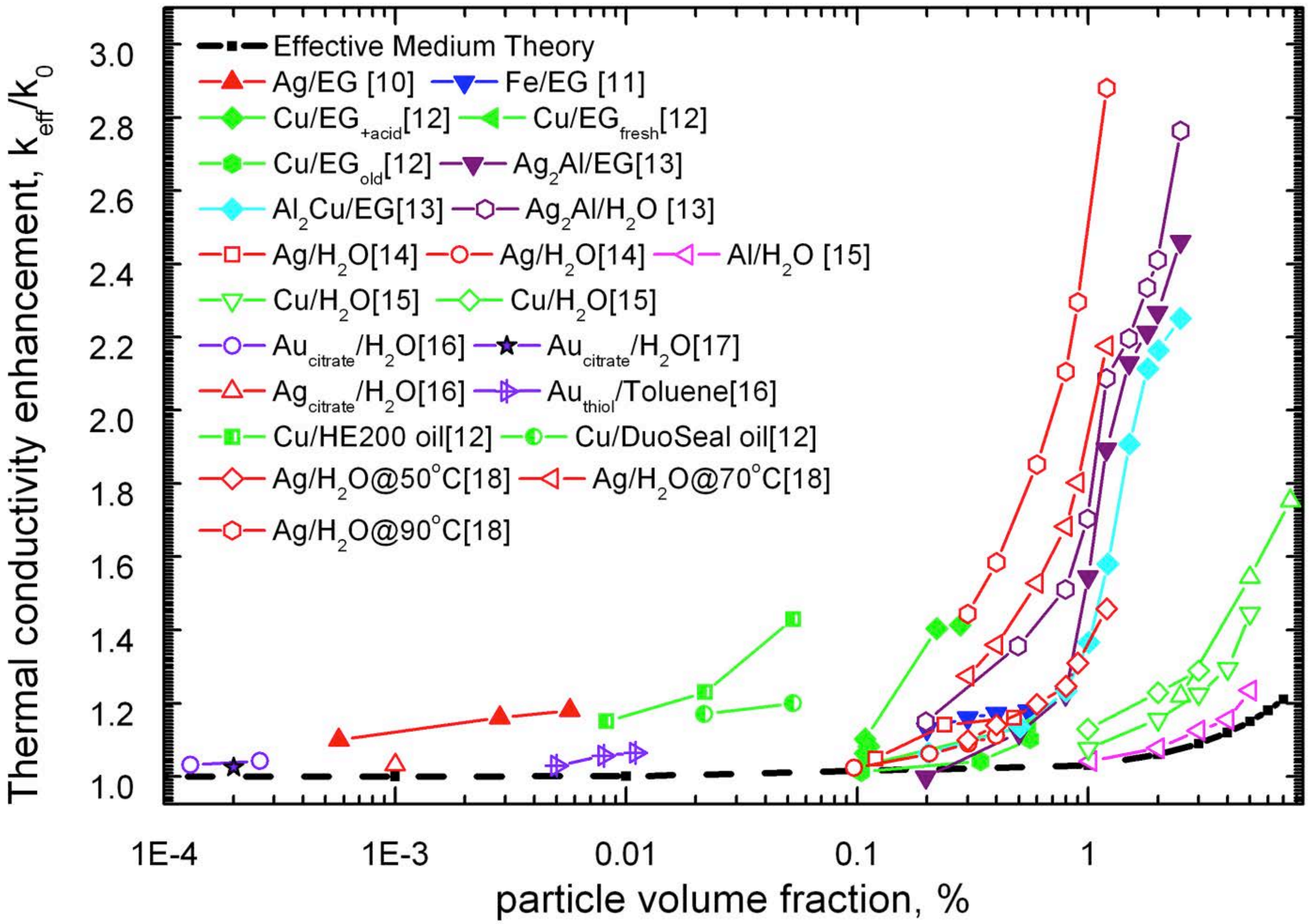
Relevance

- Fluids containing nanoparticles have a <u>proven</u> ability to increase thermal conductivity and heat transfer and hence reduce the size, weight and number of heat exchangers for cooling power electronics.



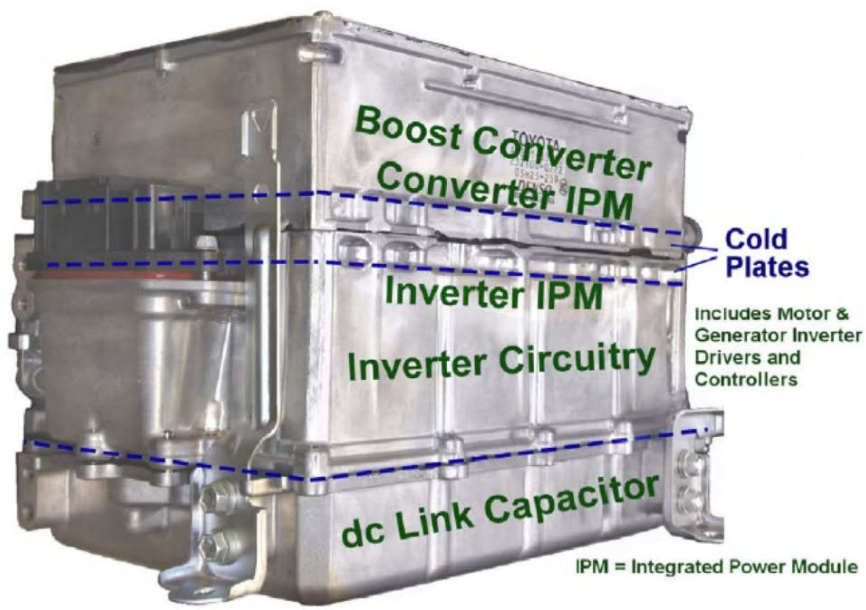
Effectiveness of heat transfer for 4 vol.% SiC in EG/H_2O and H_2O

Literature Data – large enhancements reported



Assessment for power electronics (FY11)

- Determine if nanofluids can be used to improve cooling of HEV power electronics while eliminating the low temperature coolant system.
- Assess the feasibility of engineering nanofluids to cool HEV electronics using only the high temperature coolant system.
- Develop a research program for engineering candidate nanofluids for HEV applications.



Approach

- Specifications of the heat exchanger*
  - Heat flux = 100 W/cm^2
  - Power semiconductor junction temperature – 150°C
  - Convective heat flow to coolant (50-50 EG/water) – 105°C, only the high temperature cooling system is needed in this case
  - Laminar flow

- Estimate properties of nanofluid to meet or exceed cooling requirements
  - Develop 1–D mathematical model of cooling

- Calculations performed with or w/o Thermal Interface Material (TIM)
  - Calculate junction temperature for base and nanofluid for single or double sided cooling

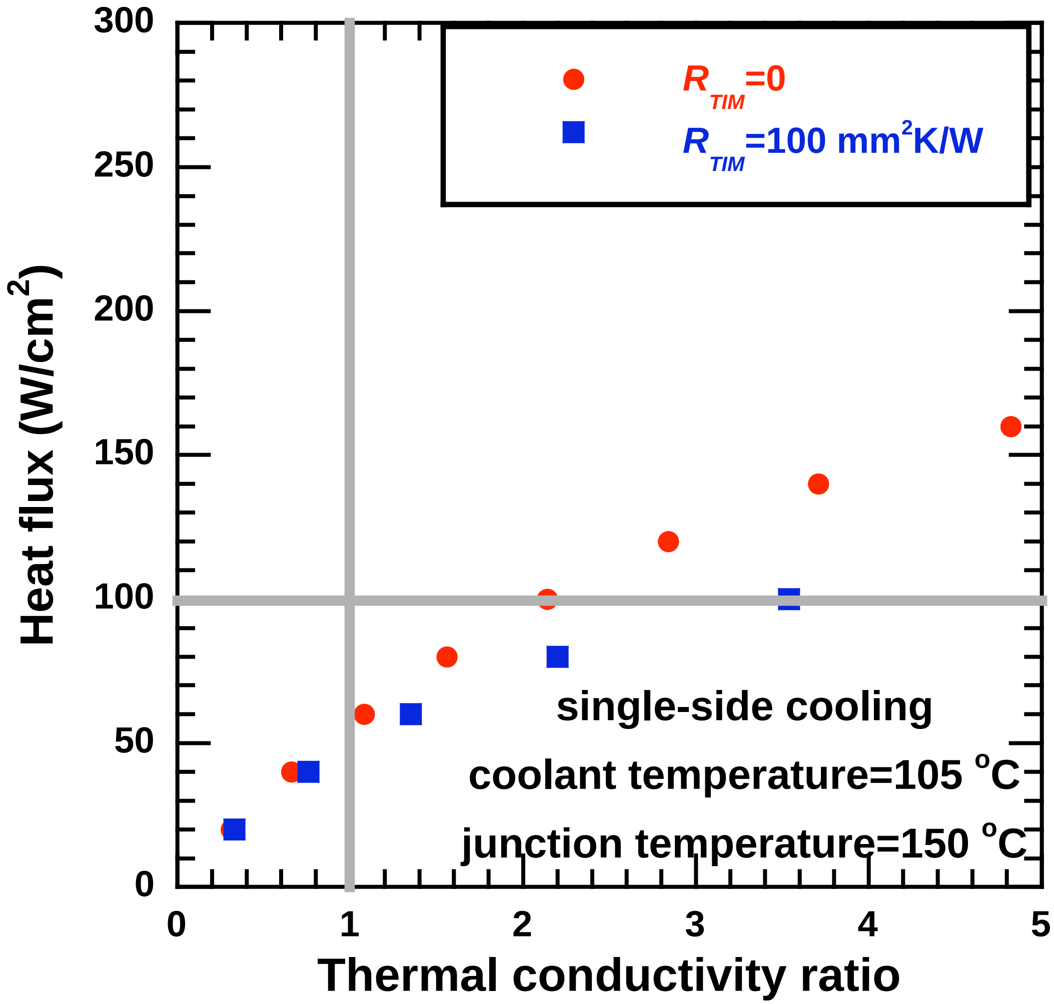
*M. O'Keefe and K. Bennion, A Comparison of Hybrid Electric Vehicle Power Electronics Cooling Options, 2007 IEEE Vehicle Power and Propulsion Systems Conference, Arlington, Texas, September 9-12, 2007.

K. Bennion and K. Kelly, Rapid Modeling of Power Electronics Thermal Management Technologies, 2009 IEEE Vehicle Power and Propulsion Systems Conference, Dearborn, Michigan, September 7-11, 2009.

Results – Heat Flux – Single Sided Cooling

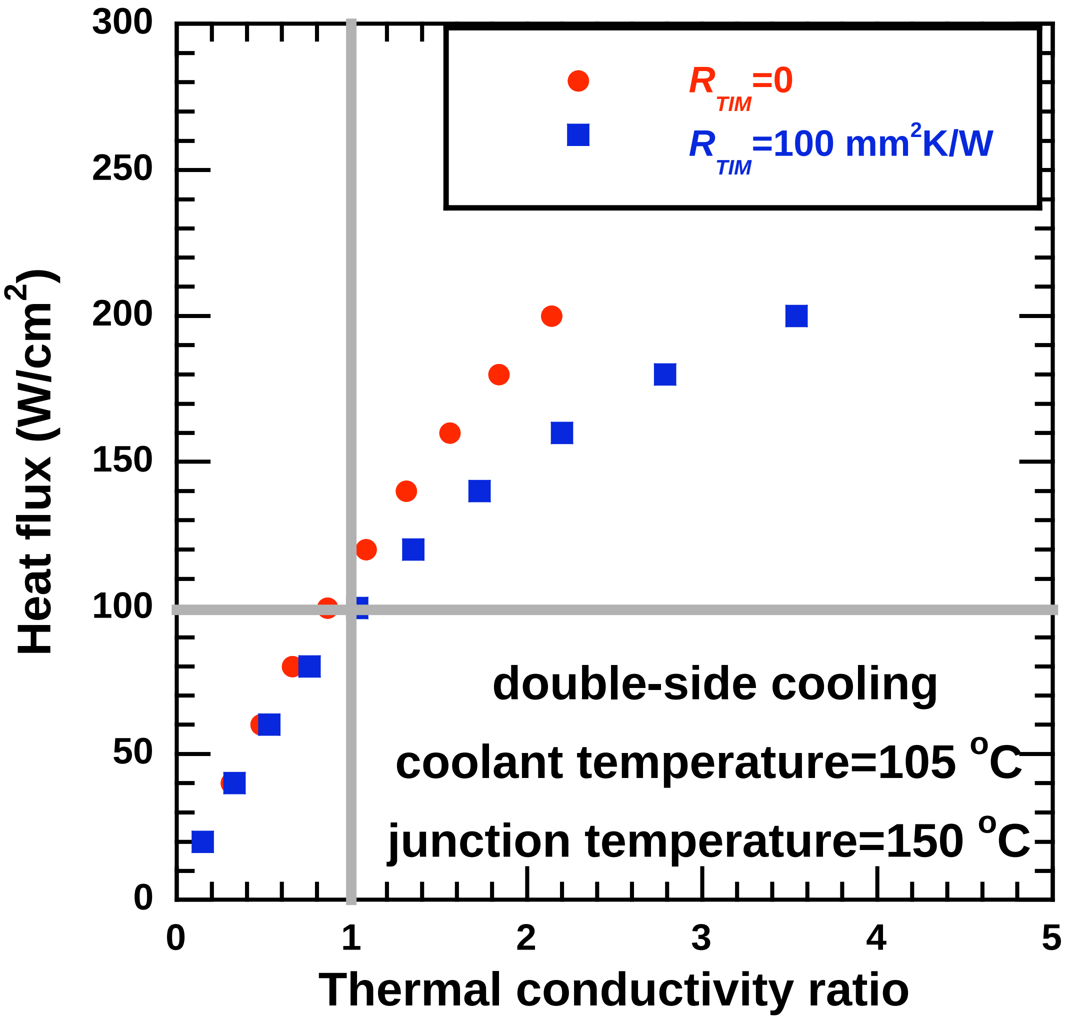
Nanofluid thermal conductivity (TC) ratio of 2 without TIM is sufficient to eliminate the low temperature coolant system.

The required nanofluid is possible with some development.



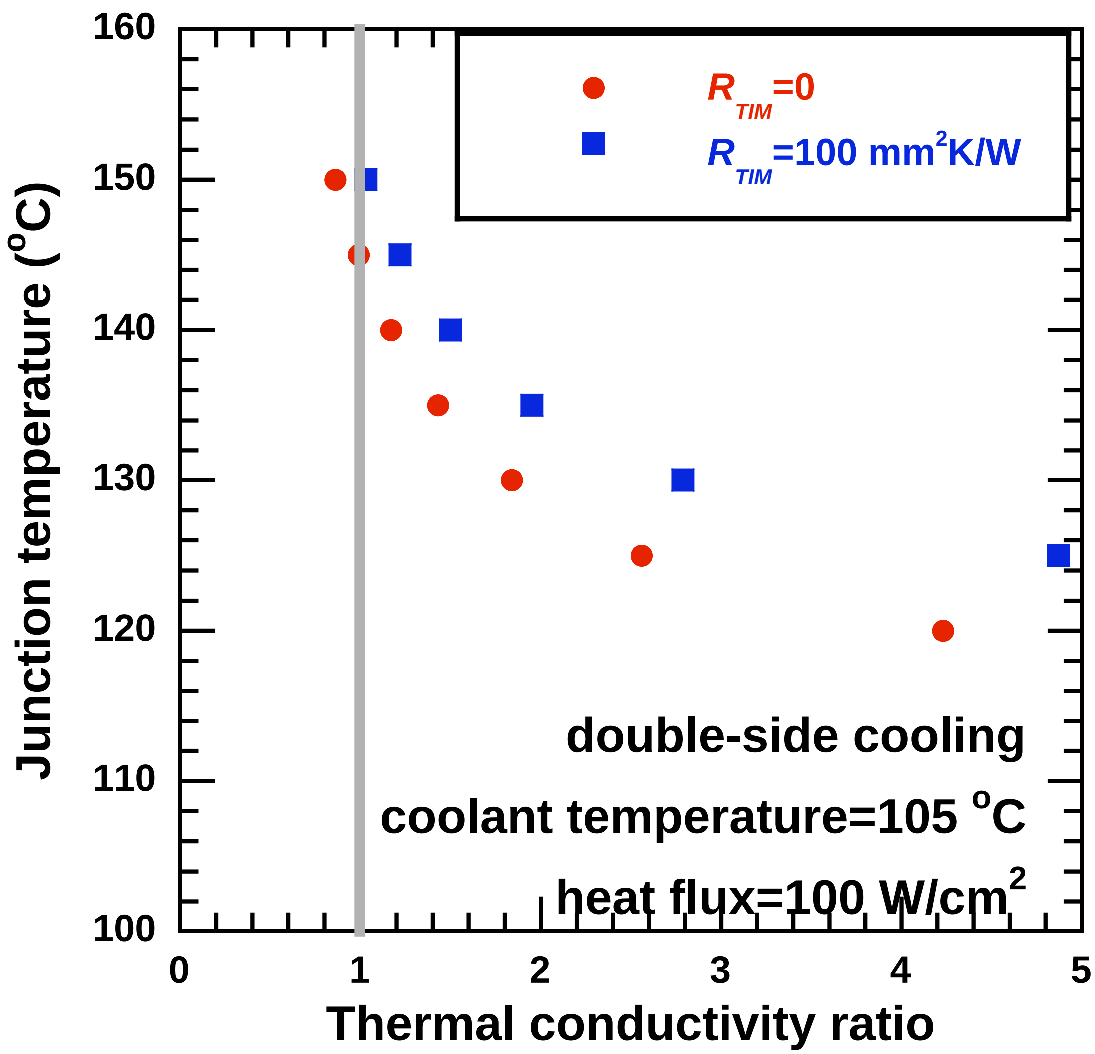
Results – Heat Flux Double-Sided Cooling

A nanofluid TC ratio of 1.5 increases heat load by ≈ 50% with TIM and by ≈ 70% without TIM.

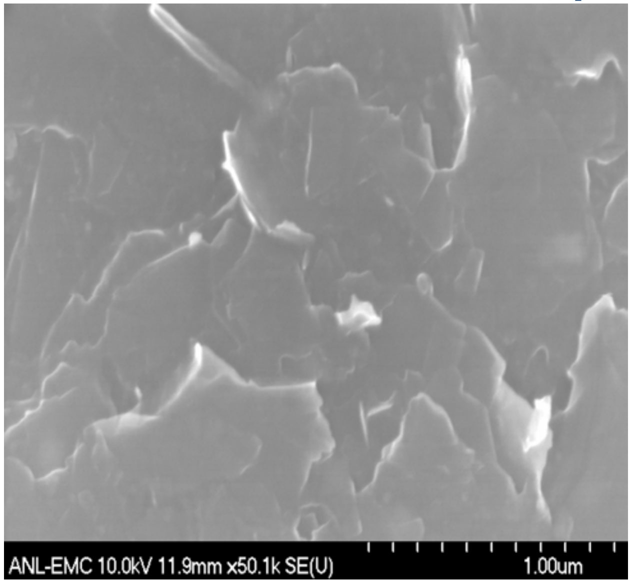


Results – Junction Temperature – Double-Sided Cooling

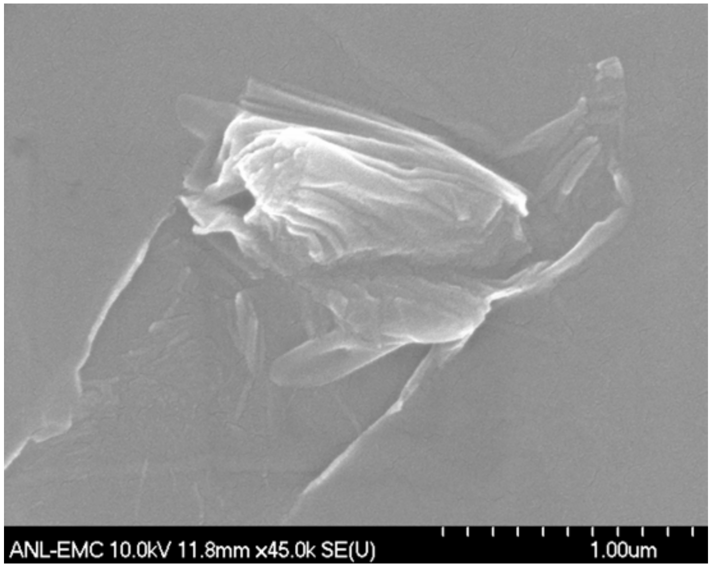
Nanofluid thermal conductivity ratio of 1.5 decreases semi-conductor junction temperature to ≈ 139°C with TIM and to ≈ 135°C without TIM



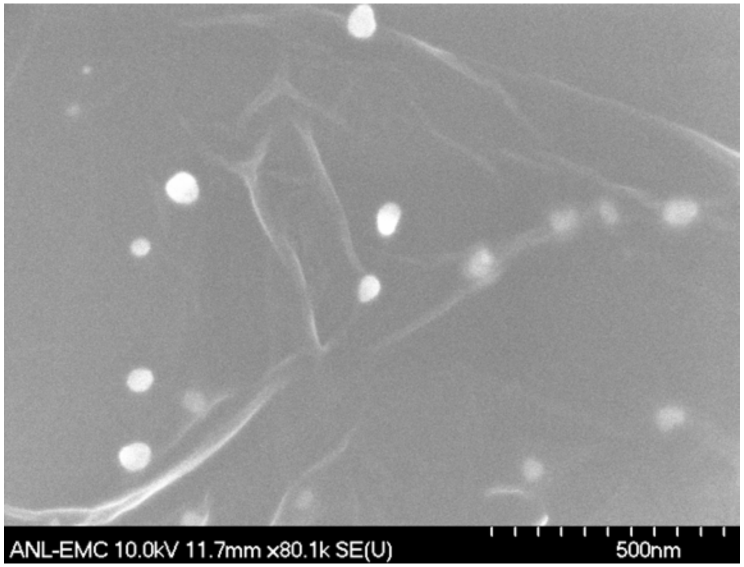
Carbon-based Nanoparticles



Graphite – Valvoline



Graphene oxide – ANL



Graphene oxide with Cu nanoparticles – ANL

Are such nanofluids possible? Thermal Conductivity – Valvoline Graphite in 50/50 Ethylene Glycol/Water + surfactant

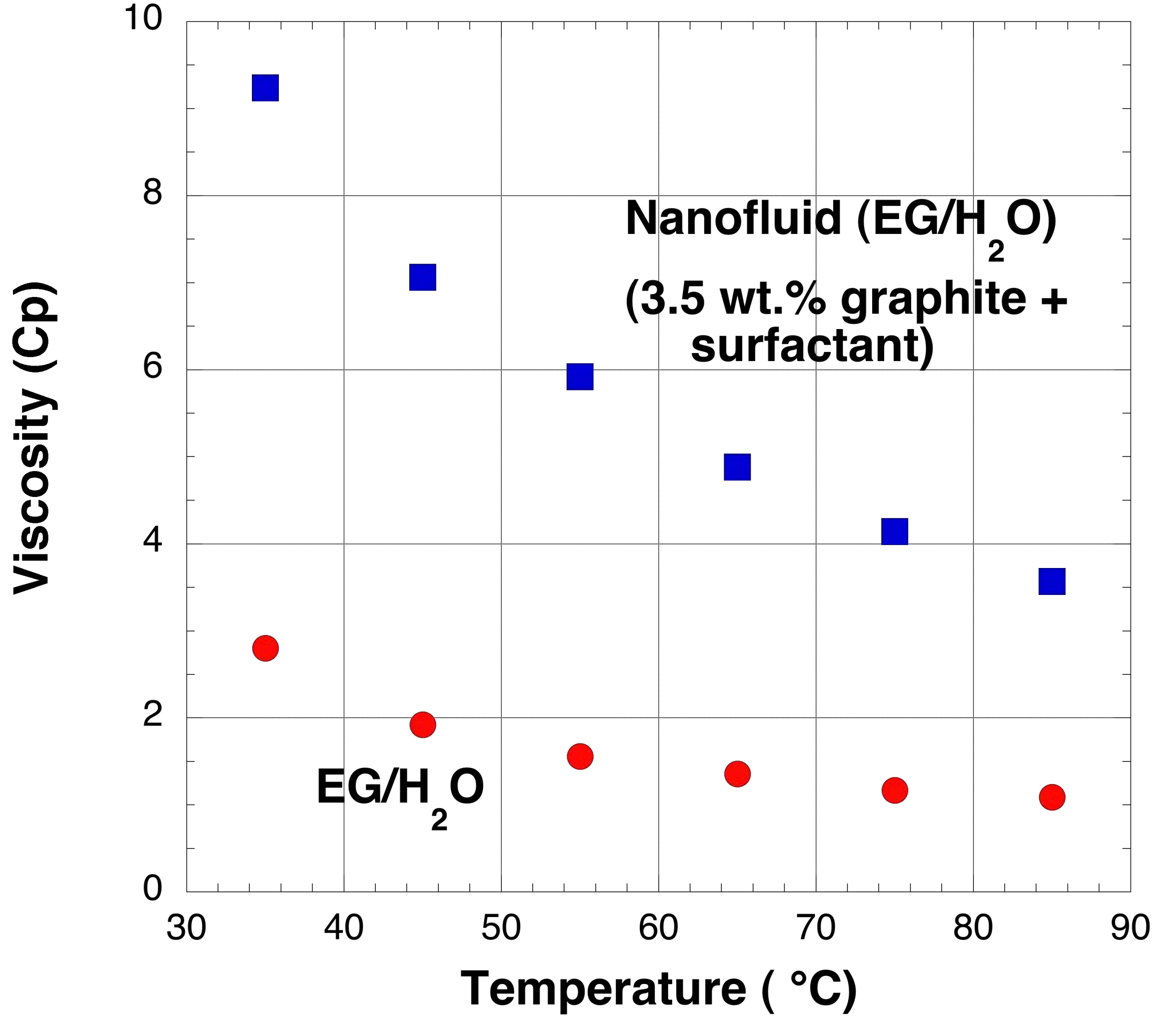
Sample Number	Weight percent (%)	$TC_{nf}/TC_{base\ fluid}$ @ Room Temperature (%)
1	3.5	49.0 ± 2
2	6.0	65.0 ± 5

5 wt. % Graphene Oxide Nanosheets

Fluid	TC enhancement (%) 10–60°C	reference
Water	30.2	1
Propyl glycol	62.3	1
Liquid paraffin	76.8	1
Ethylene glycol	61.0	2

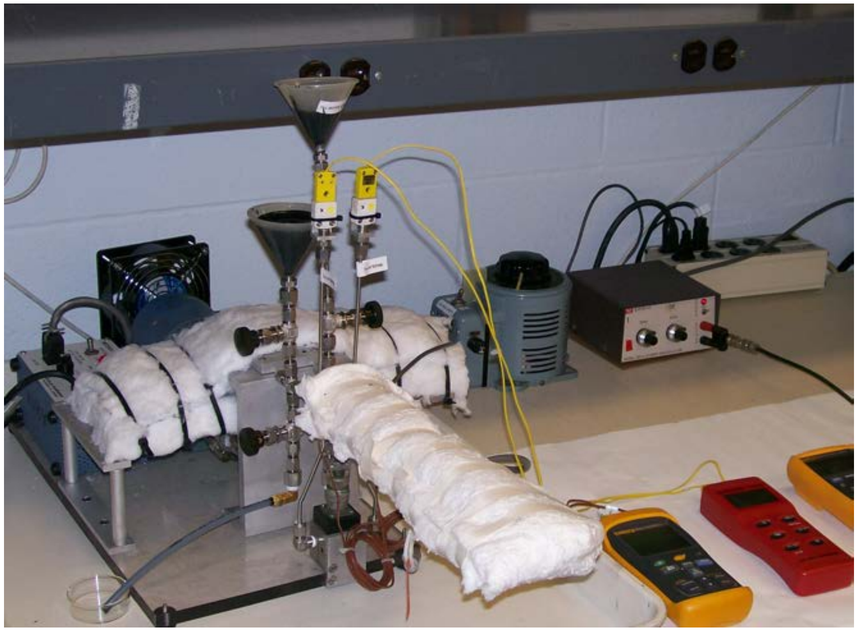
[1]Wei Yu, H. Xie, and W. Chen, JAP 107, 094317 (2010)
[2]Wei Yu, H. Xie, and D. Bao, Nanotechnology 21, 055705 (2010)

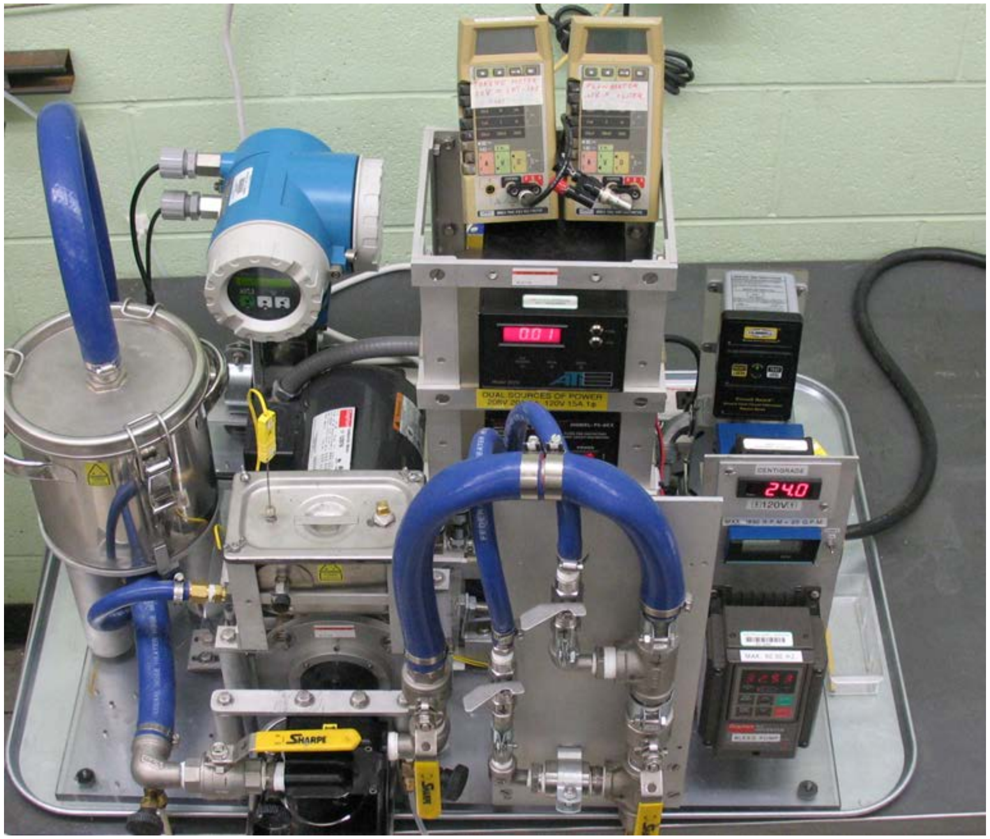
Potential Problems using Graphite (Valvoline) NPs Viscosity



Pumping power of NF/base fluid (@85°C) ≈ 3.5x

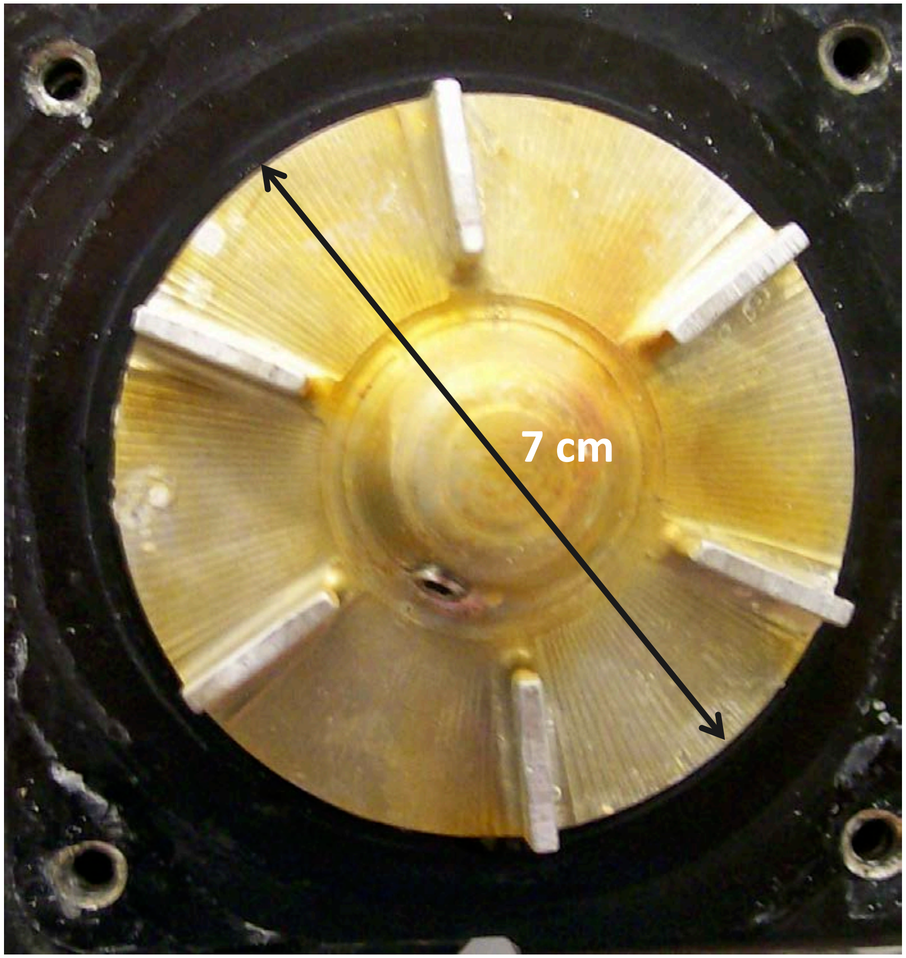
Potential Problems with Graphite NPs





No clogging or erosion observed after hundreds of hours

Little erosion (0.65%) for SiC nanofluid after hundreds of hours for 20 l/min≤V≤28 l/min(1400-1900 RPM



Pump impellor from racing car water pump

Conclusions

- ***Calculations indicate that the DOE goal of eliminating the low temperature coolant system for cooling power electronics can be achieved if the ratio of heat transfer coefficients (equal to the ratio of thermal conductivities in laminar flow) of the nanofluid to the base fluid is about 2 without the TIM in single-sided cooling.***
- ***In double-sided cooling, the low temperature coolant system can be eliminated and the current standards of 100 W/cm^2 heat flux and/or 150^{o}C junction temperature can be improved substantially with a thermal conductivity ratio of about 1.5 with or without the TIM.***
- ***A review of the literature and ANL data indicate that the requirements for a nanofluid can be achieved using inexpensive and non-toxic metal or graphitic nanoparticles.***
- ***Graphene oxide in EG/H2O promising, however, must lower viscosity***
- ***No erosion or clogging observed for graphite-based nanofluids.***

Path Forward

- Develop nanofluids with required thermal conductivity ratios
  - Concentrate on graphene oxide or intermetallic nanoparticles
  - Modify in-situ processing using EG/water as fluid
  - Size
  - Concentration
  - Surface chemistry control to reduce viscosity
  - Measure viscosity, thermal conductivity, heat transfer, clogging and erosion
- Continue to work with Valvoline, Saint Gobain, and Toyota
- Test in an instrumented heat exchanger

Publications on Nanofluids for DoE

(in refereed journals)

- **Effects of Nanofluid Coolant in a Class 8 Truck Engine,** S. K. Saripella, W. Yu, J. L. Routbort, and D. M. France. SAE Technical Series Paper, 2007-01-2141 (2007.)
- **An Investigation of Silicon Carbide-Water Nanofluid for Heat Transfer Applications - Mechanical Effects and Thermal Conductivity**, D. Singh, E. Timofeeva, W. Yu, J. Routbort, D. France, D. Smith, and C. Lopez. J. Appl. Physics, **105**, 064306 (2009)
- **Review and Comparison of Nanofluid Thermal Conductivity and Heat Transfer Enhancements**, W. Yu, D. France, J. Routbort, and S. Choi, Heat Transfer Engineering **29**, 432-460 (2008).
- **Heat transfer to a silicon carbide/water nanofluid**, W. Yu, D. France, D. Smith, D. Singh, E. Timofeeva, and J. Routbort, Intl. J. Heat and Mass Transfer **52**, 3606-3612 (2009)
- **Particle Shape Effects on Thermo-physical Properties of Alumina Nanofluids**, E. V. Timofeeva, J. Routbort, and D. Singh, J. Appl. Physics **106**, 014301 (2009)
- **Application of SAXS to Study Particle Size Dependent Thermal Conductivity in Silica Nanofluids**, G. Chen, W. Yu, D. Singh, D. Cookson, and J. L. Routbort, J. Nanoparticle Research **10**, 1109-1114 (2008).
- **Mechanisms and Models of Effective Thermal Conductivities of Nanofluids,** W. Yu, D. France, D. Singh, E. Timofeeva, D. S. Smith, and J. L. Routbort, Journal of Nanoscience and Nanotechnology 10, 1-26 (2009).
- **Particle Size and Interfacial Effects on Heat Transfer Characteristics of Water and α-SiC Nanofluids**, E. Timofeeva, D. S. Smith, W. Yu, D. M. France, D. Singh, and J. L. Routbort, Nanotechnology, **21**, 215703 (2010).
- **Thermophysical Property-related Comparison Criteria for Nanofluid Heat Transfer Enhancement in Turbulent Flow**, W. Yu, D. France, E. Timofeeva, D. Singh and J. Routbort, Appl. Phys. Letters **96**, 213109 (2010)
- **Base fluid and temperature effects on the heat transfer characteristics of SiC in ethylene glycol/H_2O and H_2O nanofluids**, E. Timofeeva, W. Yu, D. France, D. Singh, and J. Routbort, JAP, **109**, 014914 (2011).
- **Pumping Power of a Water-Based Nanofluid Containing Alumina Nanoparticles**

  J. Routbort, D. Singh, E. Timofeeva, W Yu, and D. France, J. Nanoparticle Research **13,** 931(2011).
- **Nanofluids for Heat Transfer: An Engineering Approach,** E. Timofeeva, W. Yu, D. France, D. Singh, and J. Routbort, Nanoscale Research Letters **6**, 182 (2011).