Nanofluid Development for Engine Cooling Systems

Argonne NATIONAL LABORATORY

... for a brighter future

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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

Control of Thermal Conditions Underhood

FWP 49424/49386 Agreement # 16822

Erosion of Materials

FWP 49113/49381 Agreements #9416/15529

Nucleated Boiling FWP 49425 Agreement # 14758

Overview

Timeline

- Start FY2006
- End date FY2012
- Percent complete 40%

Barriers

- High viscosity of nanofluids
- Pumping power penalties
- Cost of production

Budget

- Total project funding
– DOE share
– Contractor share

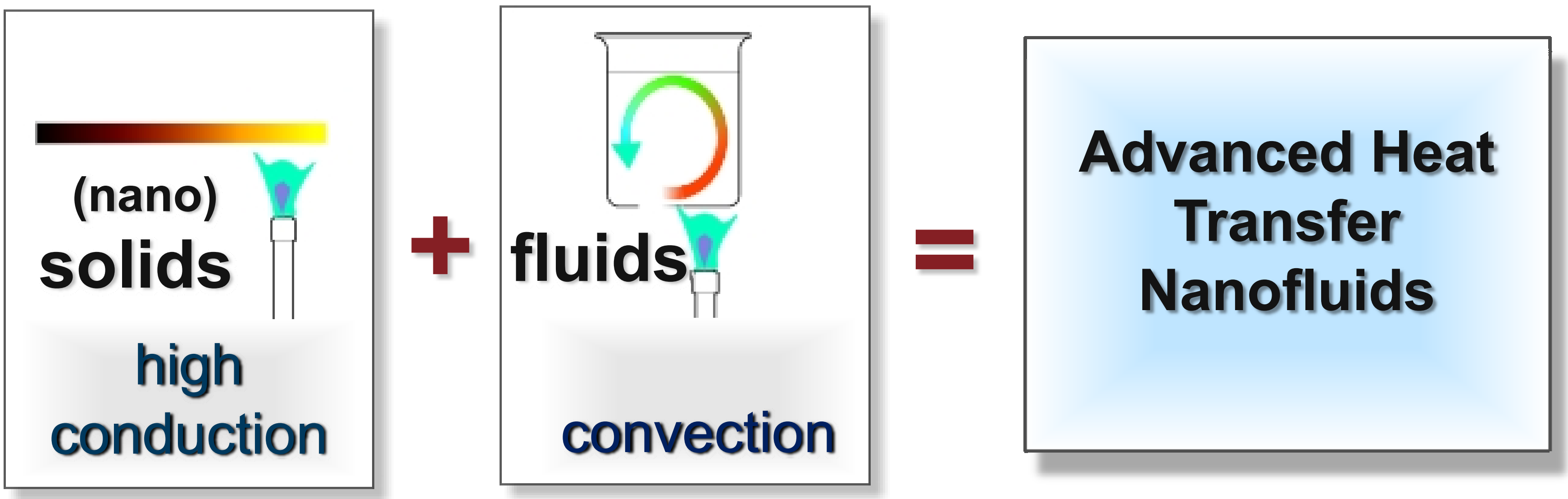
See vss_13_Routbort

- Funding received in FY08: $350K
- Funding for FY09: $400K

Partners

- TARDEC/WFO
- Saint Gobain-cost share
- Michelin WFO/cost-share
- Industrial Technologies Program (DOE)

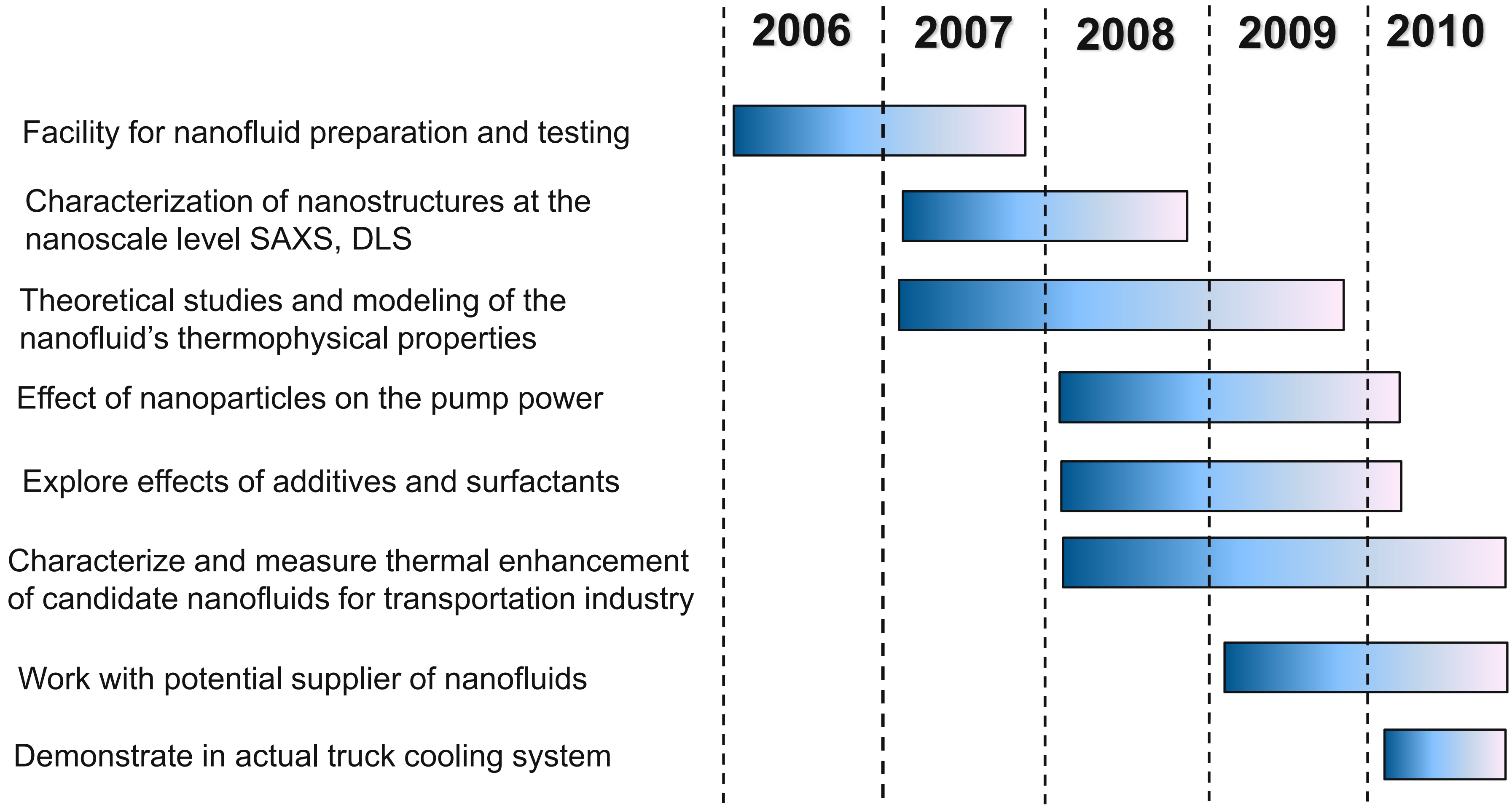
Study Objectives



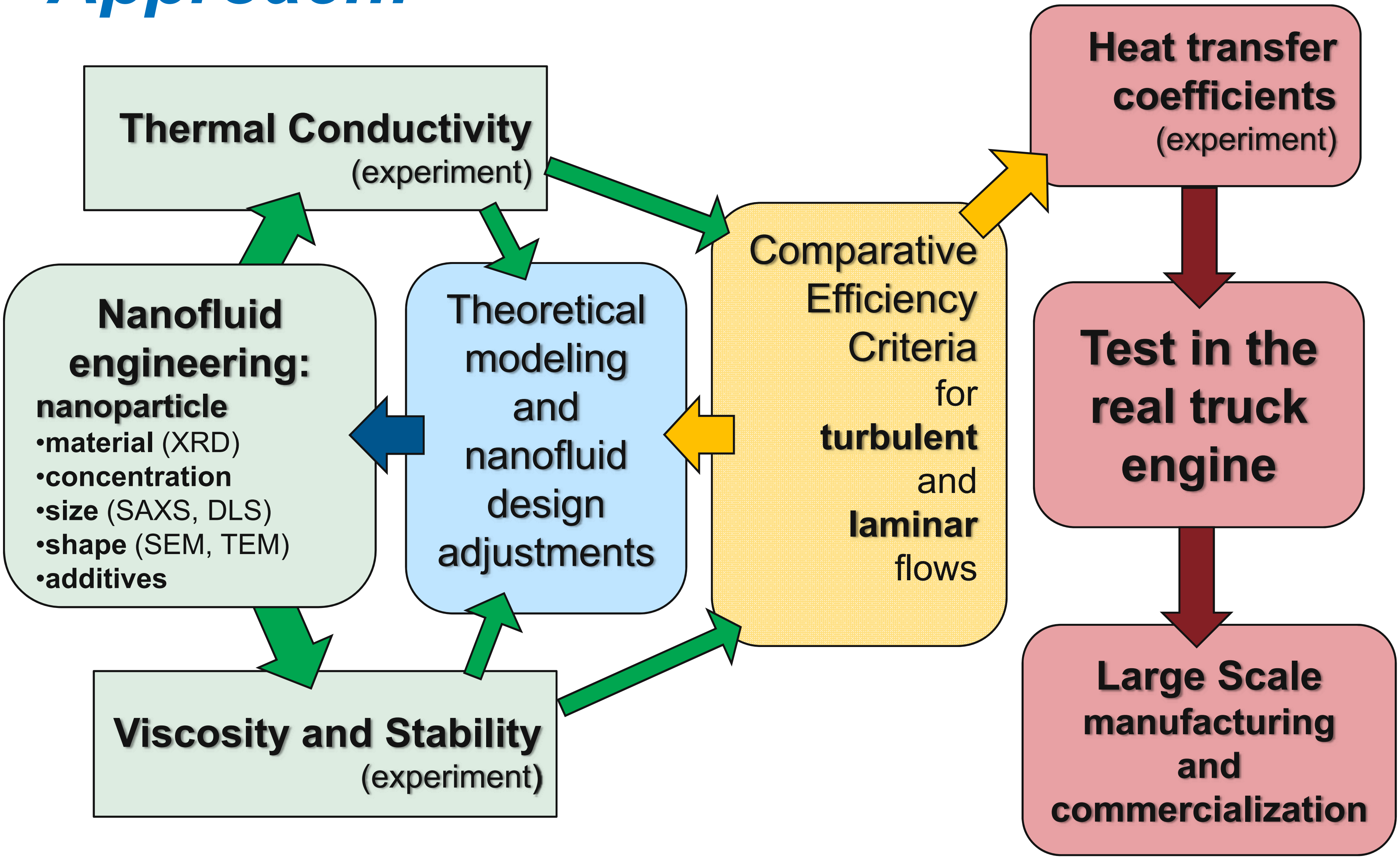
- Development of experimental database and theoretical understanding of thermo-physical properties of nanofluids

- Engineering of high efficiency coolants, that would allow reduction of size of vehicle cooling system and increase overall fuel efficiency

Milestones


2006
2007
2008
2009
2010
Facility for nanofluid preparation and testing
Characterization of nanostructures at the nanoscale level SAXS, DLS
Theoretical studies and modeling of the nanofluid's thermophysical properties
Effect of nanoparticles on the pump power
Explore effects of additives and surfactants
Characterize and measure thermal enhancement of candidate nanofluids for transportation industry
Work with potential supplier of nanofluids
Demonstrate in actual truck cooling system

Approach:


Thermal Conductivity
(experiment)
Nanofluid engineering:
nanoparticle
•material (XRD)
•concentration
•size (SAXS, DLS)
•shape (SEM, TEM)
•additives
Theoretical modeling and nanofluid design adjustments
Comparative Efficiency Criteria for turbulent and laminar flows
Viscosity and Stability
(experiment)
Heat transfer coefficients
(experiment)
Test in the real truck engine
Large Scale manufacturing and commercialization

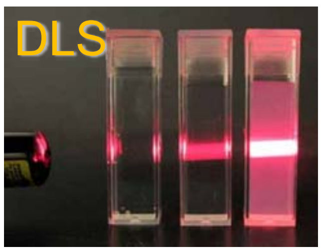
Experimental Approach:

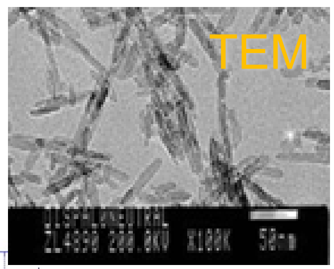
- Optimization of material properties for nanofluid manufacturing

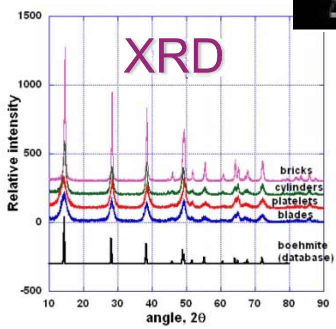
Effect of
- Particle shape
- Particle size
- Base fluid effect
- Additives

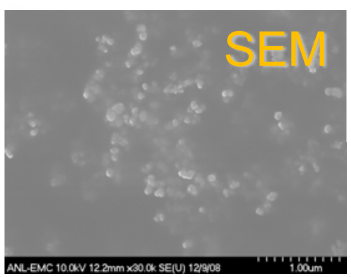
on
- Thermal Conductivity
- Viscosity

→ **Heat transfer coefficient**









- Testing of nanofluid performance at various temperatures

Theoretical approach:

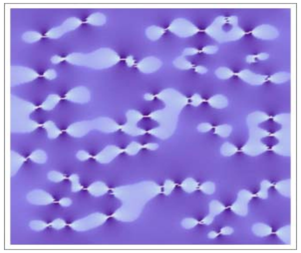
- **Figures of Merit :** *laminar* and *turbulent* flow

$$\left.\begin{aligned}\frac{k_{nf}}{k_0} &= 1 + C_k\phi \\ \frac{\eta_{nf}}{\eta_0} &\approx 1 + C_\eta\phi\end{aligned}\right\} \boxed{C_\eta/C_k < 4}$$

Prasher R. et al., Appl. Phys. Lett. **89**, 133108 (2006).

$$Mo = \frac{\rho^{0.8} c_p^{0.33} k^{0.67}}{\eta^{0.47}} \Big\} \boxed{Mo_{nf}/Mo_0 > 1}$$

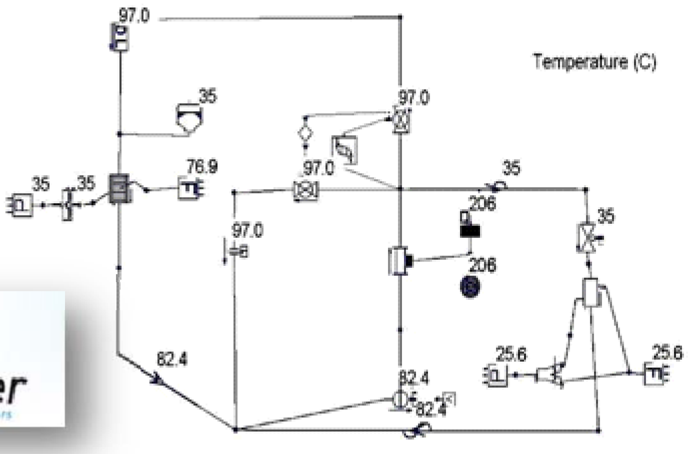
heat current through the nanofluid sample



- **Modeling** of thermal conductivity and viscosity trends on particle concentration, size, shape and properties of base fluid

- **Simulations** of nanofluid performance for heavy vehicle cooling systems using Flowmaster® thermo-fluid system simulation software

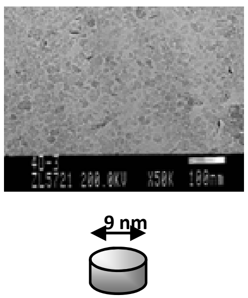
Flowmaster
Fluid thinking for systems engineers



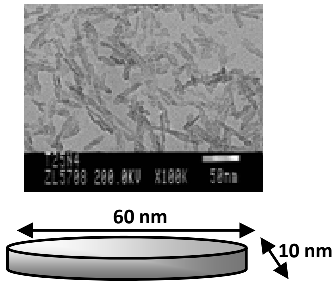
Technical Accomplishments/Progress/Results

➢ **Investigated effect of nanoparticle shape on thermal conductivity and viscosity of boehmite alumina (AlOOH) nanofluids in EG/H_2O:**

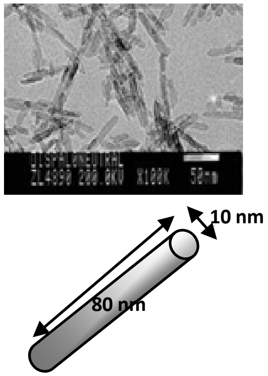
Platelets



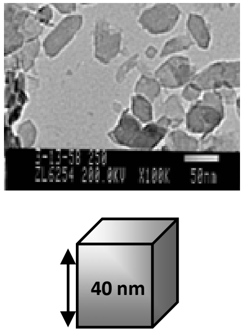
Blades

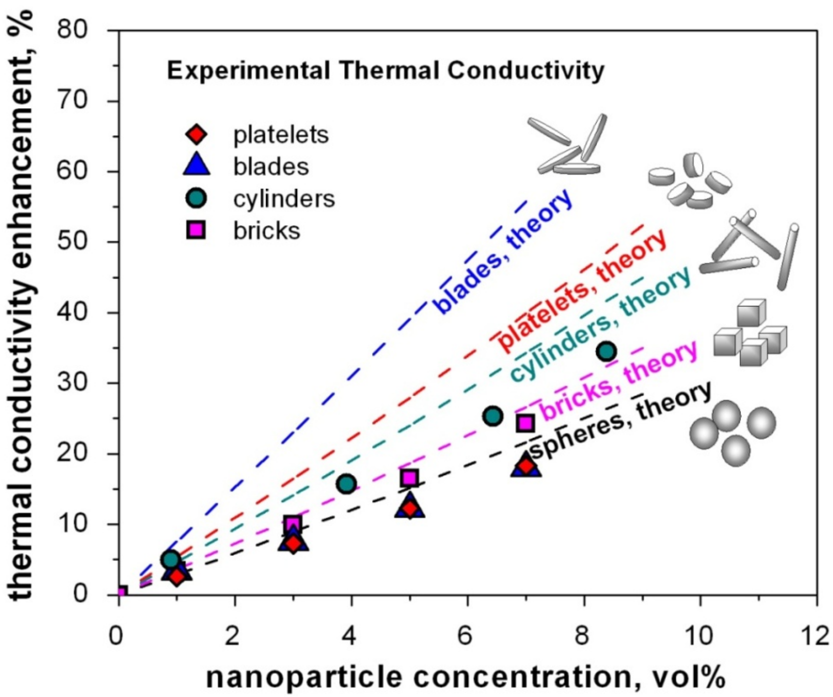


Cylinders



Bricks





•Nanoparticle phase and crystallite sizes by powder XRD

• Particle sizes and agglomeration in solution by DLS and SAXS

Thermal conductivity enhancement varies with shape of nanoparticle, but not as classical theory predicts

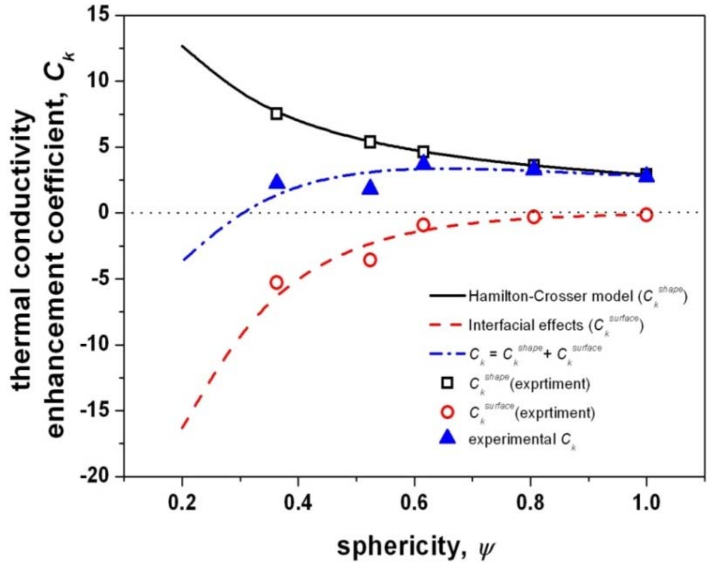
Technical Accomplishments/Progress/Results

Thermal conductivity (boehmite alumina (AlOOH) nanofluids in EG-H_2O):
Showed the importance of interfacial heat resistance (Kapitza resistance) which contribution is proportional to the total surface area of nanoparticles (i.e. varies with particle sizes/shapes (particle sphericity))

Interfacial effects interfere with particle shape effect reducing projected thermal conductivity of nanofluids

$$\frac{k_{nf}}{k_0} = 1 + (C_k^{shape} - C_k^{surface})\phi$$

Calculated
Kapitza resistance value for boehmite (AlOOH)/EG-H_2O interface

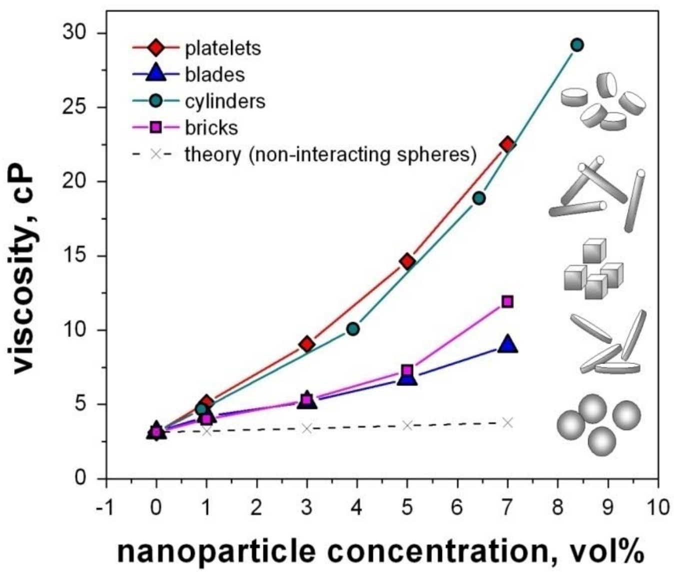


This finding is a significant accomplishment revealing new trends and directions for engineering of advanced heat transfer nanofluids

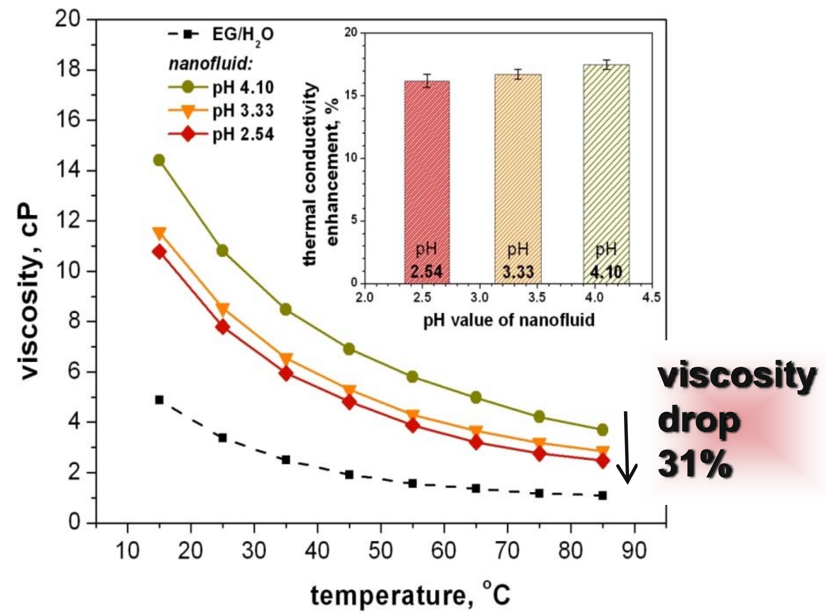
Technical Accomplishments/Progress/Results

Viscosity (boehmite alumina (AlOOH) nanofluids in EG-H_2O):

Increase in viscosity above the theoretical value on one hand is due to shape effect (structural constrains to flow) and on the other hand is due to low surface charges and particle-particle interactions



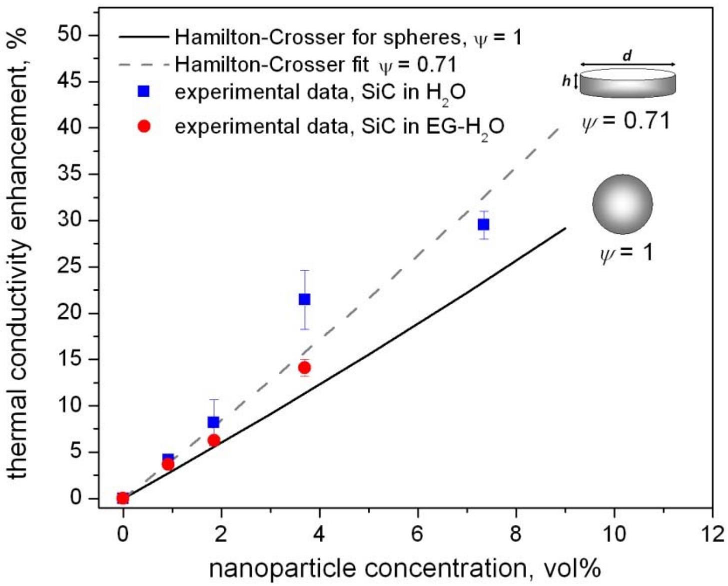
Surface charges can be modified by pH and/or surfactants, resulting in reduced viscosity with no effect on thermal conductivity

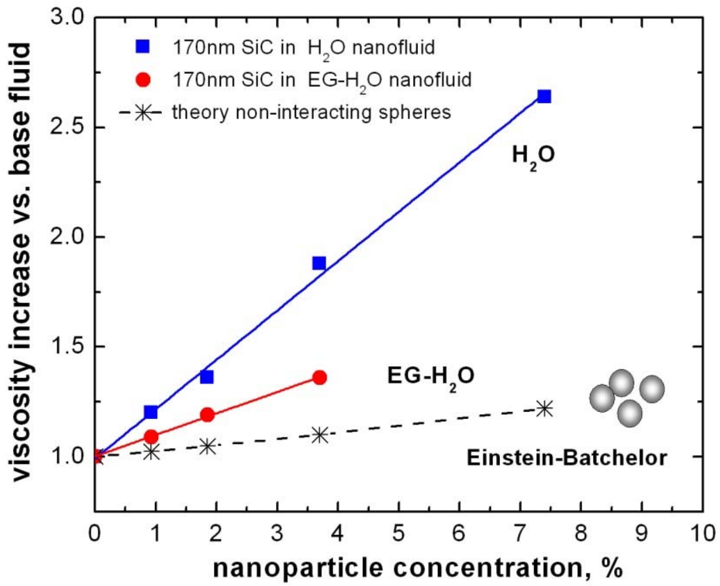


This indicates the potential of overcoming high viscosity and pumping power penalty barriers

Technical Accomplishments/Progress/Results

- **Studied thermal conductivity and viscosity of α-SiC in H_2O and EG/H_2O:**





Ratio of viscosity/ thermal conductivity increase is lower in EG-H_2O based nanofluid, indicating higher efficiencies of EG-H_2O based nanofluids for cooling applications

Future Work

- Parametric study of thermodynamic properties of nanofluid for improving cooling efficiency and possibility to reduce radiator size by more than 10%
- Engineering of nanofluids with lower Kapitza resistance at solid/liquid interface to achieve higher thermal conductivity, explore new materials for nanofluid preparation (metals and intermetallics)
- Study the effect of base fluid on the suspension performance
- Investigate the potential of viscosity modification for prospective nanofluids
- Test heat transfer properties of prospective nanofluids for transportation industry (small scale heat exchanger)
- Work with potential nanoparticle supplier and OEM partners

Summary

- **Critical parameters for efficiency of nanofluids as future coolants have been identified**
- **Complexity of nanofluidic systems has been addressed by systematic approach and advanced understanding of nanoscale contribution to viscosity and thermal conductivity has achieved**
- **Paths for overcoming high viscosity and pumping power penalties barriers have been identified**
- **Combination of experimental and theoretical studies (modeling + simulation) allows us to engineer nanofluids with desired parameters, tied to a particular application**