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Nanofluids

for Thermal Control Applications

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This presentation does not contain any proprietary or confidential information.

Purpose of Work

- Exploit the high heat transfer rates of nanofluids for transportation applications by identifying and characterizing:
  - Thermal properties
  - Physical attributes
  - Heat transfer rates
- Develop nanofluid technology for vehicle thermal control
- Improve/optimize heavy vehicle cooling system efficiency
  - Reduce system size
    - Reduce aerodynamic drag (increase in fuel efficiency of 2-5%)
  - Reduce parasitic pump power

Barriers to Commercial Nanofluid Use

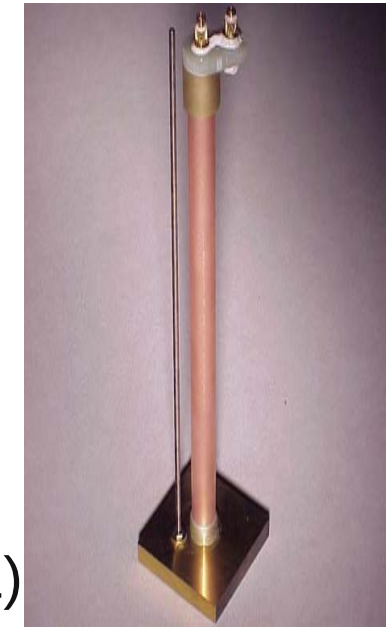
- Basic understanding and predictive capabilities
- Experimental data base of thermal and flow properties
- Commercially viable nanofluids
  - Long term stability
    - Agglomeration
    - Settling
  - High thermal enhancement
  - Minimal fluid viscosity increase
  - Minimal erosion and clogging
  - Non-toxic and environmentally benign
  - Cost effective

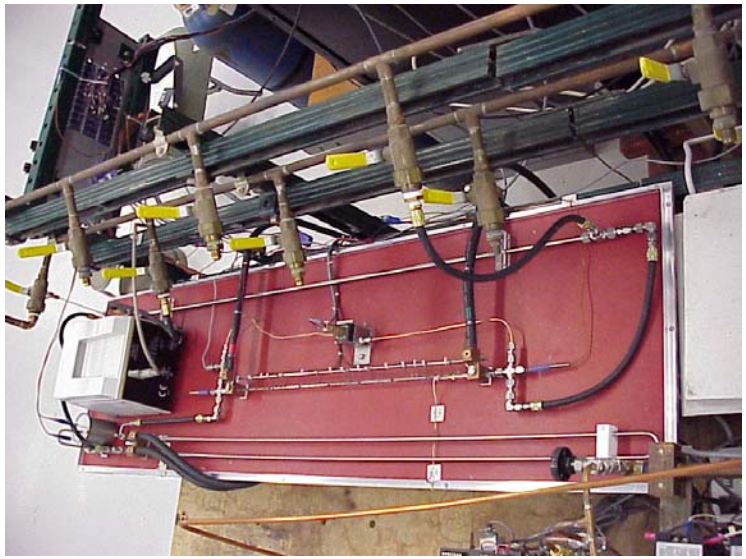
Approach to Nanofluid Development

- Measure key thermal parameters
  - Thermal conductivity
  - Viscosity
  - Heat transfer rate
- Develop models for
  - Heat transfer design
  - Nanofluid selection
  - Vehicle system design
- Measure/determine characteristics (details in nanofluid erosion presentation)
  - Particle suspension
  - Particle agglomeration
  - Particle size and shape
  - Erosion potential
- Perform system tests with transportation companies
  - Work for others in progress with major tire manufacturer

Experimental Approach

- Key nanofluid properties vs temperature
  - Hot wire technique for thermal conductivity
  - Viscometer
- Nanofluid size and shape characteristics
  - Small angle X-ray scattering (SAXS) (APS at ANL)
  - Laser scattering apparatus
  - Electron microscopy
- Convection heat transfer apparatus
- Erosion testing apparatus





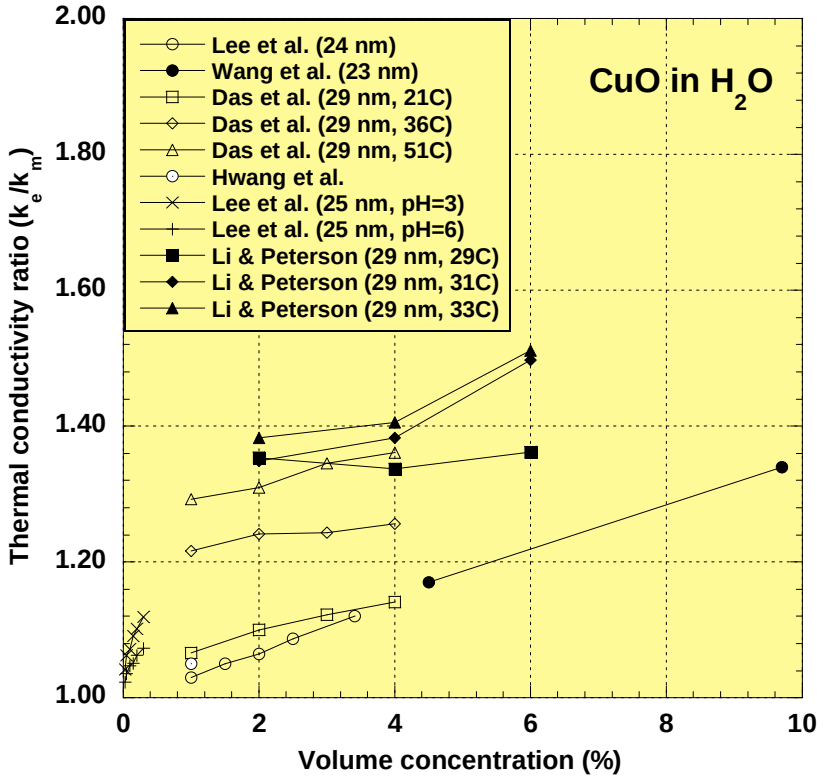
Performance Measures –
Progress in Meeting Objectives

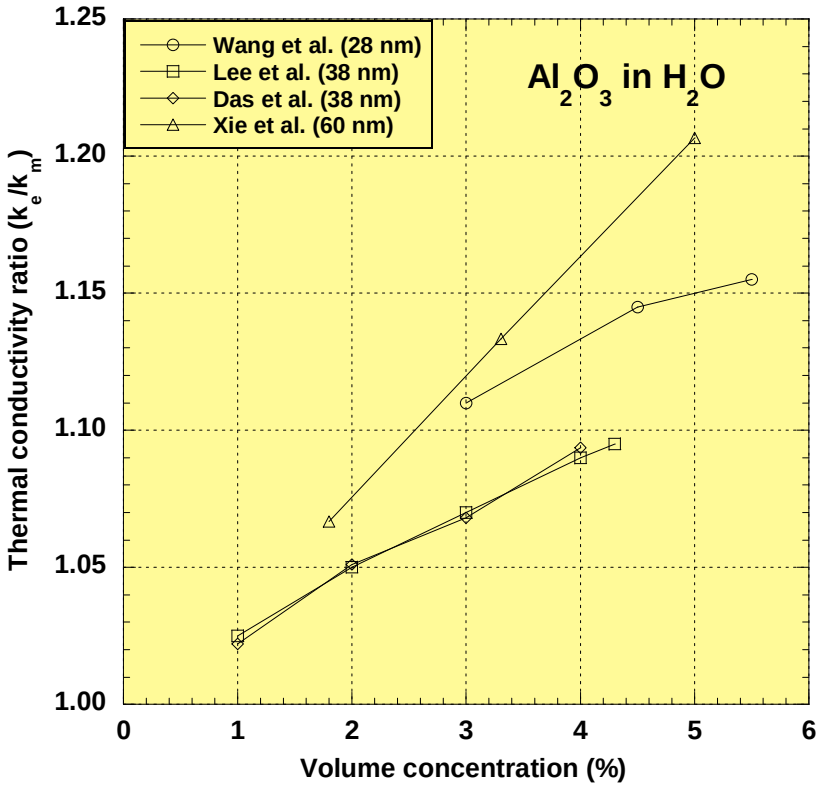
- Identification of nanofluid thermal trends
- Quantification of nanofluid potential in heavy vehicle cooling systems
- Complete nanofluid characterization capability
- Development of nanofluids in cooperation with potential commercial sources

Accomplishments

- Completed comprehensive literature review/assessment of nanofluid experiments and predictions
  - Thermal conductivity
  - Heat transfer rates
- Recast all data to consistent enhancement ratio to allow direct comparisons among results
- Identified eight areas of thermal trends
  - Reproducibility
  - Consistency
  - Multiple research laboratories

Sample results from literature assessment: Particle concentration and size effects on thermal conductivity enhancement of nanofluids





Other thermal enhancement effects assessed

- Thermal conductivity
  - Particle material
  - Particle shape
  - Base fluid material
  - Temperature
  - Additive
  - Acidity

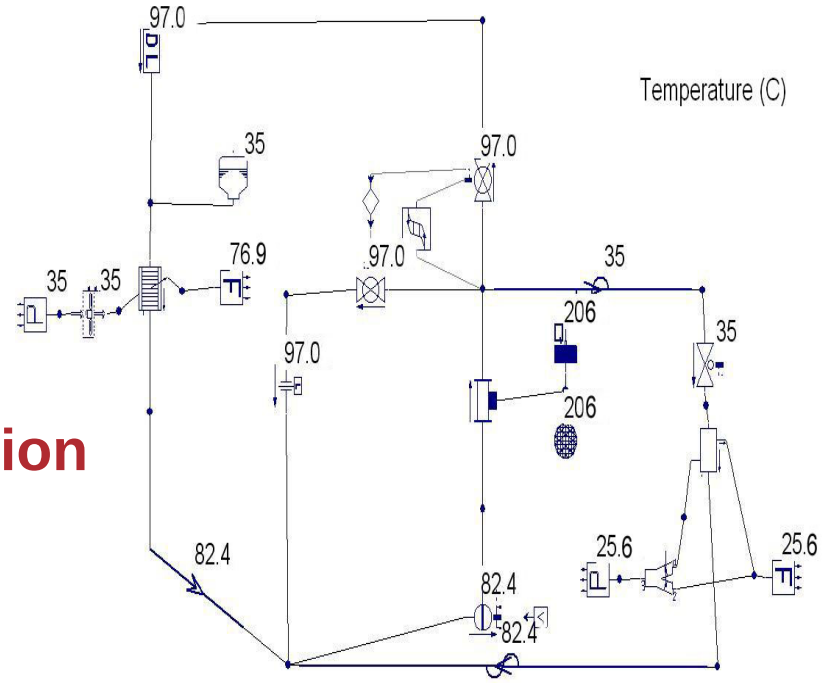
- Heat transfer rate
  - Laminar flow – single phase
  - Turbulent flow – single phase
  - Pool boiling

Accomplishments

- Numerical simulations (Flowmaster) quantifying the effects of nanofluids used as engine coolants in over-the-road heavy vehicles
  - Class 8, 500 hp, diesel (Cummins generic)
  - Three coolants
    - 50-50 water-ethylene glycol mixture = base fluid
    - 2 vol. % CuO nanoparticles in base fluid
    - 4 vol. % CuO nanoparticles in base fluid
  - Three options simulated
    - Increase fuel economy from reduced radiator size & aerodynamic drag
    - Reduced coolant pump power
    - Increased engine power

Flowmaster simulation results –
Reduced radiator size with nanofluid coolants

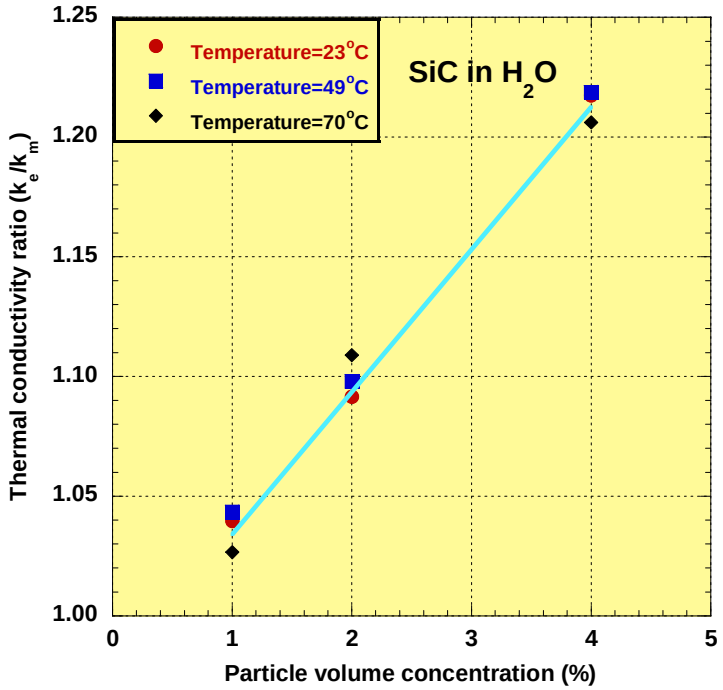
- 4 vol.% CuO in 50-50 water-ethylene glycol mixture
- 5% airside area reduction
- Reduced aerodynamic drag
  - 2.5% increased fuel economy
  - **300 x10^6 gallons/yr fuel reduction**



Base fluid temperature

Accomplishments –
Progress in development of commercial nanofluid

- Nanofluid characterization
  - Nanofluid temperature–dependent
    - Thermal conductivity
    - Viscosity
  - Nanoparticles in suspensions
    - Size
    - Shape



Thermal conductivity enhancement
- Enhancement level good
- Increases with concentration
- No temperature effect beyond H_2O

Nanofluid stability – good

Nanofluid agglomeration - minimal

Technology Transfer

- Current project with Michelin Tire Corp. - commercial application of nanofluid
- Working with potential producers of commercial nanofluids
- Contacted by
  - Major truck manufacturer
  - Military

Nanofluid Activities for Next Fiscal Year

- Continue development of commercially viable nanofluids
  - High thermal conductivity
  - Well characterized
  - Stable
- Conduct characterization tests to determine the physical structure of the nanoparticles in suspension
- Conduct experiments to determine nanofluid properties of thermal conductivity and viscosity
- Conduct nanofluid heat transfer experiments to quantify the heat transfer enhancement
- Refine models of nanostructure-enhanced and nanoparticle-mobility-enhanced thermal conductivity of nanofluids for cooling system performance simulation

Summary

- Potential for petroleum displacement
  - 300 million gallons/yr reduction in diesel fuel consumption
- Approach to research
  - Seven experimental facilities/instruments for extensive measurements of nanofluid characteristics and thermal parameters
- Technical Accomplishments
  - Literature assessment
  - Quantitative numerical system assessment
  - Progress in commercial nanofluid development
- Technology Transfer
  - Major tire manufacturer
  - Enabling technology
- Plans for Next Fiscal Year in support of commercial nanofluid development
  - Heat transfer and thermal conductivity measurements
  - Characterization and basic understanding/prediction
  - Argonne engineered nanofluids

Publications (for reviewers only)

- W. Yu, D.M. France, S.U.S. Choi and J.L. Routbort, “Review and Assessment of Nanofluid Technology for Transportation and Other Applications,” Argonne National Laboratory Technical Report, ANL/ESD/07-9, April 2007, 78pp.

- W. Yu, D.M. France, S.U.S. Choi and J.L. Routbort, “Review and Comparison of Nanofluid Thermal Conductivity and Heat Transfer Enhancements,” accepted for publication in Heat Transfer Engineering Journal.

- S. K. Saripella, D. M. France, W. Yu, Rizwan-uddin, J. L. Routbort, “Effects of Nanofluid Coolant in a Class 8 Truck Engine,” accepted for publication in the SAE Transactions.