Nanofluids for Improved Efficiency in Cooling Systems

Steve Choi

Energy Systems Division

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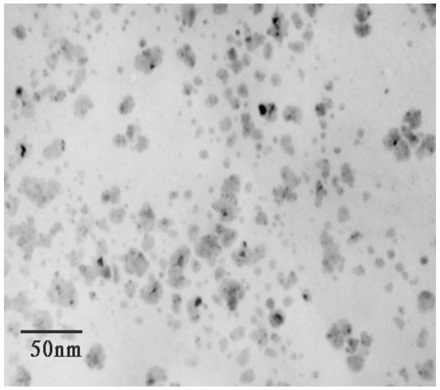
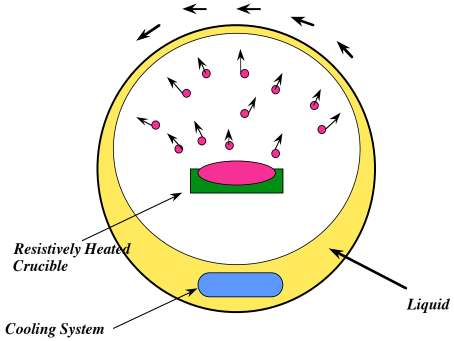
PROJECT OVERVIEW 1
PROJECT FOCUSES ON DEVELOPMENT OF NANOTECH-BASED HEAT TRANSFER FLUIDS



- Nanofluids, nanoparticle-fluid suspensions, are a new class of heat transfer fluids engineered by dispersing nanometer-size solid particles in traditional heat transfer fluids.
- Argonne researchers produced nanofluids and discovered that nanofluids have a much higher and strongly temperature-dependent thermal conductivity at very low particle concentrations than conventional radiator coolants without the nanoparticles.
- We have demonstrated that nanofluids have significantly better heat transfer properties than the base fluids.
- Nanofluids are promising future coolants for the transportation industry.
- This project is focused on the development of nanofluids as nanotech-based heat transfer fluids.



PROJECT OVERVIEW 2
NEW CONCEPTS AND TECHNOLOGY ARE REQUIRED

- The HV industry problem our project is trying to solve
  - The trend toward higher engine power and EGR inevitably leads to larger radiators and increased frontal areas, resulting in additional aerodynamic drag and increased fuel consumption.
  - Therefore, cooling is one of the top technical challenges facing the truck industry.
  - Limitations of existing technologies
    - Liquid-side: traditional coolants and oils have inherently poor heat transfer properties.
    - Air-side: current radiator designs for increasing air-side heat transfer have already adopted extended surface technology to its limits.
- Therefore, there is a steadily increasing need for new concepts and technology for improving HV cooling system performance.

PROJECT OVERVIEW 2 - Cont'd
ARGONNE HAS PIONEERED NANOFLUID TECHNOLOGY

- Our group has pioneered nanofluid technology to meet the increasingly important cooling challenge.
- The research, development and application of nanofluids are imperative and invaluable for improving efficiency in the 21CT cooling systems.

PROJECT OVERVIEW 3
PROJECT GOAL

- This project targets fuel savings for the HV industry through the development of energy efficient nanofluids and smaller and lighter radiators.
- A major goal of the nanofluid project is to reduce the size and weight of the HV cooling systems by >10% thereby increasing fuel efficiency by >5%, despite the cooling demands of higher-power engines and EGR.
  - Nanofluids enable the potential to allow higher temperature coolants and higher heat rejection in HVs. A higher temperature radiator could reduce the radiator size by perhaps 30%. This translates into reduced aerodynamic drag and fluid pumping and fan requirements, leading to perhaps a 10% fuel savings.
  - If we can reduce radiator size by even 10% by the higher heat rejection, the drag coefficient decreases by 10% and the fuel efficiency increases by 5% at highway speeds.

PROJECT OVERVIEW 3 - Cont'd
RELEVANCE TO OFCVT GOALS

- Therefore, the HVSO technical target to reduce cooling system size for a Class 7-8 truck by 8% and 21CT goal to increase heat load rejected by thermal management systems by 20% without increasing radiator size are well within reach.

PROJECT OVERVIEW 4
PLANNED DURATION

- Planned Duration: October 1999 to September 2009
- The project is in the last stage of exploratory research and, although the thermal phenomena of NFs are still mysterious, we have an understanding of some of the mechanisms of enhanced thermal properties of nanofluids.
- Now is the time to move from research to development. We need to generate practical knowledge of how nanofluids perform in the real world cooling systems in terms of fuel economy, cost, quality, and safety.
- The barriers
  - Production of nanofluids is limited only to our research. Therefore, scale-up of production volumes is the most serious technical barrier to radiator and full vehicle cooling tests primarily due to limited funding.
  - More characterization of nanofluids needs to occur before coolant systems can be designed around them.
- For achieving the project's goal through FY09 and for NF tech to impact the industry we need
  - Increased DOE funding.
  - Collaboration with the industry - use their test facilities and expertise to save time and money.

OBJECTIVES AND FY2006 FOCUS

- Project Objectives
  - Develop nanotech-based heat transfer fluids with ultra-high thermal conductivity by exploiting the unique properties of nanoparticles.
  - Characterize the thermal properties and heat transfer performance of nanofluids.
  - Determine the mechanisms of enhanced thermal properties of nanofluids.
  - Develop new models and simulation tools for nanofluids.
  - Develop and transfer nanofluid technology for vehicle thermal control to the industry.
- FY2006 Focus
  - Produce and characterize nanofluids containing monosized NPs <10 nm.
  - Conduct flow and heat transfer experiments with base fluids and nanofluids in laminar and turbulent flow.

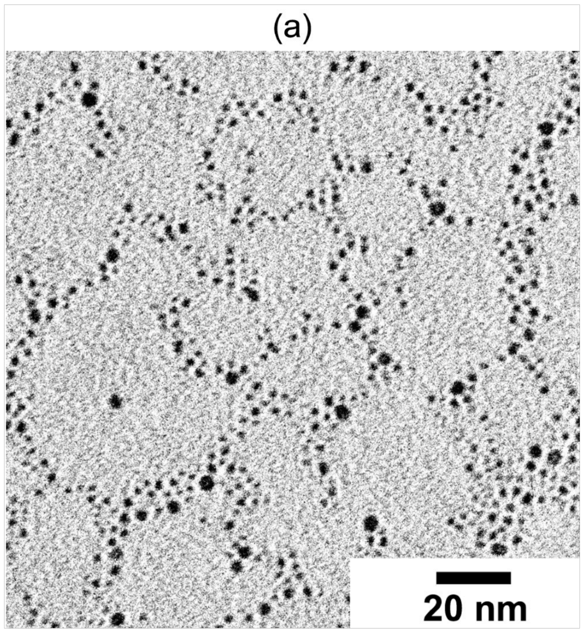
APPROACH

- EXPERIMENTAL WORK
  - Make stable nanofluids.
  - Measure the thermal conductivity of nanofluids.
  - Measure the pressure drop and heat transfer coefficient of nanofluids.
- THEORETICAL WORK
  - Discover new mechanisms for enhanced properties.
  - Develop new models of nanofluids for cooling system performance simulation.
  - Develop theory of nanofluids.
- COLLABORATIVE WORK
  - Conduct radiator and full vehicle cooling tests in collaboration with truck companies, radiator manufacturers, and coolant manufacturers.
  - Transfer nanofluid technology to the transportation industry.

INDUSTRY COLLABORATION

- We planned to initiate, during FY2006, a new CRADA with a commercial truck company, a radiator manufacturer and a coolant manufacturer which is aimed at conducting radiator and full vehicle cooling tests through 2009.
- INDUSTRIAL INTERACTIONS we have include
  - OshKosh
  - Mack
  - G&O Radiators
  - Valvoline
  - UM/GM - NSF FUNDING
  - Ford
  - DaimlerChrysler
  - Delphi
  - BP
  - Dow Chemical
- However, we postponed the CRADA initiative
  - We were not able to modify the one-step NF production system.
  - Funding for FY06 was uncertain.

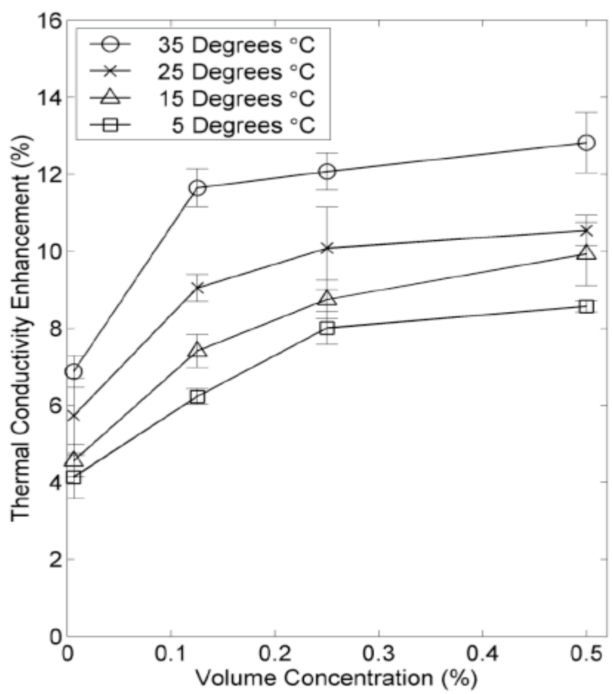
TECHNICAL ACCOMPLISHMENT SUMMARY



TEM micrograph of 2 nm gold nanoparticles. The number averaged diameter of the 2 nm gold nanoparticles is 2.28 ± 0.74 nm.

- Accomplishment 1
  - Produced and characterized nanofluids containing monosized NPs less than 10 nm.
  - At 0.5 Vol.% of 2 nm Au NPs, the thermal conductivity of the gold nanoparticle-water suspension was increased by >10% over water.
- Accomplishment 2
  - Conducted laminar flow experiments.
  - Developed a model for the effective viscosity of nanofluids by including in the Einstein viscosity equation the effect of slip velocity.

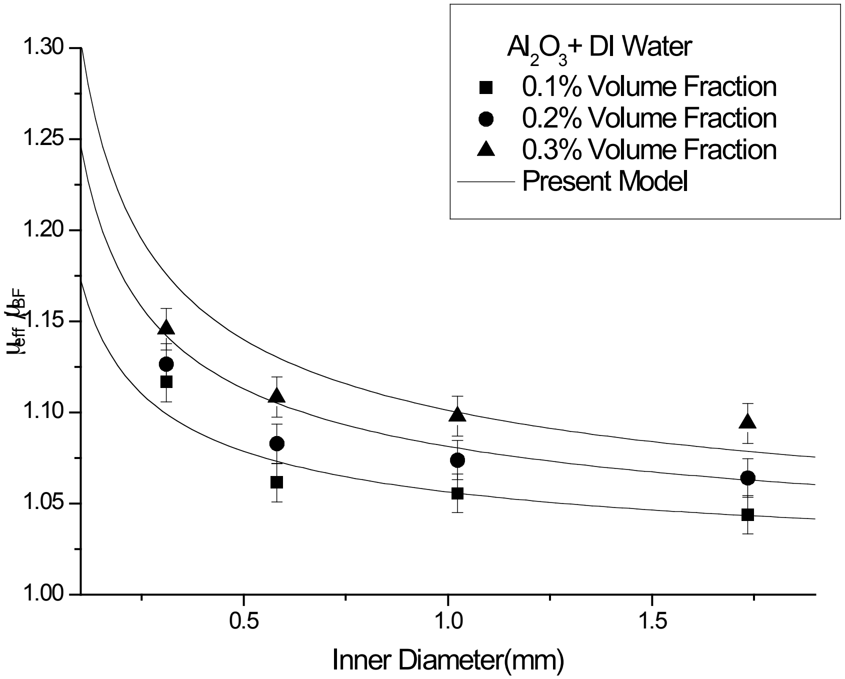
TECHNICAL PROGRESS
WHAT WAS DONE LEADING TO ACCOMPLISHMENT 1



Thermal conductivity enhancement of 2 nm gold nanoparticle in water as a function of volume concentration

- Monodisperse gold nanoparticles with 2 nm nominal diameter were produced by a single-step water-based chemical production method. In other words, the gold nanoparticles were produced via the reduction of a gold salt by tetrakis (hydroxymethyl) phosphonium chloride (THPC). The THPC serves both as a reductant and a stabilizer that inhibits particle aggregation.
- The thermal conductivity enhancement of the phosphate-stabilized gold nanoparticle-water dispersions increases with both nanoparticle concentration and temperature.

TECHNICAL PROGRESS
WHAT WAS DONE LEADING TO ACCOMPLISHMENT 2



Effective viscosity enhancement of 30 nm alumina nanoparticle in water as a function of tube diameter

- Completed the design and construction of the Nanofluid Flow Test Facility.
- Measured the pressure drop for laminar flow of 30 nm alumina nanofluids flowing through circular tubes with diameter ranging from 310 μm to 1.735mm.
- Found that the effective viscosities of the nanofluids are significantly larger than those predicted by Einstein model. More intriguingly, they are affected not only by the volume fraction of nanoparticles but also by tube diameter as shown in the Figure.
- Developed a new model for the effective viscosity of nanofluids by including in the Einstein viscosity equation the effect of slip velocity between nanoparticles and base fluid.

SUMMARY

- WE SET FOCUSED OBJECTIVES FOR FY06
  - Produce and characterize nanofluids containing monosized NPs <10 nm.
  - Conduct flow and heat transfer experiments with base fluids and nanofluids in laminar and turbulent flow.
- WE HAVE ACHIEVED THE OBJECTIVES
  - Produced and characterized nanofluids containing monosized NPs with 2 nm nominal diameter.
  - Conducted laminar flow experiments and developed a model for the effective viscosity of nanofluids.

CONCLUSIONS

- The fabrication of monodisperse nanoparticles with very small sizes is key to the thermal performance of nanofluids as our model predicts that, at the same particle loading, smaller particles will have larger thermal conductivity enhancements than larger particles.
- The new model of the effective viscosity of nanofluids could lead to the more realistic design and simulation of cooling devices with nanofluids.
- Argonne's unique nanotech-based nanofluid project has great potential for meeting the HVSO and 21CT goals and objectives.

FY2007 PLANS

- Conduct flow and heat transfer experiments with base fluids and nanofluids in turbulent flow.
- Modify the one-step nanofluid production system for a larger quantity of nanofluids.
- Study nanofluid structures and dynamics at the nanoscale level.
- Refine models of nanostructure- and nanoparticle-mobility-enhanced thermal conductivity of nanofluids.
- Initiate a new CRADA with truck companies, radiator manufacturer, and coolant manufacturer which is aimed at radiator and full vehicle cooling tests through 2009.