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Effects of Nanofluids on Heavy Vehicle Cooling Systems

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Purpose of Work

- Application of nanofluids with enhanced thermal properties in heavy vehicle cooling systems can
  - lead up to 5% reduction in radiator frontal area and consequently translate to as much as 2.5% fuel savings by reducing aerodynamic drag
  - reduce parasitic pump power losses
  - weight reduction

- Effects of nanofluids in vehicle cooling systems are not known
  - erosion of radiator material?
  - clogging of fluid lines?
  - erosion of pump material?
  - physical & thermal changes in the nanofluids over time?

Effects of nanofluids are being investigated to identify and eliminate any show stoppers

Objectives

- Determine if nanofluids degrade radiator systems
  - develop apparatus/pumping system
  - weight-loss measurements (or erosion rate) as a functio velocity and impact angle

- Develop predictive model of nanofluid erosion in engine systems

- Establish feasibility of selected nanofluids for engine applications
  - nanofluid characterizations (physical/thermal)

Approach

- Design and build a liquid erosion test apparatus
  - Fluid velocities 1-10 m/s
  - Vary fluid/target impact angles between 30-90°
  - Ambient to up to 90°C
  - Monitor fluid pressure to identify changes in fluid and/or
  - Model fluid/target impact and correlate with experiments

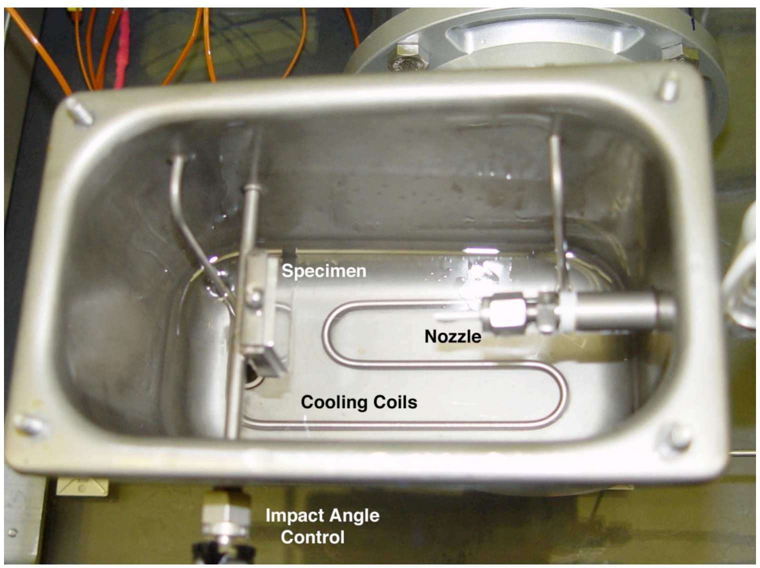
- Nanofluid characteristics
  - Particle size, shape, and agglomeration effects using Small Angle X-ray Scattering (SAXS) (APS at ANL)
  - Viscosity as a function of temperature (pumping power)
  - Laser scattering for particle size distribution
  - Electron microscopy

Performance Measures –
Progress in Meeting Objectives

- Identified potential nanofluids from commercial sources and obtained fluids for evaluation
- Completed fabrication of nanofluid erosion test facility
- Completed preliminary modeling of fluid flow/target interaction during erosion test
- Erosion tests with selected nanofluids in progress
- Completed nanofluid characterizations of selected fluids

Accomplishments

- Liquid Erosion Apparatus



SiC/water nanofluid
(Saint Gobain, MA)

- ***Material***

Al 3003 typical radiator material

- ***Measure***

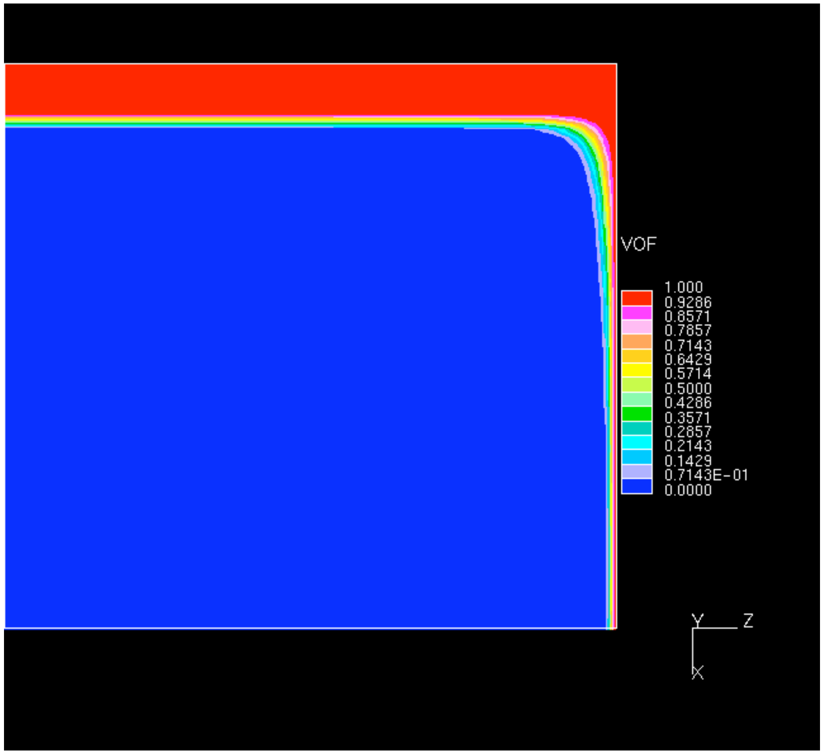
target weight loss vs. time

- ***Nanofluids investigated***

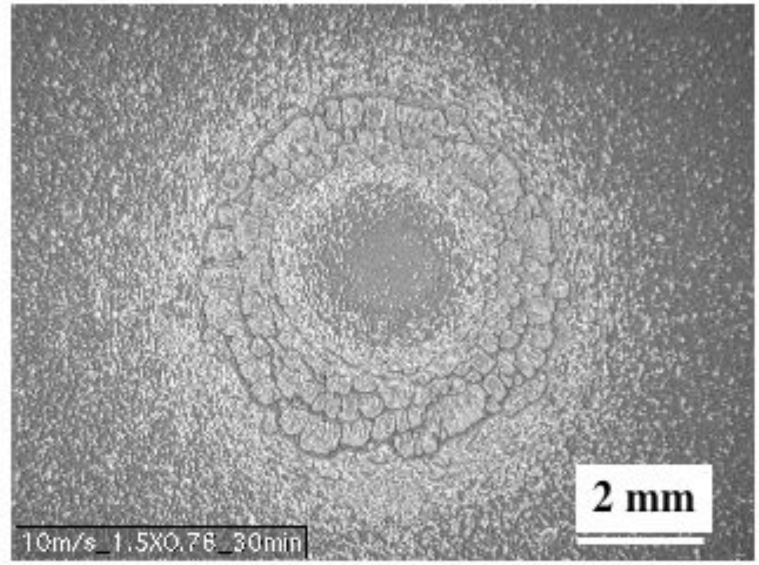
0.01% Cu in tri-ethylene glycol (in-house)
0.1 – 0.8 vol.% CuO in ethylene glycol (Nanoscale, KS)
1-4 vol.% SiC in water (Saint Gobain, MA)

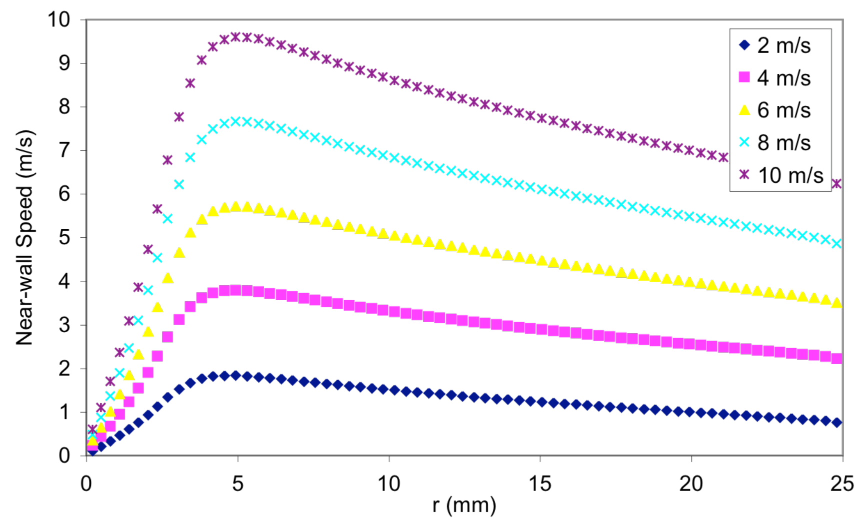
Accomplishments

- Modeling of Fluid Jet/Target Interactions



Fluid flow modeled by STAR-CD for 90° impact





Damage patterns obtained on painted sample surface consistent with the fluid flow modeling

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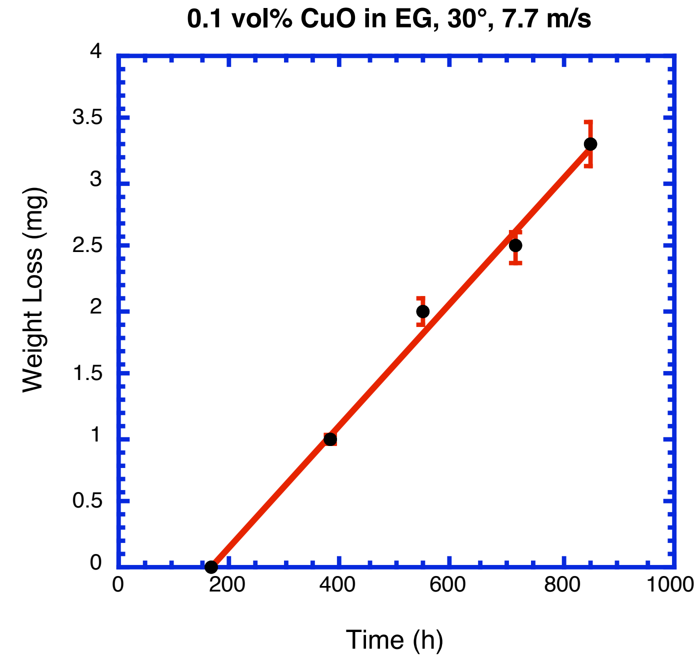
Accomplishments

No erosion observed with CuO/EG for all vol.%, V≤10 m/s,30° & 90°

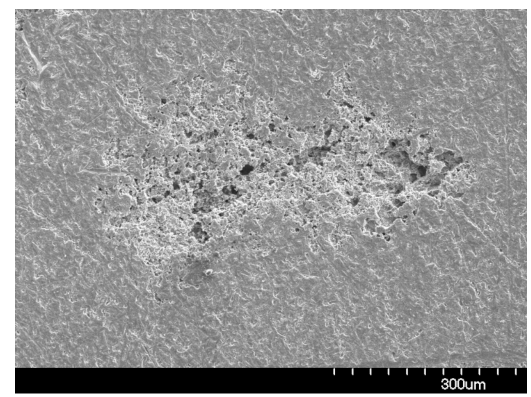
One test condition showed galvanic pitting



material loss rate ≈ 4 x 10^{-6} g/hr corresponds to ≈ 4 x 10^{-2} μm/hr or ≈ 3 mils/year for a standard radiator (2000 h/year)

Radiator velocity ≈ 1 m/s

Typical corrosion rate for steel in water is 2 mils/yr



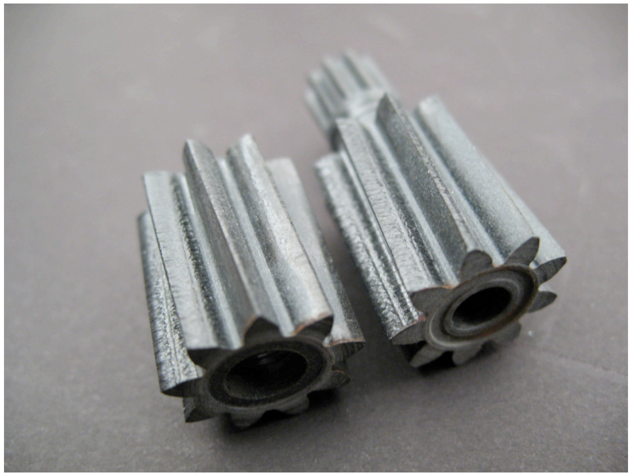
SEM of sample surface showing galvanic pitting

Accomplishments

Preliminary Erosion Results with SiC/Water Nanofluid

710 hours of testing @ 5 m/s

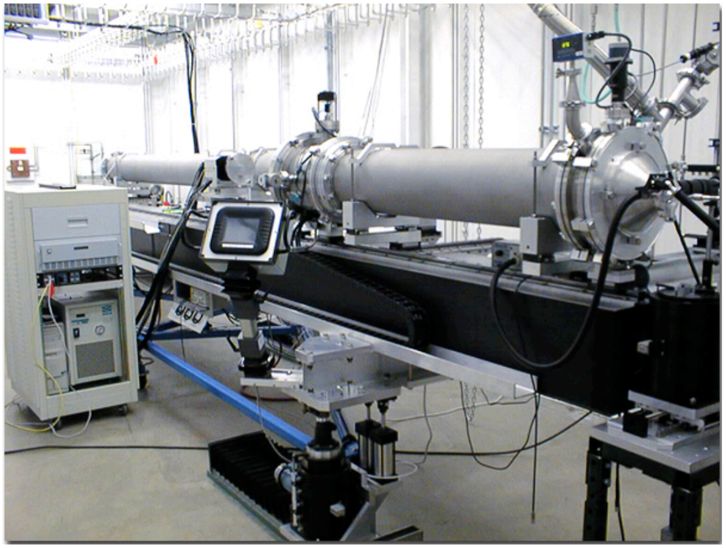
Material	Weight loss (%)
Al nozzle	0
Polymer gear - small	3.3
Polymer gear - large	4.1



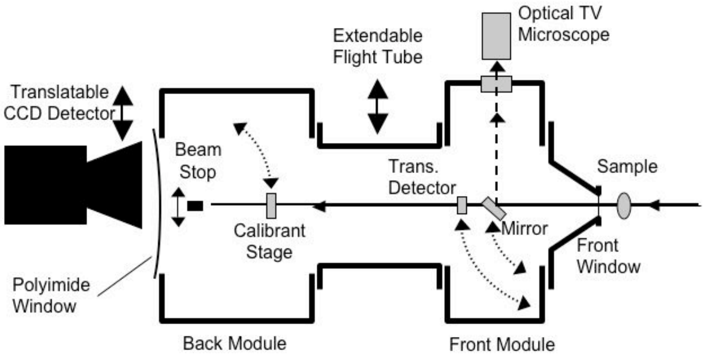
- Change in fluid velocity with time observed
- SiC nanoparticles wearing the polymeric gears
- Pumps used in vehicle systems are NOT gear pumps

Accomplishments

Particle Size Measurement Using Small Angle X-ray Scattering (SAXS)

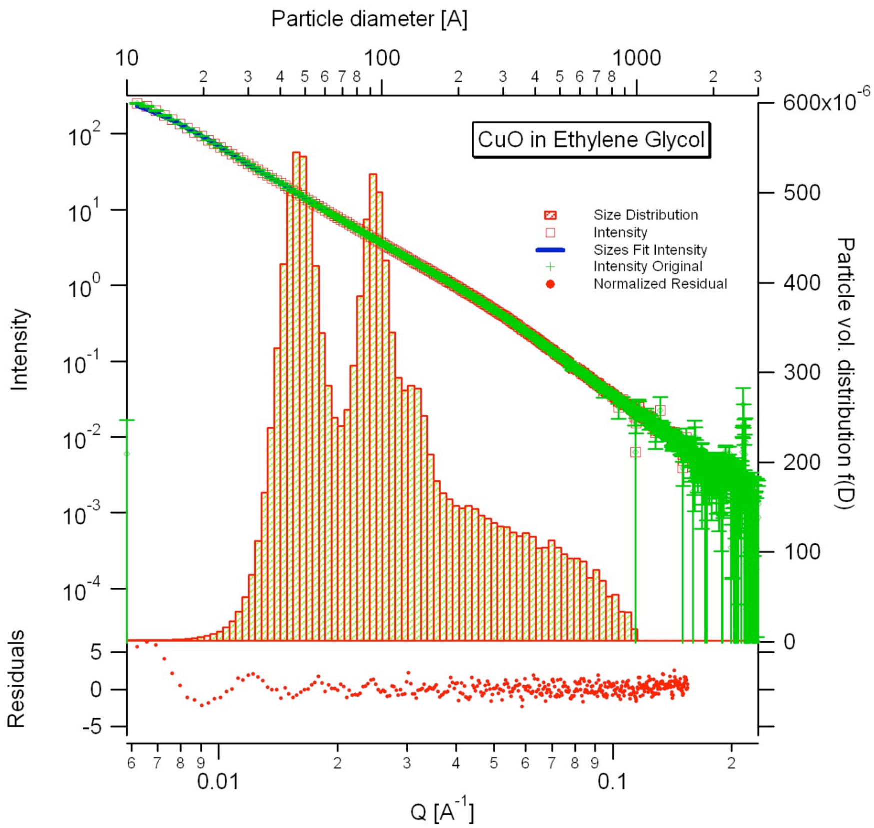


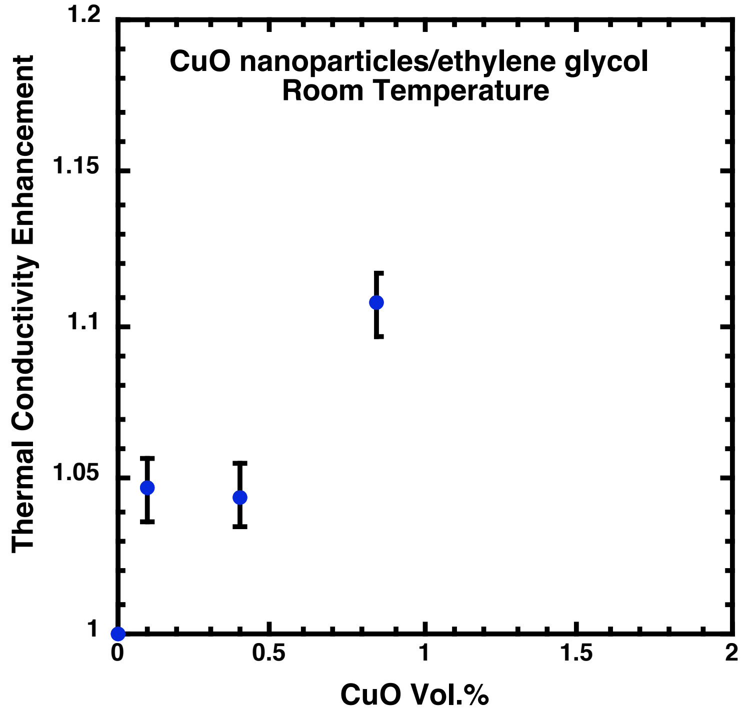
SAXS set-up at the Advanced Photon Source (ANL)



- Particle size and shape determined from scattering intensity and scattering momentum changes
- Particle size, size distributions, and shapes can be determined & used to understand the heat transfer mechanisms
- Not limited to transparent fluids
- In-situ study to investigate time dependent phenomenon such as agglomeration

SAXS Study of a CuO (0.8 vol.%)/EG nanofluid (*Nanoscale*)

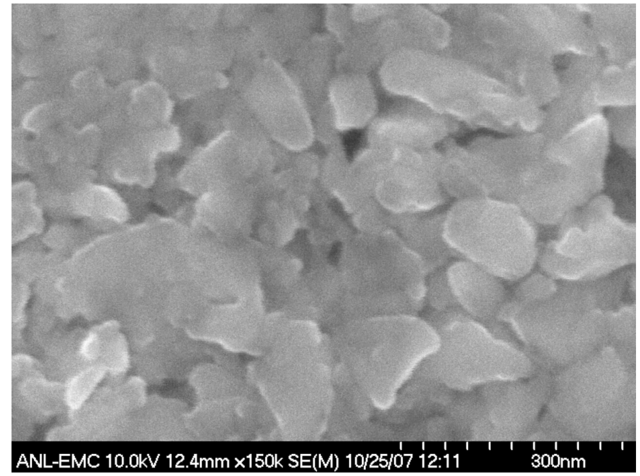




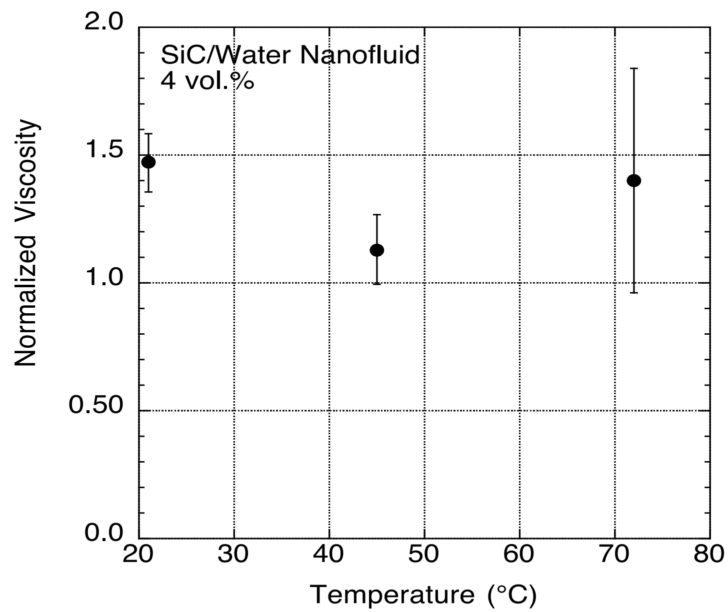
SAXS showing size distribution obtained by fitting data assuming spherical particles

Thermal conductivity enhancement

Nanofluid Viscosity Measurements



average particle size: 170 nm



Nanofluid viscosity is critical in determining overall pumping power

Technology Transfer

- Current project is a support activity for the overall nanofluid effort for engine systems application

- Collaboration established with several commercial nanofluid manufacturers
  - Saint Gobain
  - Nanoscale Corporation
  - Applied Nanoworks

- Nanofluid technology end-users
  - Michelin
  - PACCAR (Chevron)
  - Modine
  - TARDEC

Nanofluid Erosion & Characterization Activities for Next Fiscal Year

- Continue erosion tests on nanofluids selected for engine radiators
  - nanoparticle loadings
  - impact angles and velocities
  - improve on the pumping system
- Continue with the modeling of fluid flow/target impact for various impact angles
  - include effects of nanoparticles in fluids
- Conduct characterization tests to determine the physical structure of the nanoparticles in suspension & viscosity
  - use confocal microscopy to investigate nature of nanoparticles in suspension
- Correlate the nanofluid characterizations with the thermal properties

Summary

- Potential for petroleum displacement
  - 300 million gallons/yr reduction in diesel fuel consumption
- Approach to research
  - Use experimental and analytical approaches to establish the viability & characteristics of nanofluids for vehicle systems
- Technical Accomplishments
  - Nanofluid erosion system built and calibrated
  - Progress made in erosion studies using commercial nanofluids
  - Progress made in physical characterizations of nanofluids
- Technology Transfer
  - Major tire manufacturer (Michelin)
  - Nanofluid manufacturers (Saint-Gobain, Nanoscale, Applied Nanoworks)
  - Enabling technology
- Plans for Next Fiscal Year in support of Effects of Nanofluids
  - Erosion studies using engine radiator specific fluids
  - Systematic characterization of potential nanofluids and correlation to thermal properties

Publications/Presentations (for reviewers only)

- G. Chen, W. Yu, D. Singh, D. Cookson and J.L. Routbort, “Application of SAXS to Study Particle-Size-Dependent Thermal Conductivity in Silica Nanofluids ,” accepted for publication in the J. Nanoparticle Research, Nov. 2007.

- J. L. Routbort, D. Singh, W. Yu, R. K. Smith, and G. Chen, “Erosion of Radiator Materials by Nanofluids”, presented at the Nanofluids Conference, organized by the Engineering Conferences International, Copper Mountain, Colorado, September 2007.