Erosion of Radiator Materials by Nanofluids

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Overview

Timeline

- Project start FY07
- Project end FY12
- 60% complete

Budget

- Total project – see VSS_13_Routbort
- FY08 = $100 K (DOE)
- FY09 = $140 K (DOE)

Barriers

- Effects of nanofluids for thermal management in heavy vehicles are not established
  - ⇒ erosion of radiator material?
  - ⇒ erosion of pump material?
  - ⇒ power requirements to pump nanofluids?
  - ⇒ clogging of fluid lines?
  - ⇒ physical & thermal changes in the nanofluids over time?

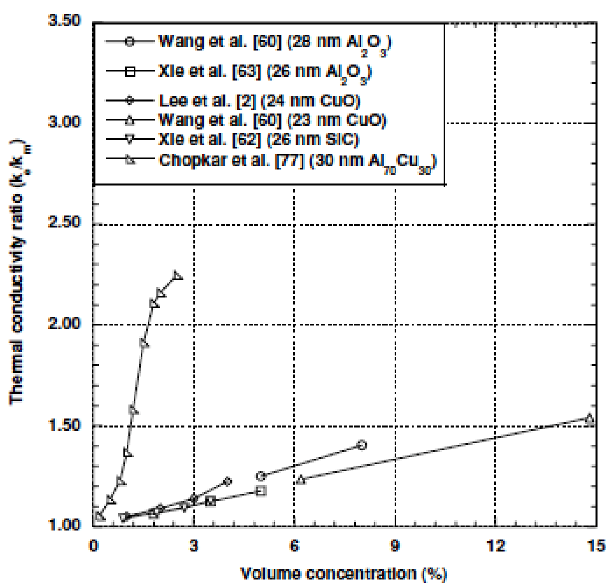
Partners

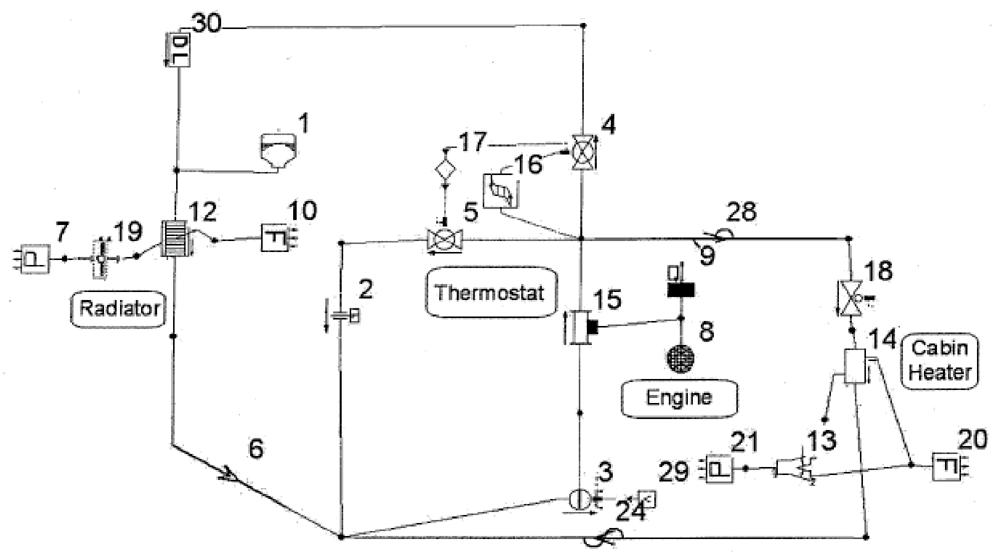
- Tardec/WFO
- Michelin WFO/cost-share

This project complements the overall effort in the area of nanofluids for thermal management

Why Nanofluids?

- Enhanced thermal conductivity
- Enhanced heat transfer coefficient? $h \propto k^{0.6}$
- CFD of a Cummins 500 hp engine using an “ideal” nanofluid indicated a 5% reduction in radiator size (SAE-2007-01-2141)





Objectives

- Use of nanofluids for thermal management in heavy vehicles can improve fuel economy by
  - ⇒ reducing radiator weight, size and shape
  - ⇒ reducing aerodynamic losses
  - ⇒ reducing parasitic losses

Effects of nanofluids in an application are unknown

Effects of nanofluids in heavy vehicle thermal management are being investigated so that show stoppers, if any, could be identified and subsequently eliminated

- This work addresses the practical issues related to the application of nanofluids for heavy vehicle applications and develop solutions of any potential problems

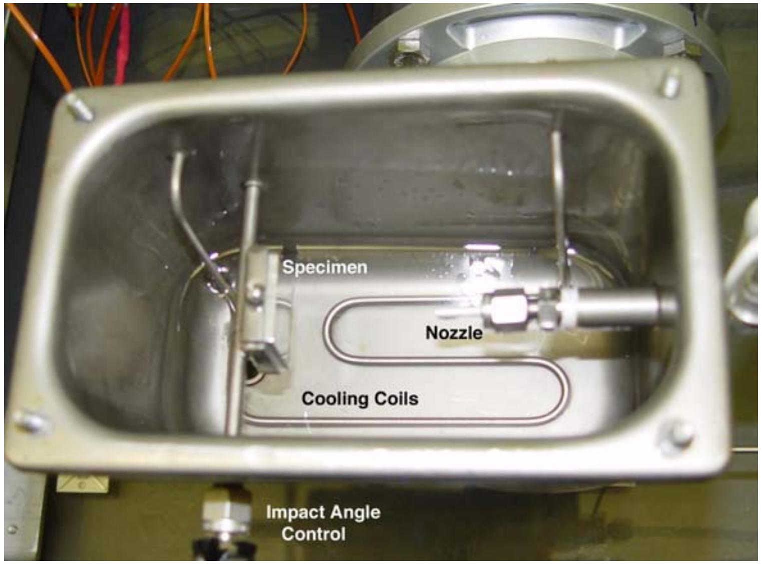
Milestones

- FY08 *(all completed)*
  - Identify critical barriers
  - Initiate collaborations
  - Design, build and calibrate erosion test rig
  - Conduct preliminary erosion experiments using selected nanofluids
  - Develop high energy x-ray techniques for measuring particle size distributions in the nanofluid
- FY09
  - Continue CFD modeling of the nanofluid/target interactions
  - Measure erosion of radiator material using SiC EG/H_2O based nanofluids
    - *velocity & impact angle*
    - *particle loading*
  - Establish nanofluid/gear pump components interactions
  - Modify erosion rig to:
    - *incorporate an automotive pump*
    - *measure pumping power required for nanofluids*
  - Develop collaborations with industry

Approach

- Determine if nanofluids degrade/erode radiator system materials
  - develop apparatus/pumping system
  - weight-loss measurements (or erosion rate) as a function of fluid velocity, impact angle, temperature, and type of nanofluid
  - monitor fluid pressure to identify changes in fluid and/or pump system
  - model fluid/target impact and correlate with experiments
- Develop predictive model if any erosive wear
- Characterize nanofluids for performance
  - particle size & distributions using laser and x-ray techniques
  - viscosity and thermal conductivity
- Conduct erosion study on an automotive pump
- Quantitatively assess power consumption using torquemeter and compare base fluid and nanofluids power requirements

Liquid Erosion Tests

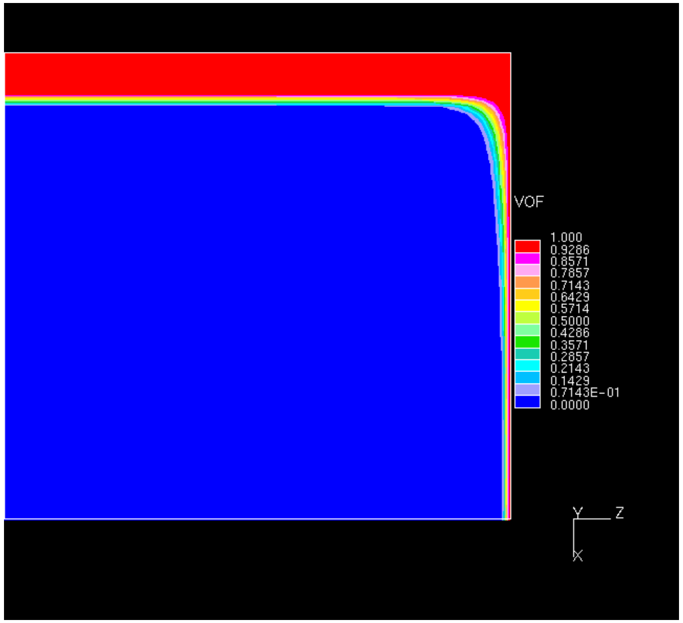


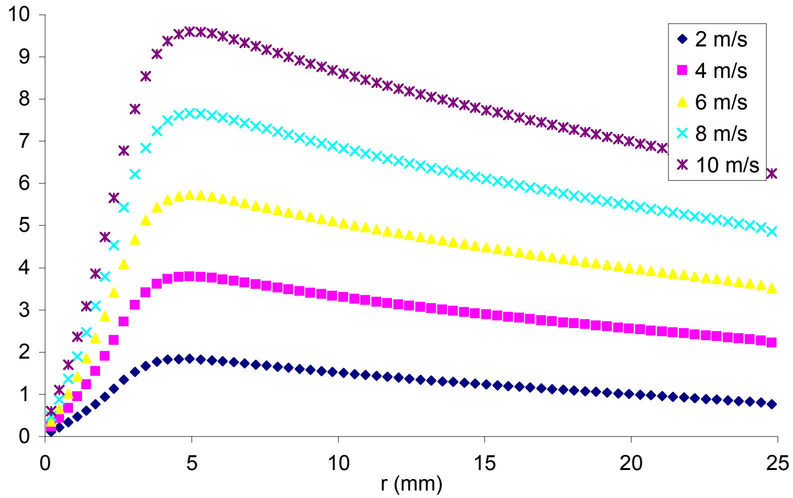
SiC/water nanofluid
(Saint Gobain, MA)

- ***Material***
  Al 3003 typical radiator material
- ***Measure***
  target weight loss vs. time
- ***Velocity & Impact Angles***
  4-8 m/s and 30-90°
- ***Nanofluids investigated***
  1-4 vol.% SiC in water (Saint Gobain, MA)
  0.1 – 0.8 vol.% CuO in ethylene glycol (Nanoscale, KS)

Modeling of Fluid Flow/Target Interactions

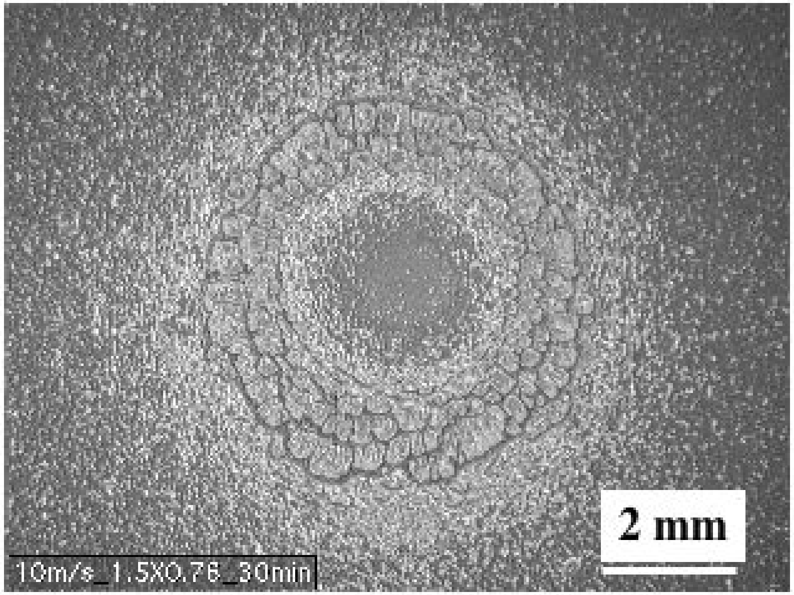
Fluid flow modeled by STAR-CD
for 90° impact



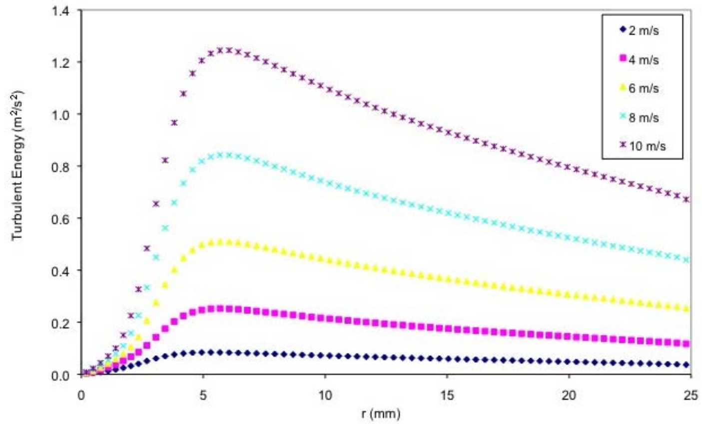


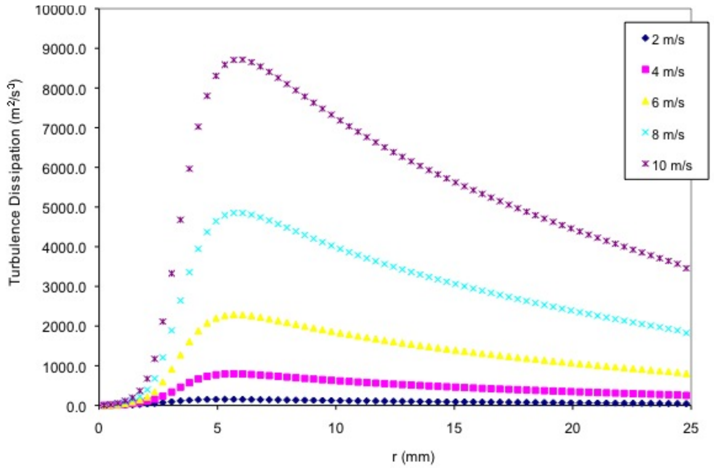
CFD modeling did not consider presence of nanoparticles in the fluid

Modeling of Fluid/Target Interactions



Pattern obtained on painted sample surface at fluid velocity of 10 m/s at 90° impact angle; dead-zone at impact area





Damage patterns on sample surface consistent with the turbulent fluid flow modeling

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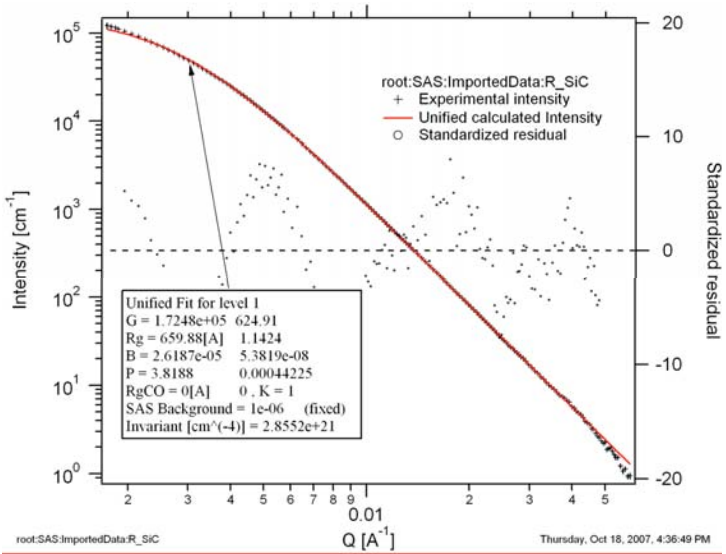
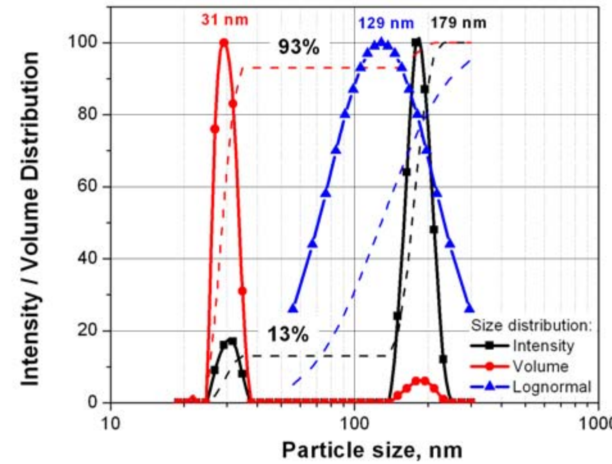
Characterization of Size/Shape of Nanoparticles

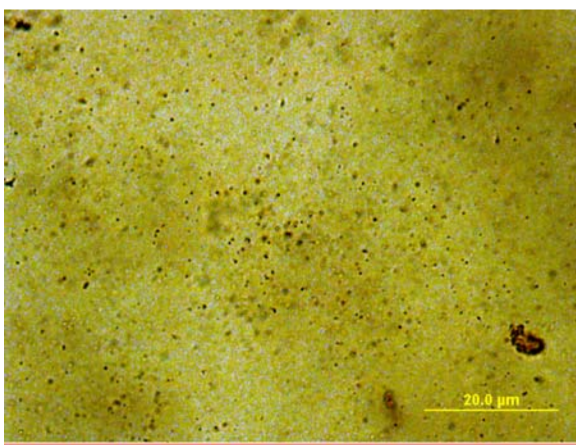


SAXS (170 nm)



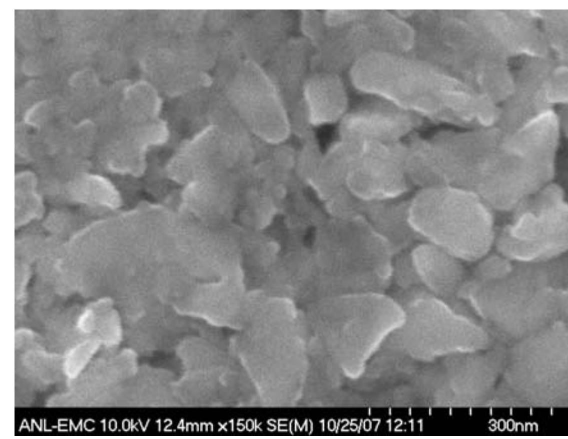
DLS (129 nm)

SiC/H_2O



Confocal Microscopy

Various particle size measurement techniques in agreement



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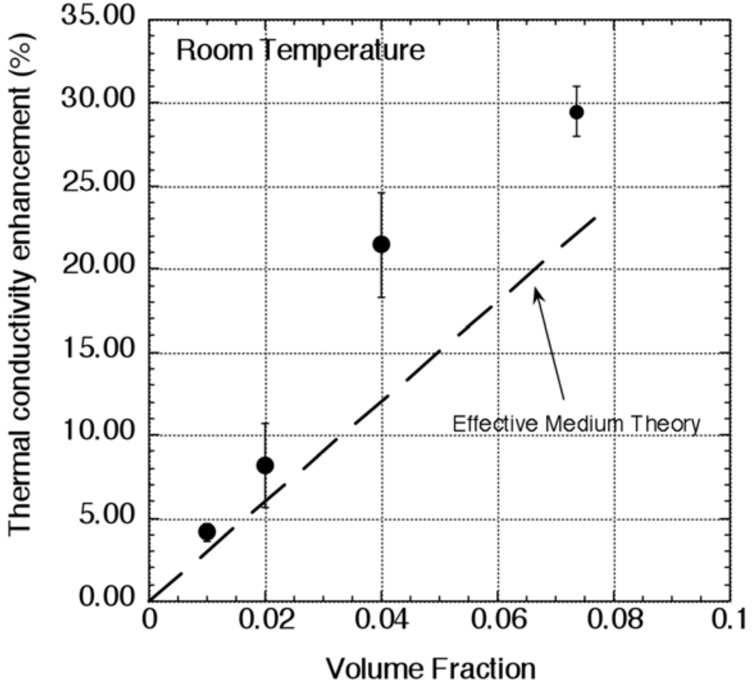
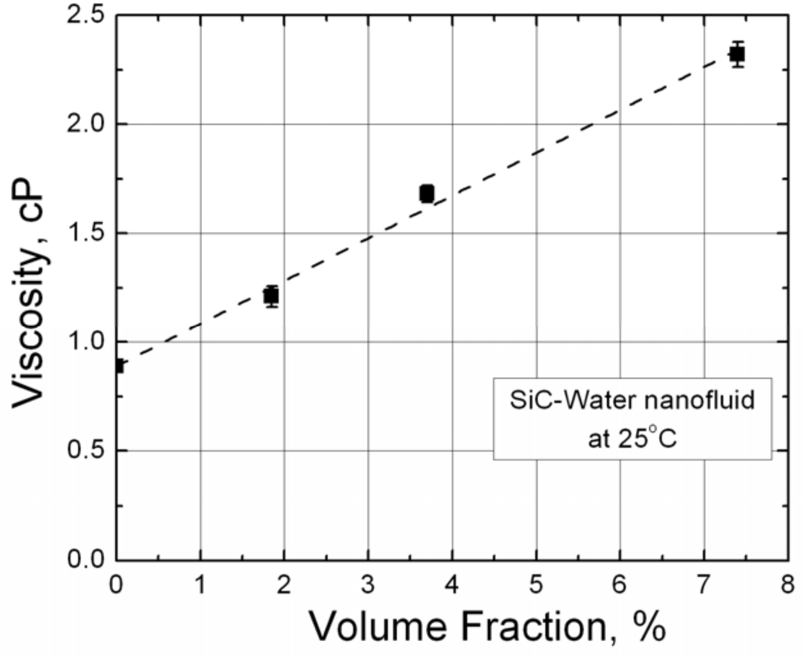
Characterization of Thermal Conductivity & Viscosity of SiC Based Nanofluid





SiC based nanofluid shows desirable thermophysical properties

Erosion Results with SiC/Water Nanofluid

710 hours of testing @ 5 m/s

Nanoparticles entrapped between polymeric gears in the pump can cause wear

- Change in fluid velocity with time observed
- Pumps used in vehicle systems are NOT polymeric gear pumps

Using peristaltic pump, NO target erosion observed for 2 vol.% SiC nanofluid at 8 m/s and impact angle 30° for > 700 h testing

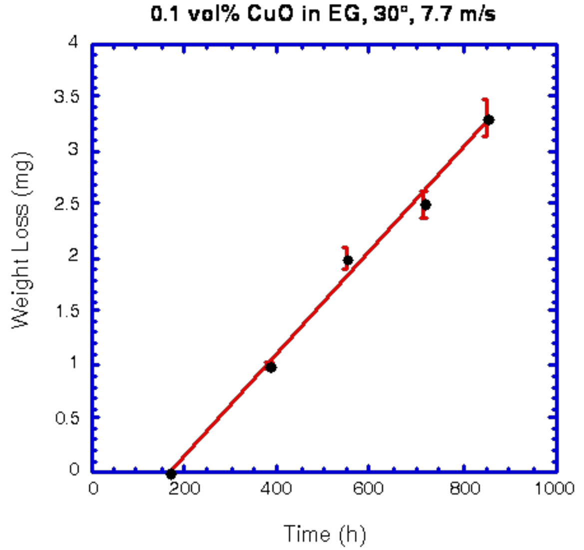
Erosion with CuO/EG nanofluid

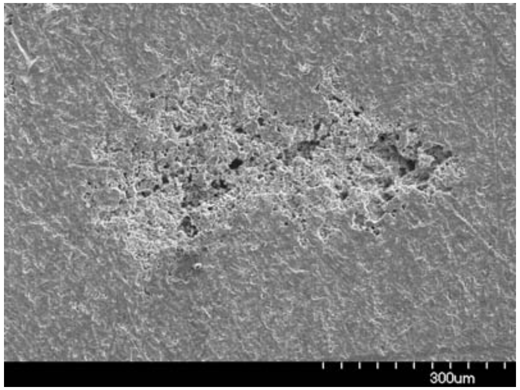
NO erosion observed with CuO/EG for all vol.%, V≤10 m/s, 30° & 90°

One test condition showed galvanic pitting and NOT erosion

material loss rate from galvanic pitting ≈ 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 operation) >> erosion appears to have minimal effect

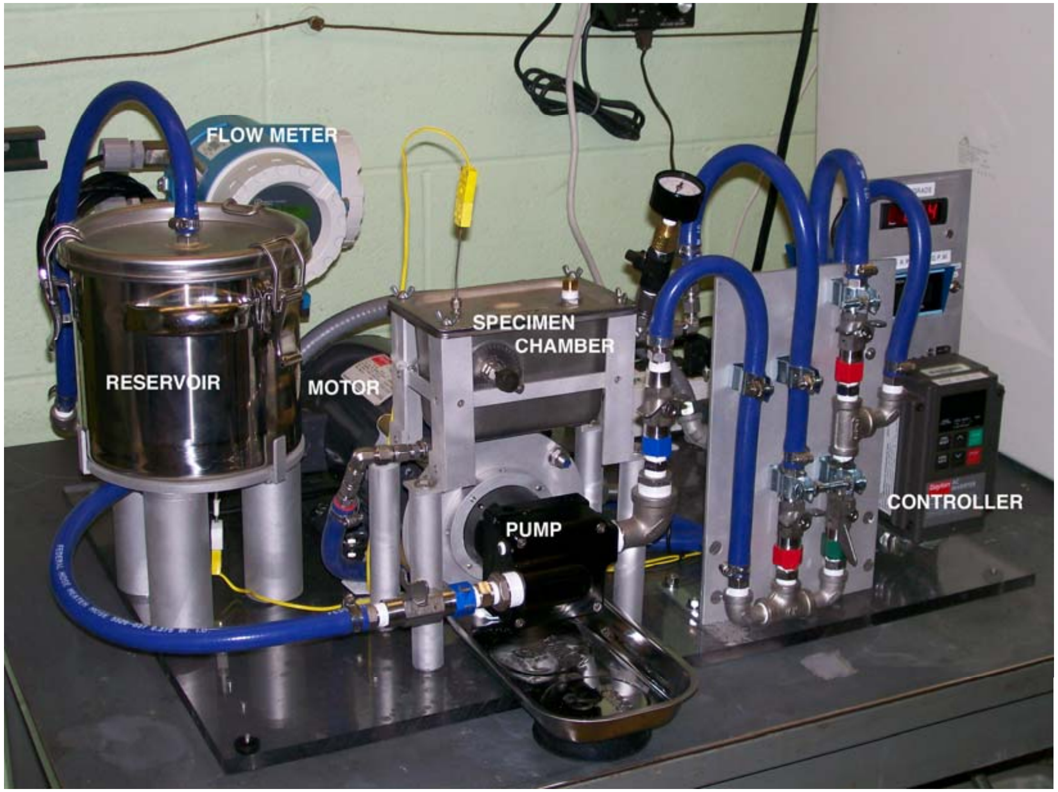
Typical corrosion rate for steel in water is 2 mils/yr





SEM of sample surface showing galvanic pitting

Modified Erosion Apparatus Completed



Modified erosion apparatus will allow to:

- Study erosion of target material at fixed angle & velocity
- Study erosion of automotive pump
- Measure power required to pump nanofluids and the base fluids using a torquemeter installed on shaft connecting pump and motor

Experiments from the modified erosion apparatus will be critical for not only the erosion studies, but will also provide critical data that will help corroborate predictive pumping powers calculated from viscosity, flow measurements and the CFD modeling work being conducted on complementary projects on nanofluids

Path Forward

- Continue erosion tests with new nanofluids being developed
- Conduct CFD modeling of fluid/target interactions, including the effects of nanoparticles
- Conduct tests with the modified erosion apparatus
  - measure erosion rate on the automotive pump impallar
  - measure pumping power of nanofluids and base fluids
  - determine efficiency of the nanofluids
- Determine long-term performance of selected nanofluids
  - compare thermo-physical properties before and after erosion tests
- As part of the overall nanofluid effort, provide guidance to the industrial partner(s) on the heavy vehicle cooling applications

Conclusions

- Identified critical barriers for the use of nanofluids for cooling applications
- Completed characterizations of selected nanofluids
- Completed modeling of base fluid flow/target interactions during erosion test
- Erosion tests with SiC and CuO based nanofluids does not show any erosion on the target material, however, nanofluids could affect the pump system
- Completed modification of nanofluid erosion test facility to measure erosion in an automotive pump and the power requirement to pump nanofluids