Erosion of Radiator Materials by Nanofluids

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Project ID
pm008

Vehicle Technologies – Annual Review – May 10, 2011

Sponsored by ***Propulsion Systems Materials***

Overview

Timeline

- Project start FY07
- Project end FY12
- 80% complete

Budget

- FY09 = $140 K (DOE)
- FY10 = $252 K (DOE)
- FY11 = $84 K (DOE)*

* Continuing resolution

Barriers

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

Partners/Interactions

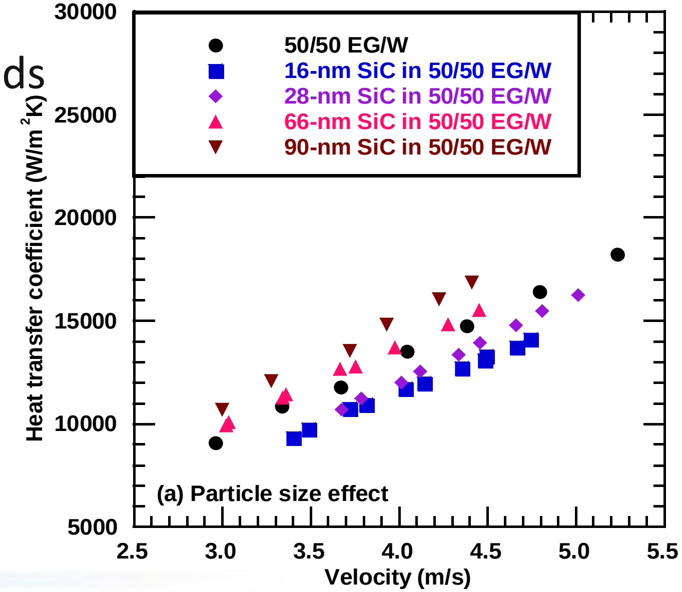
- Tardec/WFO – project finished
- Michelin WFO/cost-share – project finished
- Saint Gobain/cost-share – project ends FY11
- Valvoline (Ashland Oil)/cost-share – FY12

This project complements the overall effort in the area of nanofluids for thermal management with emphasis on cooling for power electronics

Relevance

- Fluids containing small nanoparticles have a proven ability to increase thermal conductivity and heat transfer. Hence they have applications to reduce the size of heat exchangers or radiators. Other applications include energy storage for solar applications (project with DOE Solar), cooling of power electronics (proposal pending), industrial cooling (project with Industrial Technology Program, etc.

- Q: However, will the nanofluids cause damage to cooling systems?
- A: ***Not observed to date***
- Q: Will the increased viscosity of the nanofluid result in much higher pumping power required?
- **A: See Poster**
- Q: Will nanofluids stay in suspension over long periods
- and not clough the cooling system?
- A: ***NOT if engineered properly***

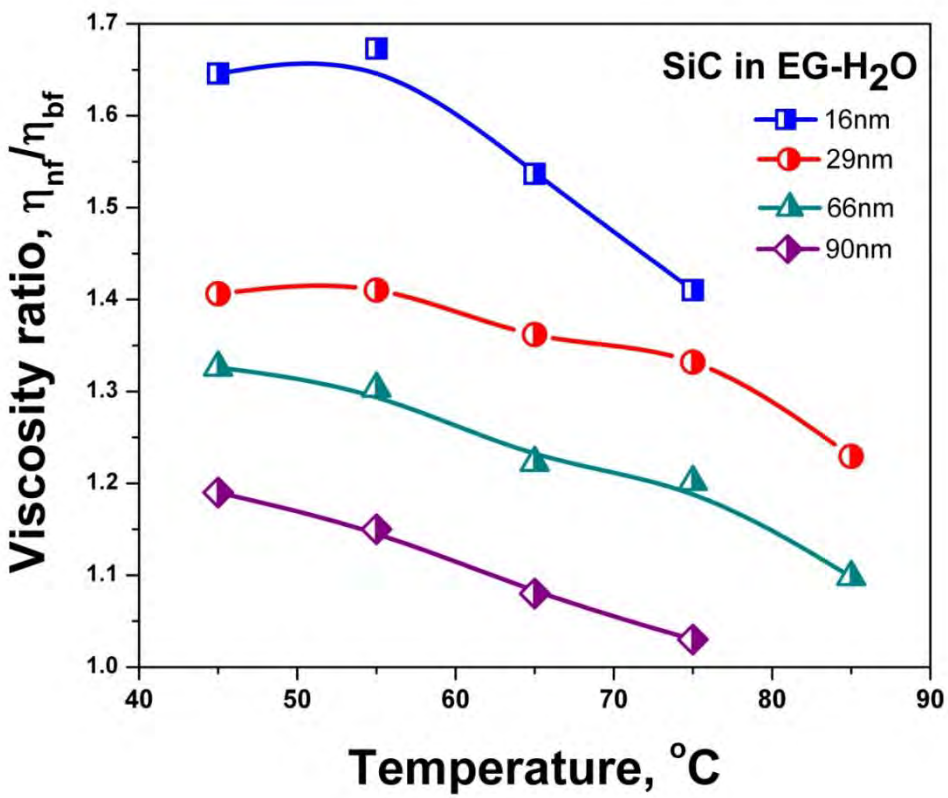


Heat transfer for 4 vol.% SiC In EG/W @ 55°C in turbulent region

Timofeeva, et al. JAP109, 014914 2011

Objectives — FY10

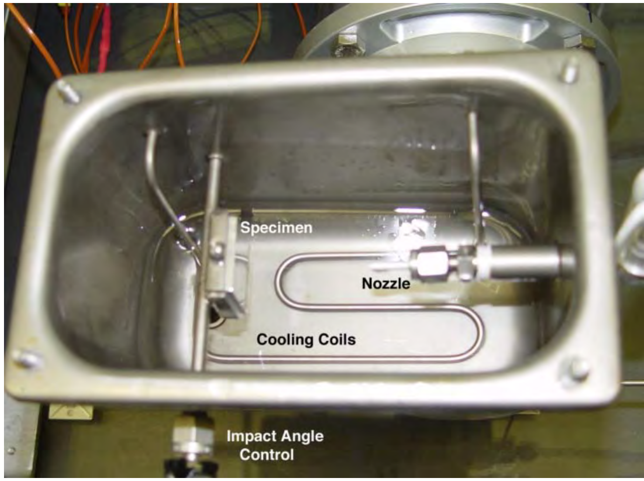
- *Determine if increased viscosity would increase pumping power and negate any energy savings from more efficient heat transfer and smaller heat exchangers*



Note larger nanoparticles and higher temperatures result in lower viscosities

Milestones

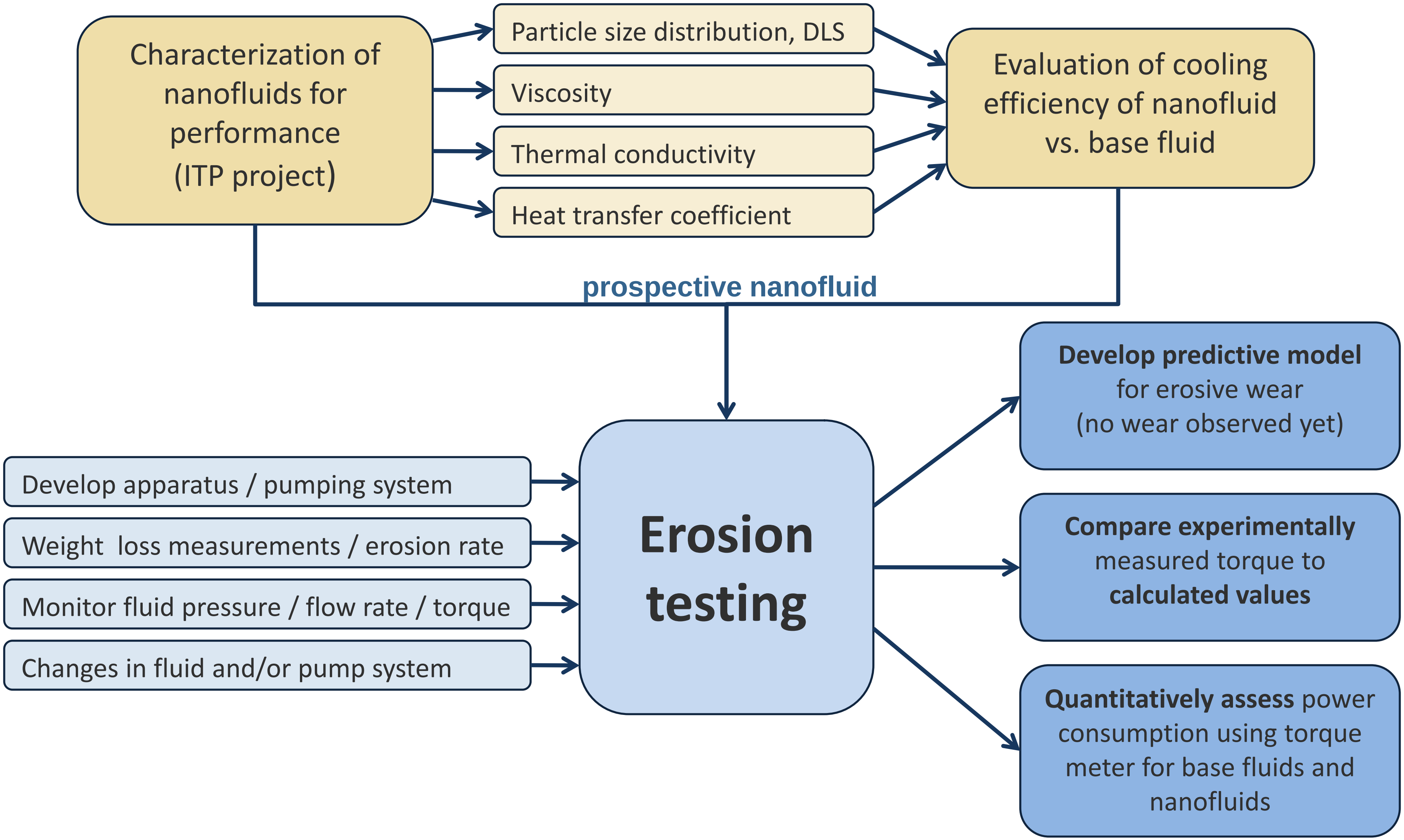
- FY09 (all complete)
  - Measure erosion of radiator materials using SiC EG/H_2O based nanofluids
    - Velocity & impact angle
    - Particle size & loading
  - Modify erosion rig to:
    - Incorporate an automotive pump
    - Measure pumping power of various nanofluids
  - Develop collaborations with industry



Erosion tank–cover removed

- FY10
  - Continue to measure erosion of materials using various nanofluids
    - Finish SiC EG/H_20 nanofluids (from Saint Gobain) (nearly complete)
    - Start graphite based nanofluids (from Valvoline) (fluids too viscous)
  - Correlate increased pumping power of candidate nanofluids measured from new computerized data collection system with theory (complete)
- FY11
  - Measure erosion and pumping power of nanofluids containing "new ANL-produced" nanoparticles resulting in much higher thermal conductivity enhancements

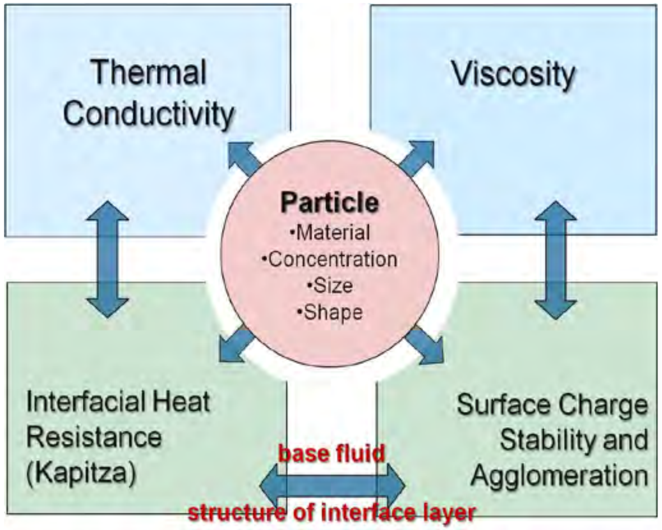
Approach


Characterization of nanofluids for performance (ITP project)
Particle size distribution, DLS
Viscosity
Thermal conductivity
Heat transfer coefficient
Evaluation of cooling efficiency of nanofluid vs. base fluid
prospective nanofluid
Develop apparatus / pumping system
Weight loss measurements / erosion rate
Monitor fluid pressure / flow rate / torque
Changes in fluid and/or pump system
Erosion testing
Develop predictive model for erosive wear (no wear observed yet)
Compare experimentally measured torque to calculated values
Quantitatively assess power consumption using torque meter for base fluids and nanofluids

Experimental Parameters

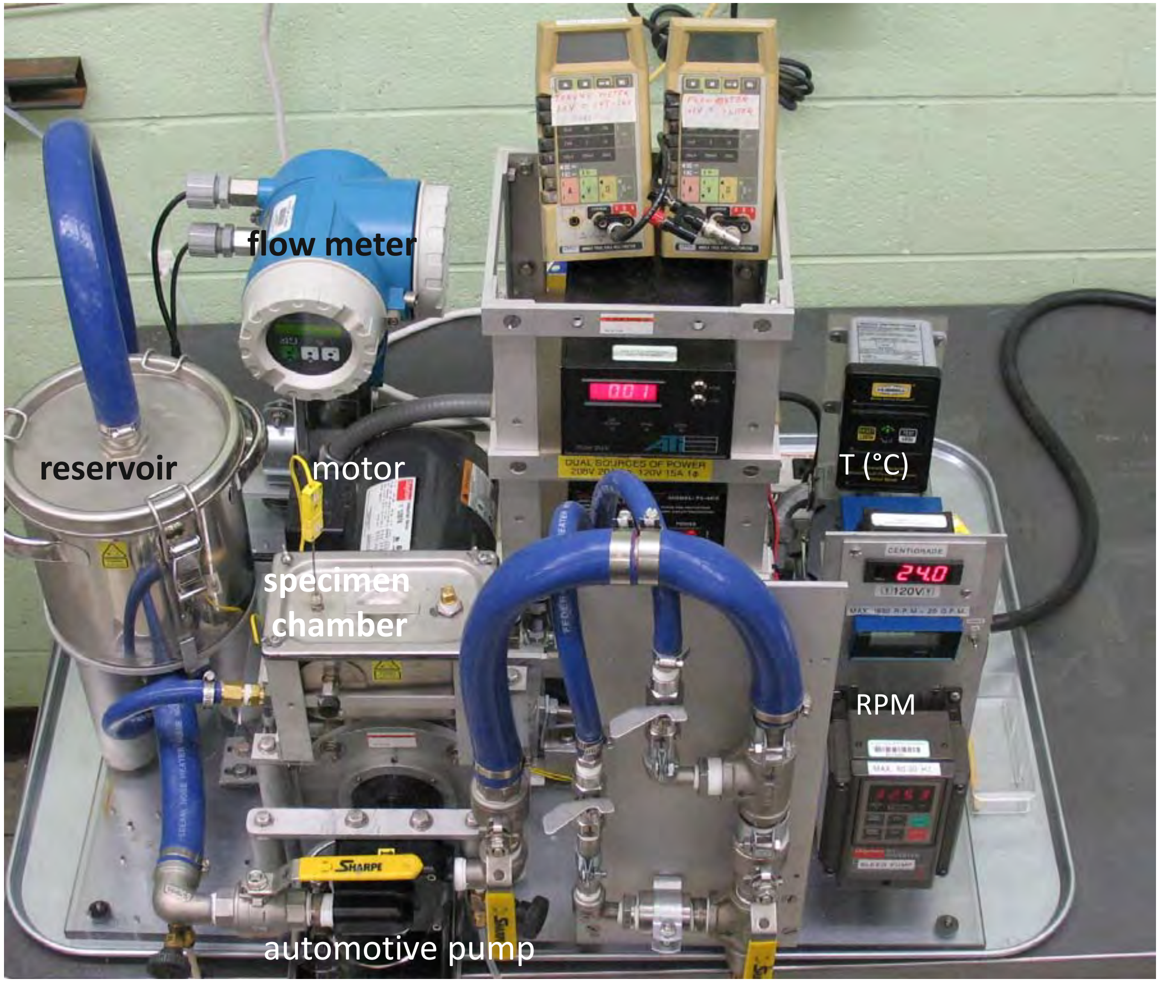
- Engineering approach to heat transfer nanofluid design+
- Erosion measurements
  - Target material – 3003 aluminum
  - Impellor – cast aluminum (unknown spec)
  - Weight loss at 2-10 m/s for 30 and 90° impact angles (radiator velocities ≈1m/s
- Nanofluids Investigated
  - 0.1 – 0.8 vol.% CuO in ethylene glycol (FY09)
  - 2 – 8 vol.% Al_2O_3 in water
  - 0.5 – 4.0 vol.% SiC in water and in ethylene glycol/water (50/50 vol%)
  - Various particle sizes (16 nm to 90 nm)
- Torque Measurements
  - Al_2O_3 nanoparticles in water
  - SiC nanofluids
  - Compare to calculated pressure drops

Multiple variables in Nanofluids



+**Nanofluids for Heat Transfer: An Engineering Approach,** E. Timofeeva et al., Nanoscale Research Letters, in press (2011).

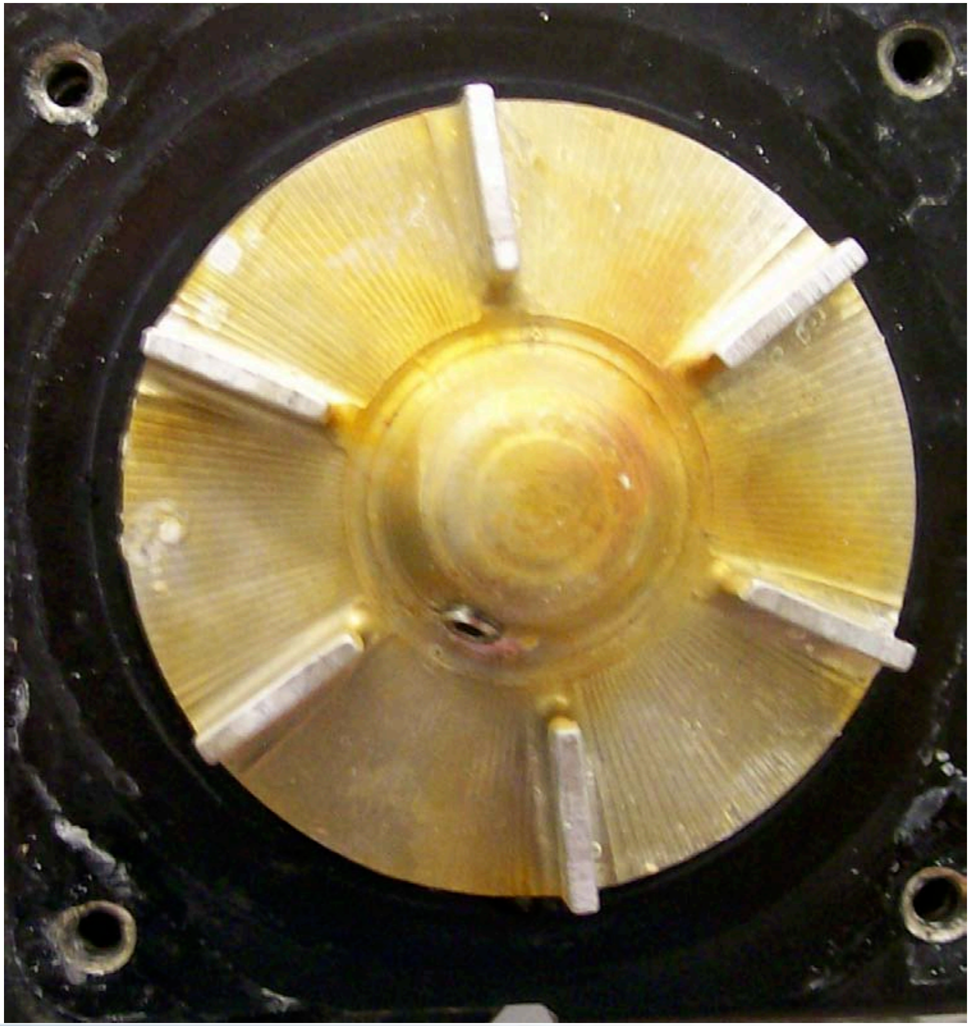
Accomplishments: Pumping Power Apparatus



Torque meter and
Data logger hidden behind

Calculated values of Power based on frictional factors of tube with 5 elbows and 2 Expanders at V=25m/s.

Accomplishments: Corrosion, but little erosion (0.65%) of impellor after hundreds of hours pumping SiC containing fluids at high speeds (20-28 l/minute)



Pumping Power—Calculation

$$P_{shaft} = \tau\omega = P_{pumping} / \eta = Q\Delta p / \eta = \Delta p(\pi d^2 / 4)V / \eta$$

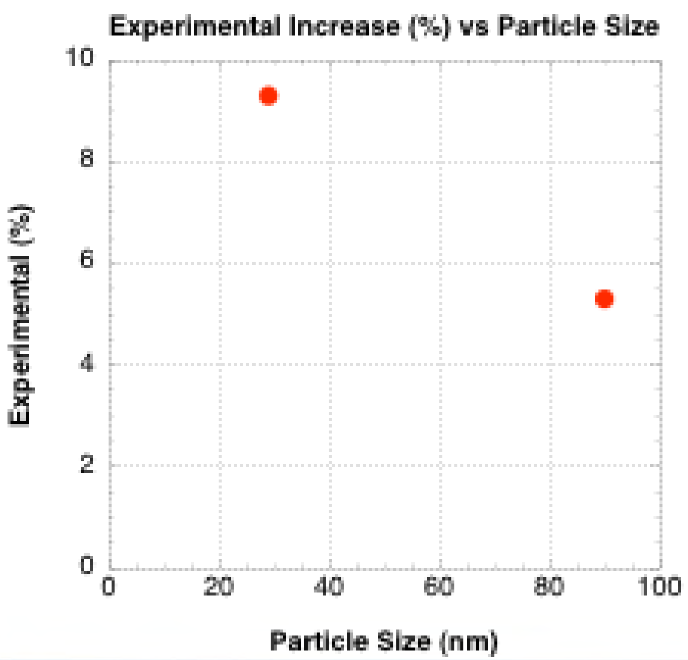
$$P_{shaft} = \frac{Q\Delta P}{\eta} = \frac{(\pi d^2/4)V[\rho g h + 2\rho V^2 (L/d) f + \sum_i K_i (1/2)\rho V_i^2]}{\eta}$$

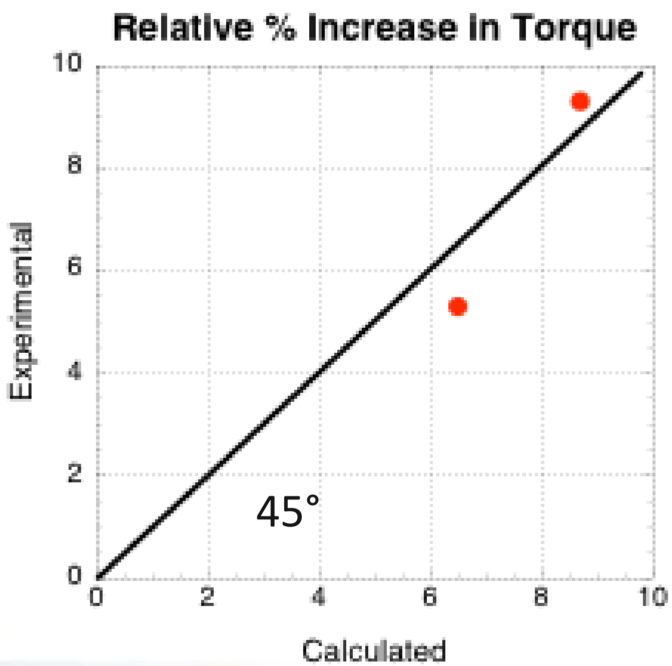
Fanning Friction Factor $f = 0.0791\,\mathrm{Re}^{-0.25} = 0.0791(\rho V d/\mu)^{-0.25}$

V = velocity
μ = viscosity
K = friction factor of each component
L = length
d = diameter
ρ = density
η = pump efficiency
R_e = Reynolds number

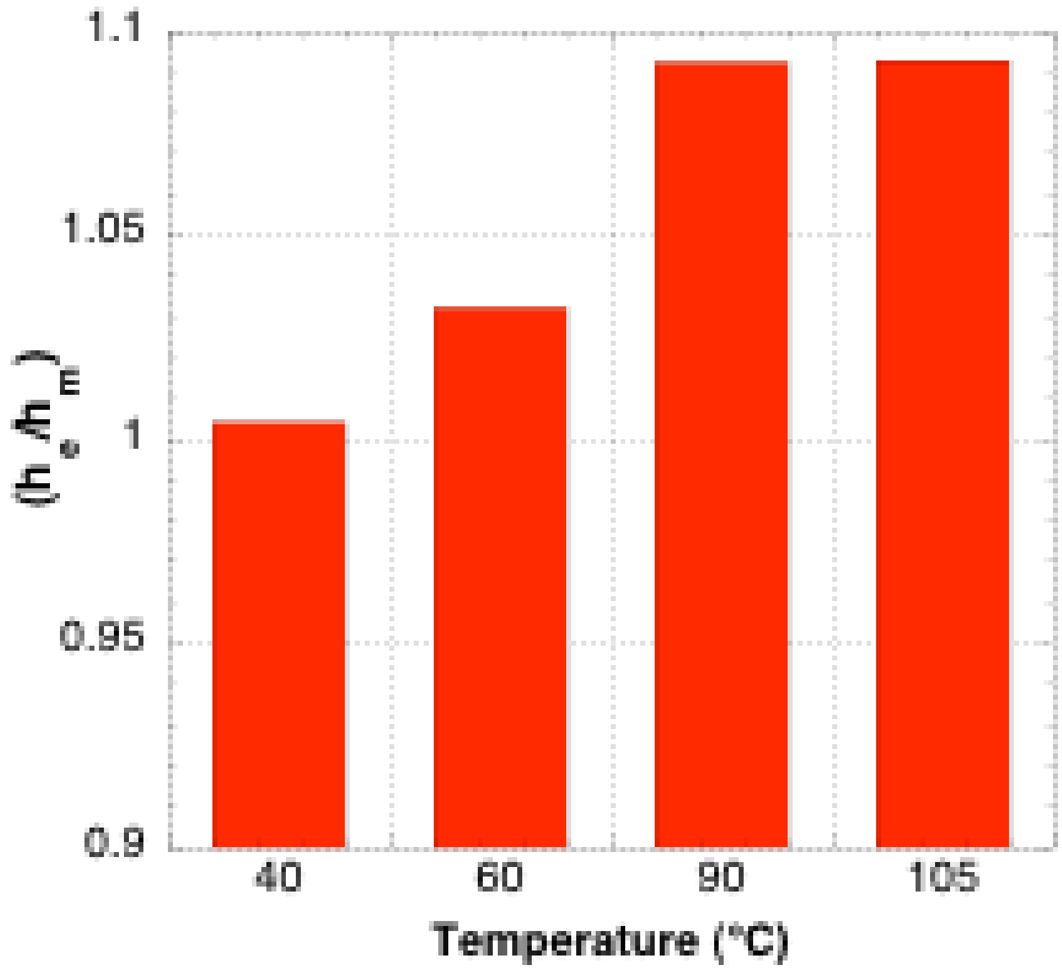
Calculated vs Experimental Torque for SiC in EG/H_2O @ 30°C

Volume % SiC (particle size)	Relative % increase in torque – calculated	Relative % increase in torque – experimental
2.2 (29 nm)	8.7	9.3
4.0 (90 nm)	6.5	5.3





h_{nano}/h_{base} vs. T at constant pumping power for 4 vol.% 90nm—SiC for turbulent flow



Based on property data, experimental values a slightly higher

Collaborations

- TARDEC (Work for others, $200K) – completed
- Michelin (Work for others, $300K) – completed
- DOE Office of Industrial Technologies – on going until end of FY11
- DOE Office of Solar – on going
- Saint Gobain – partner in OIT project to develop manufacturing capacity for nanofluids ($75K)
- Nanoscale (Kansas City, supplied nanofluids)
- Sasol supplied Al_2O_3 nanoparticles
- Ashland Oil (Valvoline), new partner in OIT project, graphitic based nanofluids request to partner in Tardec project in FY12

Path Forward

- Continue erosion tests with “new – ANL produced” nanofluids being developed
- Measure pumping power on “new – ANL produced” 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
- Test newly developed nanofluids in an application for cooling power electronics

Conclusions

- Designed an engineering approach to select nanoparticles/fluids for optimal heat transfer based on detailed experiments and theoretical interpretation (ITP project)
- Erosion using a variety of nanfluids under accelerated flow conditions isn’t a significant problem (FY 09 & FY 10)
- Pressure losses in a “real” system can be calculated based on considering the nanofluid as a single-phase fluid
- Increased pumping power in the SiC/EG-water system decreases as the nanoparticle size increases and will become negligible at heat exchanger operating temperatures