Argonne NATIONAL LABORATORY

Overview of Thermal Control Program at Argonne

J. R. Hull

April 2006

THE UNIVERSITY OF CHICAGO

A U.S. Department of Energy laboratory managed by The University of Chicago

Energy Efficiency and Renewable Energy

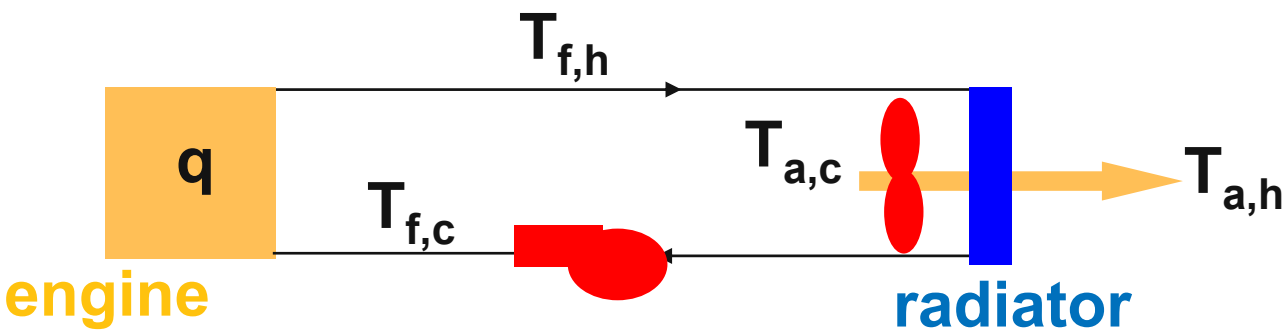
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Outline and Objective

- Provide programmatic overview for next three talks
  - Nucleate Boiling - D. France and W. Yu
  - Nanofluids - S. Choi
  - Possible Erosion by Nanofluids - D. Singh
- Evaporative Cooling
  - Work done in past but on hold at the moment

Primary Effects of Cooling System on Energy Use in Vehicles

- Aerodynamic Drag
  - Radiator size
- Parasitic Power
  - Fan
  - Coolant pump
- Engine creates heat, at rate q, that must be rejected at the radiator

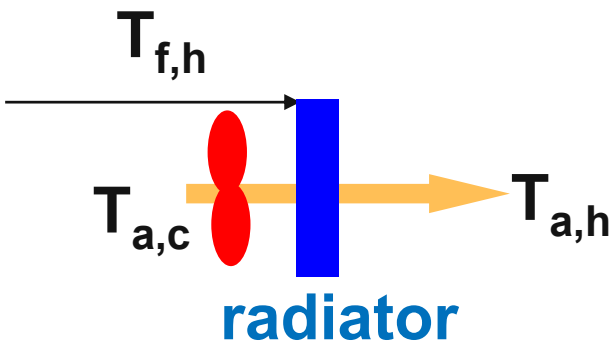


Radiator Surface Area A to Reject Heat q

$q = m\, c\, \Delta T_a$

$m = \rho\, v\, A$

- m is mass flow rate of air
- c is heat capacity
- ΔT_a is temperature difference
  - $= T_{a,h} - T_{a,c}$
- ρ is density
- v is velocity



General Methods to Increase Rejected Heat q at Radiator

$m = \rho\, v\, A$

Increase area A (aero drag increases)

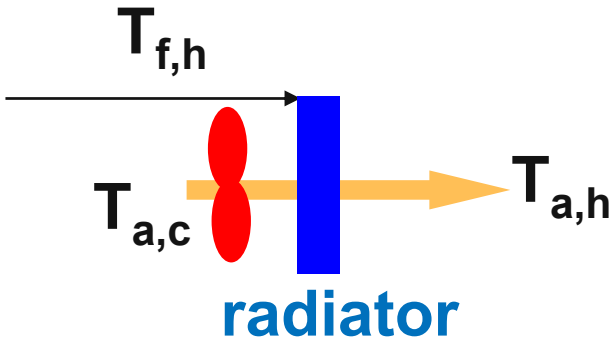
Increase v is velocity (increases parasitic fan power)

$q = m\, c\, \Delta T_a$

Increase c, heat capacity (selective evaporative cooling)

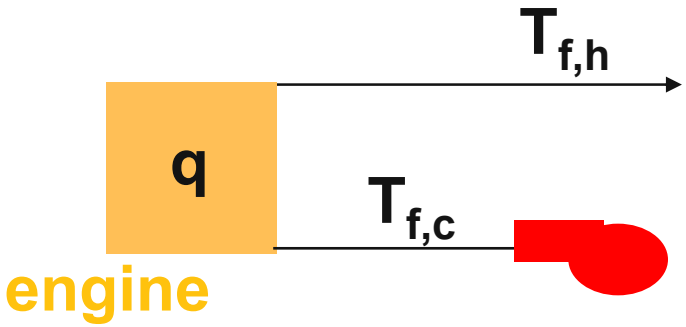
Increase ΔT_a is temperature difference ($T_{a,h}$ is limited by maximum value of $T_{f,h}$ - requires higher temperature coolant)

- nanofluids improve properties of higher temperature coolants



Reduce Parasitic Pumping Power for Coolant

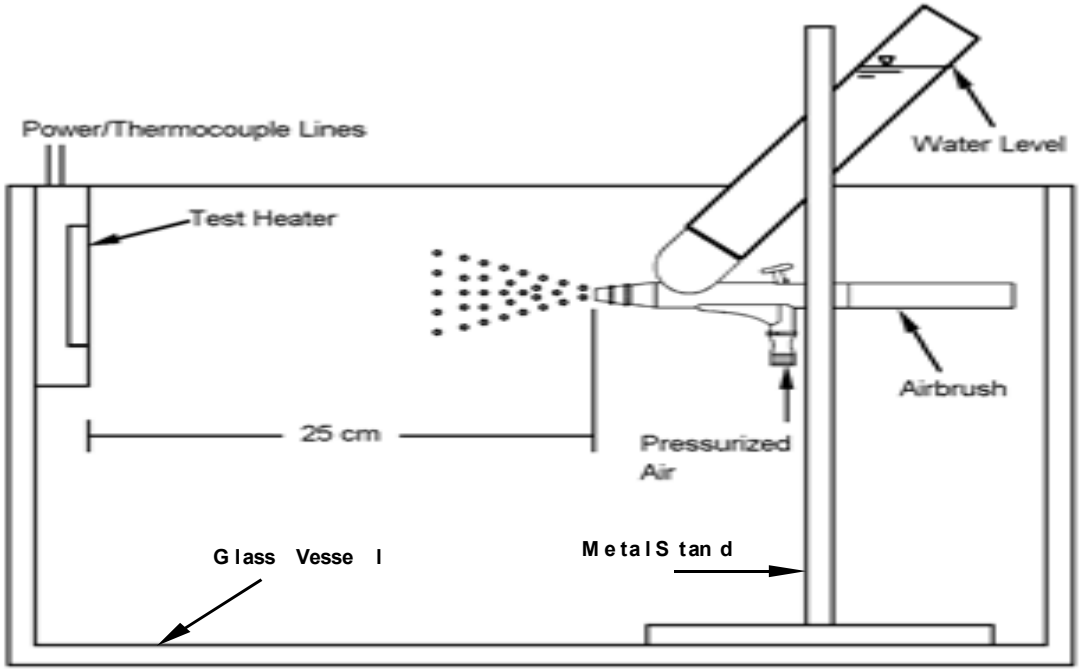
- At the engine, $q = m\,c\,\Delta T_f$
- m (and flow passage size around the cooling loop) determines pumping power
- Increase ΔT_f
  - Requires higher temperature fluid (and nanofluids to improve heat transfer properties of these fluids)
- Make more use of nucleate boiling at engine to increase effective heat capacity, c, of fluid



Evaporative Cooling Concept

- Use evaporative cooling to increase air-side heat transfer in contrast to air cooling alone in conventional radiators.
- Use evaporative cooling primarily at peak heat loads.
- Potentially recover water from air-conditioning (or potentially, fuel-cell) condensate to minimize amount of water carried.

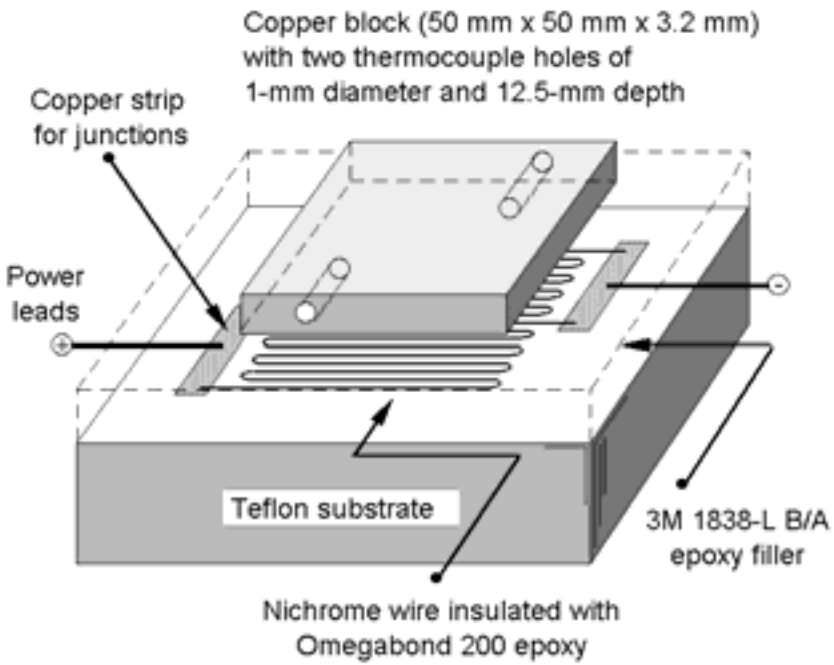
Experimental Facility



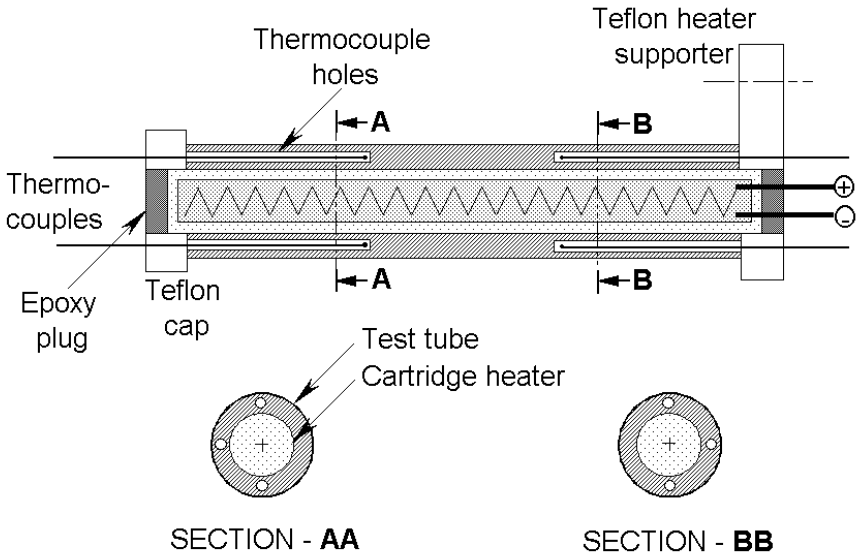
- Designed, fabricated, and operated an experimental facility to study evaporative cooling with plain and coated surfaces
- Cooling mode - Air cooling vs. evaporative cooling
- Air pressure in the nozzle was fixed at 7 psig throughout the study.

Tested Heater Shape

Flat Heater
5x5 cm Cu block

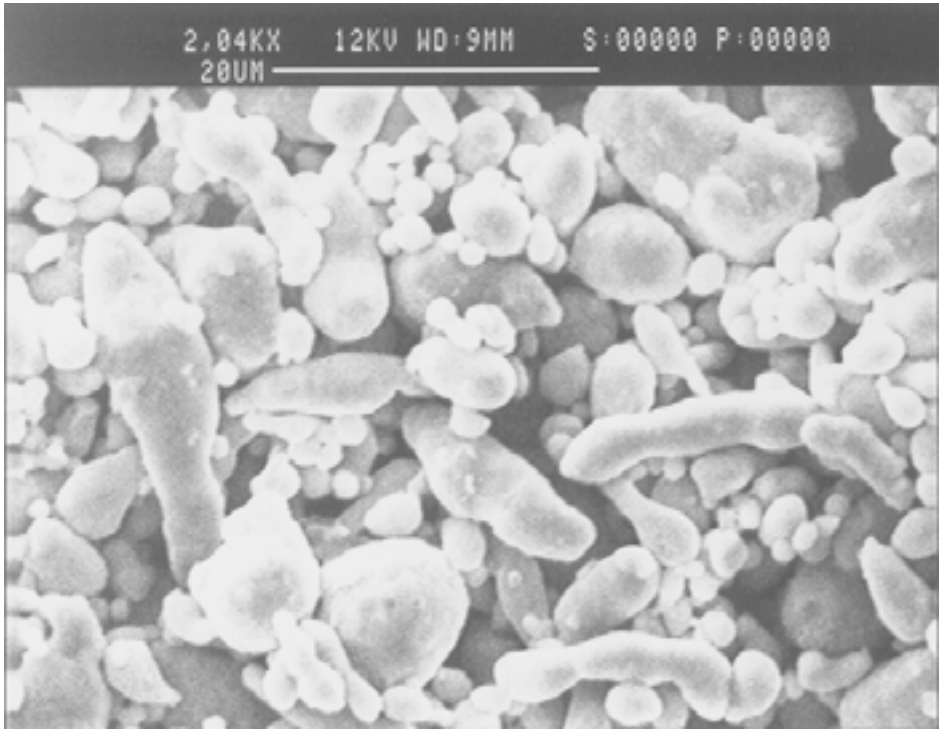


Cylindrical Heater
1.6 cm D 7.6 cm L



Diameter = 15.6 mm
Length = 76.2 mm

Heater Surface



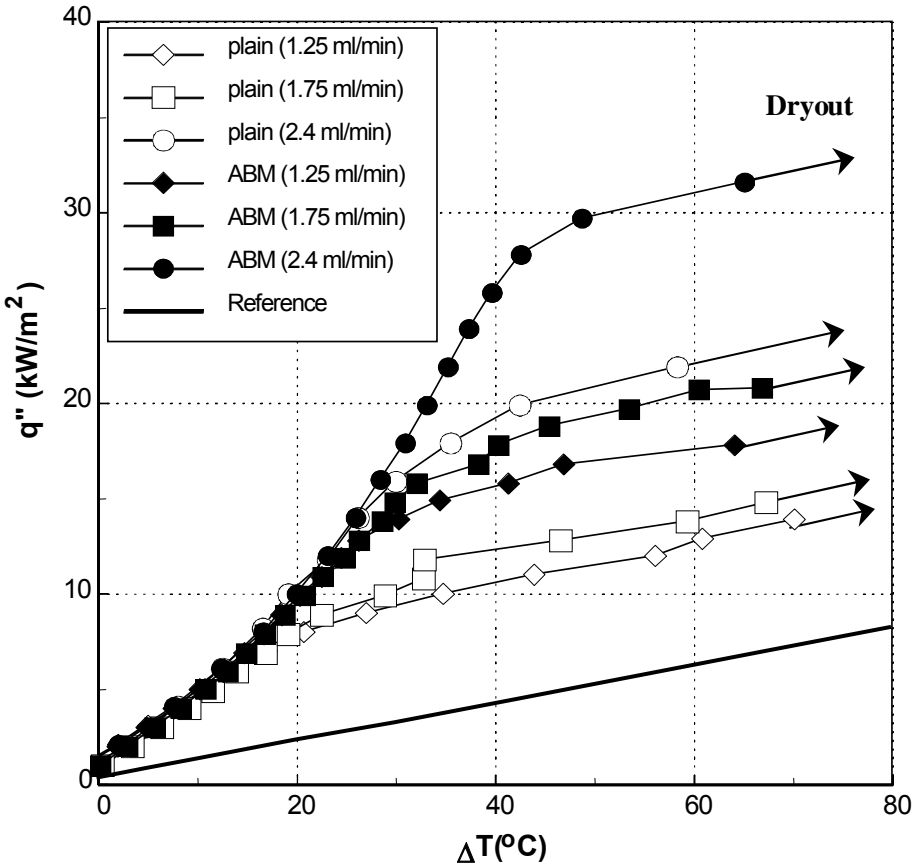
SEM of Microporous Coating

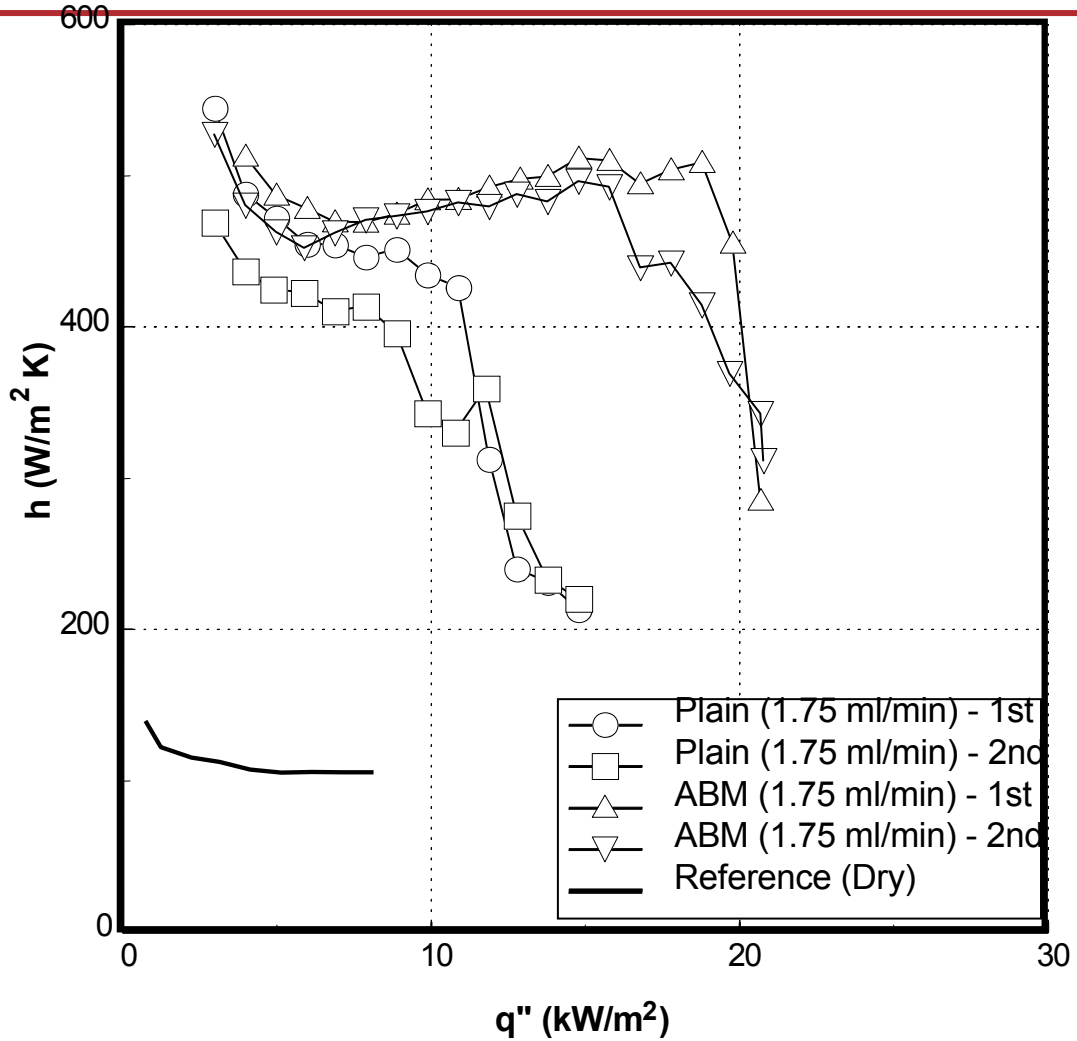
- **Plain surface**
- **Microporous surface**
  - Al particles: 8 - 12 µm
  - Ceramic epoxy
  - Microporous coating thickness: 50 and 100 µm

Test Results

Effect of Water Flow Rate on Heat Transfer Performance (Flat Heater)

- Water amounts (1.25-2.4 ml/min) have no effect on evaporative cooling for microporous coating when heat flux is < 10 kW/m^2.
- For higher heat fluxes, the heat transfer increased with the water flow rate for both plain and microporous surfaces.
- The microporous coating extended the dryout heat flux by a factor of 3 (~30 kW/m^2) over the plain surface.



Test Results
Heat Transfer Coefficient vs. Heat Flux for Flat Heater

- EC on microporous surface enhances the heat transfer coefficient by **up to ~400%** relative to uncoated, dry surface.
- Similar enhancement characteristics were observed for cylinders compared to flat cases.
- Significance: The area required for evaporative cooling is small.