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Efficient Cooling in Engines with Nucleate Boiling

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OVT Merit Review

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This presentation does not contain any proprietary or confidential information.

Purpose of Work

- Utilize the high heat transfer rates of boiling engine coolants under high heat load conditions to:
  - Reduce cooling system size and weight
    - Potential to reduce aerodynamic drag
    - Reduce fuel consumption
  - Reduce parasitic pumping power
  - Enable precision cooling of engine areas

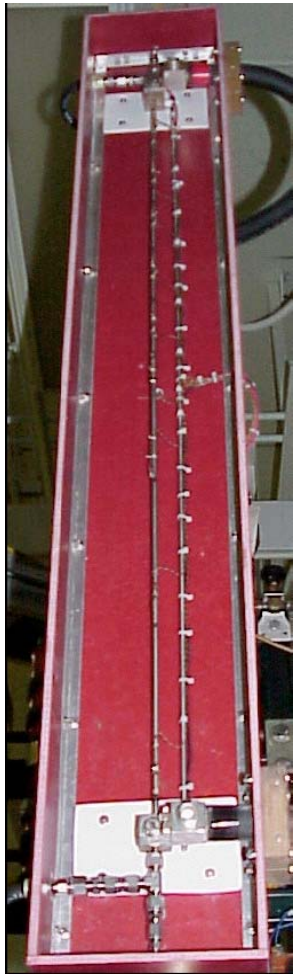
Barriers to Utilization of Boiling Heat Transfer in Engines at High Heat Load Conditions

- Change coolant system design approach
  - From: attempt to suppress coolant boiling under all conditions
  - To: utilization of high boiling heat transfer rates at high heat loads

- Preprogram results almost non-existent for
  - The combination of binary mixture boiling and small channels
  - Ethylene glycol/water boiling

Approach to Boiling Coolant Technology Development

- Develop boiling coolant technology for engine applications
  - Design, fabricate, and utilize a unique experimental facility
    - Horizontal flow
    - Vertical flow
  - Experimentally determine boiling heat transfer rates and pressure drops
    - Emphasis on small coolant passages of head region
    - Emphasis on boiling of binary coolant mixtures of water & ethylene glycol
  - Determine boiling heat transfer limits
    - Critical heat flux
    - Two-phase flow instability
- Develop models for
  - Vehicle coolant system design
  - Heat transfer design



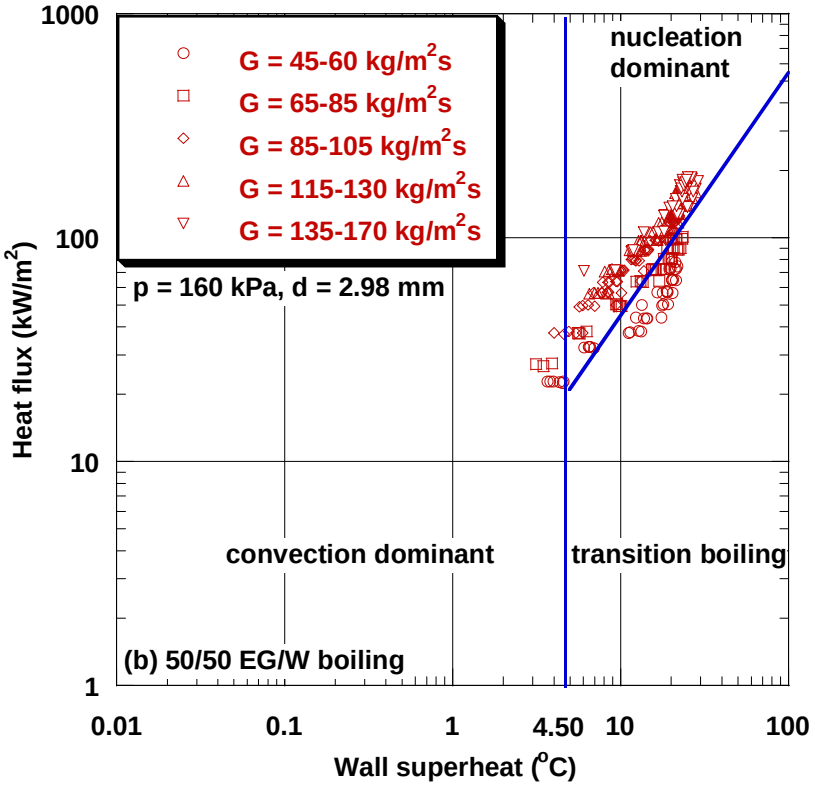
New vertical test section

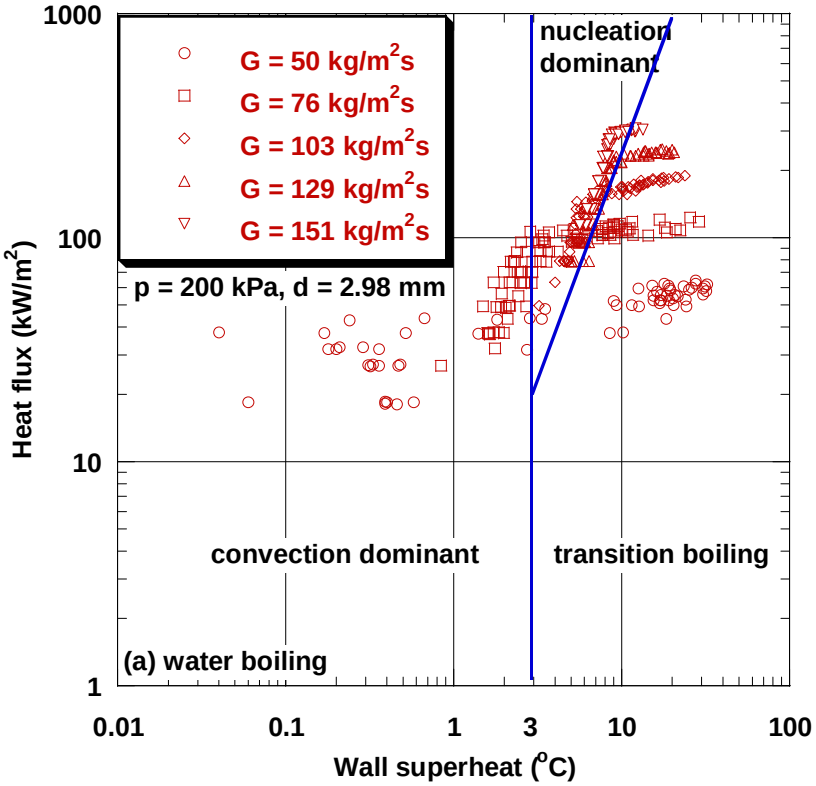
Performance Measures

- Successful boiling experiments with water and ethylene glycol mixtures
- Interpretation and correlation of data for use in engine cooling-system design
- Design and implementation of vertical test section
- Development of vertical versus horizontal boiling technology

Accomplishments

- Developed a new procedure, based on equilibrium ideal-mixtures and Raoult's law, to calculate boiling temperatures along the test section and, subsequently, local heat transfer coefficients
- Completed experiments & data analysis for boiling heat transfer and pressure drop in **horizontal** flows to water and ethylene glycol/water mixtures



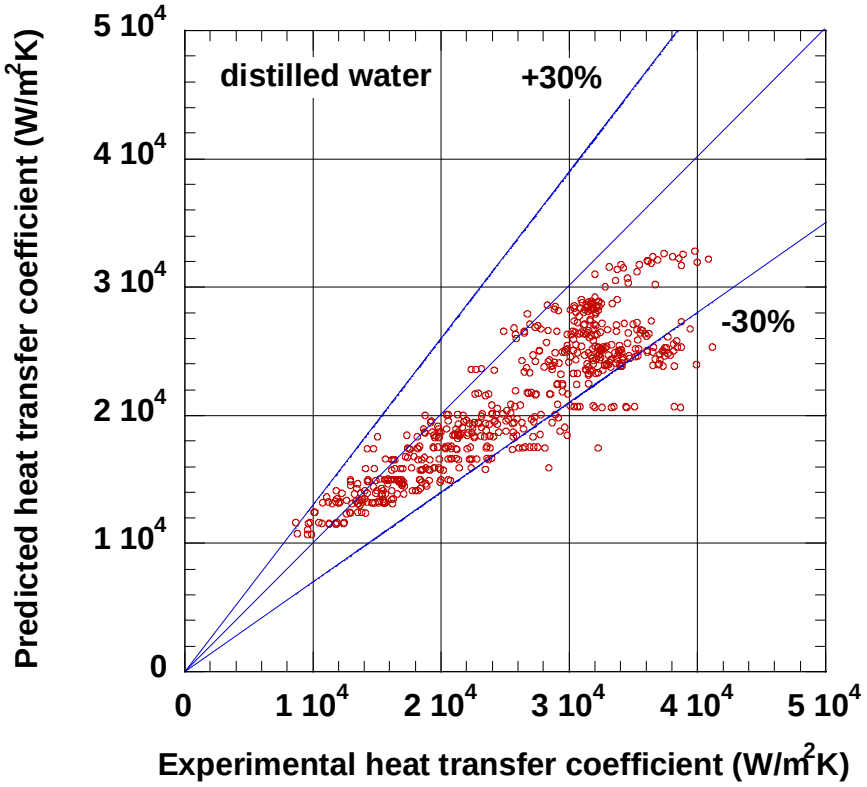


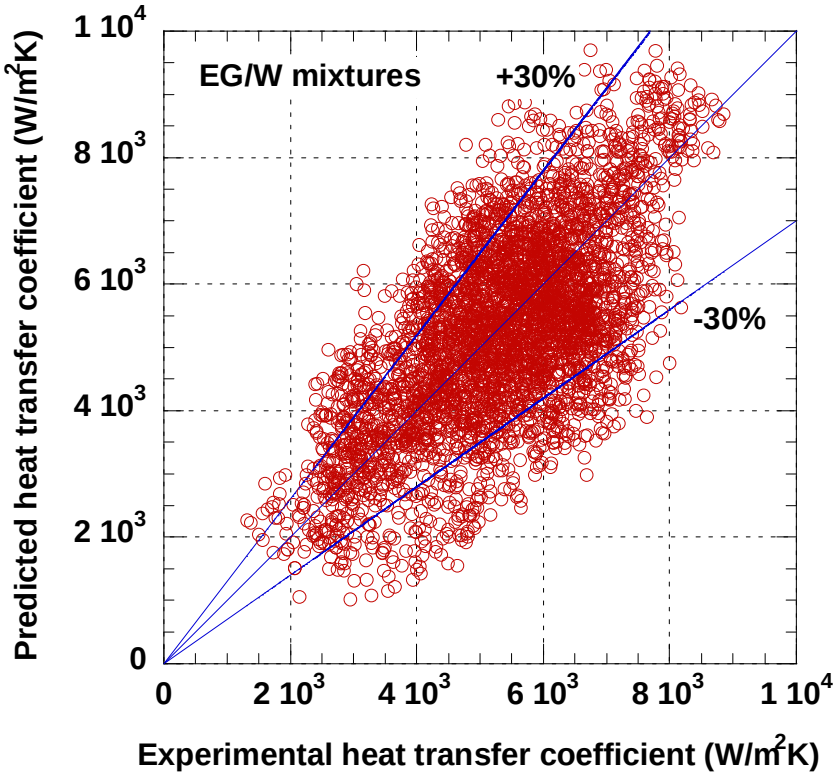
Accomplishments

- Developed a pressure drop correlation, modified from Chisholm's correlation, with a concentration factor to better predict pressure drops for ethylene glycol/water mixtures
- Developed a general correlation for boiling heat transfer, modified from ANL earlier work, for flow boiling in small channels, including: refrigerants, water, and ethylene glycol/water mixtures
  - Predicts data for ethylene glycol & water concentrations
    - 50/50
    - 60/40
    - 40/60
  - Water
  - Refrigerants 12 & 134a

$$h/h^* = \left[1+6v(v-0.5)\right](BoWe_l^{0.5})^{0.5}\left[(\rho_l/\rho_v)^{-0.5}(\mu_l/\mu_v)^{0.7}\right]^{-1.5}$$

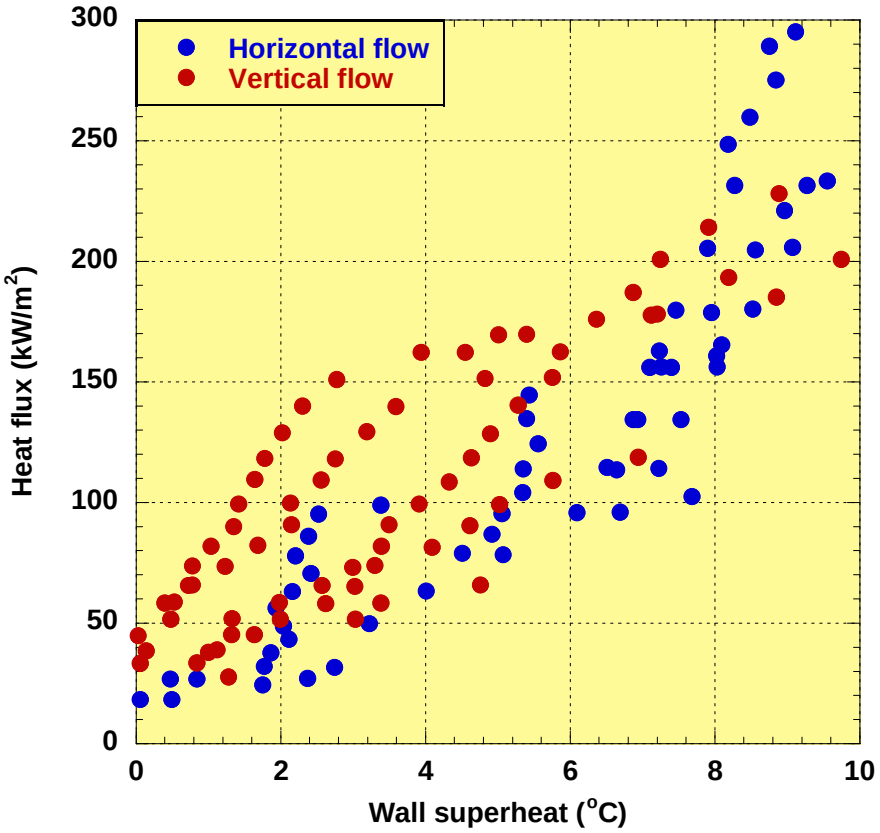
Horizontal Boiling Heat Transfer Coefficients

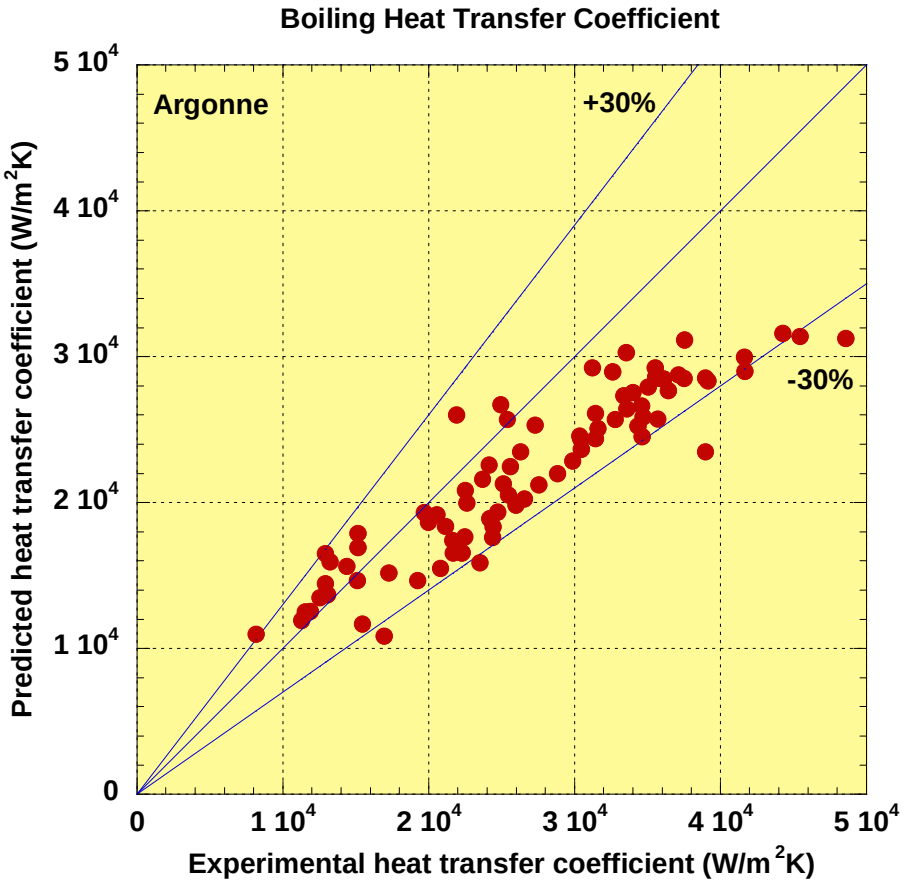




Accomplishments

- Designed & fabricated a new vertical experimental test section
- Performed preliminary experimental tests and data analysis for two-phase, vertical, flow-boiling of pure water





Future Activities

- Systematic two-phase heat transfer experiments of water and ethylene glycol/water mixtures with vertical flows to provide essential information for design of nucleate-boiling cooling systems
- Study the effect of vertical versus horizontal flows on two-phase heat transfer
- Experimentally determine heat transfer characteristics for subcooled flow boiling of water and ethylene glycol/water mixtures
- Perform systematic experiments with alternative fluids

Summary

- Potential for petroleum displacement similar to nanofluid coolant of ≈ 300 x 10^6 gallons fuel/yr through reduced cooling system weight, reduced parasitic pumping power, and reduced aerodynamic drag
- Approach to research uses unique experimental facility for the study of horizontal and vertical flow-boiling water and ethylene glycol mixtures
- Technical Accomplishments
  - Horizontal flow boiling heat transfer and pressure drop
    - Extensive data base developed
    - Correlated data for engine cooling-system design
    - Critical heat flux and flow instability limits established
  - Vertical flow boiling heat transfer and pressure drop
    - Test section completed
    - Preliminary results obtained and compared with horizontal flow
- Technology Transfer by publications & citations
- Plans for Next Fiscal Year
  - Vertical boiling heat transfer experiments of water and ethylene glycol/water
  - Comparisons of vertical and horizontal boiling heat transfer results
  - Correlation of data for engine cooling-system design purposes

Publications & Technology Transfer (for reviewers only)

- **The first general journal paper from the program**
  - ***W. Yu, D.M. France, M.W. Wambsganss and J.R. Hull, "Two-phase pressure drop, boiling heat transfer, and critical heat flux to water in a small-diameter horizontal tube," International Journal of Multiphase Flow, Vol. 28, 2002, pp. 927-941.***
    - **Received 21 citations July 2002 through December 2005**
    - **Unusually high citation number representative of**
      - **Peer recognition**
      - **pioneering work**
      - **transfer of information**
    - **Citations included prominent researchers**
      - **G. Hetsroni, I. Mudawar, & S. G. Kandlikar**
- ***W. Yu, D.M. France, V. Vellore-Ramamoorty, and J. Hull, "Small-Channel Flow Boiling of One-Component Fluids and an Ethylene Glycol/Water Mixture," Experimental Heat Transfer Journal, Vol. 18, 2005, pp. 243-257.***