Experimental Investigation of Coolant Boiling in a Half-Heated Circular Tube

Final CRADA Report

Energy Systems Division

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Summary of Major Accomplishments:

Coolant subcooled boiling in the cylinder head regions of heavy-duty vehicle engines is unavoidable at high thermal loads due to high metal temperatures. However, theoretical, numerical, and experimental studies of coolant subcooled flow boiling under these specific application conditions are generally lacking in the engineering literature. The objective of this project was to provide such much-needed information, including the coolant subcooled flow boiling characteristics and the corresponding heat transfer coefficients, through experimental investigations. The major accomplishments of this project are:

Summary of Major Accomplishments:

1. A unique experimental test section was designed and fabricated at Argonne National Laboratory. Its material (AISI type 1010 carbon steel), dimensions (10.9-mm inside diameter, 12.7-mm outside diameter, and 50.8-mm heated length), and heating condition (only from the bottom of the experimental test section) simulated the cooling channels in the cylinder head regions of heavy-duty vehicle engines.
2. A series of experimental tests was conducted for water and ethylene glycol/water mixtures at volume ratios of 40/60 and 50/50 under various test parameters covering the cooling operation conditions in heavy-duty vehicles. The test parameters were five fluid flow velocities in the range of 0.125–1.5 m/s, four fluid inlet subcooling temperatures in the range of 10–25 °C, and three system pressures in the range of 15–45 psia. For each combination of the test parameters, experimental data were collected for multiple heating power levels under both single-phase flow and two-phase flow conditions.
3. A new data reduction procedure was developed that allowed the calculation of the heat transfer coefficients of subcooled flow boiling only on the bottom surface of the experimental test section by separating the overall heat transfer into two parts, top single-phase convection and bottom subcooled flow boiling.
4. Boiling curves were generated for each combination of the test parameters based on the experimental data. The boiling curves show two typical heat transfer regions of single-phase convection and subcooled flow boiling. The transition from single-phase convection to subcooled flow boiling was indicated by a smaller wall superheat increment for the same heat flux increment when subcooled flow boiling occurred. A merging pattern was found, especially for low fluid flow velocities, for the boiling curves of various fluid inlet subcooling temperatures.
5. Subcooled flow boiling heat transfer coefficients were determined from the experimental data based on the data reduction procedure developed in this study that separated overall heat transfer into top single-phase convection and bottom subcooled flow boiling. Predictive correlations were developed for the experimental subcooled flow boiling heat transfer coefficients as functions of the boiling heat flux, the convective heat transfer coefficient predicted by the Dittus-Boelter correlation, the ethylene glycol volume concentration, and a boiling number term based on the experimental data. These correlations predict almost all of the experimental data within $\pm 20\%$ with their mean deviations $< 10\%$.

Summary of Technology Transfer Benefits to Industry:

The data, analyses, and correlations from the experimental investigations of this project provide many benefits to the participant PACCAR, Inc. as well as other related industrial companies. These benefits include:

1. The experimental data and analyses provide quantitative results on potential cooling performance with subcooled flow boiling in the cooling channels in the cylinder head regions of heavy-duty vehicle engines, such as conditions for subcooled flow boiling and its heat transfer rates. Such information is currently lacking in the engineering literature.
2. The experimental data and analyses also provide necessary information for optimizing heavy-duty vehicle engine cooling through the combined use of single-phase convection and two-phase subcooled flow boiling.

Summary of Technology Transfer Benefits to Industry:

3. The experimental data and the predictive correlations obtained in this project ensure that any numerical simulations are based on reliable inputs and therefore any results from those numerical simulations are the reflection of actual cooling system performance.

4. The experimental data and the predictive correlations can also be used for designing heavy-duty vehicle engine cooling systems incorporating coolant subcooled flow boiling.

These benefits will lead to an increased heavy-duty engine cooling system efficiency, improved heavy-duty engine operation conditions, and an enhanced heavy-duty engine thermal efficiency.

Other Information/Results: (Papers, Inventions, Software, etc.)

W. Yu, D.M. France, D. Singh, R.K. Smith, J. Ritter, T. Vijlbrief, and Y. Menger, Subcooled Flow Boiling of Ethylene Glycol/Water Mixtures in a Bottom-Heated Tube, *International Journal of Heat and Mass Transfer*, vol. 72, pp. 637–645, 2014, DOI: 10.1016/j.ijheatmasstransfer.2014.01.051.

W. Yu, D.M. France, W. Zhao, D. Singh, and R.K. Smith, Subcooled Flow Boiling Heat Transfer to Water and Ethylene Glycol/Water Mixtures in a Bottom-Heated Tube, *Experimental Heat Transfer*, May 2015, DOI: 10.1080/08916152.2015.1046018.

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