2009 BFRL Project Description

Project Title: Nanofluids Heat Transfer Measurements

August 18, 2008

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Co-Investigator(s):

BFRL Program: Healthy and Sustainable Buildings

Objective: To support the goal of Net Zero energy buildings[1] by developing a fundamental understanding of the mechanisms associated with heat transfer enhancement of nanolubricants for improving the energy efficiency of chillers by 2013. Nanoparticles of various size, shape, and material will be investigated.

Problem:

What is the problem? The U.S. Department of Energy (DOE) champions Net Zero energy buildings -- buildings that produce as much energy as they consume.[2,3] According to DOE's Office of Energy Efficiency and Renewable Energy, *"Buildings now use 72 percent of all electricity and account for 80 percent of all electric expenditures[4]."* Considering that space cooling is responsible for nearly 13 % of total building electric expenditures[1], significant reductions in building energy consumptions and carbon dioxide emissions are to be realized with improvements in the energy efficiency of refrigerant chillers. For 2003, approximately 3.1 quads of energy were expended on chillers in the U.S. alone.[5]

Nanolubricants are lubricants containing dispersed nanoparticles with the purpose of improving thermal conductivity and lubricity. Recent BFRL work has demonstrated that nanoparticles can significantly improve refrigerant/lubricant-boiling performance. The potential for improving the boiling heat transfer is unknown because a fundamental understanding of how the size, shape, and material of a nanoparticle can be chosen to optimize refrigerant boiling does not exist. For this reason, the measurement science developed in this project will form the basis of a nanolubricant evaluation for use by manufacturers of new chillers and operators of existing chillers.

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[1] *Moving Toward Zero Energy Homes http://www.eere.energy.gov/buildings/info/documents/pdfs/35317.pdf*

[2] *Zero Energy Buildings – A Critical Look at the Definition, www.nrel.gov/docs/fy06osti/39833.pdg*

[3] *Energy Efficiency in Buildings, http://www.wbcsd.org/DocRoot/seqH6hKIxVrTRYxAhemYEEBSummaryReportFINAL.pdf*

[4] *DOE Buildings Energy Data Book http://buildingsdatabook.eren.doe.gov/*

[5] *http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set10/2003pdf/c13.pdf*

Why is it hard to solve? It is difficult to develop a fundamental model/understanding because the phenomenon is governed by many parameters, e.g., boiling site density, nanoparticle properties, refrigerant properties, concentration, heat flux, etc. In addition, complex interactions between nanoparticles and bubbles within the lubricant excess layer determine if a boiling heat transfer degradation or enhancement is achieved. Because of the large number of influential parameters, it is impossible to conduct a full-factorial experimental design to determine which parameters are controlling and in what way. Consequently, we must rely on measured data to assist in the choice of the nanoparticles for study. The lack of refrigerant/nanolubricant boiling heat transfer measurements and a corresponding model for prediction makes it very difficult to understand the fundamental mechanisms that govern the nanoparticle/bubble interaction.

How is it solved today, and by whom? The measurement science is not available that characterizes refrigerant/nanolubricant boiling heat transfer properties. DOE focuses on the development and demonstration of energy technologies but, together with industry, depends on NIST to develop the measurement science needed to evaluate energy technologies. The literature on single-phase nanofluids heat transfer is expanding. However, the single-phase heat transfer studies can contribute little to the understanding of refrigerant/nanolubricant boiling. BFRL's prior work in nanolubricants for enhancing refrigerant pool boiling remains the sole source for this measurement science.

Why NIST? This project is anticipating the needs of the U.S. refrigeration and air-conditioning industry by enabling the development of new technology that can be used to improve the efficiency of chillers and, thus, the competitiveness of the industry. By being the leader in the development of refrigerant/nanolubricant boiling heat transfer measurement science, BFRL can be the source for critical knowledge on the performance of refrigerant/nanolubricant boiling.

This project is aligned with BFRL's strategic priority in Measurement Science for Net Zero Energy, High-Performance Buildings because the project's goal is to provide a simple means by which chillers used to cool buildings can operate with improved performance. In addition, this project is aligned with BFRL's core competency in Measurement Science for Building Energy Technologies because the project will achieve its goal via fundamental measurements.

Approach:

What is the new technical idea? Optimizing heat transfer enhancement with nanolubricants can best be explored fundamentally by studying the effects of nanoparticle size, shape, and material on performance. So far in our studies we have determined that a nanoparticle's thermal conductivity is not necessarily the primary determining factor for whether a heat transfer enhancement is achieved or not. Nanoparticle concentration seems to play a more important role than thermal conductivity, but the reasons for this are not fully understood. Particle agglomeration was not studied yet, but it is also expected to play a role as a determining factor. By systematically investigating the key parameters that characterize nanolubricants, we can unlock the fundamental mechanisms that govern refrigerant/nanofluid boiling.

Our competence in understanding and modeling refrigerant/lubricant mixture pool boiling will form the basis from which we will develop the understanding of the mechanisms that govern

refrigerant/nanolubricant pool boiling. The new understanding can be used to develop a refrigerant/nanolubricant pool-boiling model based on the salient characteristics of the nanoparticles. The model can be used to predict the boiling performance of refrigerant/nanolubricants mixtures that have not been measured and to maximize heat transfer to improve the chiller efficiency.

Why can we succeed now? The PI has developed a fundamental knowledge base and predictive capability for the boiling of refrigerant/lubricant mixtures in response to the growing demand for energy efficient chillers. This competence can be used to interpret the measured effects that nanoparticles have on refrigerant/lubricant boiling. For example, the boiling models can be used to estimate the magnitude of the boiling enhancement as caused by the increase in lubricant thermal conductivity due to the nanoparticles. In addition, the Federal investment in nanotechnology via the National Nanotechnology Initiative (NNI)[6] over the past eight years has generated a wealth of enabling sciences, technologies and advancements that can be used to support the present project.

What is the research plan? The FY09 project will investigate the effect of a 1 % diamond nanoparticle volume fraction on boiling heat transfer. This directly supports the goal of Net Zero energy buildings by adding another piece to the puzzle of developing a fundamental understanding of the mechanisms associated with heat transfer enhancement with nanolubricants for improving the energy efficiency of chillers. Previous BFRL projects investigated the influence of CuO concentration on R134a/lubricant pool boiling. These studies showed that concentration was a strong governing parameter. For example, a 4 % volume fraction CuO solution of the base lubricant of one mixture gave a heat transfer enhancement of between 40 % and 275 %, while overall heat transfer degradations where observed for the 2 % volume fraction CuO solution.

The study will start with tests of R134a mixed with the pure base lubricant. Roughly eighty discrete operating points will be recorded to characterize the steady-state heat flux versus temperature (boiling curve) of three mixtures with different lubricant mass fractions (0.5 %, 1 %, and 2 %). These will be the reference measurements for the study. Then, diamond nanoparticles will be added to the base lubricant to form the nanolubricant containing 1 % of nanoparticles (by volume). In order to determine the effect of the nanolubricant, the boiling curve for three mixtures of R134a and the nanolubricant will be measured at the same three mass fractions as was done for the R134a and the pure base lubricant. Ratios of the heat flux for the R134a with the nanolubricants to the heat flux for the R134a with the pure base lubricant will be made as a function of heat flux for each of the three compositions.

The nanoparticle size will be measured with the use of our recently purchased non-invasive backscatter (NIBS) light scattering apparatus. In addition, the thermal conductivity and the viscosity will be measured.

FY10 and FY11 projects will determine the influence of a 4 % carbon-nanotube volume fraction nanolubricant and a 4 % magnetized-chromium volume fraction nanolubricant on R134a pool boiling, respectively. The results of these projects will be essential for the

[6] http://www.nano.gov/

completion of the FY12 and FY13 reports on the fundamental mechanisms of refrigerant/nanolubricant pool boiling.

How will teamwork be ensured? The PI will oversee a contractor in the measurement of boiling data. The PI will analyze the measurements, develop models and/or understanding, and write the reports. The contractor has over thirty years experience operating apparatus and five-years measuring boiling heat transfer. On occasion, other laboratories, divisions, and groups will be consulted and asked to assist in the property measurements of our test nanolubricants. We are currently part of the International Nanofluid Properties Benchmark Exercise.[7]

Outside BFRL Funding: There are no current non-STRS funding sources for this project. The Office of Naval Research's Program Officer, Dr. M. Spector, has shown interest in the project by inviting the PI to present project results at a government workshop.[8]

Recent Results:
Output: Kedzierski, M. A., and Gong, M., 2007, "Effect of CuO Nanolubricant on R134a Pool Boiling Heat Transfer with Extensive Measurement and Analysis Details," NISTIR 7454, U.S. Department of Commerce, Washington, D.C. (submitted to International Journal of Refrigeration)

Output: Kedzierski, M. A., 2007, "Effect of CuO Nanoparticle Concentration on R134a/Lubricant Pool Boiling Heat Transfer with Extensive Analysis," NISTIR 7450, U.S. Department of Commerce, Washington, D.C. (ASME conference version published in 2008 and selected and accepted for ASME Journal of Heat Transfer special issue)

Output: ASHRAE Seminar, "Boiling with Refrigerants and Nanolubricants," 2007 Annual meeting, Long Beach, CA.

Outcome: Created new knowledge and understanding of the potential of nanolubricants for chillers, which has resulted in industry interest.

Standards and Codes: No project outcomes or impacts relate directly to standards and codes.

Deliverable: 9/09 NISTIR on the effect of diamond nanolubricants composition and properties on R134a pool boiling, approved by WERB. (M.A.Kedzierski)
Deliverable: 2010 Measure and report the effect of nanolubricants (4 % carbon nanotube volume fraction) on R134a pool boiling on a smooth surface. (M.A.Kedzierski)
Deliverable: 2011 Measure and report the effect of nanolubricants (4 % magnetized chromium dioxide volume fraction) on R134a pool boiling on a smooth surface. (M.A.Kedzierski)
Deliverable: 2012 Report on refrigerant/nanolubricant pool-boiling model based on the salient characteristics of the nanoparticles. (M.A.Kedzierski)

[7] http://128.150.4.107/awardsearch/showAward.do?AwardNumber=0812804
[8] http://space-power.grc.nasa.gov/iapg/

Final Deliverable: 2013 Report on the model and its application for obtaining improved chiller performance (M.A.Kedzierski)