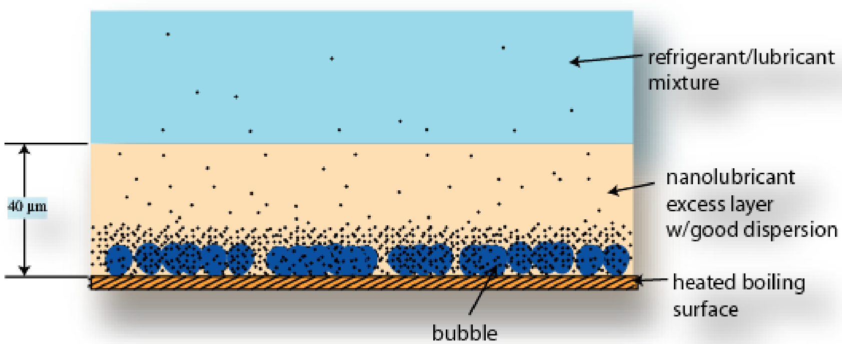

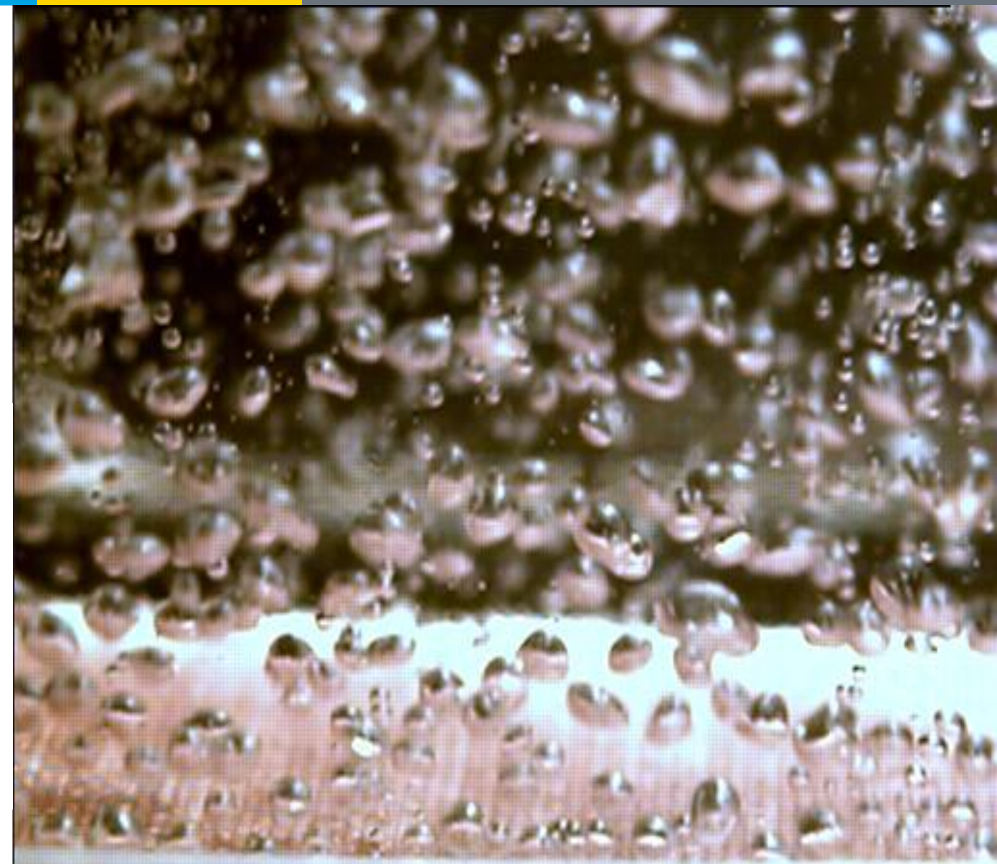

Nanolubricants to Improve Chiller Performance

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Purpose & Objectives

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Problem Statement:

Enabling technology for improving the efficiency of chillers that cool large buildings with nanolubricants. (Nanolubricants are not currently used in chillers.)

Develop fundamental understanding of how nanolubricants enhance refrigerant/nanolubricant. What nanoparticle size, what material, how much, dispersion quality, etc.?

An accurate, predictive tool to predict the enhancement induced by nanolubricants is needed in order to accelerate the evaluation and application of nanolubricants in chillers.

Purpose & Objectives

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Impact of Project: Low-cost “retrofitting the existing building stock” because the additional costs of the nanolubricant is expected to be marginal.

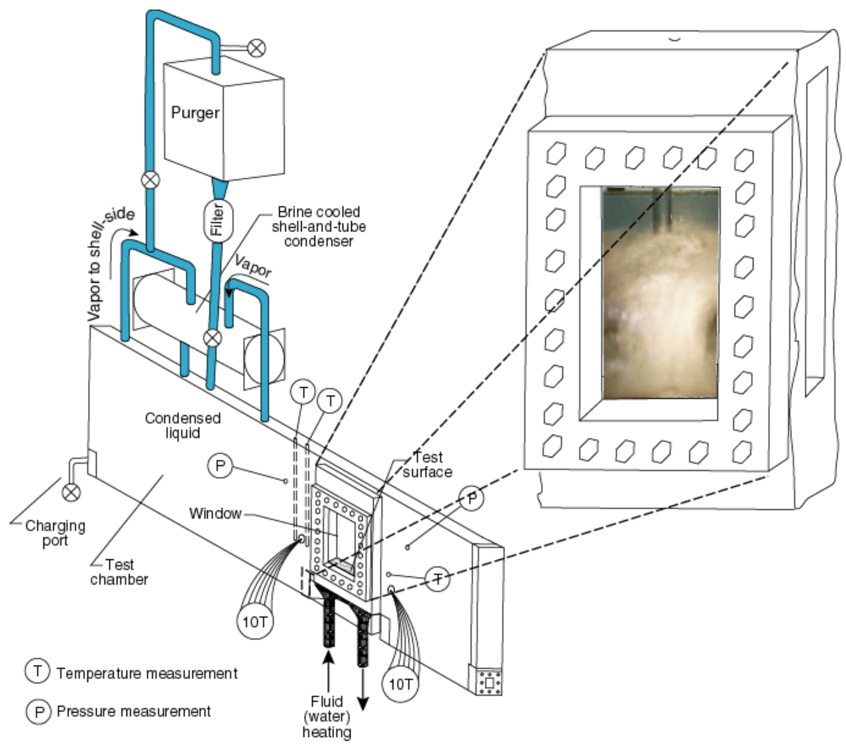
Final Product: A predictive tool to accelerate the development of new efficiency promoting products (nanolubricants) for chillers that provided air-conditioning for large buildings.

Project Focus: To reduce the energy used to air-condition large buildings. Use industrial partners to facilitate the realization of nanolubricants becoming a new product for chillers.

Approach

- Pool-boiling rig used to measure heat transfer performance of R134a/nanolubricant mixtures with nanoparticle of varied characteristics.

- Key Issue: Understanding how nanoparticle and lubricant properties affect boiling performance
- Key Issue: Translating that understanding into a single predictive tool that involves all the salient governing parameters.
- Key Issue: Guide industry in use of new tool.

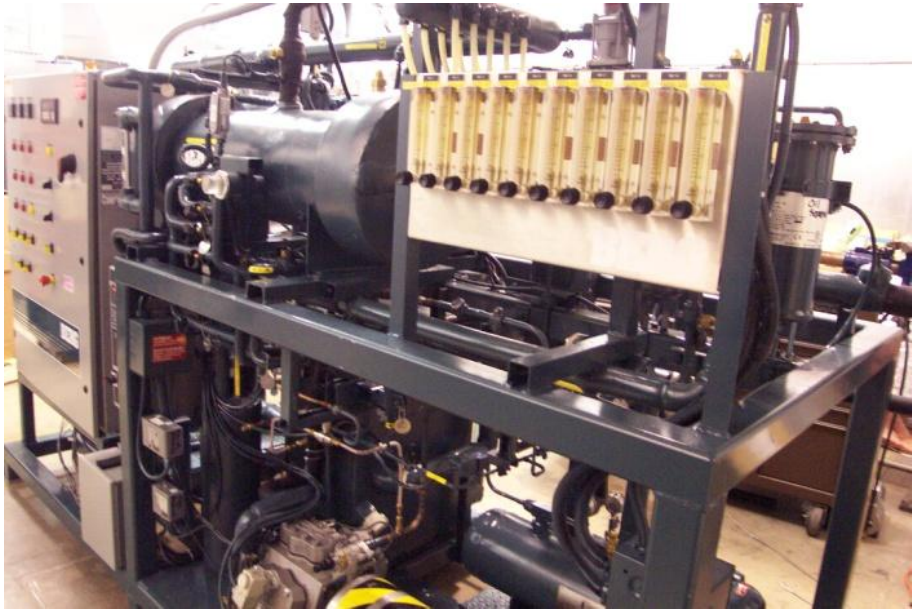


Approach

Distinctive Characteristics ➡ Multifaceted Approach:

(1) The direct involvement of a chiller manufacturer, a lubricant manufacturer, and nanofluid manufacturer, in concert, provides essential guidance in order to maximize the potential impact on the energy use in buildings.

(2) NIST is solely supporting a project to test a nanolubricant in an actual chiller.



(3) NIST has more than 20 years experience measuring and modeling refrigerant/lubricant boiling.

Accomplishments and Progress

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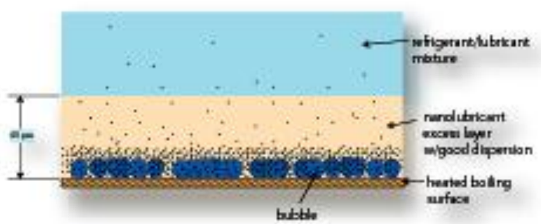
R134a/Al_2O_3 nanolubricant exhibited average enhancement of approximately 18 %, 102 % and 113 % depending on nanoparticle surface density



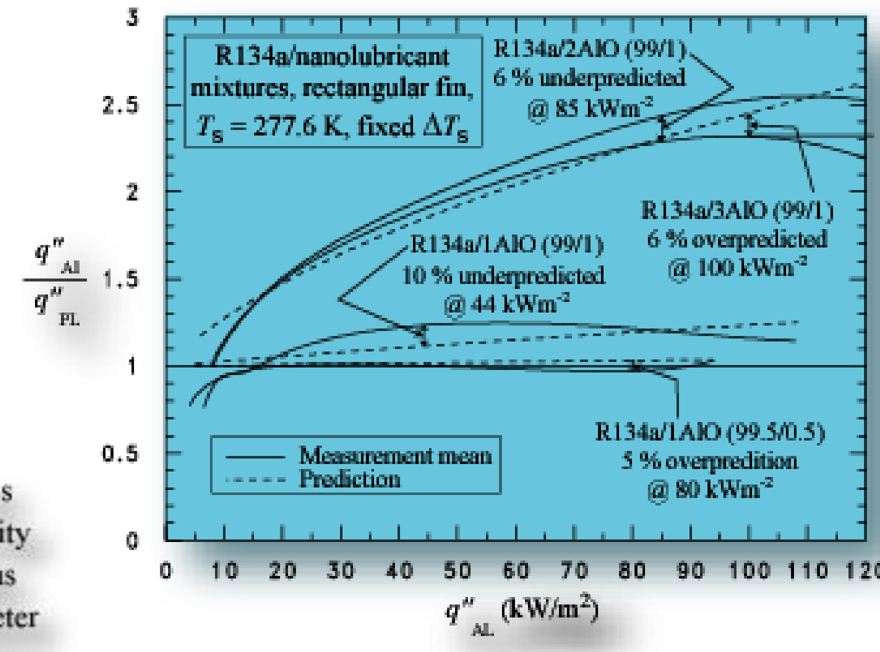
M = mass
u = velocity
r = radius
D = diameter
N = number

Conservation of momentum for nanoparticles impacting a single bubble

$$\frac{N_{np}}{N_b} M_{np} u_{np_i} + M_{b_i} u_{b_i} = \frac{N_{np}}{N_b} M_{np} u_{np} + M_{b_f} u_{b_f}$$

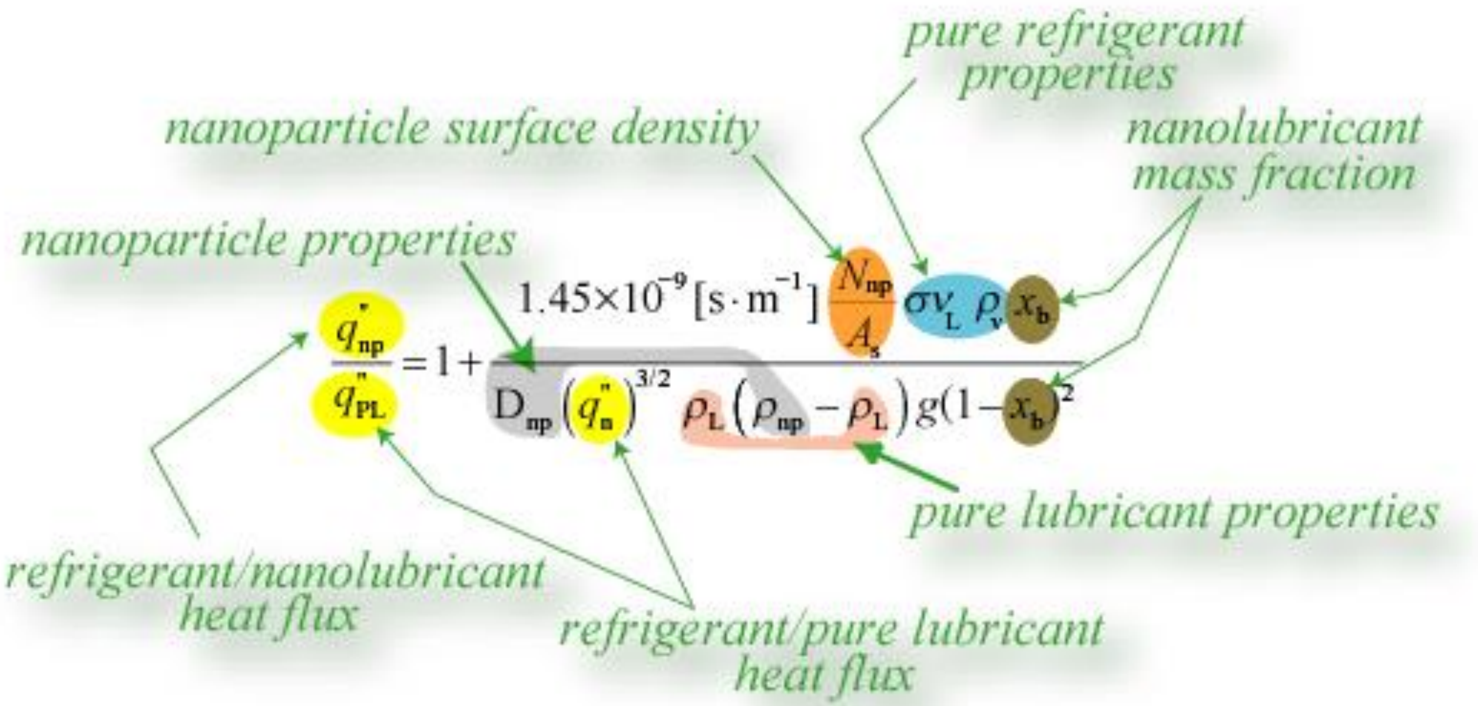
Change in kinetic energy of the nanoparticle is equal bubble surface work

$$\frac{1}{2} M_{np} u_{np_f}^2 - \frac{1}{2} M_{np} u_{np}^2 = 4\pi\sigma\left(r_{b_f}^2 - r_{b_i}^2\right)$$



The model and the measurements agreed to within 10 % for all of the data with heat fluxes less than 100 kWm^{-2}.

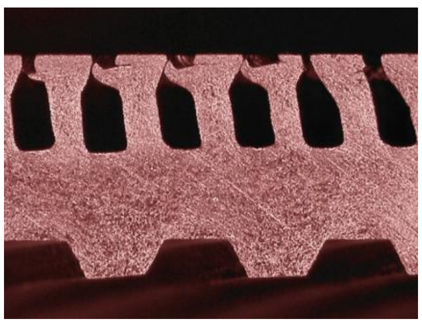
Semi-Empirical Model for Refrigerant/Nanolubricant Boiling Fitted to Single Constant

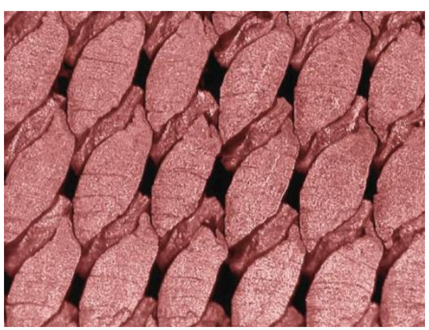


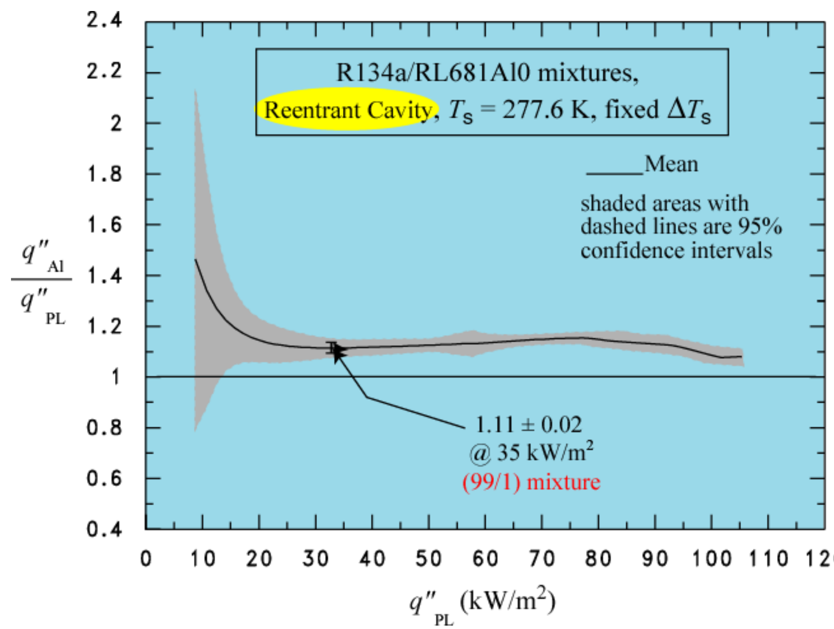
$$\frac{q''_{np}}{q''_{PL}} = 1 + \frac{1.45\times10^{-9}[\mathrm{s}\cdot\mathrm{m}^{-1}]\dfrac{N_{np}}{A_s}\sigma v_L \rho_v x_b}{D_{np}\left(q''_n\right)^{3/2}\rho_L\left(\rho_{np}-\rho_L\right)g(1-x_b)^2}$$

Progress on Goals: Understanding has been translated into a single predictive tool that involves all the salient governing parameters. Still need to guide industry.

It was originally believed that the reentrant cavity boiling surfaces like the Turbo-BII could not be enhanced with nanolubricants. Last year boiling tests with the Turbo-BII and R134a/nanolubricant produced a heat transfer enhancement of roughly 10%.







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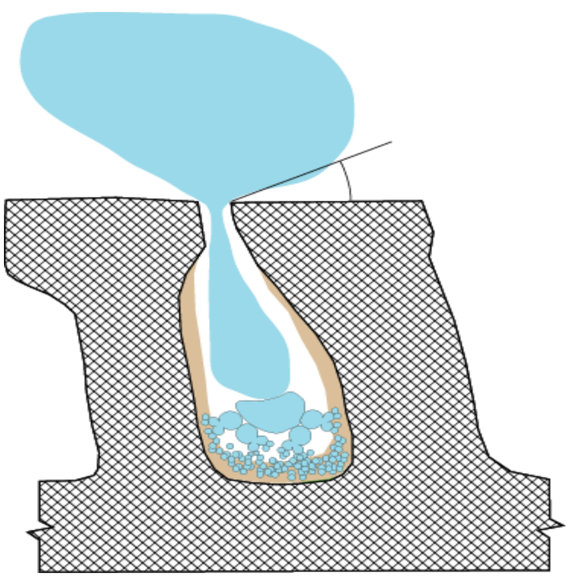
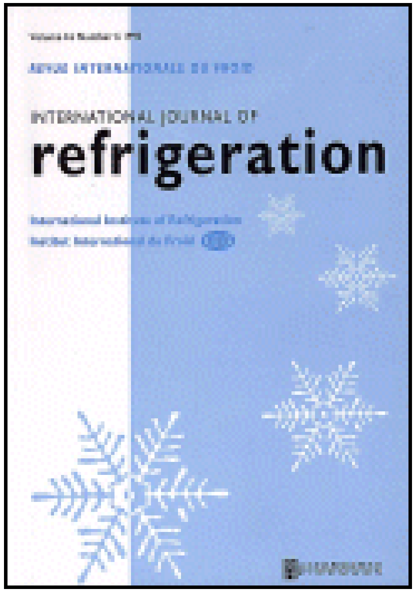
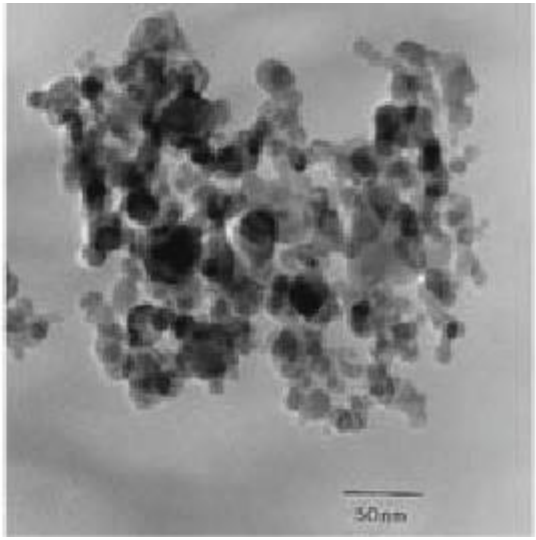
- Awards/Recognition: International Journal of Refrigeration Best Paper Award (2009) "Effect of CuO Nanolubricant on R134a Pool Boiling Heat Transfer," Int. J. Refrigeration, Vol. 32, pp. 791-799.





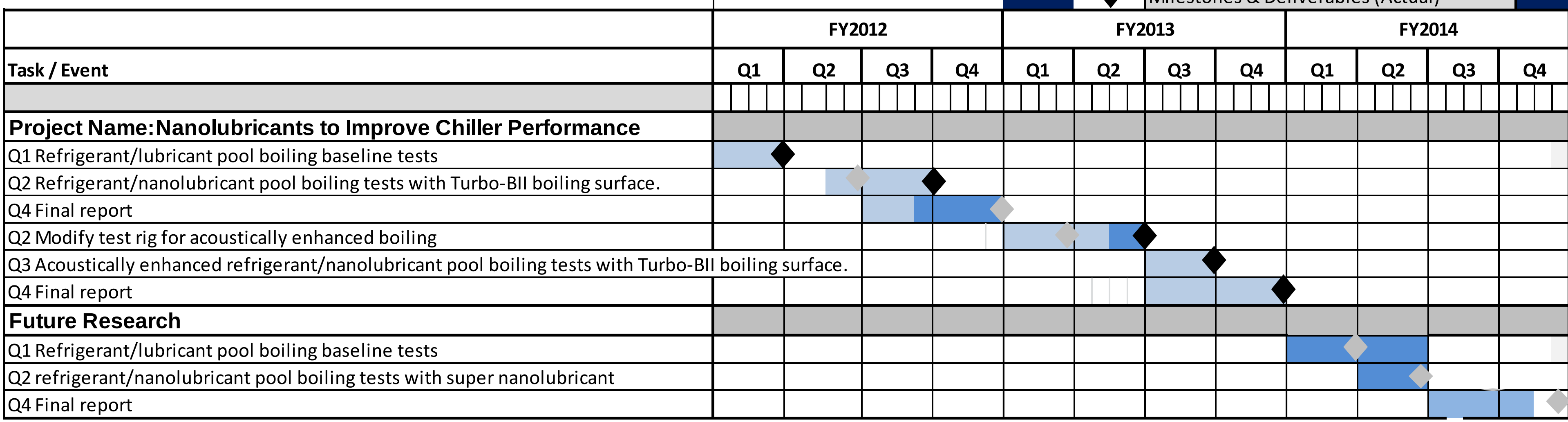


Project Plan & Schedule

Slipped milestones resulted from having to retake all measurements with the original nanolubricant that contained the original surfactant. Meetings with Nanophase Technologies had resulted in the decision to try a different surfactant, which did not work properly. Further meetings lead to the next phase of the project to test a super nanolubricant: a highly concentrated nanolubricant will make commercialization much easier.

Summary	
WBS Number or Agreement Number	
Project Number: DE-EE0002057/004	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)



Project Budget

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Variances: There have been no variances from planned budget. Project plan has been modified in order to leverage an opportunity and investigate the potential for acoustic enhancement.

Cost to Date: $700k

Additional Funding: NIST is supporting a companion project that is testing the nanolubricant in an actual chiller

Budget History					
FY2010		FY2011		FY2012	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$200k		$200k		$200k	

Project Integration, Collaboration & Market Impact

Partners, Subcontractors, and Collaborators:

TRANE

CPI ENGINEERING SERVICES, INC.

nanophase
Nanoengineered Products

Technology Transfer, Deployment, Market Impact:

Buildings account for 80 % of all electric expenditures in U.S.

3.1 U.S. quads

Space cooling is 13 % of total building electric expenditures

Significant reductions in building energy consumptions and carbon dioxide emissions are to be realized with improvements in the energy efficiency of refrigerant chillers.

1 % increase in the efficiency of existing chillers would save an equivalent of nearly 1 days oil usage for the nation.

Project Integration, Collaboration & Market Impact

Communications:

ASHRAE Seminar “Boiling with Refrigerants and Nanolubricants,” 2011 Winter Meeting, Las Vegas, NV.

Invited Speaker for Philadelphia Chapter of the Society of Tribologists and Lubrication Engineers (STLE) meeting, February 17, 2011, Lafayette Hill, PA. Title: “Nanolubricants for Improving Chiller Performance”

Kedzierski, M. A., 2013, “Viscosity and Density of Al_2O_3 Nanolubricant,” Int. J. Refrigeration, in printing for Vol. 36.,

Kedzierski, M. A., 2012, “R134a/Al2O3 Nanolubricant Mixture Boiling on a Rectangular Finned Surface,” ASME J. Heat Transfer, Vol. 134, 121501.

Kedzierski, M. A., 2012, “Viscosity and Density of CuO Nanolubricant,” Int. J. Refrigeration, Vol. 35, No. 7, pp. 1997-2002.

Project Integration, Collaboration & Market Impact

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Communications:

Kedzierski, M. A., 2012, "Effect of Al_2O_3 Nanolubricant on a Passively Enhanced R134a Pool Boiling Surface," I. J. Trans. Phenomena, Vol. 13, No. 1, pp. 59-71.

Kedzierski, M. A., 2012, "Effect of Al_2O_3 Nanolubricant on a Turbo-BII R134a Pool Boiling Surface," *Proceedings of MNHMT2012 3rd Micro/Nanoscale Heat & Mass Transfer International Conference*, Atlanta, Georgia, MNHMT2012-75024.

Kedzierski, M. A., 2011, "Effect of Al_2O_3 Nanolubricant on R134a Pool Boiling Heat," Int. J. Refrigeration, Vol. 34, pp. 498-508.

Kedzierski, M. A., 2010, "Effect of Al_2O_3 Nanolubricant on R134a Pool Boiling Heat Transfer with Extensive Measurement and Analysis Details," NIST Technical Note 1663, U.S. Department of Commerce, Washington, D.C.

Venerus, D., et al., 2010, "Viscosity Measurements On Colloidal Dispersions (Nanofluids) For Heat Transfer Applications," Applied Rheology Journal, Vol 20, Issue 4, 44582.

Next Steps and Future Plans: Refrigerant/nanolubricant boiling tests with super condensed nanolubricant that will facilitate commercialization of a nanolubricant for use with refrigeration and air-conditioning chillers. Guide industry.

Success Means: Greatly simplifies the implementation of nanolubricants in existing chillers in the field. Existing oil would not have to be removed and replaced. Instead the highly concentrated nanolubricant could just be added.

Success Means: Simplifies the implementation of nanolubricants in newly manufactured chillers. Manufacturer would not have to modify lubricant charging amounts.