Boiling with Refrigerants and Nanolubricants

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Presentation Outline

Background

Objective

Experimental Setup and Procedure

Measurement Results

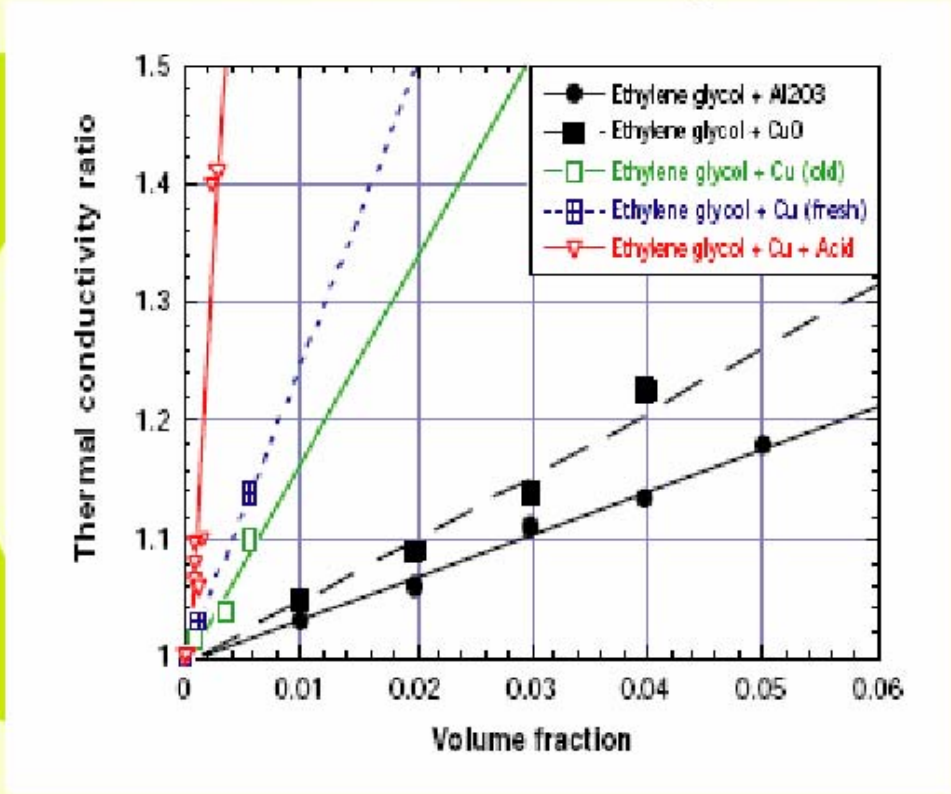
Mechanistic Speculation

Conclusions

Can Nanofluids Improve Refrigerant Boiling?

metal & metal-oxide dispersions

40 % improvement in thermal conductivity for a 0.4 % volume fraction

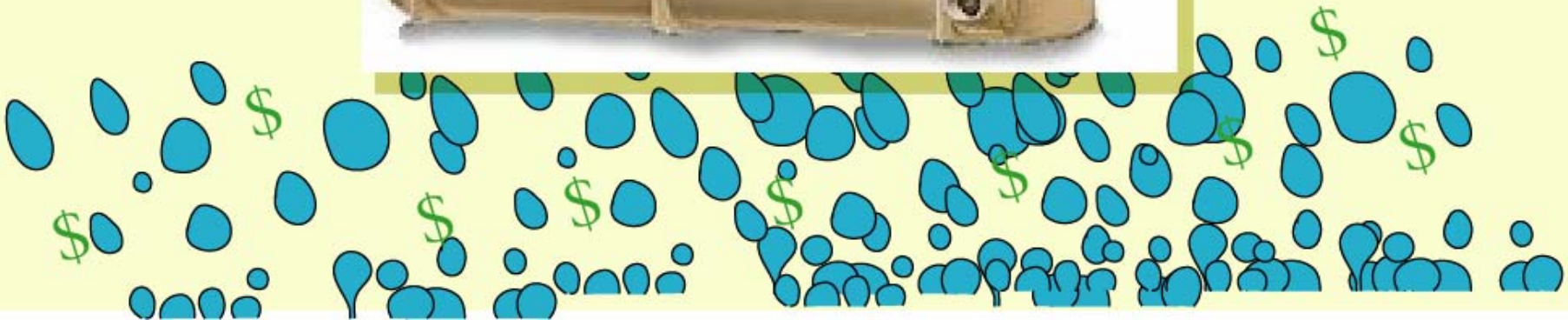


Appl. Phys. Lett. 78, 718-720, Eastman et al. (2001)

gives opportunity for improving air-conditioning chiller performance

Potential Impact of Nanofluids for Chillers

If nanofluids improve chiller efficiency by 1 %, a savings of 320 billion kWh of electricity or an equivalent 5.5 million barrels of oil per year would be realized in the US alone



Objective

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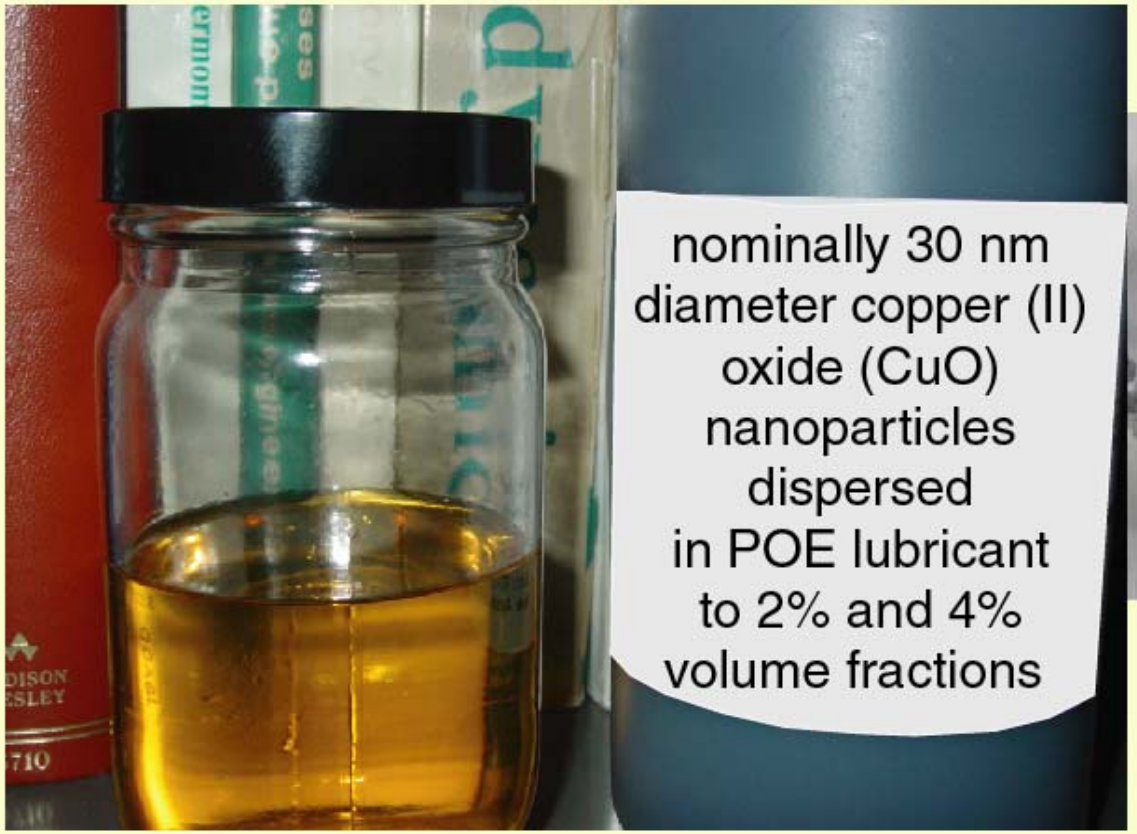
quantify the influence of CuO nanoparticle concentration on the boiling performance of R134a/polyolester mixtures on a roughened, horizontal flat surface

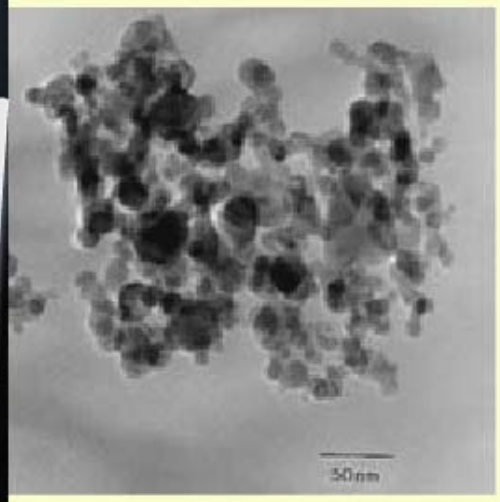
Approach:

Measure R134a/lubricant pool boiling heat transfer for with and without CuO nanoparticles (30 nm DIA particles at two volume fractions)

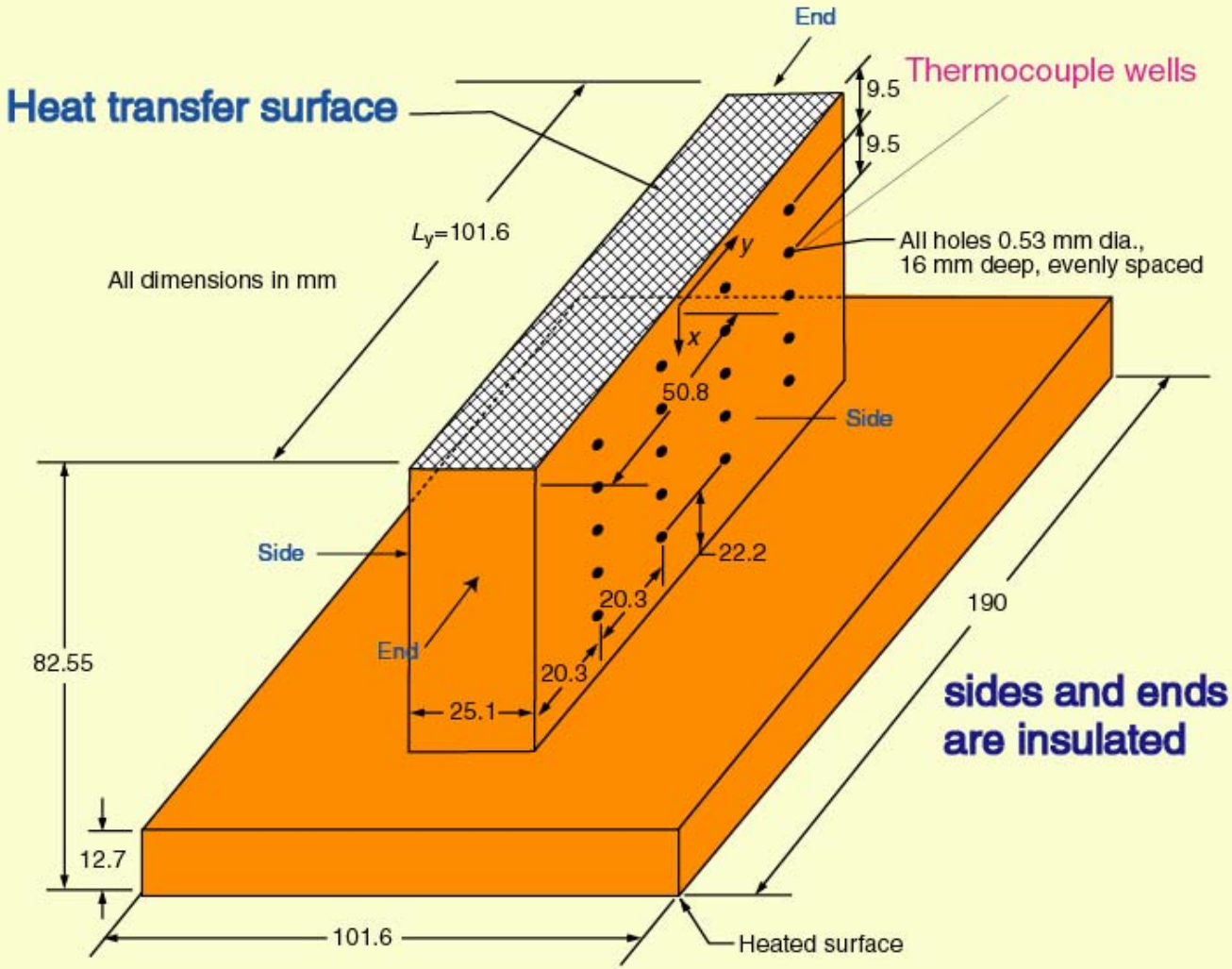
Lubricant Based, CuO Nanofluid

Base lubricant was a POE with a nominal kinematic viscosity of 72.3 $\mu m^2/s$ at 313.15 K

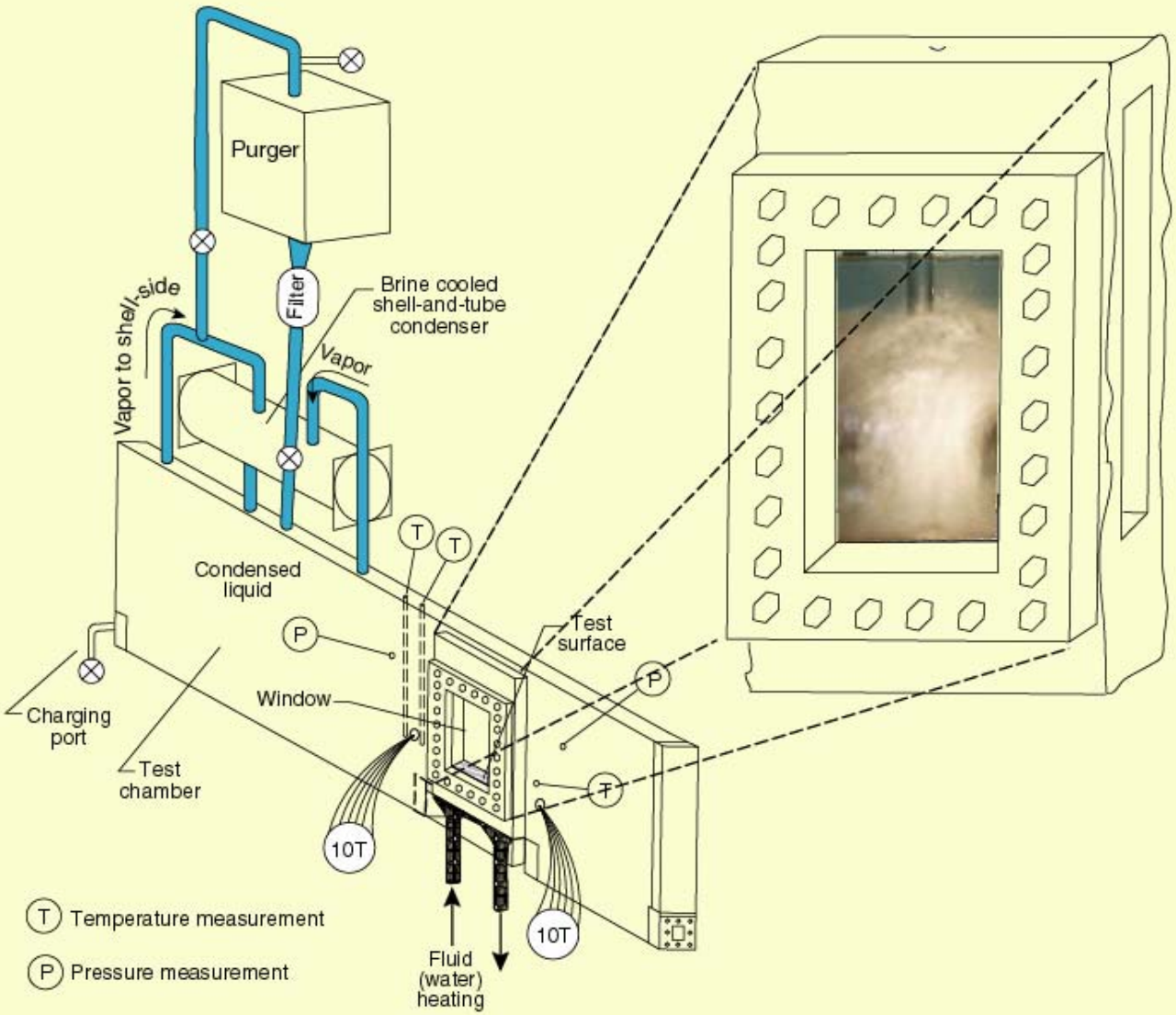




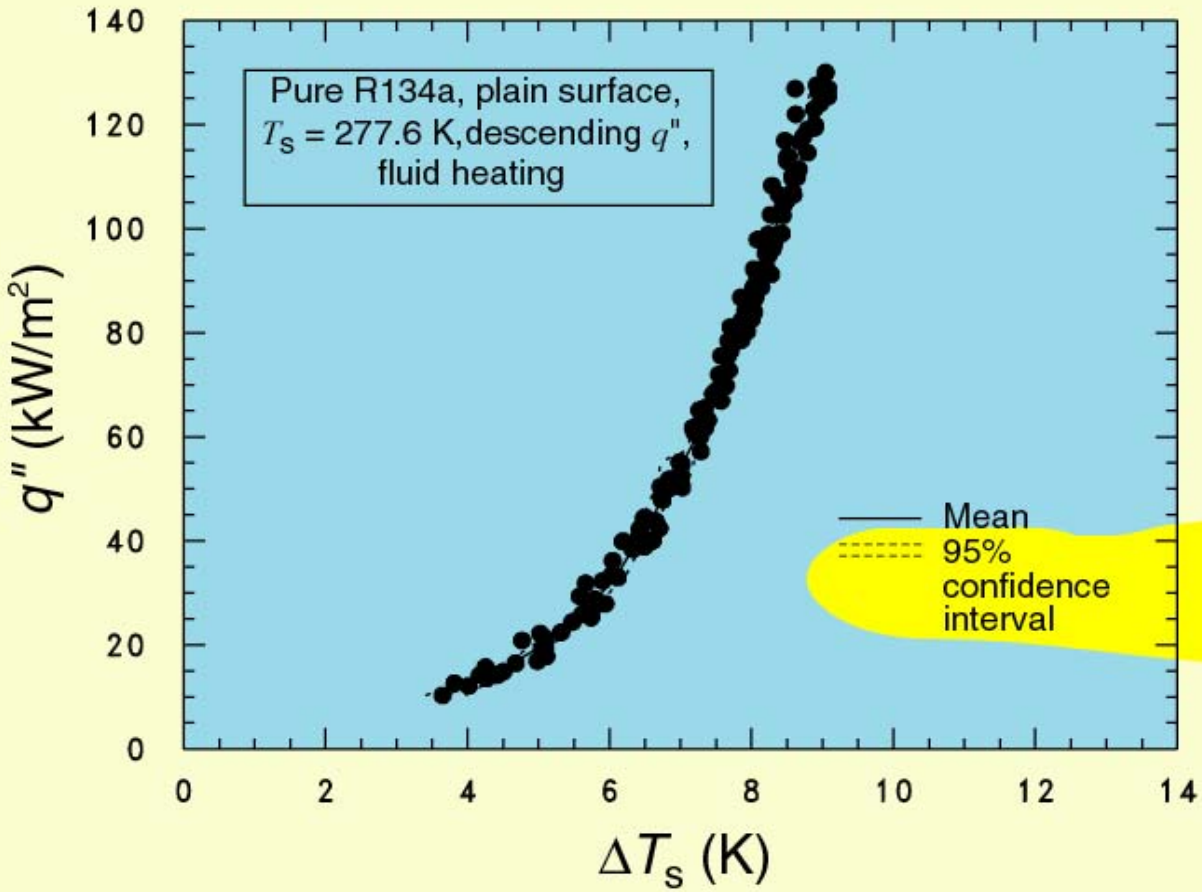
OFHC Test Surface



Schematic of Test Apparatus



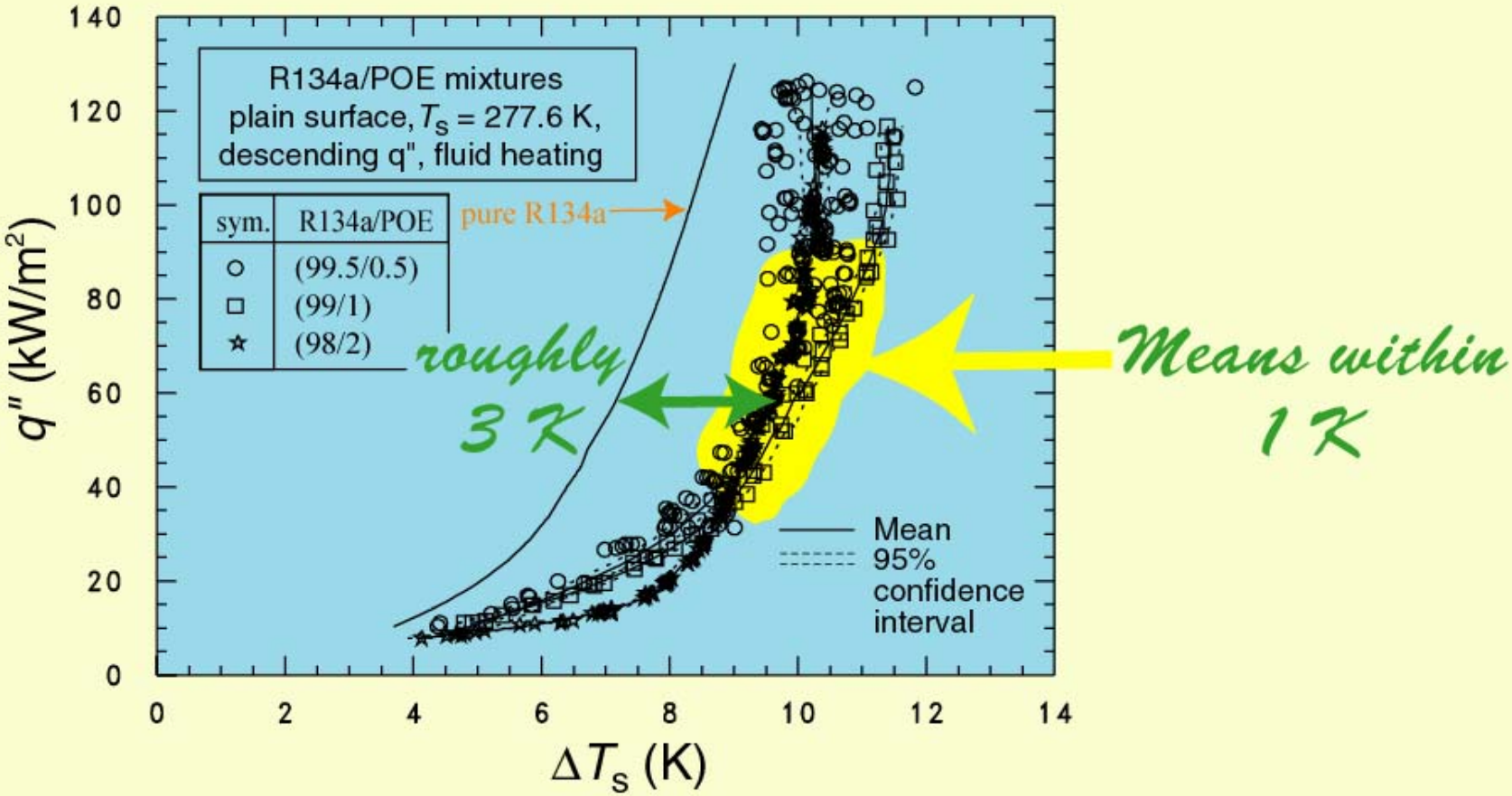
Pure R134a Pool Boiling



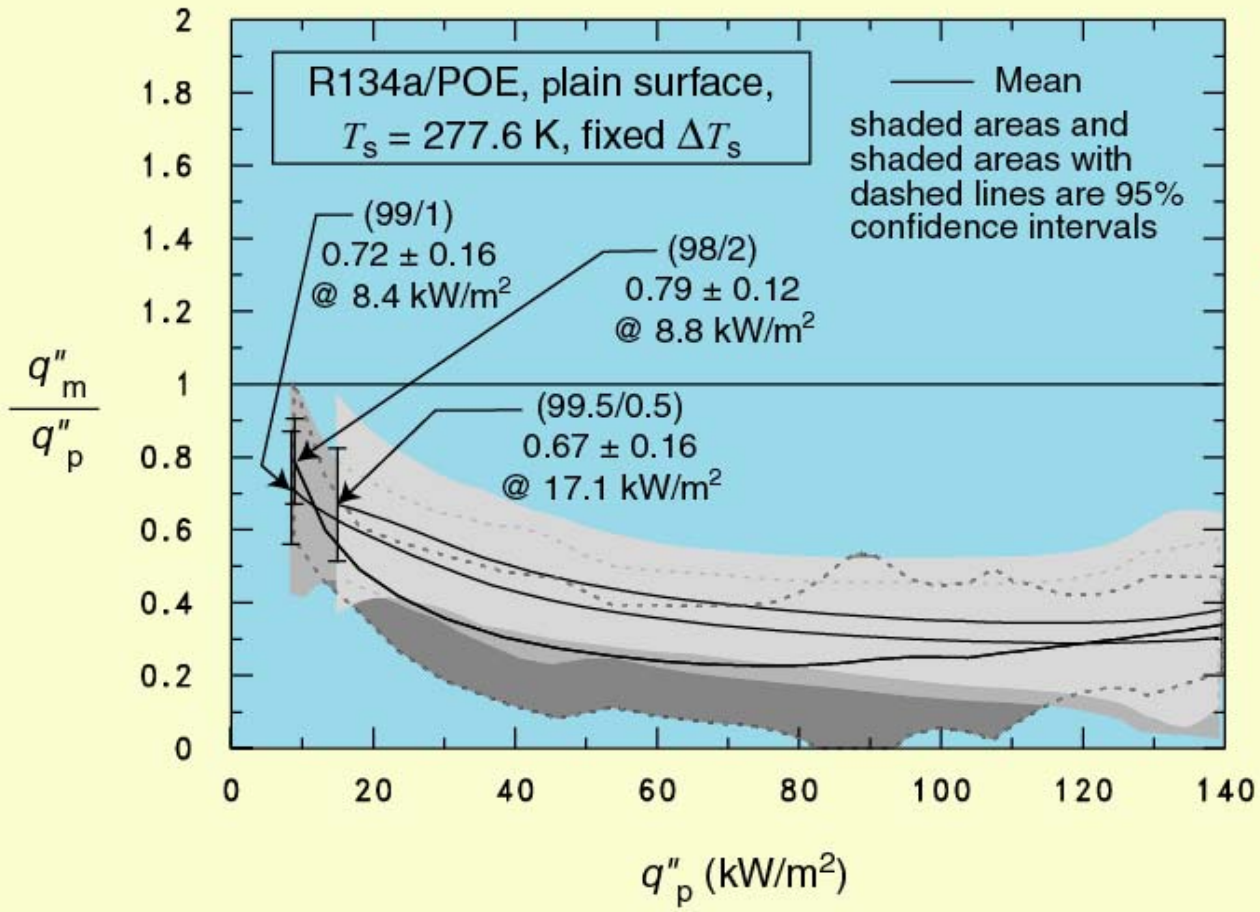
145 pts. taken over 13 days

apprx. ±0.1 K

Effect of Pure Lubricant on Boiling

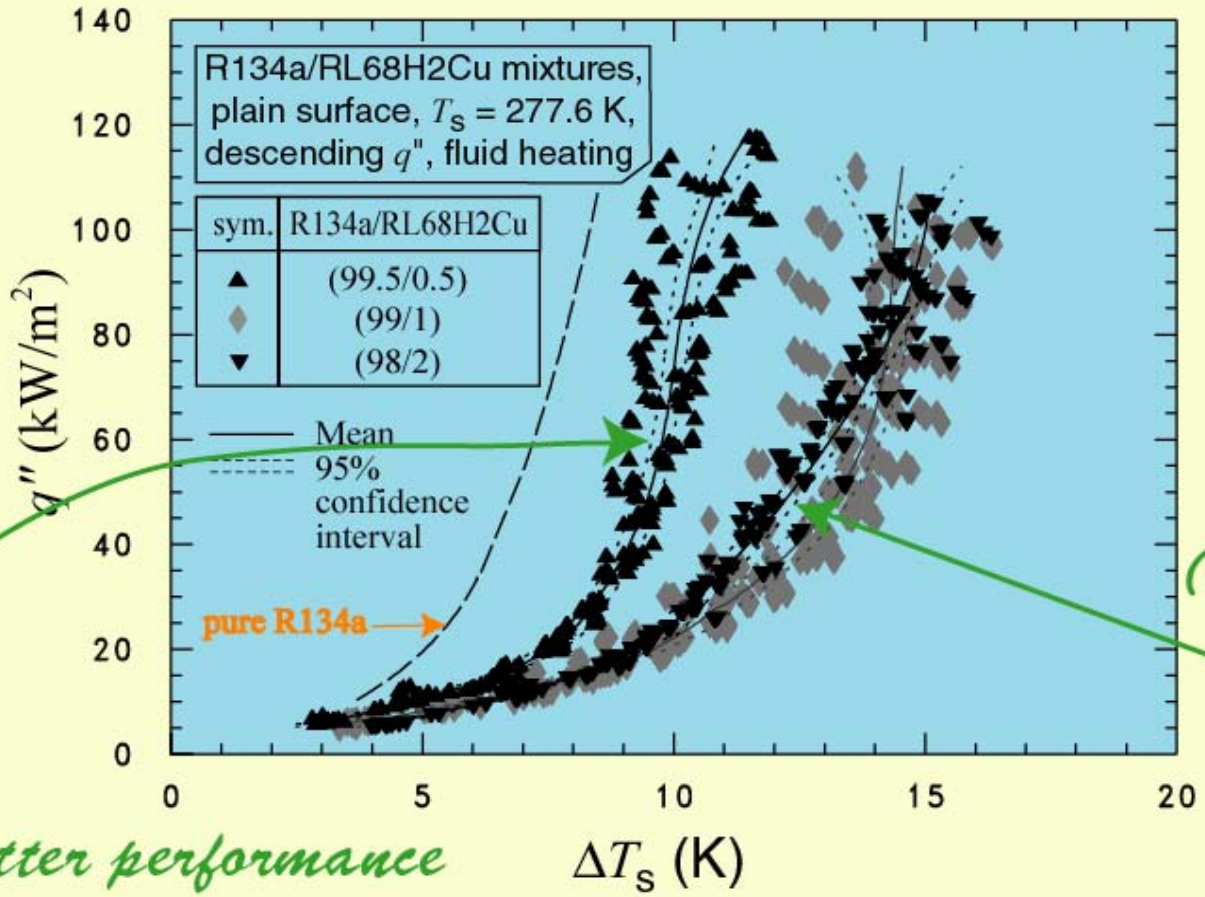


Effect of Pure Lubricant on R134a Boiling



Degradation increases with lubricant mass fraction

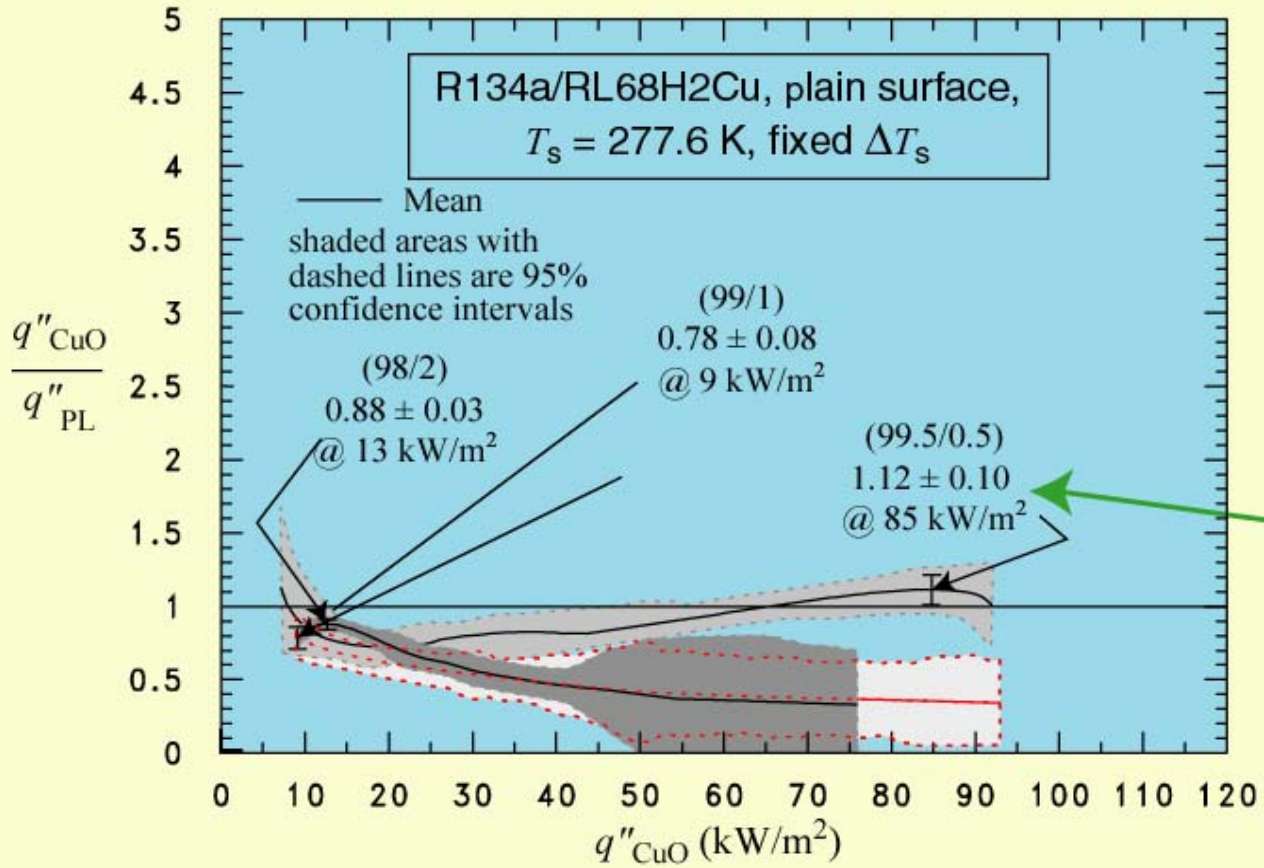
Effect of 2% Vol. Frac. CuO Nanoparticles on R134a/POE Lubricant Boiling



(99/1) and (98/2) mixture heat transfer similar

better performance with (99.5/0.5) mixture

Effect of 2% Vol. Fraction CuO Nanoparticles on Boiling



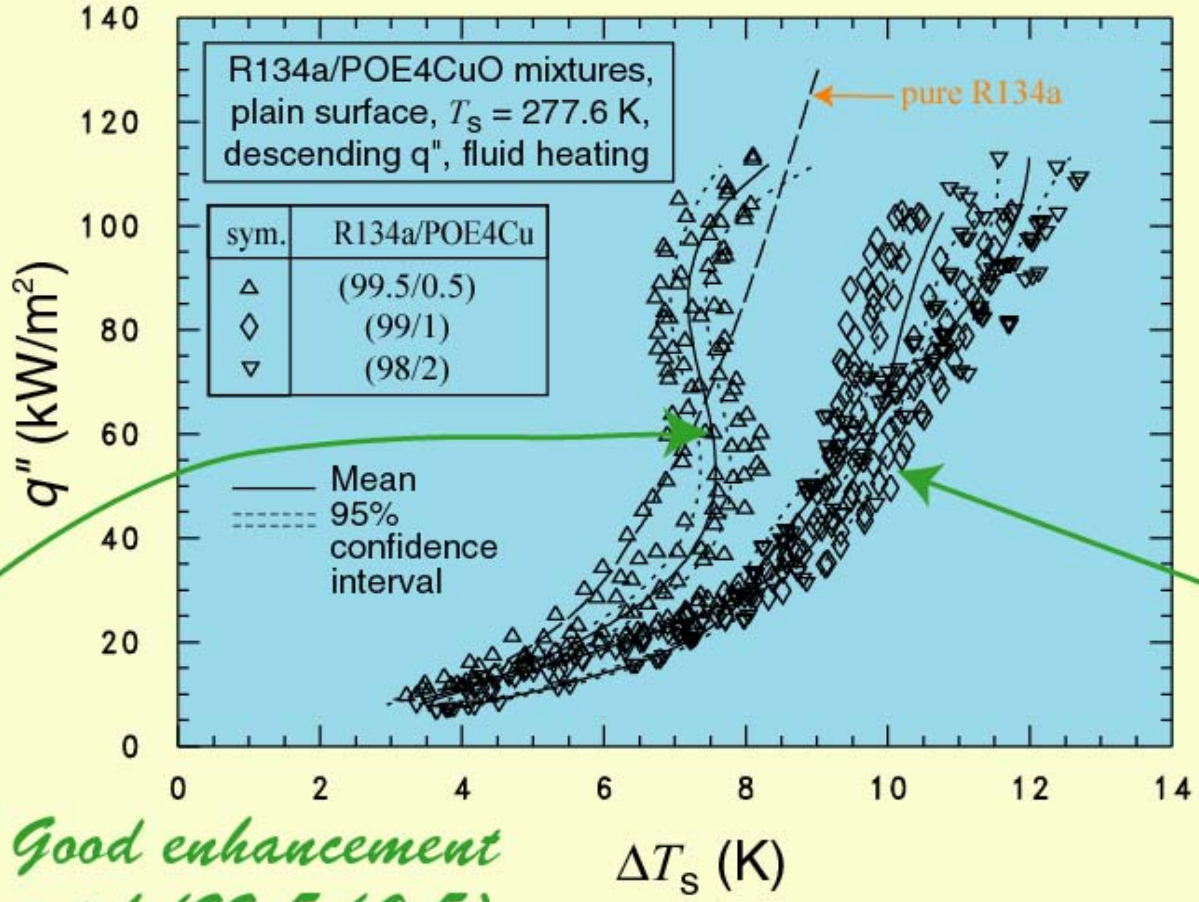
Average ratio:

0.5%	0.9
1%	0.4
2%	0.5

0.5% mixture is roughly between 0.73 and 1.12

Degradation may be due to fill of nano-size cavities causing a loss in active sites

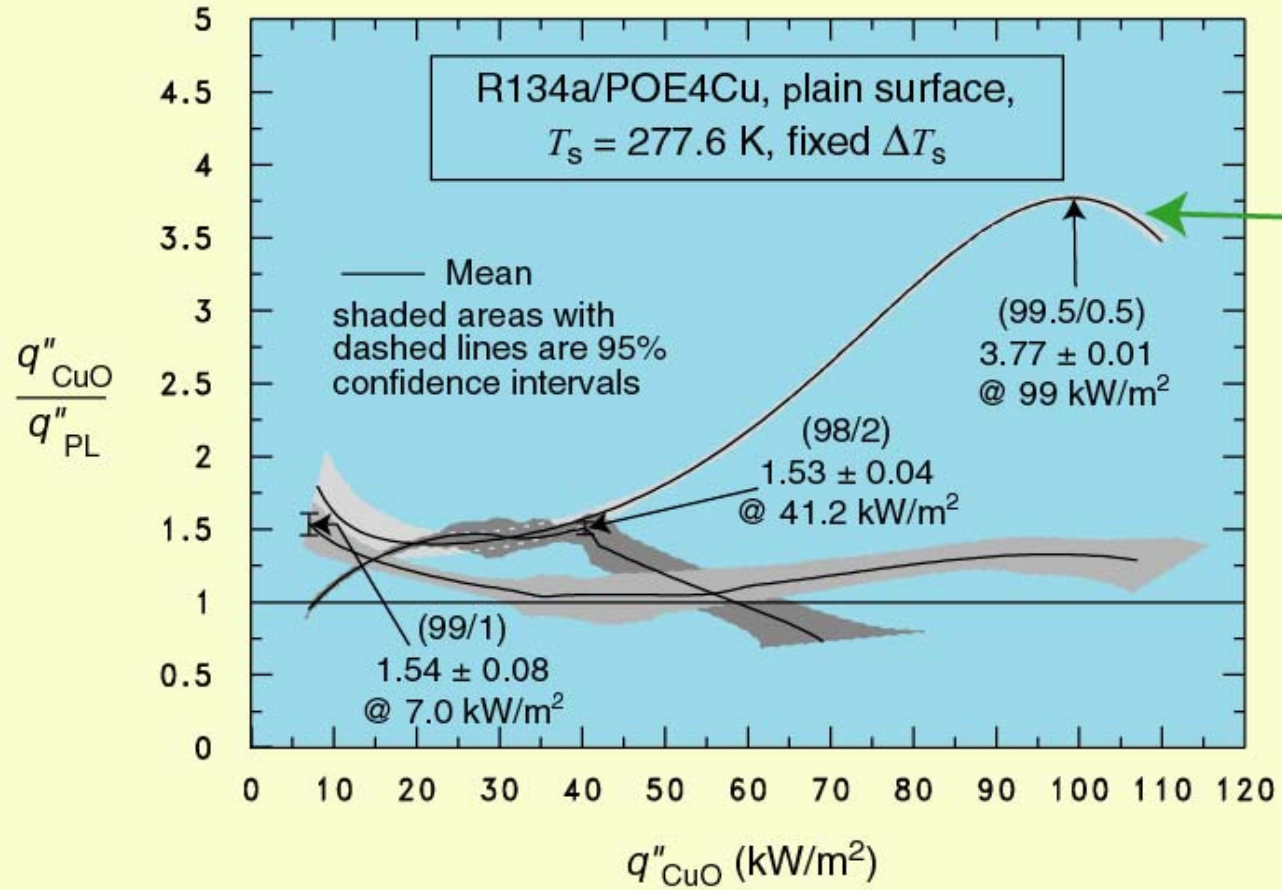
Effect of 4% Vol. Frac. CuO Nanoparticles on R134a/POE Lubricant Boiling



Good enhancement with (99.5/0.5) mixture

(99/1) and (98/2) mixture heat transfer similar

Effect of 4% Vol. Fraction CuO Nanoparticles on Boiling



0.5% mixture is roughly between 1.5 and 3.75

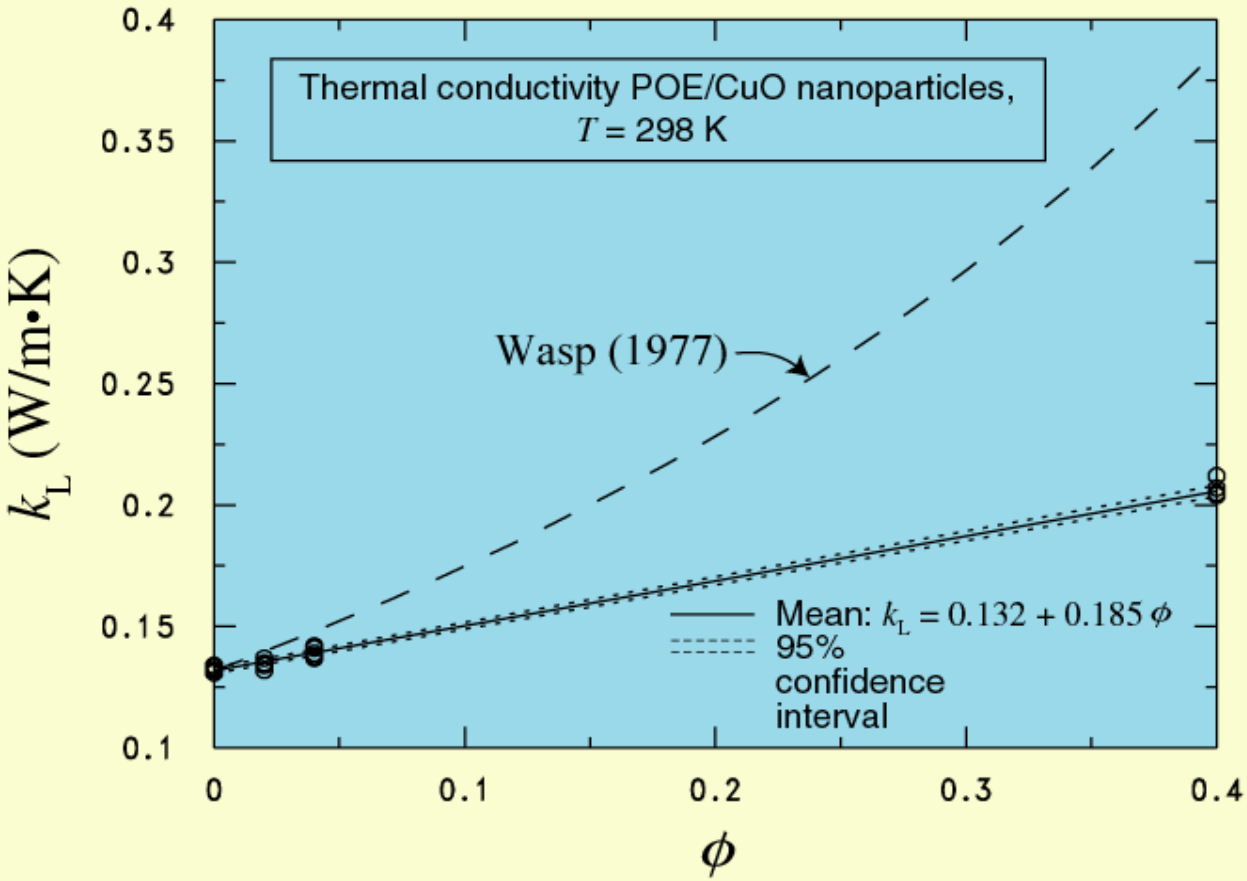
Average ratio:

0.5% → 2.4

1% → 1.19

2% → 1.12

Nanolubricant Thermal Conductivity



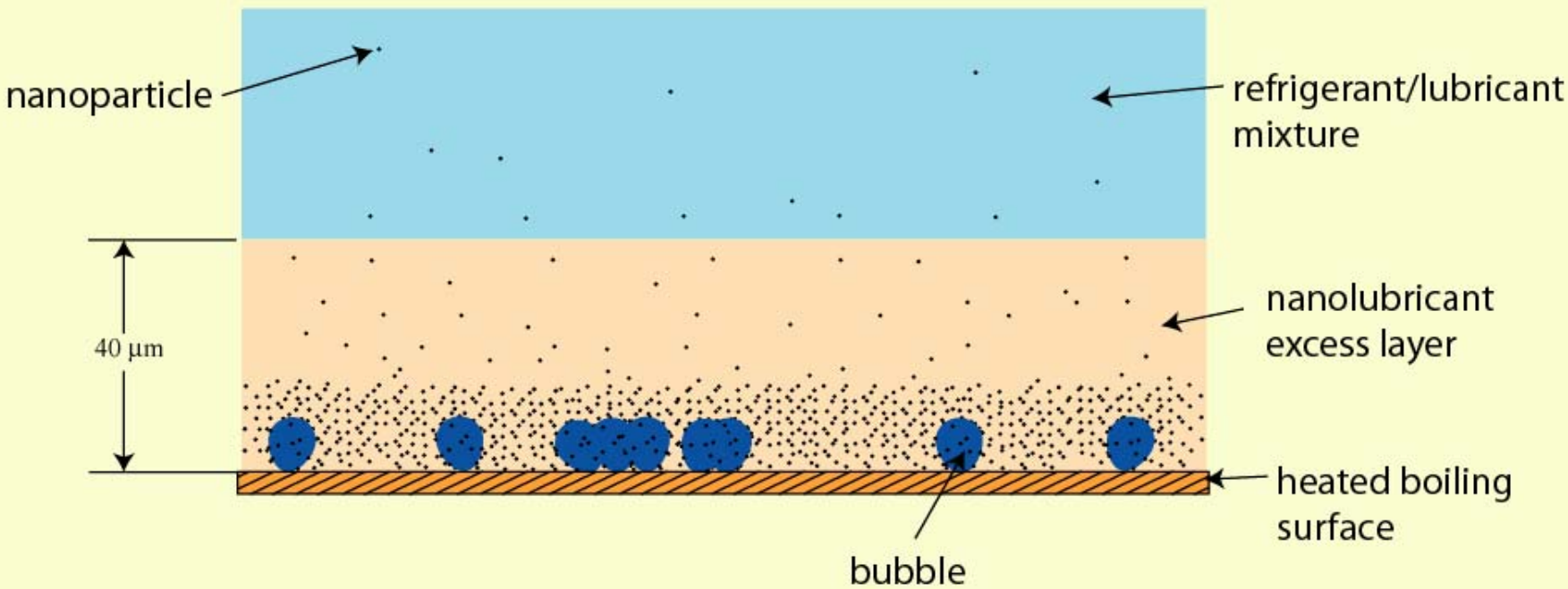
k_{CuO} =20 W/mK

two orders of magnitude greater than that of POE

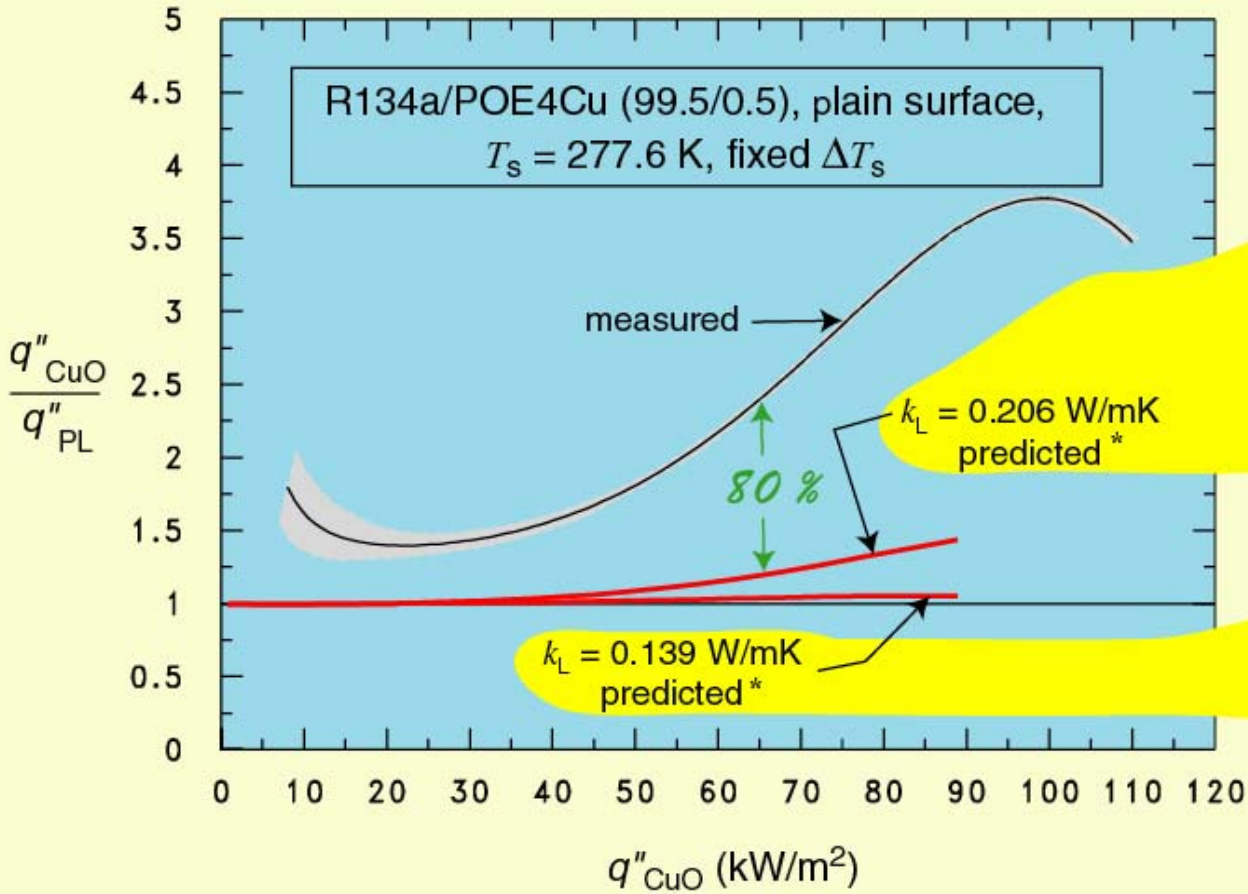
improvement in the thermal conductivity significantly beyond that proportional to the volume fraction of the nanofluid was not obtained.

Nanoparticle Accumulation in Lubricant Excess Layer

Enhancement of the lubricant's thermal conductivity may in fact be greater than what the bulk concentration suggests



Effect of Increased k_L on Boiling



at 40% volume fraction accumulated in lubricant excess layer

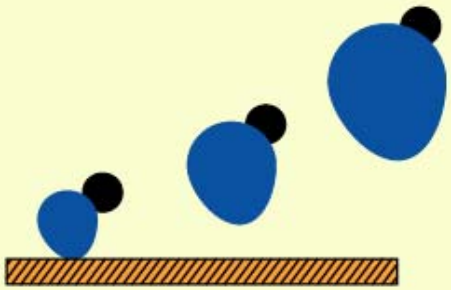
at bulk nanoparticle volume fraction (4%)

Approx 20 % of the enhancement may be due to increased thermal conductivity

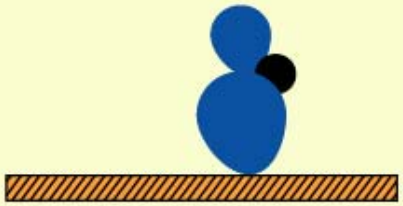
*Refrigerant/lubricant pool boiling model Kedzierski 2003 ICR

Proposed Enhancement Mechanism

enhanced bubble growth caused by bubble/
"hot" particle interation

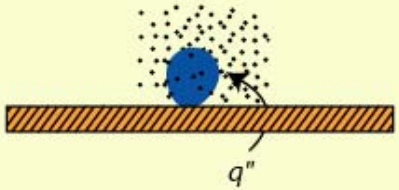


secondary nucleation on "hot" partical in fluid

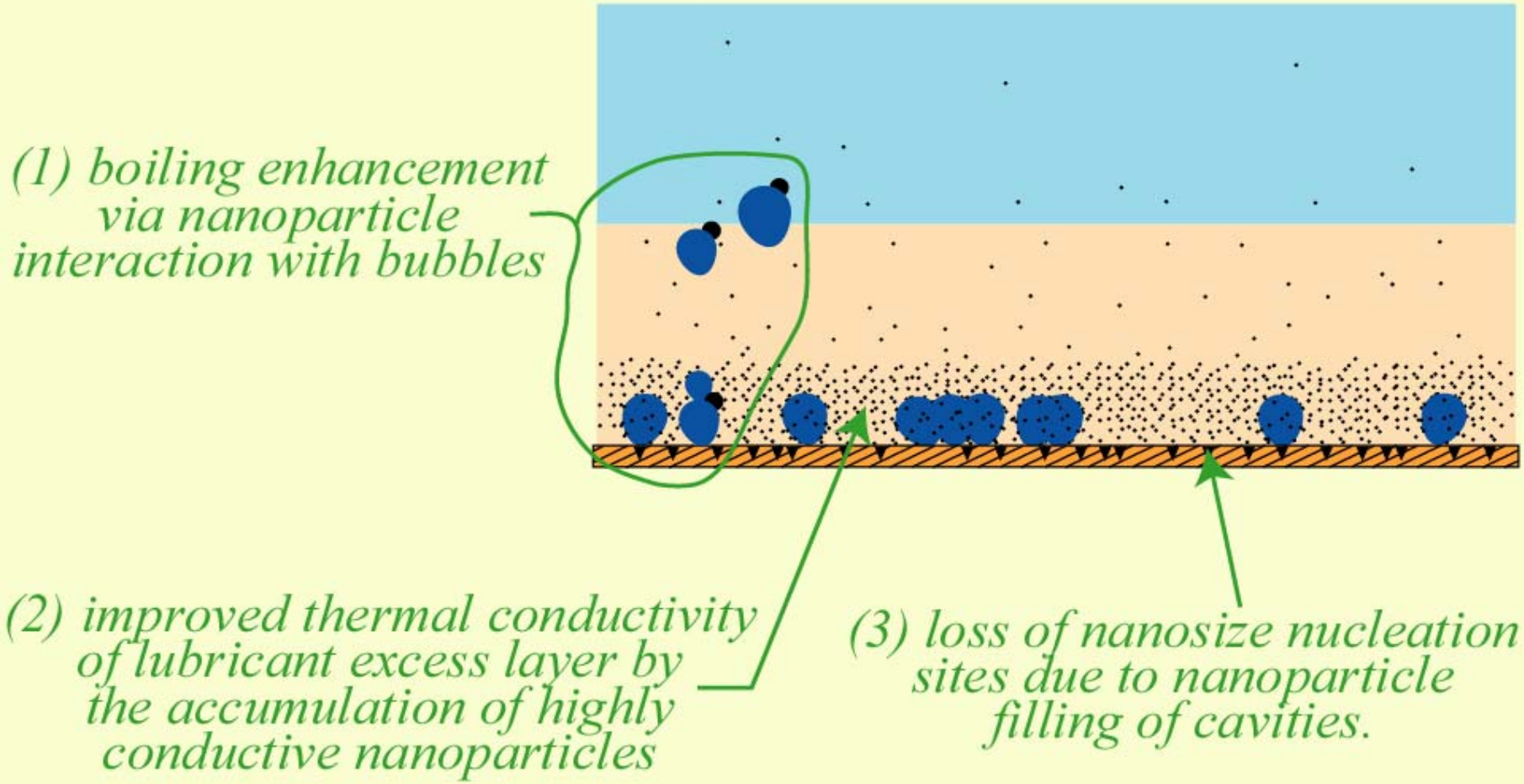


particle mixing

primary nucleation at wall may be suppressed
or enhanced depending on relative magnitude
of increased conduction to liquid



Enhancement or Degradation Realized Based on the Coupling of three heat transfer mechanisms:



Volume fraction determines if enough particles remain from mechanism (3) to be used in mechanisms (1) and (2)

Conclusions

- For the 0.5 % mass fraction (4 % CuO volume fraction nanolubricant), the nanoparticles caused a heat transfer enhancement relative to the heat transfer of pure R134a/polyolester (99.5/0.5) between 50 % and 275 %.
- Increase in the mass fraction of the 4 % CuO volume fraction nanolubricant resulted in smaller boiling heat transfer improvement: on average 19 % and 12 %.
- Although the nanoparticles increased the thermal conductivity of the lubricant, the increase in thermal conductivity appears to be responsible for only a small portion (potentially 20 %) of the boiling heat transfer enhancement.

Conclusions (cont.)

- The 2 % CuO volume fraction apparently was less than the required threshold CuO volume fraction, which resulted in reduced active boiling sites causing a corresponding degradation in the boiling heat transfer.

- An overall improvement in the boiling heat transfer will result if the enhancement due to nanoparticle interactions more than compensates for the boiling heat transfer degradation as caused by the filling of boiling cavities with nanoparticles.