De-Scaling the Peak: The Impact of a Polarized Refrigerant Oil Additive on Chiller Performance at a U.S. Postal Service Processing & Distribution Center

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ABSTRACT

According to the CEC, up to 70 percent of California's electricity demand during peak times comes from air conditioning equipment. One approach to reducing this demand has been proposed by the manufacturers of polarized refrigerant oil additives (PROAs).

PROAs have generated as much controversy as perhaps any other technology in the energy efficiency industry. Proponents have claimed energy efficiency gains of up to 40%, whereas others have labeled the chemicals as "snake oil." Published evaluations of the effectiveness of PROAs reflect these disagreements. A well-known study conducted by NIST finds some energy efficiency gains associated with PROA technology under certain conditions, while a variety of other studies found no assignable energy efficiency benefits.

Recently, the U.S. Postal Service was approached by the manufacturer of a PROA product and agreed to conduct a field test of their additive on a 1,000-ton chiller at a large USPS facility. Our institution was asked to design and lead this test on their behalf. Our team designed a comprehensive test based on ASHRAE Guideline 14-2002. Detailed environmental and performance characteristics were measured over a baseline period. Similar measurements were taken in the post-PROA injection period. Overall, the results of this study suggest that the theory presented in the NIST 2004 study is correct. The parameters of this particular chiller, which utilizes R134a with York "K" lubricant, when installed with the PROA product under investigation, do not lead to apparent improvements of energy performance of this chiller system. Other full-scale chiller tests utilizing different combinations of lubricant and PROA products would be required to determine the efficacy of polarized refrigerant oil additives more generally.

Problem Description

Introduction

The cost of energy used to provide comfortable conditions is a significant operating expense in buildings where people and operating equipment are the primary occupants. The electricity demand during peak demand is frequently comprised in large measure from the use of air conditioning equipment such as chillers.

Finding ways to improve chiller performance has been the focus of the HVAC&R industry for some time. One such way that has been suggested is the use of a polarized refrigerant oil additive (PROA) in the refrigerant oil. Various PROA products have been on the market for more than 15 years, but the efficacy of such products has never been demonstrated categorically. Further, some of these early products were known to contain chlorides, which may harm the chiller system or release ozone-depleting compounds. Newer products have subsequently come on the market that are said to not contain chlorides, but their efficacy has also not been demonstrated in the literature. The research reported in this paper responds to a call for full-scale testing of PROA products that was included in the most significant paper yet published in this area (Kedzierski 2004).

Lawrence Berkeley National Laboratory (LBNL), working under an Inter-Agency Agreement with the US Postal Service (USPS) was requested to evaluate the efficacy of a particular polarized refrigerant oil additive, PROATEQ®, for use in USPS chillers. For the remainder of this paper, the additive under investigation will be referred to as PROA-Subject.

A 1,000 ton York chiller at a USPS Facility site in Coppell, Texas near Dallas was selected to evaluate the potential energy savings, if any, that might be obtained from the use of PROA-Subject. Actual field measurements commenced July 1, 2005 and ended on December 7, 2005. PROA-Subject was introduced into the system on September 15, 2005. The period between July 1, 2005 and September 14, 2005 was used to establish the baseline performance of the chiller system without PROA-Subject and the period after this date was used to evaluate system performance with the oil additive.

This paper will proceed in four sections, the first of which includes a general description of lubricant additives, technology theory and a literature review. The second section will describe the monitoring process and the chemical testing and flow validation measurements. The third section will describe the results and the fourth section discusses the findings from this study and provides recommendations for future research.

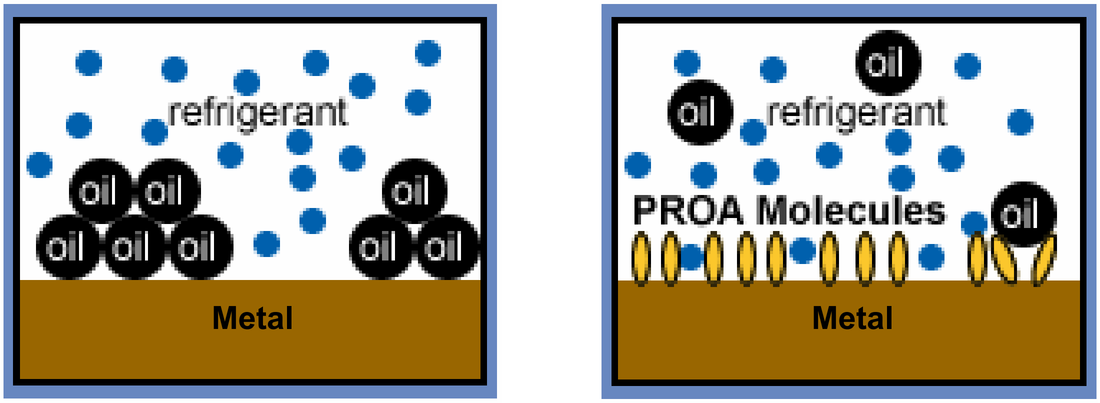
Lubricant Additive Description

In air conditioning systems, the refrigerant flows from the compressor through the condenser and evaporator cores. One of the arguments made by PROA manufactures is that a small amount of oil is carried along with the refrigerant; this oil deposits and forms an insulating barrier on the interior surface of the heat exchanger. This insulation, or scaling, according to this argument, inhibits heat transfer and reduces the system's operating efficiency. As discussed in the Literature Review section below, this contention has subsequently been shown to be too simplistic (Shen 2005). In 1990, a U.S. patent was awarded to a chlorinated α-olefin or paraffin lubricant additive which claimed to be sufficiently polar to attach to the "highly electron charged" metal surface via Van de Waals forces and displace the oil at the surface (see Figure 1) (Wilkins 1990).

Aside from unresolved questions about their impact on energy efficiency, concerns about the use of the chlorinated PROA products led, in 1996 to the release of a new product that reportedly contains no α-olefin or chlorinated paraffin (Kedzierski 2004). Since then, several non-chlorinated PROA products have been introduced on the market (EnergyIdeas Clearinghouse 2004); the specific product evaluated in this test was selected because of its role in the Kedzierski (2004) study and because of its prominence in the market.

Little specific technical information is available regarding PROA-Subject; the specific chemical composition of the product is proprietary information. However, according to the manufacturer, PROA-Subject provides extensive benefits beyond improving the energy efficiency of the chiller; these additional benefits were not evaluated in this test.

Figure 1. How PROA Compounds Work



* (EnergyIdeas Clearinghouse 2004)

Literature Review

A number of studies have attempted to test the aspects of the claim that PROAs can reduce the insulative build-up of oil on heat exchange surfaces thereby increasing energy efficiency.

Levins et al (1996) of Oak Ridge National Laboratory evaluated the impact of a PROA product on a heat pump unit, which was tested for several days at standard conditions (95 degrees F). The results of this test showed little effect from the PROA on cooling performance.

CDH Energy Group (2001) evaluated a PROA product on two unitary air conditioners. The general approach was to complete a pre/post test, spanning a period of three weeks. The results of this test showed very little energy savings.

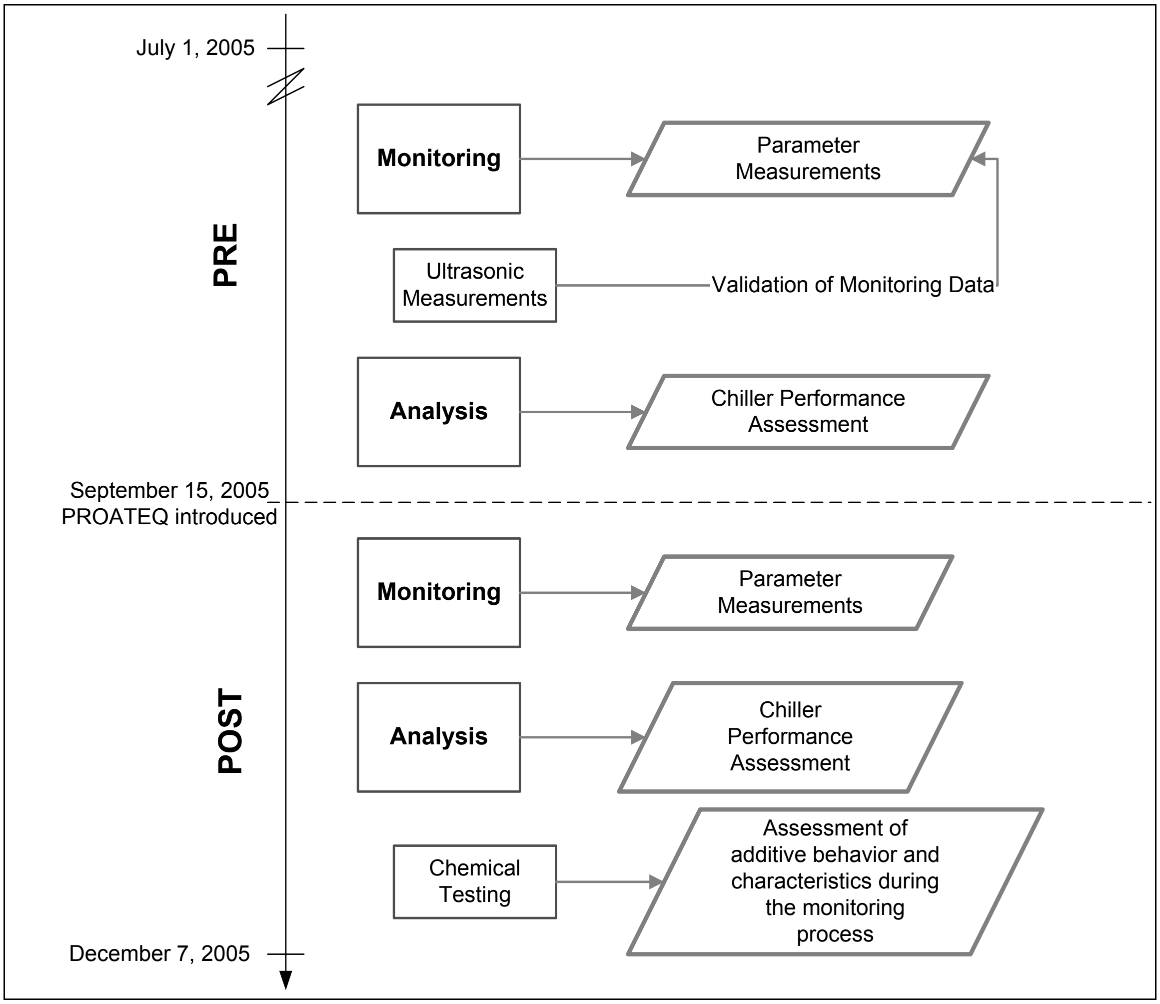
Kedzierski (2004) of the National Institute of Standards and Technology (NIST) published a report entitled *Effect of Refrigerant Oil Additive on R134a and R123 Boiling Heat Transfer Performance and Related Issues for GSA*. For the particular combinations of refrigerants and lubricants used in these tests, Kedzierski found significant improvement in the efficiency of the heat exchange from the use of PROA-Subject. He qualified his findings with respect to chiller performance, noting, "heat transfer improvements do not necessarily guarantee improvements in and/or changes in chiller performance because of other factors that influence HVAC equipment performance (p. 16)."

Kedzierski (2005) followed his earlier work with a second report in which he concludes that, "if the viscosity of the additive is greater than that of the lubricant, an enhancement of the pool boiling (effectively, heat transfer characteristics) may be expected if the additive exists as a monolayer on the surface" and that "the probability of this occurrence (i.e., the formation of a monolayer) if the additive and the lubricant differ chemically (p.4)."

Shen et al (2005) prepared a comprehensive summary of the various studies that have investigated the influence of lubricant contamination on the heat transfer of refrigerants. Contrary to the simplistic relationship described by most PROA manufacturers, the findings from the literature reveals that, "The influence of refrigeration lubricants on pool and flow boiling (again, effectively heat transfer characteristics) of refrigerant-oil mixtures is a complex subject and a consistent relationship cannot be identified. Instead, the influence varies greatly depending on oil concentration, operating parameters, and application (p. 341)."

Procedures and Methodology

Figure 2. Flowchart of Monitoring and Analytical Framework



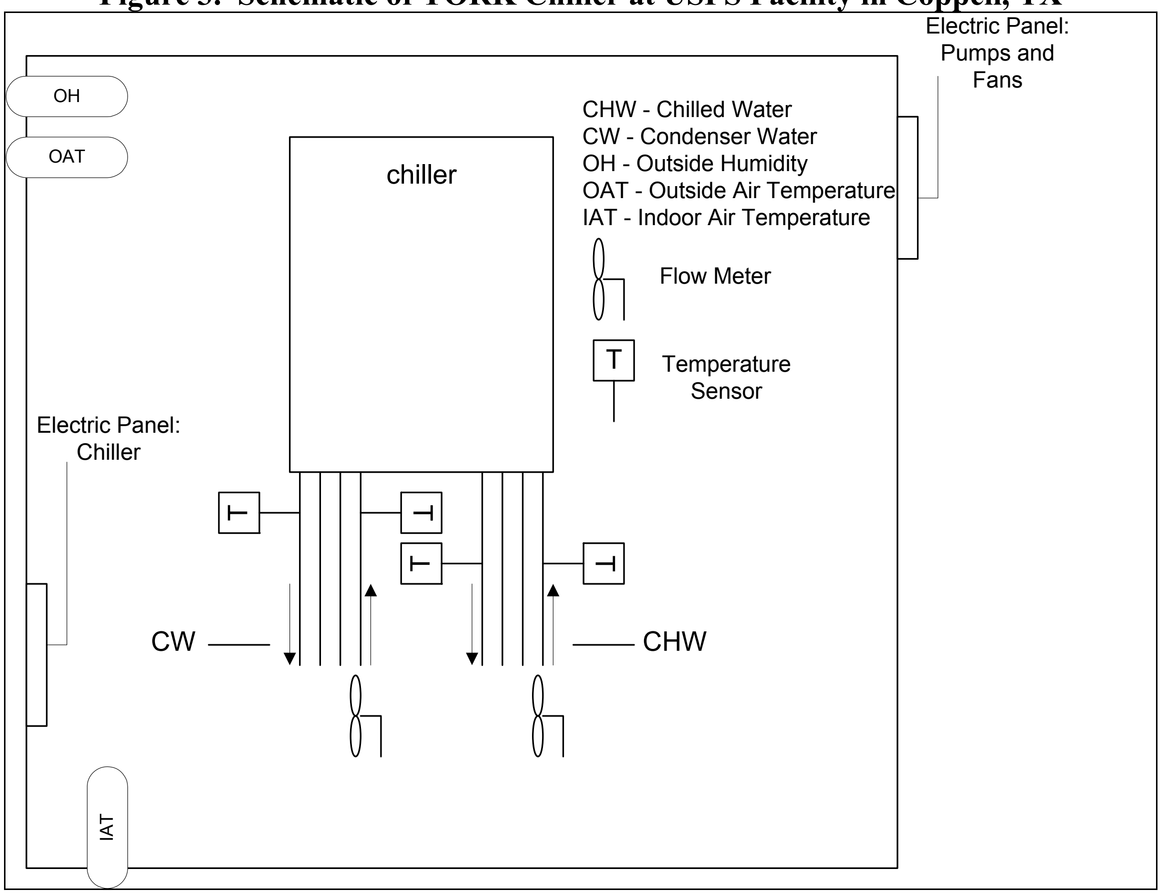
Chiller Monitoring

In this study, chiller performance was evaluated based on a measurement plan and measurement and verification procedures, found in ASHRAE Guideline 14-2002, Clause 7 and Annex E3: Retrofit Isolation Approach for Chillers. This evaluation differs slightly from ASHRAE in that savings is determined by comparing post-installation predicted energy use using a pre-installation model and post-installation data. An annual load frequency distribution is not required since an annual savings determination is not needed. The objective of this monitoring is to determine the change in power used at comparable loads due to the use of the PROA-Subject additive.

The chiller monitoring was performed on a YORK (water cooled) Millennium Centrifugal Chiller with VSD rated at 1000 Tons capacity, model number YKHHHBJ1-CZE. This chiller utilizes refrigerant R134a and uses York "K" Oil. Measurements included 5 power inputs, 6 temperature inputs, 1 relative humidity input and 2 flow inputs (see Figure 3). Data was gathered on the following monitored points:

- Chiller Power
- Chiller Chilled Water Supply and Return Temperatures
- Chiller Condenser Water Entering and Leaving Water Temperatures
- Chiller Chilled Water Supply Flow
- Chiller Condenser Water Supply Flow
- Outdoor Ambient Temperature and Relative Humidity
- Indoor Ambient Temperature (Sample Zone Space Temp)
- Primary and Secondary Chilled Water Pump Power,
- Condenser Water Pumps and Cooling Tower Fans Power

Figure 3. Schematic of YORK Chiller at USPS Facility in Coppell, TX



Point data is gathered at one minute intervals and averaged every 15 minutes. Measures were taken to ensure data quality, for example, in the case where chiller power is below 150 kW at the one minute interval and any change in condenser when entering water temperature greater than $0.5^{o}F$ over the 15 minute interval were flagged as indicators of changing conditions.

Analytical Methodology

These measurements were analyzed utilizing the temperature dependent model found in ASHRAE Guideline 14-2002. This model was used to characterize pre- and post-installation performance, in which chiller thermal load, chiller supply water temperature, chiller condenser entering water could be used to predict chiller power. The final results of the model are presented as the conventional efficiency measure of COP and kW/ton. The model allows for the prediction of the chiller COP for a wide array of measured input parameters including: chiller load, chiller chilled water supply temperature, and entering and return condenser water temperature. The methodology accounts for equipment measurement errors and modeling uncertainties. In the case where pre- and post-installation energy use varies from period-to-period in response to changes to known independent variables, the savings uncertainties were determined.

Chemical Testing of Lubricant Additive

Chillers are expensive assets and, therefore, all possible adverse outcomes, such as affecting elastomers, gasket, or metallic components, that may result due to the introduction of oil additives must be understood. In order to address these concerns, a chemical analysis was performed as part of this study. This analysis used lubricant samples from the chiller that had been operating with refrigerant/lubricant and PROA-Subject.

The study was performed with 4 samples: one sample representing unused lubricant with PROA-Subject and three samples collected during the test period labeled 7-day sample, 45-day sample, and 75-day sample. These samples were analyzed for Total Acid Number (TAN), moisture content, by Ion Chromatography (IC) to determine their acid concentrations and by Atomic Emission Spectroscopy to determine their elemental metal concentrations.

Four test methods were used to analyze the samples. These methods include the determination of the Total Acid Number (TAN) mg KOH/g, Moisture content (ppm), Ion Chromatography (to analyze for halide from refrigerant decomposition and for organic acids from lubricant decomposition) (ppm), and the Concentrations of Dissolved Metals (ppm).

Flow Validation Measurement

Long-term chiller and condenser flow measurements are within the scope of the study. The accuracy of the insertion flow meter method is within 3%. To test the validity of the collected flow measurements data, we performed additional measurements utilizing ULTRASONIC methodology using Controltron's System 1010E equipment (typical accuracy is within 2%). Spot-measurements were obtained to identify the turbidity and flow of the water; particles in the water may impact the efficacy of the additive and/or the chiller. In addition, during the ultrasonic test information on the diameter and thickness and diameter of the chilled and condenser water supply pipe were obtained.

Results

Chiller Performance

The chiller monitoring data has been aggregated and analyzed. As shown in Figures 4a and 4b the model is a good predictor of performance with an R-squared value of 0.91 for pre-installation and an R-squared value of 0.90 for post-installation.

Figure 4a. Pre-Installation Calculated Chiller Power vs. Measured Chiller Power

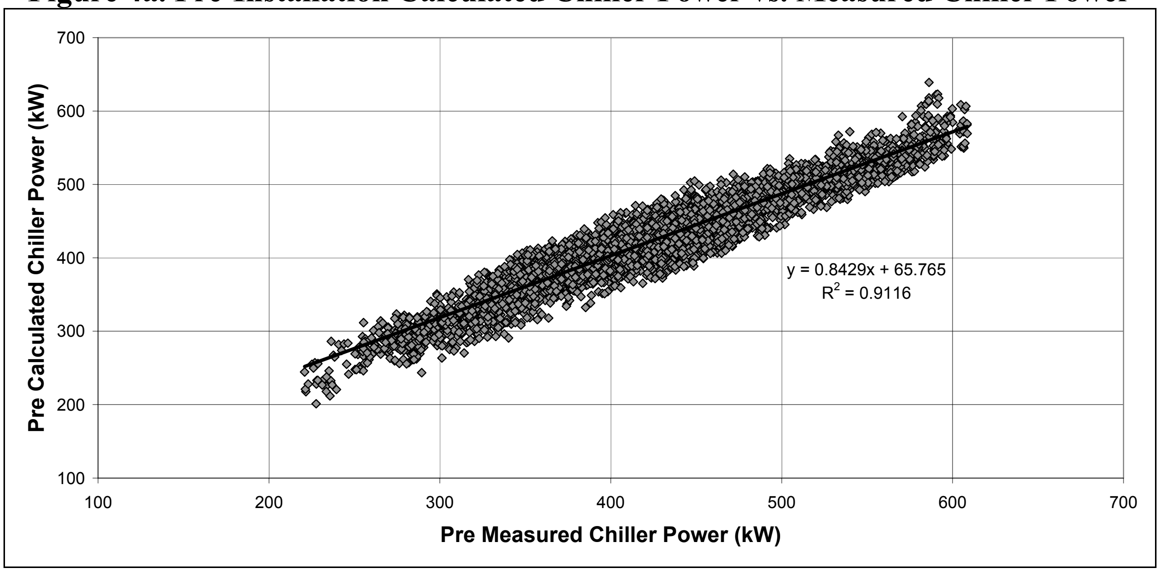
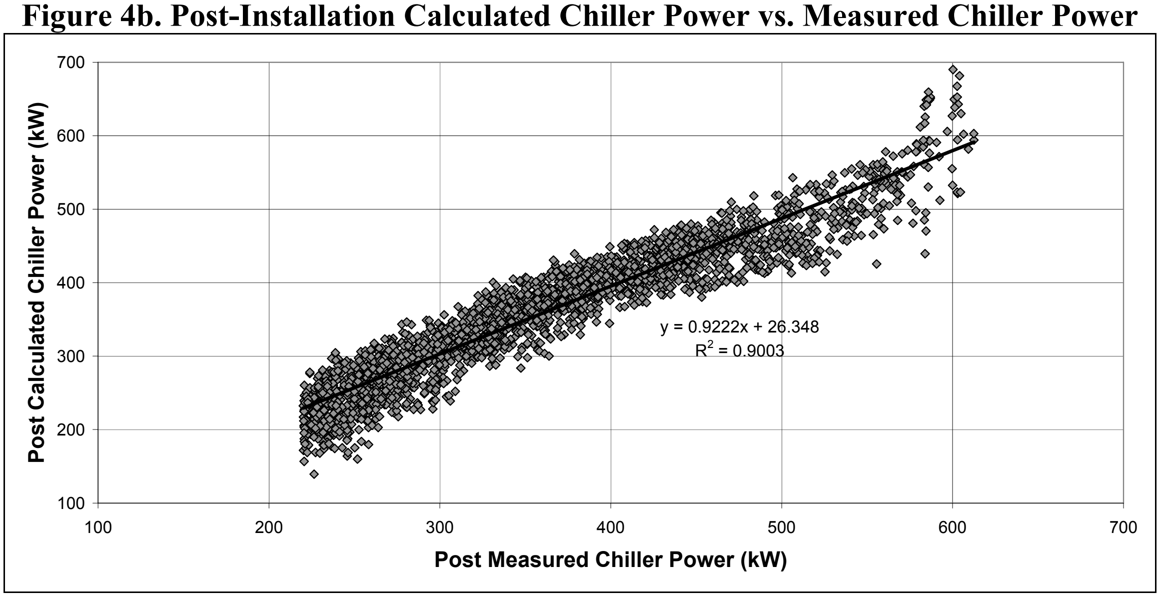


Figure 4b. Post-Installation Calculated Chiller Power vs. Measured Chiller Power



A comparison of pre- and post-installation calculated chiller power versus measured chiller power is shown in Figures 5a and 5b.

Figure 5a. Pre-Installation (Calculated Chiller Power vs. Measured Chiller Power)

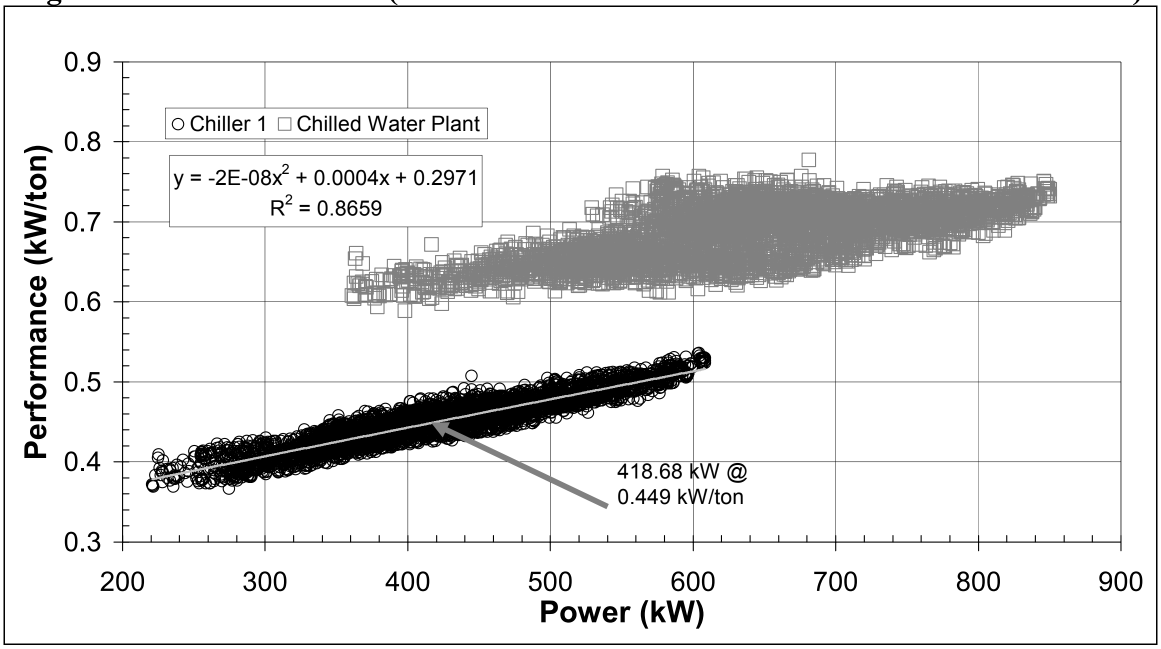
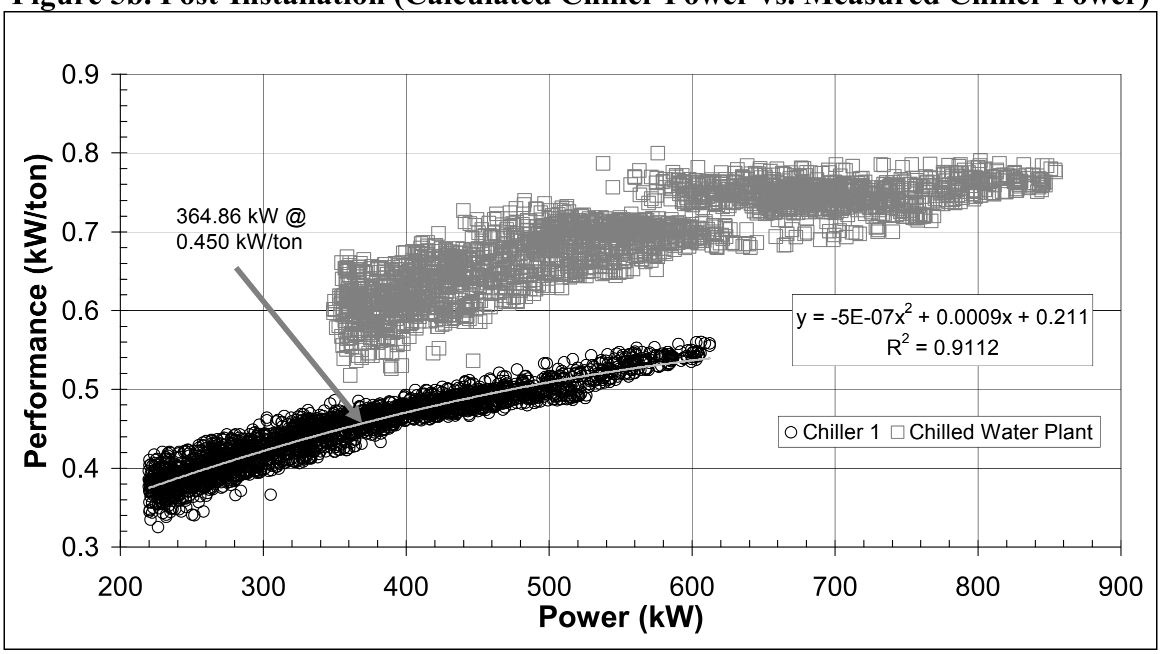


Figure 5b. Post-Installation (Calculated Chiller Power vs. Measured Chiller Power)



As shown in Figure 5a, the mean measured pre-installation power is 418.68 kW at 0.449 kW/ton and as shown in Figure 5b, the mean measured post-installation is 364.48 kW/ton. The chiller model was then used with post-installation data to predict the pre-installation chiller power where the mean calculated pre-installation chiller power is found to be 362.5 kW at 0.449 kW/ton. The results of the prediction are then compared with measured chiller power to determine savings, which is found to be -2.02 kW ± 10.93 kW at 90% confidence limit. These values are found within the acceptability range of model error. This would imply that no effect could be measured due to the installation of the oil additive.

Chemical Testing of Lubricant Additive

The results of the chemical analyses of the lubricant and PROA-Subject mixture samples are shown in Tables 1 and 2. Compared to the clean, new lubricant York K, the lubricant sample with PROA-Subject showed significantly higher water content, total acid number, acid ion concentrations (particularly acetate, pentanoate, and chloride), boron and phosphorus ion concentrations.

Table 1. Total Acid Number and Ion Chromatography Results

Lubricant Sample	Water	TAN	Ion Chromatography Results					
	(ppm)	(mg KOH/g)	Flouride	Acetate	Formate	Pentan-oate	Chloride	Sulfate
Clean York K	83	0.8	0	0	0	48	1	6
York K with PROA-Subject	397 388*	>9.0	0	72	0	161	81	9
Used lube 19097 hr	63	0.9 0.9*	0	0	0	9	1	7
Used lube 19997 hr	50	0.8	0	0	0	40	1	13
Used lube 1578 hr	328 303*	0.6	0	0	0	12	1	4

* Duplicate measurement

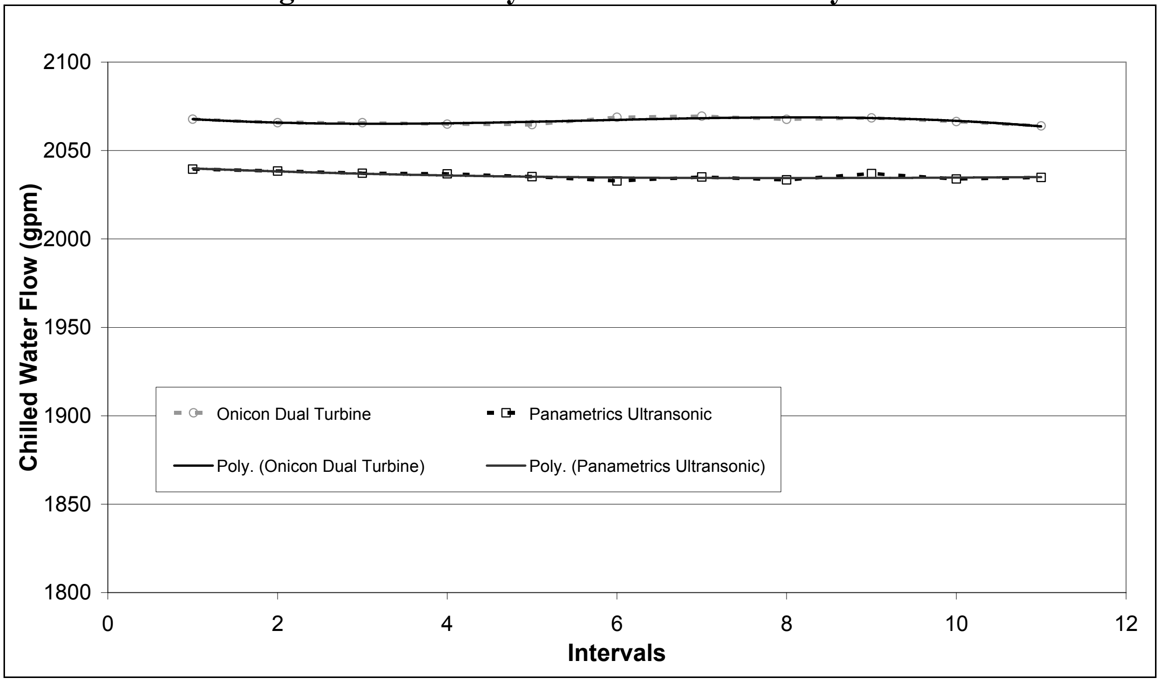
Table 2. Metal Analysis Results

Lubricant Sample	Dissolved Metal Concentrations ppm									
	Fe	Cr	Al	Pb	Cu	Sn	Si	B	K	P	Zn
Clean York K	<1	<1	3	<1	2	5	<1	17	<10	305	<1
York K with PROA-Subject	<1	<1	<1	<1	<1	<1	<1	68	15	2349	<1
Used lube 19097 hr	<1	<1	<1	<1	1	3	<1	18	<10	424	<1
Used lube 19997 hr	<1	<1	2	<1	2	4	<1	18	<10	345	<1
Used lube 1578 hr	<1	<1	5	<1	3	5	<1	17	<10	278	<1

Flow Validation Measurement

We compared both the chilled and condenser water flow for the two measurement systems, Onicon and Controltron (see Figure 8). The overall results were within the range of error of the two systems-Onicon System (insert flow) vs. Controltron's System (ultrasonic). With the Onicon flowmeter, the results reveal a chiller water average flow of 2037 gpm whereas the ultrasonic flow results reveal a chiller water average flow of 2068 gpm; a difference of 1.5%. The ultrasonic measurements also determined that the aeration of the chilled water was ~ 1% and the condenser water <1% of the water volume. Therefore, for the analysis we used our long-term Onicon based flow measurements.

Figure 8. Onicon System vs. Controltron System



Discussion

The results of the lubricant analyses, as given in Chemical Testing of the Lubricant Additive section, did not show any refrigerant/lubricant decomposition in the presence of the PROA-Subject. As shown in Tables 1 and 2, the three used lubricant samples showed TAN, ion salt, and ion metal concentrations values comparable to the clean, new lubricant. These results seem to indicate that the PROA-Subject was being depleted in the lubricant oil mixture. This depletion can be attributed to two possible reasons. The first is that PROA-Subject has been deposited on the heat transfer surfaces, and the second is that the filter/drier may have removed it from the system. A separate study would be required to determine the reason for this phenomenon.

Overall, the results of this study suggest that the theory in the NIST 2004 study is correct. The parameters of this particular chiller, which utilizes R134a with York “K” lubricant when installed with PROA-Subject, do not lead to apparent improvement of the energy performance of this chiller system. As discussed in the Literature Review section, the viscosity of the additive is not greater than that of York oil-type “K”, which according to the NIST theory eliminated the likelihood of enhancement.

Although efforts were made to control for external factors that influence the chiller performance, we could not fully account for all possible factors, such as: seasonal cooling load differences and unscheduled maintenance operations. These other unaccounted for factors may influence the performance of PROA-Subject in this chiller system. Other full-scale chiller tests that utilize different combinations of lubricant and PROA-Subject would be required to determine the efficacy of PROA-Subject in those operating environments.

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