FEDERAL TECHNOLOGY ALERTS

Polarized Refrigerant Oil Additive

Technology for Improving Compressor and Heat Exchanger Efficiency

Abstract

Polarized refrigerant oil additives (PROA) save energy and equipment by increasing the efficiency of heat exchange systems and reducing equipment wear. The technology, especially developed for air-conditioning and refrigeration compressors, forms a boundary film on metal parts and provides lubrication while protecting parts from friction degradation. It forms a microscopic chemical layer, without the introduction of solid particles.

The two most important benefits of PROA treatment are improved heat transfer in the evaporator and condensing coils and increased lubricity of the refrigerant oil. There are several side benefits that can extend equipment life. Although it is difficult to estimate energy savings from a specific application, field reports are generally positive, and ongoing independent laboratory and field testing should yield improved data. Otherwise, the only apparent barriers to rapid implementation of PROA technology in the Federal sector are user acceptance and correct application.

This Federal Technology Alert (FTA) provides detailed information and procedures that a Federal energy manager needs to evaluate most PROA applications. The New Technology Demonstration Program (NTDP) technology selection process and general benefits to the Federal sector are outlined, and the energy savings and other benefits of PROA treatment are explained. Guidelines are provided for appropriate application and installation.

A case study is presented to give the reader a sense of the actual costs and energy savings and how they can be estimated when the PROA technology is evaluated for use in the Federal sector. Current manufacturers, technology users, and references for further reading are included for prospective users who have specific or highly technical questions not fully addressed in this FTA. Procedures for estimating life-cycle costs and energy use are provided in the appendixes.

About the Technology

Although there are many types of refrigerant oil additives currently on the market, this Federal Technology

Alert deals with a specific type of additive, a polarized refrigerant oil additive (PROA), designed to improve the efficiency of heat exchangers in air-conditioners, chillers, heat pumps, and refrigeration systems, in addition to increasing the lubricity of refrigerant oil and reducing wear on compressor parts. Its unique formulation distinguishes it from other oil additives.

This special class of additives contains an activated polar molecule (highly charged at one end). The charged molecule has a strong affinity for metal, and coats metal surfaces in the compressor with an essentially single-molecule thin layer. This layer not only increases the ability of oil to lubricate moving parts in the compressor, but also displaces the build-up of refrigerant oil in condenser and evaporator coils thus improving heat transfer of heat exchangers. It is the build-up inside heat exchanger coils that most reduces the heat transfer ability of the system.

History of the Technology

The PROA technology was developed as a result of 20 years of work and 10 years of testing by three scientists. In 1990, a U.S. patent was awarded to Charles Wilkins, Jack Hammack, and Charles Thompson (U.S. Patent 4,963,280).

Application Domain

The PROA technology can be safely used to treat air-conditioners, heat pumps, refrigeration units, and freezing equipment in the private and Federal sector. It can be used to treat screw-type compressors, hermetically and semi-hermetically sealed positive displacement (reciprocating) compressors, scroll compressors, and centrifugal chillers. It is not applicable to absorption chillers. The PROA treatment can be applied to all sizes of air-conditioning and refrigeration systems.

Energy-Saving Mechanism

To understand how PROA works, consider briefly the make-up of a heat-exchange system. The cooling action in an air-conditioning or refrigeration system is created through the use of a compressible fluid that moves heat from one location to another. During the process of expanding and condensing, heat is either absorbed or rejected through a copper (or similar metal) coil.

Refrigeration systems also include a lubricant (often called refrigerant oil), which circulates continuously through the compressor to lubricate moving parts. Frequently, oil escapes the compressor area and moves with the refrigerant through the rest of the system. The oil entrained in the refrigerant travels from the compressor to the condenser and evaporator, where it attaches itself to the metal surfaces on the inside of the heat exchanger coils, in effect insulating them. The result is reduced heat transfer ability,
which in turn effectively reduces capacity and increases run-time in order to obtain the same amount of heat transfer.

The addition of PROA to refrigerant oil in the compressor introduces an a-olefin molecule, a chlorinated paraffin, which remains in a liquid state as it moves throughout the system with refrigerant oil. The activated polar molecule in PROA is carried in a non-particular (contains no particles) oil base which readily mixes with refrigerant oil. Each molecule, possessing a negatively charged region, seeks to attach itself to the metal surfaces throughout the refrigeration system. The molecule displaces other molecules, including dirt, carbon deposits, and oil, eventually forming a thin layer. Because the polar molecules have no affinity for each other, the layer is a single molecule thick. Figure 1 shows a diagram of this process.

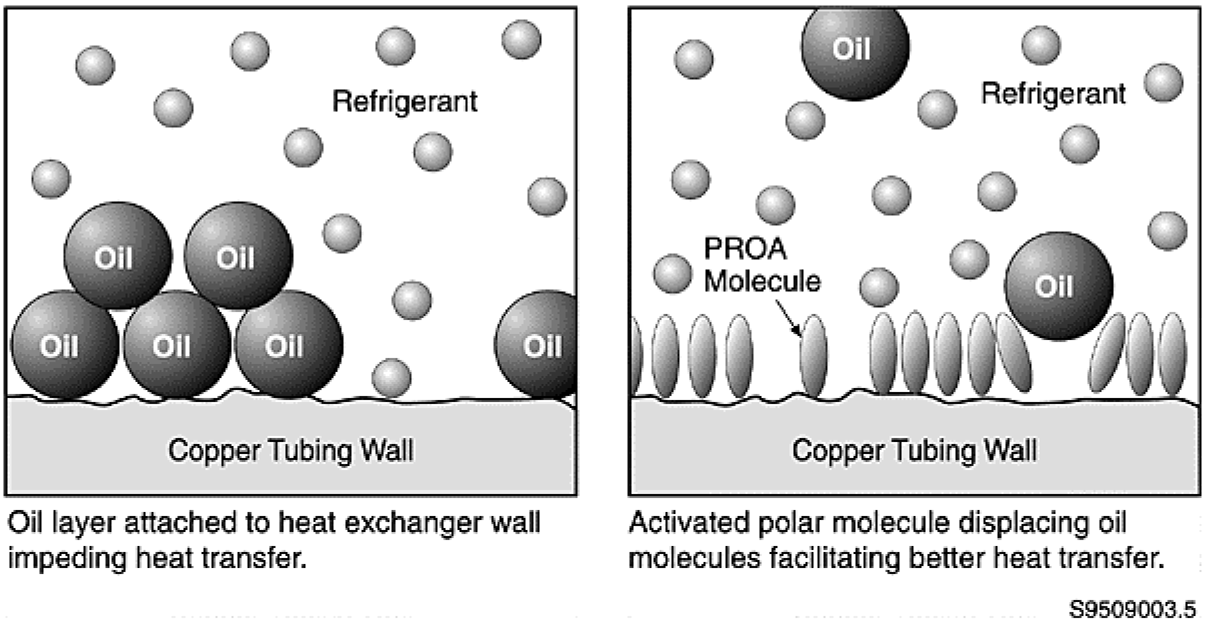

Fig. 1. Interaction of PROA Molecules

Benefits

The two most important benefits of PROA treatment are improved heat transfer in the evaporator and condensing coils and increased lubricity of refrigerant oil. These two important benefits produce several other side benefits:

- restored volumetric capacity --The addition of a stabilized boundary layer on all moving parts improves the seals made between moving parts and reduces the amount of "blow-by," volume lost during compression through bad seals.
- reduced run-time--By improving the heat transfer rate of the evaporator and condenser, the system capacity is affectively increased. With increased capacity, compressors that cycle don't need to run as long to produce the same amount of heat transfer, resulting in energy savings.
- reduced mechanical friction--By coating the metal surfaces of moving parts in the compressor, mechanical friction between the parts is reduced. Improved lubricity reduces corresponding wear on parts and excess heat generated.
- extended equipment life--Reduced mechanical friction, wear on moving parts, and excess heat generated all serve to extend the life of equipment.

- quieter operation--Field experience has shown that PROA treatment often produces a smoother, quieter running system.

Installation

Installing PROA is a simple process, but adherence to a few precautions will greatly facilitate its effectiveness. PROA should always be installed by a licensed professional to avoid any accidental release of refrigerant to the atmosphere.

Pretreatment Inspection. It is recommended that a qualified HVAC technician perform a standard maintenance inspection before any refrigeration system is treated with PROA. This inspection should verify that the following conditions exist:

- Head pressure and suction pressure within design limits
- Adequate refrigerant in the system and absence of oil or refrigerant leakage
- Cleanliness of coils and filters
- Thermostats or control systems functioning properly
- Heat exchanger coil fins free of dust, dirt, and corrosion.

The pretreatment check is important because these conditions all affect the performance of the system. In addition, it is important to ensure proper functioning so as to avoid the expense of retreatment should the system fail or lose oil or refrigerant before the PROA has dispersed through the system.

PROA Treatment. The amount of PROA to be added is determined by the volume of oil in the compressor. The ratio of PROA to compressor oil is 95% compressor oil and 5% PROA. The easiest way to treat a compressor is to remove 5% of the compressor oil and replace it with the same volume of PROA. It is important that the recommended amount of PROA not be exceeded.

The basic PROA treatment procedure is as follows. First, start the unit and keep it running throughout the installation. Introduce PROA into the unit's cool gas suction line schraeder valve. A charge oil pump designed specifically for the system should be used to decrease the risk of introducing contaminants. It is important that no moisture be allowed to enter the system during this process.

If the system is smaller than 25 tons (88 kW) of cooling, PROA may be introduced in a single treatment. However, if more PROA is required, it is important to use two equal treatments to obtain the 95%-5% mixture.

It is common to see a slight increase in energy consumption immediately following treatment as PROA begins to move throughout the system and oil and other particles are dislodged. Dividing the treatment into smaller doses minimizes this affect.

Post-Treatment. PROA takes one to two weeks of normal operation to disperse completely throughout the system. As the activated polar molecules bond to metal, they displace oil and carbon deposits on tube surfaces. Particularly in older systems, these deposits and oil returning to the compressor may clog in-line filters and driers.

Variations

Introducing the PROA into the oil reservoir in the compressor crankcase is the simplest, but not the only way to introduce the PROA treatment. In hermetically sealed compressors, it is added through the low-pressure port on the refrigerant line. Experience with residential heat pumps with hermetically sealed compressors showed that most require the addition of a tap valve to the low-pressure end of the refrigerant line. PROA is then added using a "Dial-a-Charge" or similar charging cylinder. Whether PROA is added to the refrigerant line or the oil reservoir, the important thing is that the compressor remains free from contamination.

Federal Sector Potential

Potential savings achievable by this technology were estimated as a part of the technology assessment process of the New Technology Demonstration Program (NTDP). This FTA was developed under the NTDP.

Technology Screening Process

New technologies were solicited for NTDP participation through advertisements in the Commerce Business Daily and trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties. Based on those responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were
also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies). [Note: This solicitation process is on-going and as additional suggestions are received, they are evaluated and become potential NTDP participants.]

The energy savings and market potentials of each candidate technology were assessed using the modified version of the Facility Energy Decision Screening (FEDS) software tool, developed for the Federal Energy Management Program (FEMP), U.S. Army Construction Engineering Research Laboratory (CERL), and Naval Facilities Engineering Service Center (NFESC) by Pacific Northwest National Laboratory (PNNL) (Dirks and Wrench 1993).

During the solicitation period in which the PROA technology was suggested, 21 of 54 new energy-saving technologies were assessed using FEDS. 33 were eliminated in the qualitative pre-screening process because they fell outside NTDP parameters, were not ready for production, were not truly energy-saving technologies, were not applicable to a sufficient fraction of existing facilities, or were not a U.S. technology. Eighteen of the remaining 21 technologies were judged life-cycle cost-effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings.

Estimated Market Potential

PROA is just beginning to penetrate the market. It was chosen for this Technology Alert because of its wide range of equipment availability and large number of potential applications. PROA has a firmer niche in the private sector, where over 500 cooling systems have been treated. Penetration into the Federal-sector market has been much slower.

It is difficult to estimate the total number of cooling systems currently in service in the United States. As of 1986, there were just over 4 million commercial buildings with 57 billion ft^2 (5,295 km^2) of floor space in the United States (OTA 1991). In 1993, in the United States alone, over 4,419,000 new air-conditioning, refrigeration, or heat pump units were shipped, amounting to an installed capacity of approximately 154 trillion Btuh (45 million kW). These figures do not include absorption chillers for which PROA is not applicable. The number is expected to increase through the year 2000 and beyond (Richman 1995).

Because the purpose of a Technology Alert is to evaluate the effectiveness of new technologies in the Federal sector, this report focuses on Federal use. The Federal Government owns and leases approximately 500,000 buildings of various sizes, construction, and occupancy use, of which 51,000 are considered office buildings containing approximately 1 to 2 billion ft^2 (92 to 186 km^2) of floor space. The Federal Government also owns an additional 422,000 housing units for military families (OTA 1991).

In 1989, the energy used in Federal buildings cost the U.S. Treasury around $3.5 billion (not including leased facilities where utility bills are included in the lease price). Electricity is dominant with $2.4 billion spent in 1989. To estimate the potential savings from PROA technology, multiply the amount the Federal Government spent on electricity in 1989 by 34% to estimate the amount spent on Federal-sector cooling in 1989 (EPRI 1986). If those systems were treated with PROA, the increased efficiency (assume 15%) would result in a savings of approximately $122 million per year, not including the cost of treatment.

Another potential application for the Federal sector would be to use PROA treatment in all public or subsidized housing. In 1989, the Federal Government spent about $4 billion to subsidize all or part of the utility bill in about 9 million households. Subsidized housing is often older and poorly maintained, offering a prime environment for PROA treatment.

Estimates of the potential market impact from PROA are rough estimates based on numerous assumptions regarding the actual savings obtained, the number of cooling systems that currently exist, and the ability to fully penetrate the Federal sector. This estimate does not include savings in demand charges or extended equipment life, for which data were unavailable.

Laboratory Perspective

The PROA technology has been studied in the laboratory and in the field. It has been tested in accordance with ASTM D3233-73, ASTM D2272, and ASTM D-471 standards by independent laboratories. A sample of the laboratory testing is included here:

- *Disposal*--PROA does not put any additional restraints on waste oil in regards to recyclability or waste oil disposal (PSI July 2, 1993).
- *Carcinogenic*--PROA is non-carcinogenic (U.S. Patent 4,963,280).
- *Lubricity*--Lubricity Testing proved that ordinary oil samples (untreated) failed under pressures of 300 psi. Samples treated with the PROA did not even fail at the test's maximum pressure of 4500 psi. This is a 1,400% increase in lubricity (Falex 1988).

- *Oxidation*--Oil samples were exposed to oxygenated environment at 90 psi (620.5 kPa) and heated to 302°F (150°C). As oil samples absorb oxygen (oxidize), pressure drops. The longer the sample takes to drop to 25 psi (172.4 kPa), the more resistant it is to oxidation, and therefore the better protection it provides for compressor components. Untreated oil samples took 14 minutes to drop to 25 psi (172.4 kPa), while samples treated with PROA took 25 minutes. The introduction of PROA increased the oil's resistance to oxidation 78.5% (PSI May 31, 1993).
- *Seal Degradation*--PROA reduced swelling in Neoprene by 29% and in Nitrile by 81% over untreated refrigeration oil. PROA also effectively conditions Neoprene, Viton A, PFE seals, Buna N, Nylon 66, Hastelloy, Mylar, Polypropylene, and Carpenter 20. Not only does PROA not adversely affect compressor seals, it actually provides life-extending benefits (AutoResearch July 1, 1993).

  A copy of the Material Safety Data Sheet (MSDS) is included in Appendix A.

Application

This section addresses the technical aspects of applying PROA treatment. The range of applications and climates in which the technology can best be applied are discussed. The advantages, limitations, and benefits in each application are enumerated. Design and integration considerations for the PROA technology are highlighted, including costs, options, installation details, and utility incentives.

Where to Apply PROA

The technology can be applied in the private and Federal sector in air-conditioners, heat pumps, refrigeration, and freezing equipment. Equipment must be either scroll compressors, positive displacement (reciprocating) compressors, screw-type compressors, or centrifugal chillers. PROA is not applicable to absorption chillers. The PROA treatment can be used safely in all sizes of air-conditioning and refrigeration systems. PROA can be used in any system where temperatures range between -65°F (-53.9°C) and 400°F (204.4°C).

PROA is compatible with R-134a, R-124, R-125, and R-22, common refrigerants for the 1990s. It is also compatible with refrigerants from the Methane series (R-10 to R-50), the Ethane series (R-110 to R-170), and the Propane series (R-216ca to R-290). It is also compatible with Chlorodifluoromethane (R-502), Sulfur Dioxide (R-764), and Carbon Dioxide (R-744). Consult the manufacturer for information about additional compatibility.

The active ingredient in PROA treatment, the activated polar molecule, is available in a carrier solution of either mineral or synthetic oil. When ordering PROA for a specific refrigeration system, be sure to request the type of carrier oil that is installed in that system.

The PROA treatment is most effective in older compressors. In a newer unit, with good seals and little wear, less oil is drawn into the condenser and heat exchanger. The PROA treatment often shows only a 3% to 7% increase in efficiency. Although newer systems experience a smaller increase in efficiency, the PROA treatment will help to keep them from degrading by preventing build-up on the heat exchangers in the first place.

What to Avoid

PROA is currently not recommended for applications using ammonia as the refrigerant. Testing is under way to study the interaction of PROA with ammonia. If the combination is proven safe, ammonia systems would offer substantial savings because more oil is carried in an ammonia stream than with other refrigerants.

Equipment Integration

Introducing PROA should not harm a refrigeration system, since it contains no solids, Teflon, or ash (all of which are harmful to air-conditioning systems). A letter from the Carrier Corporation to one manufacturer, dated March 1989, stated that "At this time, Carrier knows of no negative effects [of PROA] on the reliability of Carrier compressors." However, the Carrier Corporation did state that Carrier cannot be responsible for the behavior of any post-market additives added to their compressors. The Magnusson-Moss Consumer Product Warranty Act of 1992 provides that manufacturers may not void a warranty if a third-party lubricant is added unless that equipment manufacturer can demonstrate that the lubricant caused harm to the equipment.

Cost

The price for PROA treatment varies with manufacturer, amount purchased, and current market demand for the product. The cost for the PROA product ranges from $25 to $50 per ounce ($0.845/ml to $0.690/ml) on the commercial market. The current Federal-sector purchase price, through the Defense General Supply Center, is $30 per ounce ($1.014 per ml) plus a 17% handling fee. As previously noted, the product is applied at 5% by volume of refrigeration oil.(a)

The total cost of treatment includes the following elements:

- *Cost of the PROA product.* Cost depends on the amount of oil in the system and/or the surface area of the evaporators and condensers. Volume discounts are often available.
- *Labor*. Estimate the cost of labor for the pre-installation check-up and actual installation (15 minutes to an hour, depending on the amount of effort required). Include labor for return visits for second treatment (if needed) and to clean filters and traps. Include travel time for technician if it is applicable.
- *Available service port*. Does the system have an available service port? Some systems require addition of a tap valve by a qualified professional, and a few even require removal of the refrigerant before addition of the valve.
- *Verification of savings*. If verifying energy savings is a part of the project, the cost of data collection, manipulation, and verification may or may not be included in the total cost of the project.

Utility Incentives and Support

Many utilities are promoters of technologies that reduce electric demand, and many offer incentive programs to support the implementation of these technologies. Unfortunately, because PROA is a relatively new technology, few utilities have specific rebates for PROA installation. However, a customized approach is often available where rebates are based on the actual energy savings regardless of the technology employed. Contacting the serving utility representative to see what custom incentive programs are available is strongly recommended, especially on large applications.

A recent publication by the Electric Power Research Institute (EPRI) reported current demand-side management (DSM) programs available in the United States, surveying 295 public utilities, 218 distribution cooperatives, and 124 investor-owned utilities. Although 1127 DSM programs targeting HVAC systems and efficient refrigeration appliances were identified, none specifically targeted PROA technology. Programs are available that pay a percentage of the cost based on expected energy savings, and some that are customized to create a 2-year payback for the customer (EPRI 1993).

A no-cost installation is also possible through an Energy Savings Performance Contract (ESPC). This approach is spelled out in President Clinton's Executive Order 12902 of March 8, 1994. Federal sites are encouraged to enter into agreements where the contractor bears all the cost of installing energy-saving technologies, including instrumentation to verify energy savings. In return for providing the technology, the contractor gains a share of the energy savings for a fixed period of time. The "contractor" may be a private company, utility, or other agency. The percentage of energy savings the contractor receives and the length of time he/she will receive these payments are negotiable and need to be spelled out in the ESPC agreement (Executive Order 12902, Sec. 114, March 8, 1994). This option is available from at least one PROA manufacturer. The manufacturer provides the PROA treatment, labor (if needed), and monitoring equipment. In exchange, the contractor receives 50% of the energy savings for the next 10 years.

Technology Performance

The PROA technology is relatively young. Testing of the product occurred during the late 1980s, and the patent was awarded in 1990. Much of the field experience to date has taken place in the private sector, some as early as 1987. No major demonstration has taken place in the Federal sector, although the product has been installed in two U.S. Post Offices. Because air-conditioning systems in the private sector are often identical to those found in the Federal sector, performance evaluations in the private sector will apply to similar installations in the Federal sector.

Field Experience

The following are the results of one field study and a laboratory study that demonstrate the results experienced with PROA treatment.

Austin, Texas: The City of Austin, Texas, Resource Management Department conducted a test of five different energy-saving technologies. The test was conducted on a large gymnasium served by six 10-year-old, 10-ton (35 kW) packaged Lennox air-conditioners. All six units were tuned up, filters changed, belts adjusted, and refrigerant charges checked.

Several weeks of baseline data for each unit were recorded. Five of the units were selected at random to install an energy-saving technology, one of which was PROA. The study found that the compressor with PROA ran "significantly quieter." The energy consumption was reduced 22.0% from 1173 kWh to 915 kWh. Capacity was slightly reduced by 1.8%. The estimated end user cost for the PROA treatment was $680. The estimated first-year savings was $422 based on a typical cooling year. The simple payback was estimated at 19 months.

*Oak Ridge, Tennesse*e. The product was tested at Oak Ridge National Laboratory (ORNL) in a controlled laboratory environment. A 15-year-old air-to-air heat pump was removed from the field and placed in a test chamber regulated to a constant 95°F (35°C) per ARI test standards. The compressor was treated with PROA and run in a steady-state condition (no cycling) for 9 days. The compressor appeared less noisy during startup and operation after PROA treatment. Power consumption was reduced 1.8%. There was no discernible difference in peak demand.

Based on this test, PROA treatment would not be recommended. However, because the unit was operated in a steady-state mode, the influences of startup energy and unit cycling were not reflected (Baxter 1995).

Energy Savings

Typical energy savings from PROA treatment are difficult to predict. Energy savings for each treated compressor vary according to age, compressor type, size, maintenance history, and loading.

A portion of the energy savings may be due to the O&M maintenance performed prior to treatment with PROA, especially in units with poor maintenance history. Unfortunately, with the data available it is impossible to separate the improvements from proper O&M and the improvements from PROA treatment.

Energy Consumption. PROA is most effective in reducing energy consumption in older compressors. In a new unit, good seals and little wear cause less oil to be drawn into the condenser and heat exchanger. The PROA often shows a 3% to 7% increase in efficiency. However, with units five years old or greater, efficiency can be improved to anywhere from 10-30%. Savings as high as 36% have been reported.

One manufacturer reported 23 demonstration installations where the average (mean) energy savings was 21.2% (standard deviation = 6.3%). Figure 2 shows a histogram of these 23 installations plotted as the percentage savings versus the number of times that savings occurred. With an average of 21.2%, 95% of all the values fall within a confidence interval from 14.8% to 27.5%. The energy savings at these installations were reported by local personnel; therefore, no means exists of establishing accuracy or standardizing the data collection procedure. In only one case was it clear that weather variability (cooling load) during the study period was considered.

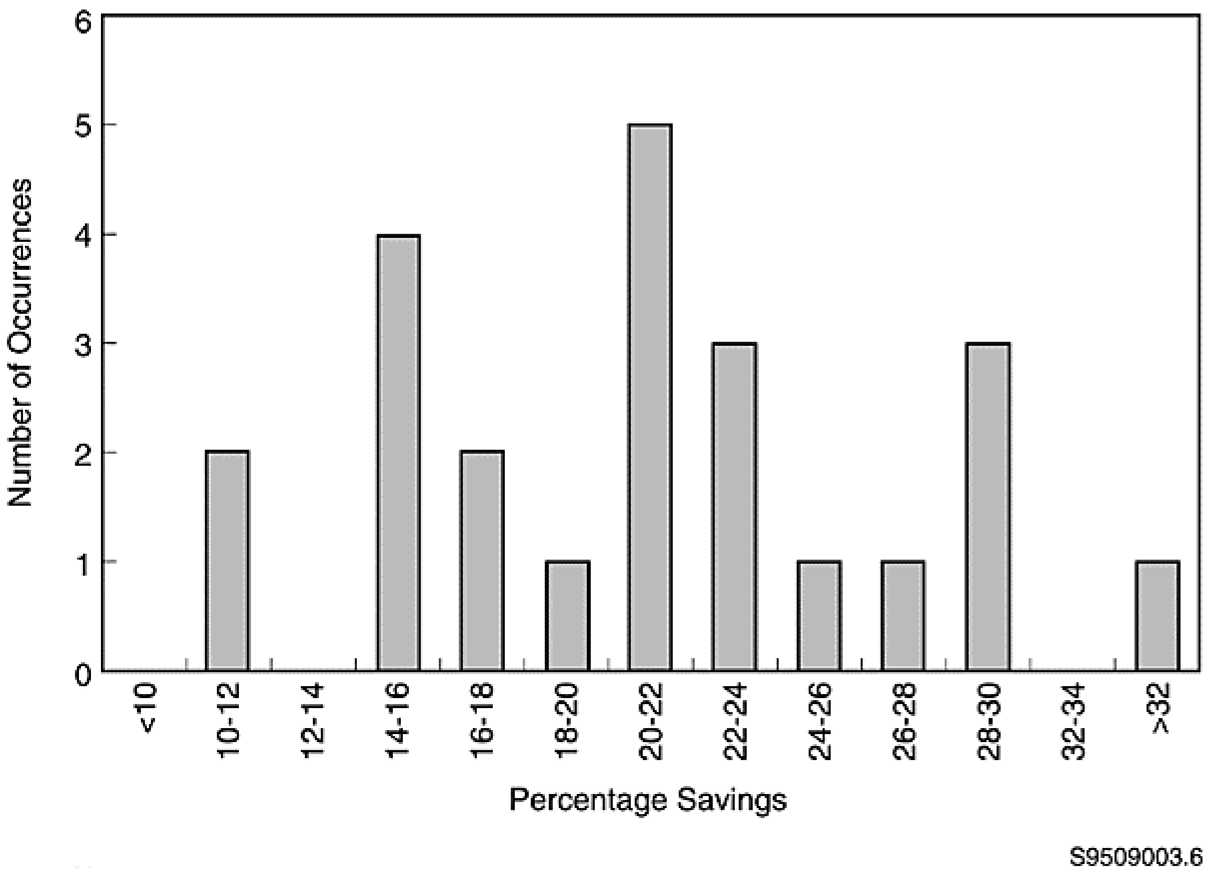

Fig. 2. Energy Savings Reported by Manufacturer

One method of estimating energy savings would be to assume the 23 installations reported by the manufacturer in Figure 2 represent a typical distribution of energy savings. Instead of using the average (mean), 21.2%, to estimate energy savings, use 14.8%, the lower limit of the confidence interval. This is a conservative estimator since 95% of the results will be greater than 14.8%. This is probably a safe approximation for refrigeration systems that are inside a building and have a constant load (e.g., coolers and refrigerators) and for air-conditioning systems in warmer climates (greater than 1000 cooling degree days).

14.8% can be used as an estimator when nothing else about the system is known. However, the following attributes affect energy savings:

- *Age*. If the compressor is less than five years old, actual savings will be less--often only 3 to 7% for compressors less than 2 years old.
- *Size.* Theoretically the percentage energy savings should remain the same, regardless of system size; in practice, large central cooling systems are better maintained and controlled more closely. Percent energy savings will therefore be reduced on larger systems.
- *Climate*. If the air-conditioning system being treated operates in a cooler climate (less than 1000 cooling degree days) where reduced cooling load causes shorter run-time and more cycling, the total savings will also be less and payback periods longer.

Using the installations in Figure 2, all the factors affecting energy savings were analyzed. It was found that the age of the system at the time of PROA treatment is the most important variable in predicting energy savings.

Figure 3 shows the 16 systems for which age data were available plotted versus energy savings. The solid line in Figure 3 is the regression line that is the best fit for the data.

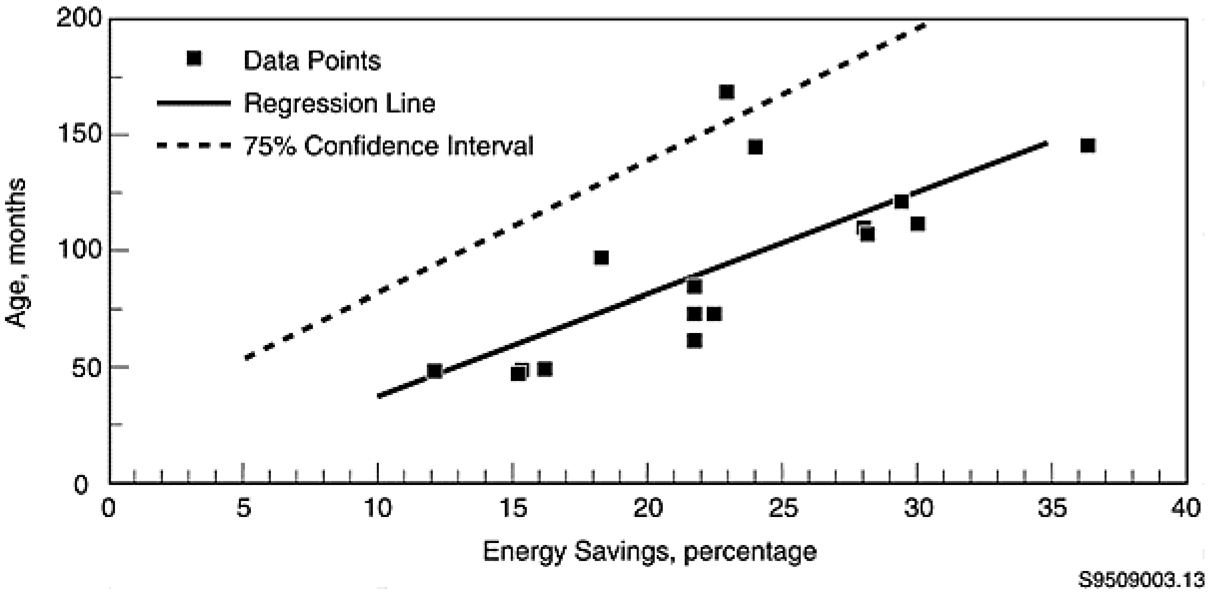

Fig. 3. Compressor Age Versus Energy Savings

Using system age to estimate energy savings is possible by identifying the age of your system on the Y-axis in Figure 3, tracing horizontally to the regression line, tracing vertically to the X-axis, and reading the energy savings. To obtain a conservative estimate, use the dashed line in Figure 3, which represents the upper limit of the 75% confidence interval. The actual savings should be greater than your estimate 75% of the time. Remember, this estimating procedure is imprecise considering the number of other variables affecting energy savings and the small number of data points in this sample.

Electric Demand. In most cases, a reduction in electric demand is realized after PROA treatment. Generally, the highest demand occurs at startup, as the compressor works the hardest to get stationary parts moving. PROA treatment increases lubrication, which reduces the amount of work required to start compressor parts moving.

The best example of reduced demand at startup was experienced at Sonny's Real Pit Bar-B-Q in Tuscaloosa, Alabama. Sonny's two 7.5 ton (26 kW) air-conditioning units were treated with PROA in May 1992. Figure 4 shows the 15-minute average amperage draw plotted versus time of day for a day before and after PROA treatment that were determined to have identical loading. Peak demand on Sonny's two units was reduced almost 31% following PROA treatment. On a walk-in cooler in South Saint Paul, Minnesota, demand was reduced 2.7% following PROA treatment.

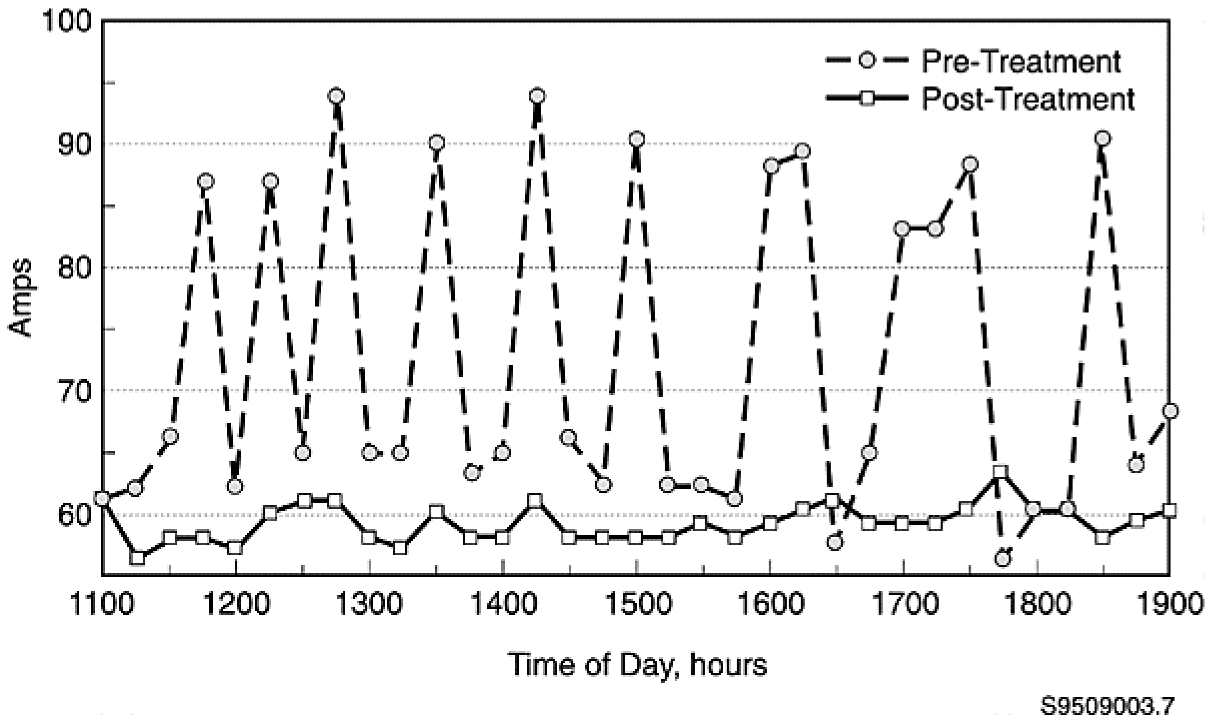

Fig. 4. Reduced Electric Demand at Startup

Like consumption savings, demand savings will vary with each individual system. Unfortunately, estimates of demand reduction are difficult to quantify because of insufficient supporting data. The demand reduction experienced at Sonny's Real Pit Bar-B-Q should not be treated as typical.

Maintenance

PROA is an additive; there are no elements of the technology that require any maintenance per se. However, the treatment using PROA has some effect on the standard maintenance of compressors and refrigeration systems.

Since PROA bonds to the metal surfaces in the system, much of the product remains in the system even if oil is lost or the system is drained. After every third oil change, the system should be treated with 10% of the original amount of PROA to maintain the proper level in the system. Thus, if 10 ounces (284 ml) of PROA were used initially, an oil change should include an additional 1 ounce (28 ml) of PROA.

Other Impacts

PROA takes one to two weeks (during normal operation) to fully spread through the system. As the polar molecules bond to metal, they displace oil, carbon molecules, and dirt on the tube surfaces. Particularly in older systems, these deposits and oil returning to the compressor may clog in-line filters and driers. Several weeks after initial treatment, it is recommended that in-line driers and filters be checked for accumulated debris that the PROA has displaced from the surfaces inside the compressor and piping.

Case Study

Because it is a relatively new technology, PROA has not had a major demonstration in the Federal sector. The case study described here concerns an application in the private sector and is presented so that the mathematics and data requirements might be better understood. Parallel to the actual case study, additional discussions provide relevance to the Federal sector. This case study should provide a step-by-step process to identify potential energy savings, install PROA, and verify the savings at a Federal facility.

This case study was chosen because it is the most heavily instrumented installation available. Despite the small size of the refrigeration system, the lessons learned can be generalized to systems of all sizes.

Facility Description

The test was performed on a walk-in cooler at a large restaurant in South Saint Paul, Minnesota. The cooler is powered by a 1 hp (0.75 kW) Copeland air-cooled compressor. The compressor and condenser are located in a mechanical room on the roof of the restaurant. The refrigeration system is 12 years old and uses R-12 as the refrigerant.

The utility serving the restaurant is Northern States Power. The electricity charges for "electric small general service" are a basic monthly charge of $7.95; an energy charge of $0.0730/kWh from June through September and $0.0630/kWh all other months; and a small resource adjustment (Northern States Power rate schedule).

PROA Installation

It was determined that the refrigeration system was a good test location for treatment with PROA. It fit all the application parameters as presented in the Applications section of this document. The compressor is a hermetically sealed reciprocating compressor, requiring 1 ounce (28 ml) of PROA treatment.

Test Methodology

The best way to determine pre-retrofit energy use is to install an electric meter or data logger with kWh capability. Whole-building utility bills are poor indicators of the true performance of energy savings; outside influences can distort energy-savings data. Energy use should be monitored at a level which includes the compressor, all fans, and controls.

The baseline energy use should be in a form that will be easy to compare to the post-treatment period. Total kilowatt-hours used over a fixed period of time such as a week is a good indicator. Note also the maximum demand in kW; since reduced demand is one possible benefit of PROA treatment, it is important to determine whether peak demand has been reduced.

For this case study, baseline energy data were collected for 3 weeks prior to treatment with PROA. This baseline period is called period 1. The refrigeration system on the cooler used 1155 kWh during the 3-week period and had a maximum demand of 3.34 kW. Assuming the load on the cooler is fairly constant throughout the year, this equates to an annual energy consumption of 20,020 kWh and an average monthly demand of approximately 3.5 kW.

Savings Potential

An estimate of the actual savings is difficult to make, since performance improvements vary depending on age, type of system, maintenance history, loading, and other parameters. Two procedures for estimating percent energy savings are presented in this Technology Alert. The first uses the data in Figure 2 to approximate the energy savings as 14.8%. The second uses the age of the system and Figure 3 to approximate energy savings. Because we know the age of the system (144 months), we will use the second procedure. The estimated energy savings is 21% using the 75% confidence interval regression line.

The monitored baseline energy consumption was 1155 kWh. If the PROA treatment produces a 21% savings, 242 kWh or approximately $17 should be saved over a three-week period with identical cooling load. Assuming the cooling load is constant over the entire year,(b) the estimated annual energy savings is 4,204 kWh and $294.

Life-Cycle Cost

The installation cost for treating a system with PROA is very site-specific. When calculating life-cycle cost, be sure to identify all variables that might increase the installation cost. (see Cost section of this report to help identify hidden costs.) The cost for this case study includes an installation cost of $175.00 for the PROA treatment. No additional energy, non-energy, or annual O&M cost is required for the PROA additive. This life-cycle cost analysis is based only on savings in energy use. There is no demand savings since the restaurant is charged only on it's electric consumption. Additional savings from increased equipment life have not been included because no quantitative data are available.

Feeding these numbers and the annual energy estimates into the 1995 Building Life-Cycle Cost (BLCC) program gives the results shown in Figure 5. See Appendix B for more details about the BLCC program and life-cycle costing in the Federal sector.

The BLCC program showed that treating the compressor with PROA produces a net savings of $2,405 over the 10-year study period. The Saving-to-Investment Ratio (SIR) for the project is 14.74, and the Adjusted Internal Rate of Return (AIRR) is 36.11. Simple payback for the PROA treatment occurs during year 1.

Verification of Energy Savings

After treating a system with PROA, it should be allowed to stabilize as the PROA molecules are dispersed throughout the system. After about 2 weeks, repeat the baseline monitoring procedure to determine post-treatment energy use.

The system in our case study was monitored for four more 3-week periods to see whether efficiency continued

to increase. During the last 3-week period, period 5, the system used 878 kWh and had a maximum demand of 3.25 kW. A comparison of periods 1 and 5 indicated that energy consumption was reduced 277 kWh or 24.0% and peak demand was reduced 0.09 kW
or 2.7%.

Implementation and Post-Implementation Experience

The energy savings in the case study is based on the assumption that the cooling load remained constant during the study period. While this assumption should be accurate, the data showed that the average temperature in the mechanical room was 9.3% less during period 5 than period 1 (see Figure 6). A decrease in ambient temperature means that the amount of work the compressor had to do to provide the same amount of cooling decreased, affecting the coefficient of performance of the system. Unfortunately, insufficient data exist to normalize for this effect.

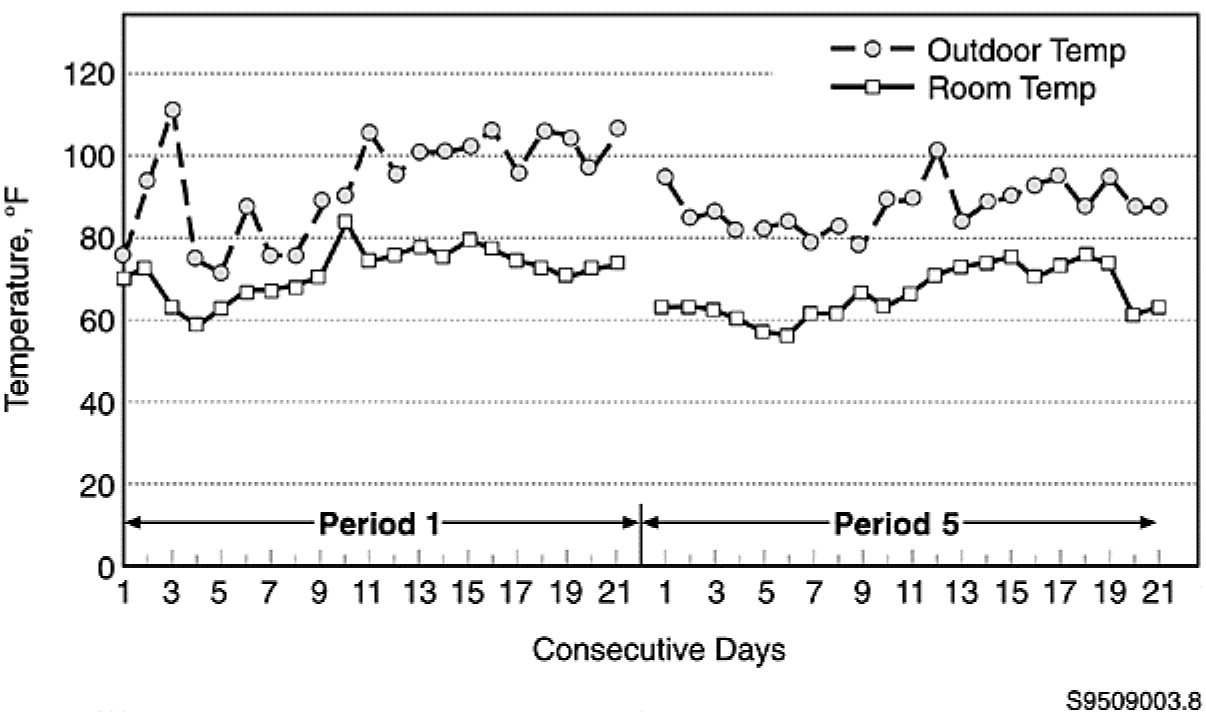

Fig. 6. Temperatures During Study Period

The site has other peculiar features. For example, if we plot mechanical room temperature versus outside temperature, we see that the mechanical room temperature was higher than the outdoor temperature during the entire study period (see Figure 6). On June 7, 1994, the average temperature in the room was 110.7°F (43.7°C). It would appear that the mechanical room should be vented to the outdoors during part of the year.

The Technology in Perspective

This special class of refrigerant oil additives has been shown through laboratory testing, field testing, and theoretical analysis to be technically valid and economically attractive in many applications.

Energy savings have been reported for a number of onsite applications since 1987. Unfortunately, due to the lack of standardization in the way data were collected and energy savings reported, results should be treated as approximate. In the next few years, additional independent laboratory and field testing should produce more reliable results.

NIST BLCC: COMPARATIVE ECONOMIC ANNALYSIS (VERSION 4.20-95)
BASE CASE: NO TREATMENT (a)
ALTERNATIVE:PROA ADDED (b)
Principal Study Paremeters:

Analysis Tyhpe: Federal Analysis--Energy Conservation Projects
Study Period: 10.00 CAUG 1995 THROUGH JUL 2005
DISCOUNT RATE: 4.0% REAL (EXCLUSIVE OF GENERAL INFLATION)
BASE CASE LCC FILE: PROA_BASE.LCC
ALTERNATIVE LCC FILE: PROA_TRMT.LCC

COMPARISON OF PRESENT-VALUE COST

	BASE CASE: NO TREATMENT	ALTERNATIVE: PROA ADDED	SAVINGS FROM ALT.
INITIAL INVESTMENT ITEM(S): CASH REQUIREMENT AS OF SERVICE DATE	$0	$175	-$175
SUBTOTAL FUTURE COST ITEM:	$0	$175	-$175
ENERGY-RELATED COST	$13,088	$10,508	$2,580
SUBTOTAL	$13,088	$10,508	$2,580
TOTAL P.V. LIFE-CYCLE COST	$13,088	$10,683	$2,405
NET SAVINGS FROM ALTERNATIVE PROA ADDED COMPARED TO ALTERNATIVE NO TREATMENT NET SAVINGS=P.V. OF NON-INVESTMENT SAVINGS -INCREASED TOTAL INVESTMENT		$2,580 $175	
NET SAVINGS		$2405	

NOTE: THE SIR AND AIRR COMPUTATIONS INCLUDE DIFFERENTIAL INITIAL COSTS, CAPITAL REPALCEMENT COST, AND RESALE VALUE (IF ANY) AS INVESTMENT COSTS, PER NIST HANDBOOK 135 (FEDERAL AND MILCON ANALYSIS ONLY).
SAVINGS-TO-INVESTMENT RATION (SIR)
FOR ALTERNATIVE PROA ADDED COMPARED TO ALTERNATIVE NO TREATMENT

$$SIR = \frac{\text{P.V. OF NON-INVESTMENT SAVINGS}}{\text{INCREASED TOTAL INVESTMENT}} = 14.74$$

ADJUSTED INTERNAL RATE OF RETURN (AIRR)
FOR ALTERNATIVE PROA ADDED COMPARED TO ALTERNATIVE NO TREATMENT
(REINVESTMENT RATE = 3.00%; STUDY PERIOD = 10 YEARS)
AIRR = 36.11%

ESTIMATED YEARS TO PAYBACK

SIMPLE PAYBACK OCCURS IN YEAR 1
DISCOUNTED PAYBACK OCCURS IN YEAR 1

ENERGY SAVINGS SUMMARY

ENERGY TYPE	**UNITS**	**ANNUAL**	**CONSUMPTION**		**LIFE-CYCLE**
		BASE CASE	**ALTERNATIVE**	**SAVINGS**	**SAVINGS**
ELECTRICITY	kWh	20,020	15,816	4,204	42,040
		EMISSIONS	REDUCTION	SUMMARY	
ENERGY TYPE		**ANNUAL**	**EMISSIONS**	**ANNUAL**	**LIFE-CYCLE**
ELECTRICITY					
C02 (kg):		11,629.4	9,187.3	2,442.1	24,420.6
SOx (kg):		97.7	77.2	20.5	128.0
NOx (kg)		49.9	39.4	10.5	104.7
Total					
CO2 (kg)		11.629.4	9,187.3	2,442.1	24,420.6
SOx (kg):		97.7	77.2	20.5	128.0
NOx (kg):		49.9	39.4	10.5	104.7

Fig.5. Building Life-Cycle Cost (BLCC) Output

The remaining barriers to rapid implementation of this technology involve user acceptance and correct application. Additional data would aid in a more precise method for estimating energy savings in any specific application. This FTA is intended to address these concerns by reporting on the collective experience of PROA users and evaluators and by providing application guidance.

Relation to Other Technologies

As previously mentioned, the PROA discussed in this FTA is a special class within a whole line of refrigerant additives. Because of the large number of companies manufacturing additives, the study was limited to the special class of additives related to the patented process and the a-olefin molecule. Whether or not other additives have achieved similar success is beyond the scope of this FTA. This report makes no claims, express or implied, about the effectiveness of other products. Given sufficient interest, other additives can be addressed in future NTDP initiatives.

The True Test

Unfortunately, the PROA does not lend itself to a definite means of estimating energy savings for specific applications. Potential users who are interested in the PROA technology, but are still skeptical, are encouraged to try one of the following approaches.

Ask for a guarantee. If a salesman is promising a 20% savings, ask him to guarantee at least a 10% savings or a refund of the treatment price. At least one manufacturer has indicated that they will guarantee at least a 10% energy savings on units at least 2 years old or the treatment cost will be refunded.

Share the Energy Savings. Energy Savings Performance Contracts (ESPC) are available through local utilities and private companies. The ESPCs make it possible to share energy savings by providing up-front capital to install energy-saving technologies. Sharing the financial savings is one way to share the risk and save energy with little or no up-front capital.

Try a test pilot. Before treating multiple units with PROA, try the additive first on one unit and have the unit carefully monitored to document energy savings. Warning: Simply watching the electric bill may not be the best way to document savings. Changes in use, equipment loading, the number of cooling degree days, etc., may influence the results.

Who is Using the Technology

The list below includes private-sector contacts, agencies, and locations that already have the new technology installed and operating. The reader is invited to ask questions and learn more about the new technology for sites where names and telephone numbers are provided.

Alabama Mental Health
and Mental Retardation
Taylor Hardin Secure Medical
Tuscaloosa, Alabama
contact: Bob White
(205) 556-7060

Benton H. Wilcoxon Municipal Iceplex
Huntsville, Alabama
contact: Doug Minor
(205) 883-3773

Bridgeman's Restaurant
4560 Robert Street
South Saint Paul, Minnesota
contact: Jay Jacobson
(612) 424-2111

City of Tuscaloosa, City Hall
Tuscaloosa, Alabama
contact: Jerry Moon,
facilities manager
(205) 349-0144

Crook's Supermarkets, Inc.
Nashville, Tennessee
contact: Clarence E. Hackney,
Vice President/CEO
(615) 352-2999

House of Golf
Sarasota, Florida
contact: Dan Davis, General Manager
(813) 925-7888

McAbee Construction Company
Tuscaloosa, Alabama
contact: Tommy Muckenfuss,
vice president for construction
(205) 349-2212

West Freezing, Inc.
Biloxi, Mississippi
contact: Fritz Mitzel, Plant Manager
(601) 432-7932

Additional Testing:

Oak Ridge National Laboratory
controlled laboratory tests
contact: Jim Sand
(615) 574-5819

Additional Information:

Environment & Energy Resource Center (non-profit)
427 Saint Clair Avenue
Saint Paul, Minnesota
contact: Rick Anderson
(612) 227-7847

For information on Energy Saving Performance Contracts, contact The Federal Energy Management Program (FEMP) Help Desk at (800) 566-2877.

For Further Information

Lab Test Reports

AutoResearch. "FRIGAID/Seal Material Compatibility Testing." Testing done by AutoResearch Laboratories, Inc. In accordance with ASTM D-471. July 1, 1993.

Falex Corporation. "Sundial Lubricity Evaluation." Testing done by Falex Corporation, Aurora, Illinois. In accordance with ASTM D3233-73. Letter to Dr. Wilkins, Sundial Corporation. March 11, 1988.

Professional Service Industries (PSI) a. "FRIGAID Recyclability Testing." Testing done by Professional Service Industries, TAI/Fabor Division, Chicago, Illinois. Letter to Matt Ross, Energy Conservation Products, Inc., Sarasota, Florida, July 2, 1993.

Professional Service Industries (PSI) b. "FRIGAID Oxidation Resistance Testing." Testing done by Professional Service Industries, TAI/Fabor Division, Chicago, Illinois. In accordance with ASTM D2272. May 31, 1993.

Van Baxter. "Summary of Test Results On Vintage Heat Pump with Oil Additive." Letter to L.D. Martin, Jr., Huntsville, Alabama. Testing done by Oak Ridge National Laboratory, Oak Ridge, Tennessee. August 30, 1995.

Utility, Information Service, or Government Agency Tech-Transfer Literature:

J.A. Dirks and L.E. Wrench. 1993. "Facility Energy Decision Screening (FEDS) Software System." PNL-SA-22780. In Proceedings of the Energy and Environmental Congress. Minneapolis, Minnesota. August 4-5, 1993.

E.E. Richman, Current and Projected Commercial Space Heating, Space Cooling, and Water Heating Equipment Use in the United States. Pacific Northwest Laboratory, Richland, Washington. January 1995.

Electric Power Research Institute (EPRI). May 1993. 1992 Survey of Utility Demand-Side Management Programs. EPRI TR-102193 V1. Electric Power Research Institute, Palo Alto, California.

Engineering Weather Data. TM 5-785, NAVFAC P-89, or AFM 88-29. Departments of the Air Force, the Army, and the Navy. July 1, 1978.

Executive Order 12902 of March 8, 1994. "Energy Efficiency and Water Conservation to Federal Facilities." Weekly Compilation of Presidential Documents. vol. 30, p. 477.

Georgia Institute of Technology. The Commend Planning System: National and Regional Data and Analysis, EPRI EM-4486, Electric Power Research Institute, Palo Alto, California, March 1986.

U.S. Congress, Office of Technology Assessment (OTA). Energy Efficiency in the Federal Government: Government by Good Example? OTA-E-492, U.S. Government Printing Office, Washington, D.C., May 1991.

U.S. Department of Commerce. Air-Conditioning and Refrigeration Equipment, Including Warm Air Furnaces: 1988, U.S. Department of Commerce, Bureau of the Census, MA35M(88)-1, September 1989.

User, Third-Party Field Studies, and Case Studies:

Anderson, Richard, and Rebecca Biel, Bridgeman's Data Report, Environment and Energy Resource Center, Saint Paul, Minnesota. September 1994.

Minor, Doug. Evaluation Report: Enhanced Lubricant Chemistry vs. Chiller Efficiency. Benton H. Wilcoxon Municipal Iceplex, Huntsville, Alabama. 1994.

Young & Pratt. City of Austin Air Conditioning Efficiency Improvement Retrofit Report. Prepared by Young & Pratt Service, Inc. for the City of Austin, Texas. October 7, 1988.

Other References:

Duffy, Gordon. "New Lubricant Enhancer Adds Energy-Saving Bonus," The Air Conditioning, Heating, and Refrigeration News. 1989 ASHRAE/ARI Exposition Issue.

ACHRN. "Grant Money Available for Conservation Plans," The Air Conditioning, Heating, and Refrigeration News. p. 16, December 5, 1994.

Contacts

General Contacts

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