Detecting and Eliminating Causes of Coil Corrosion

By Alan H. Brothers, Ph.D.

External coil corrosion appears to be on the rise. While the possible causes of coil corrosion can stem from poorly manufactured copper, chemical residue from coil manufacturing, and other problems that initiate the corrosion process long before the coils arrive on a jobsite, the majority of problems occur when environmental acids corrode coils from the outside in.

A case in point is an American fruit processor that has replaced dozens of coils in the past year at a South American facility. The maintenance engineer had used Mainstream Engineering's internal acid detector, QwikChek®, and acid eliminator, QwikShot®, which is injected into the refrigeration system to vaporize moisture/acids and send them to the filter/drier to fix his corrosion problem because he erroneously believed the corrosion was happening from the inside out. Although the QwikCheck acid test indicated no acid, coil corrosion continued at the same alarming rate. Mistakenly convinced acid was corroding the coil from the inside, the plant engineers lodged complaints about the accuracy of the acid test method and efficacy of the acid eliminator. Mainstream Engineering, a research & development company that provides both the U.S. military and NASA with solutions to HVAC problems, sought to answer the fruit processor's problem and discovered the coils were corroding from the outside in, not vice-versa.

While no particular environmental chemical has yet been pinpointed at the South American plant, the problem could arise from a number of issues. For example, most fruit processors use ethylene gas generators to ripen fruits such as bananas. Combustion byproducts from the catalytic generator combined with moisture, prevalent in humid, equatorial regions, form a weak acid that eats pinhole leaks into the coil tubing in a year or less. The mixture of ethylene gas, high humidity, and a myriad of cleaning chemicals used to ensure sanitation at the facility will inevitably form a volatile mix of coil-corroding gaseous contaminants.

Few U.S. service technicians will find themselves in a South American fruit plant, but similar circumstances that result in the rapid corrosion of coils can be found at sites ranging from residential systems or commercial rooftop units to industrial refrigeration applications. Only the composition of the environmental contaminants and/or chemicals may vary. For example, a rooftop unit in a coastal area could be corroded from ocean salt. Household bleaches, aerosol sprays, high humidity, and other prevalent factors found in every home can damage an indoor residential unit coil. An abundance of fertilizers, industrial plant processes, pollution, or acid rain can corrode outdoor condensing coils.

The following list illustrates sources of coil corrosion that could be overlooked by service technicians:

- fermenting yeast (lactic acid from milk) in a bakery walk-in cooler

- chlorine from an indoor swimming pool or aquatic process

- urine (ammonia) from dead animals in meat processing plant coolers

- sulfur from well water used in cleaning coils or rooms with coils

- fertilizer (ammonia) in agricultural building evaporative coolers

Two Types of Environmental Corrosion

 The two most common forms of coil corrosion are pitting and formicary. These two corrosive processes can occur in as little as a few weeks after installation. More typically, corrosion will begin appearing within a one-to-four-year period. The ability to distinguish between pitting and formicary corrosion might help detect and eliminate the cause. For example, pitting is typically caused by the presence of chlorides or fluorides. Chlorides are found in numerous items such as snow-melting crystals,

toilet bowl/tile cleaners, dishwasher detergents, fabric softeners, vinyl fabrics, carpeting, paint strippers, etc. Fluorides are used in many municipal water treatment plants. Pitting, which appears on the exterior of the copper tube, is usually visible to the naked eye. It is caused by an aggressive attack of an anion, which is a negative-charged chemical species. The anions search for positive-charged species called cations, which are abundant in copper. Pitting will eventually break through to the inside of the tubing and create a leaking condition.

Formicary corrosion is associated with pinholes in the copper tube walls. Although this type of pinhole corrosion is not usually visible to the naked eye, some black or blue-gray deposits often can be seen on the surface. Formicary corrosion also exhibits a subsurface network of microscopic corroded tunnels within the tubing wall that resemble ant nest-type structures, immensely larger than the surface pinholes above them. Formicary corrosion is caused by organic acids such as acetic and formic acids. Acetic acids or the derivative acetate are abundant in numerous household products such as adhesives, paneling, particle board, silicone caulking, cleaning solvents, vinegar, foam insulation, and dozens of other commonly found products in the home or commercial/industrial workplace. Formic acid can be found in cosmetics, disinfectants, tobacco and wood smoke, latex paints, plywood, and dozens of other materials.

Given these common products containing organic acids attack copper, it is not surprising that coil corrosion occurs at alarming rates. The rise in corrosion the last 20 years might also be aggravated by the trend in tighter building construction methods, which allows less outside air induction to dilute or clear away these corrosive, indoor buildups. Even so, both pitting and formicary corrosions need two additional ingredients—oxygen and water. While oxygen is nearly unavoidable, limiting moisture might help the service technician fight or decelerate the problem.

Galvanic Corrosion

When two dissimilar metals, such as copper tubing and aluminum fins, are in contact with each other, a "galvanic couple" is formed, and the phenomenon of galvanic corrosion occurs. In this galvanic couple, the metal that corrodes and the metal that is protected depend on their relative positions in the galvanic series. Moisture is again a key factor in this corrosive process because it acts as the electrolyte needed in the reaction. Sea water accelerates the galvanic reaction because of its higher conductivity than fresh water and because salts can destroy the protective barriers on metal surfaces. The potential for galvanic corrosion is always present between two dissimilar metals. But how quickly galvanic corrosion results in system damage depends on variables like the electrolyte conductivity, the amount of oxygen present, and relative surface areas of each metal.

Keeping Coils Clean to Fight Corrosion

Outdoor condensing coils can best fight corrosion with periodic cleaning. Water is suitable, but existing corrosion and buildup typically are removed more completely with a coil cleaner. Numerous acid-based and alkaline-based coil cleaners are available. However, proper rinsing is important to avoid the coil cleaner chemical residue that could initiate the corrosion process. Some alkaline cleaners tout the fact

that they are "non-acid" to capitalize on the belief that acids cause corrosion. However, alkaline cleaners also need to be rinsed thoroughly just like acid-based cleaners because alkaline residues can also corrode aluminum and other materials.

Outdoor coils located in areas where corrosives are prevalent, such as heavy industrial areas with acid rain or coastal areas where ocean salt is a factor, should have frequently scheduled, periodic cleanings. The fruit processing plant mentioned earlier would benefit from monthly coil cleanings to help offset environmental corrosion.

Corrosion from the Manufacturing Process

While no available statistics reveal the extent of environmental corrosion, it may cause the majority of coil corrosion problems. However, the manufacturing process itself can also initiate coil

corrosion prior to installation. Manufacturing problems can be related to anything from poorly constructed copper tubing or lubricants coil manufactures use at their plants.

Replacing coils corroded during the manufacturing process or using substandard copper may not alleviate corrosion because the problem may be inherent in the product. Contact the manufacturer and/or distributor to address these issues.

Coatings to Protect Coils from Corrosion

Protective coatings are an option for new coils that are destined for corrosive applications and for existing coils that have been repeatedly replaced due to corrosion. Numerous coatings exist. However, most coil coatings are composed of either silanes or polymers. The advantage of coatings is they make coils virtually corrosion-proof when properly applied and maintained. Reducing corrosion can improve long-term performance and reduce replacement costs. The disadvantage perceived by some industry members is a decrease of up to 10 percent in heat transfer, a significant disadvantage for existing coils in the field because it affects efficiency and capacity. New coils with coatings can be oversized to offset this heat transfer loss. Some coating manufacturers actually claim an increase in heat transfer, due to the way in which water condenses and drips off coated coils.

For existing coils, some coatings can be applied in the field by specialists who clean and then spray a coating on the coil. Other coatings can be applied by service technicians in the field. Whether a field application is possible depends mostly on the depth of the coil. Other coatings require sending the coil to the coating manufacturer or a specially-trained applicator. Probably the most difficult area to reach with a coating is the gap between the fin and tube. Coatings plug this gap, preventing water and contaminants from penetrating, but they interfere with heat transfer between them.

There are two common types of coil coatings, and both differ greatly in chemical make-up and performance:

1. **Polymers**—These coatings, which are typically thick epoxy or phenolic coatings, are generally inexpensive and easy to apply. But because they are thicker than silanes, they decrease heat transfer more. Many polymer coatings are also sensitive to ultraviolet (UV) degradation and can crack off the coil surfaces over time.

2. **Silanes**—Silane-based coatings are mainly composed of alcohol and water, thus they are applied in a thinner coat. The thinness makes them more difficult to see, thus harder to maintain. However, the thinness minimizes their effect on heat transfer. Because curing is sensitive to temperature and humidity, they are usually applied only by a licensed applicator.

They are typically harder and more abrasion resistant than polymers. Silanes are quite durable because they are actually chemically bonded to the coil surfaces.

When preparing to make a service call concerning a corroded coil, identify the type of corrosion then search for environmental cause(s). If possible, eliminate the source of corrosion. For irretrievable sources, coatings might be the only answer.

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Both inorganic and organic acids are corrosive. However, inorganic acids have a higher dissociation constant making them strong and very reactive acids, while organic acids react much slower. In the case of mineral oils, elevated temperature causes the oil to ultimately break down and the ultimate products are carbon and hydrogen gas. Only in the presence of an oxidizer, such as oxygen or air, can organic acids be formed. In the case of synthetic POE oils, organic acid may be initially present (up to 8 PPM) as a residual from the esterification manufacturing process used to make the ester oil. It is therefore clear that the real acid problem in refrigeration/air conditioning systems is an inorganic acid problem not an organic acid.

During a compressor-motor burn-out, inorganic acids are formed as a result of the refrigerant decomposition at elevated temperatures. These inorganic acids which are formed are only slightly soluble in the oil. A significant portion of the inorganic acids generated during a motor burn-out remain in the vapor phase and react quickly with the materials of construction or are adsorbed in the filter/drier. Experiments have shown that the amount of inorganic acid vapor decreases by 85% in a matter of hours. However, experiments have also shown that an appreciable quantity of inorganic acid (more than enough to destroy another compressor) is also contained in the oil. The concentration of acid trapped in the oil is higher than the quantity which would be simply dissolved in the oil (remember the solubility for inorganic acid is low). This increased acid concentration is a combination of acid dissolved in the oil, acid trapped in the oil due to the oil's foaming and agitation, acid dissolved in any trapped moisture, and acid adsorbed onto the hard particles present in the oil. This inorganic acid has been shown to remain in the oil for an extremely long time and is in contact with the compressor components, including the motor windings. The inorganic acid in the oil will etch the lacquer insulation from the wire causing the motor winding to short-out electrically and resulting in a subsequent motor burn-out. An acid concentration of 50 PPM has been found to cause compressor motor burn-out in a matter of days!

One way to remove the acidic residue throughout the system is by performing several flushes of the vapor-compression system with refrigerant, since refrigerant will dissolve the oil and reduce the oil and acid concentrations by dilution. Because of EPA-mandated refrigerant recovery requirements, this is a costly and time consuming task and the cost of the refrigerant used in the flushing operation is not trivial.

An unacceptable alternative approach is to neutralize the acid by reacting the acid with a basic solution (a solid base dissolved in a liquid carrier), which results in the formation of undesirable salts as byproducts of the neutralization. Typical neutralization approaches are to neutralize the acid with a base, such as potassium hydroxide (KOH). These bases are solid and are dissolved in a non-water solvent. In such a reaction, the acid and base combine to form a metallic caustic salt and water. While the water can be removed by the filter/drier in the system, the salt remains trapped in the system and could cause problems. Since the salt is a solid it will not vaporize, but instead will remain in the system and cause corrosion!

A further problem with any acid neutralization is the addition of the proper amount of base. Too little base and the refrigerant is still acidic, too much base and the refrigerant is basic. An acidic or basic environment will cause corrosion and premature compressor life (burn-out).

Yet another problem with a neutralization reaction is that the neutralizing materials are solids and must be dissolved into a liquid solvent carrier or physically held in the vapor compression system's flow. The base can not vaporize and therefore the transport of the base throughout the system, even if dissolved in a liquid solvent, is severely limited. Some acid neutralization manufacturers have proposed that the neutralization solution be introduced in the compressor discharge, so that it will be forced through the condenser, filter/drier, TXV, and evaporator, before getting trapped in the compressor's oil supply. They explain that the liquid neutralization solution is thereby forced to travel throughout the system before becoming trapped in the compressor oil. However, the flashing at the TXV could also cause the solvent

to vaporize leaving a deposit of the solid base material, such as KOH, to clog the TXV. Even if the basic solution passes through the TXV, the solvent will likely evaporate in the evaporator leaving the solid basic material in the evaporator.

Every acid neutralization reaction will result in the formation of a salt residue, it is basic chemistry and cannot be changed. Some have proposed the use of sodium bicarbonate as the base but this acid-base reaction will produce a salt and also carbon dioxide gas (an undesirable non-condensable gas).

Finally, these acid neutralization techniques can ONLY be applied to mineral oils or alkylbenzene oils. This is because the ester-based POE oil possess amphoteric properties which make the oil behave as a base in the presence of an acid and vice versa. Consequently, the added base will react with the ester oil.

An acceptable way of removing the acid is to liberate or free it from the liquid and hard surfaces that contain the acid, and let the filter-drier in the system remove the acid. A filter-drier does an excellent job of removing acid by adsorption not by neutralization. The problem with relying on the filter-drier to remove the acid is that the significant portion of acid that is trapped on the hard surfaces and in the oil never gets to the filter-drier to be removed.

After a compressor burn-out change-out, we have measured very high concentrations of inorganic acids (significantly greater than 200 PPM) in the new compressor's oil. Theoretically this inorganic acid is not very soluble in the oil, however, this inorganic acid is being trapped in the oil and/or adsorbed on the surface of the solid particles which are present in the system (as a result of the motor burn out). In some cases this acid is also dissolved in water which is trapped in the oil. POE oil typically has much higher levels of water than other refrigeration oils. Agitation of the oil has not been found to release this trapped acid. In order to demonstrate this, an oil sample with an initial acidity value of 133 PPM (inorganic acid) was vigorously stirred for 32 hours using a magnetic stirrer. The acidity dropped 45 percent to 73 PPM. While this may seem like a significant drop, it should be pointed out that the compressor would have burned out in less than 33 hours of operation at this acid level. Therefore, the compressor would fail (burnout) before sufficient acid could be naturally removed from the oil, even if the compressor agitated the oil as much as in this experiment. However, if the trapped inorganic acid could be liberated from the oil (as well as from the acidic surfaces) in a reasonable time (and vaporized), the existing filter/drier in the system would remove this acid. QwikShot works by liberating the trapped acid from the oil and acid contaminated surfaces. QwikShot also vaporizes so that it travels throughout the system. The agitation of the acidic-oil experiment was repeated except QwikShot was added to the oil prior to stirring. After 20 minutes the acid was completely (100 %) stripped from the oil by QwikShot! The ordinary filter/drier in the vapor-compression system will adsorb the liberated acid and the QwikShot.

Ideally, the QwikShot should be introduced into the compressor's oil sump so that is can thoroughly mix with the oil during compressor lubrication. The QwikShot oil concentrations are less than 1% and will not affect the lubrication properties of the oil. As the QwikShot mixes with the oil it serves to dissolve and liberate the acid from the oil and acidic surfaces. The QwikShot and acid are vaporized (thereby leaving the oil) and travel through the system where they become adsorbed on the filter/drier (molecular sieve, carbon, or activated alumina filterdriers all work). The net result is that the acid is removed and no residue is left in the system, since both the acid and the QwikShot are adsorbed by the filter/drier. The QwikShot dosage charts are formulated so that the QwikShot will not use up the total capacity of the filter-drier, but will leave about half the filter-drier's capacity for future clean up of water or acid.

By using QwikShot a system can be thoroughly cleaned of acid without leaving any residue. This has been demonstrated by experiment. In the first experiment discussed, QwikShot was introduced into the acidic oil of an R-22 system. These tests were repeated both with and without a filter/drier in the system. Remember the performance of QwikShot depends on the use of the filter-drier to remove the liberated acid and the QwikShot from the system. The results of the tests are presented in Figures 1 through 3.

By referring to Figure 1, which shows the QwikShot in the vapor of the R-22 system, it is clear that the QwikShot is going into the vapor phase as it releases the acid from the compressor oil. However, if the filter drier is not present the QwikShot will remain in the system and eventually reach equilibrium which means no more QwikShot can vaporize and acid liberation will stop. This is also supported by Figure 2, which shows the drop in QwikShot in the oil. Note that by using the filter-drier, more than 60 percent of the QwikShot is removed from the oil in less than 6 minutes (0.1 hour).

However, the key issue is acid removal, and these results are shown in Figure 3. By referring to Figure 3 it can be seen that when a filter-drier is used about 7% of the acid is removed in less than 6 minutes (0.1 hour) and about 18% is removed after 1.5 hours. What is not shown in the Figure is that it takes about 12 to 16 hours to remove all the acid from the system. Also note that without the filter-drier the acid removal is much slower. The filter-drier should always be changed when QwikShot is added to the system. As shown in Figure 3, a failure to change the filter-drier when the QwikShot is added could result in a 3-times slower reduction in acid removal and complete acid removal may not be achieved!

The experiment described above was repeated for a R-134a system. This data is presented in Figures 4-6. The results are similar to the R-22 results, but the QwikShot removed the even more acid in 1.5 hours in the R-134a system (Figure 6).