the Conduit

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INSIDE THIS ISSUE:

Failure Analysis of Thermostats in Temperature Controlled Systems

By: Henry Kight
Metallurgical Technician

In investigating the failure of a heating and cooling system it is often found that the temperature controller is the first suspected and probably the least understood component of used to control temperature in a closed environment.

It is important in any failure analysis to document as many of the conditions found at the time of failure that may have affected an excursion in temperature resulting in damaged or degraded product.

A good place to start is a checklist of important questions to ask the customer to help understand the circumstances of failure.

Initial investigation checklist:

1. At what time was the thermal anomaly first noticed?
2. Who reported the system failure and to whom was it reported?
3. Was anything done to protect the product from further loss?
4. Was there a loss of electrical power prior to the thermal excursion?
5. Was the thermal enclosure sealed from the outside environment?
6. Has there been a recent loading of product into the thermal enclosure?
7. Has any service to the compressor system occurred recently?
8. Is data available from alarm or thermal monitoring systems that can be collected for later analysis?
9. Are the electrical connections to the thermostat, switching relays, and motors, secure and free from indications of high resistance or elevated temperature (burned connections or discolored wires)?
10. Are the thermal sensors placed in the appropriate locations and are the sensors blocked by customer product? (evaporator and defrost sensors)?
11. Have the settings on the thermostat been changed since the thermal excursion?
12. What are the thermal settings on the thermostat now?
13. What is the load on the thermostat relay contacts when they are closed now?
14. What current is specified for the motor contactor and the compressor motor itself?
15. Have there been recent temperature excursions leading up to this failure?
16. Have all important electrical connections and sensor placements been photographically documented?

As you can see there are many contributing factors to enable a thermally controlled system to operate within its design guidelines. Since the primary focus of this article is related to thermostats and temperature

controllers, we will focus on the analysis of failure of this element of the system, assuming that the problem has been narrowed to this component.

Thermostat mechanical and electrical elements

Thermostats and temperature controllers are electro-mechanical devices designed to switch heating and cooling systems in a manner that will control the temperature in a closed environment.

Sensors are connected to thermostats that through direct mechanical force (Figure 1) or through electronic switching (Figure 2), open and close electrical contacts that turn on heating and cooling systems to maintain a specified temperature.

Most thermostats and temperature controllers are designed to activate many thousands of thermal cycles with little deviation over years of reliable service.

There are a number of reasons that a thermostat may fail to control the associated heating and cooling systems to which it is connected.

As is the case with any electro-mechanical device, there is a useable service life at which the switching performance of the thermostat will degrade resulting in the necessity to replace the thermostat.

Among the possible causes of thermostat failure are the following:

1. Failure or damage to temperature sensors attached to the thermostat.
2. Contamination or degradation of mechanical systems that actuate the thermostat relay contacts.
3. Loose electrical connections on the thermostat body that provide power or connect to a load.
4. Loss of calibration of thermal sensing elements or mechanical systems that turn the system loads off and on.
5. An increase in the load applied to the thermostat relay contacts, ie. a compressor experiencing increased friction, resulting in more electrical current across the relay contacts.
6. Contamination of the relay contact surfaces.
7. Loose electrical connections at the contact attachment points.
8. Insufficient arc suppression on some electrical loads.
9. Excessive relay contact resistance.
10. Normal contact wear over time.

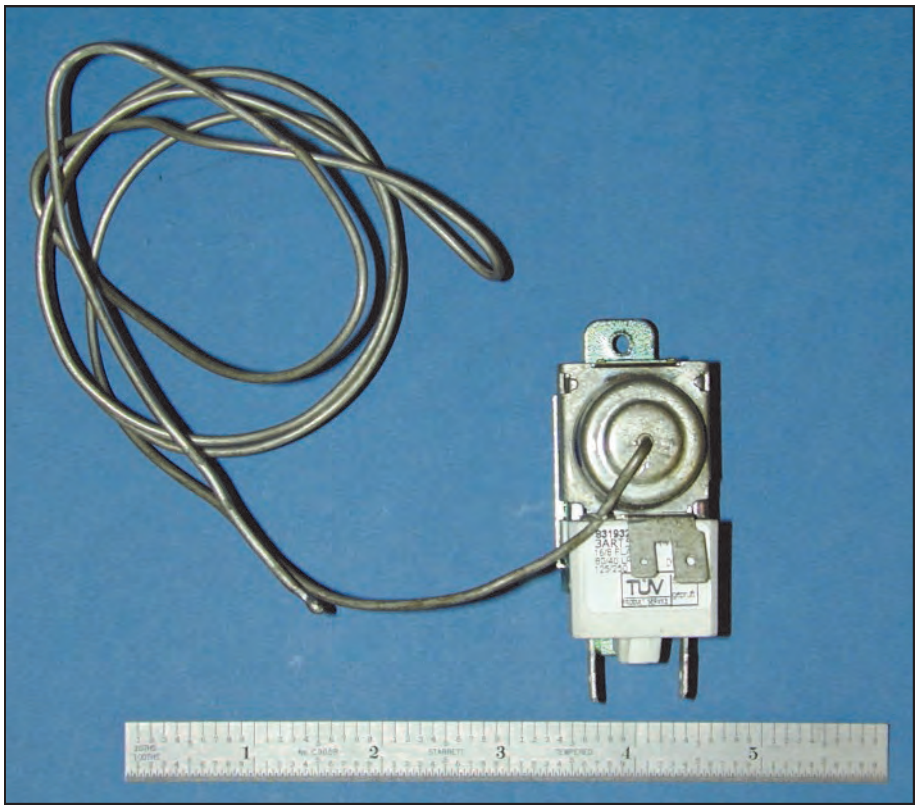

Figure 1. Capillary Tube Thermostat, which is mechanically driven

Test Sequence

A specific sequence of tests and observations may assist in narrowing the possible cause of failure in a thermostat.

It is important to document the condition of the thermostat and the associated thermal sensors prior to any destructive testing of the thermostat body. Photograph

Figure 2. Electronic thermostat

the "As Received" condition of the thermostat, including any serial numbers, model numbers and markings that will help identify the origin of this part.

In order to test the external thermal sensors attached to the thermostat one of the first examinations to be completed should be a thorough examination of the sensors and their connections to the thermostat itself.

There are three questions that need to be answered.

1. Is there any physical damage to the mechanical or electrical thermal sensing systems?
2. Do the thermal sensors initiate the switching the relay contacts at the set points indicated on the thermostat?
3. Are the thermal sensors accurate?

In order to test the accuracy of the thermal sensors, a calibrated thermal bath or environmental chamber must be used to provide an accurate thermal environment for either the sensors or the entire thermostat assembly with the sensors. The temperature range and rate of change of temperature must meet design thermal parameters of the thermostat assembly to be able to fully test the functionality of the device.

In some cases the entire thermostat assembly is located inside of the temperature controlled enclosure, as is the case in some walk-in coolers. In this case an accurate environmental chamber might be the best selection for testing a thermostat of this type.

In other instances, the thermostat body is mounted external to the temperature controlled enclosure, requiring that only the sensors be placed in a temperature controlled bath to monitor the accuracy and function of the sensors.

In both examples, the requirement is to be able to accurately expose the sensing elements to a variation of temperatures and to be able to monitor the thermostat relay contacts in a continuous manner. This test will indicate at what temperature the state, (on/off) of the relay contacts occur.

Data should be collected for temperature sweeps from high (above room temperature) to below the lowest set point (normally below freezing, 0 Degrees C.) Several thermal sweeps in both thermal directions should be made to ensure repeatability in switching.

Electrical connections to the relay contact electrical terminals should be made using a Kelvin connection method (Figure 3), allowing the measurement of contact resistance at low voltages.

Typical contact resistance values for a new contact should be on the order of a few milliohms. This resistance value will increase with contact contamination, degradation and time.

High contact resistance is an indicator of possible problems with contact contamination or degradation. It can also be an indicator of problems with the electrical contacts being switched

by the thermostat requiring later destructive disassembly of the thermostat.

Standard lab multi-meters may be used to examine the switching characteristics of a thermostat and to monitor thermocouple temperatures at the time of switching, other sophisticated data loggers may be implemented to collect data (Figure 4). In both cases it is important that the instruments are accurate and have had a recent traceable calibration performed.

Note that in the case of a test set up in an environmental chamber the opportunity is available to control the chamber temperatures and to monitor the switching parameters of the thermostat using software tools such as "Lab VIEW" from National Instruments and data logging equipment to record data for analysis (Figure 5).

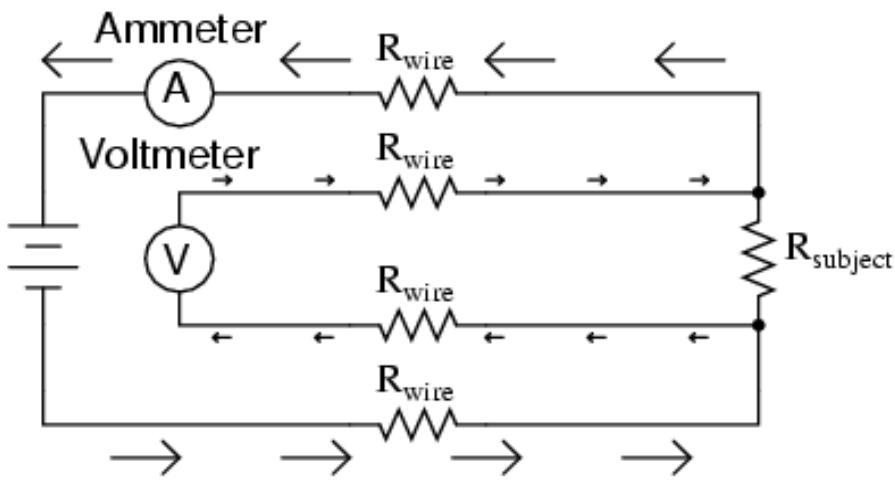

Figure 3. Schematic example of a Kelvin Connection

Figure 4. Typical thermostat performance test set-up used a thermal bath to provide thermal sweeps

Test Sequence for Thermostats

1. Record on-site failure information.
2. Take "As Received" photos of thermostat.
3. Examine electrical connection locations for high resistance heat damage.
4. Examine sensors for damage.
5. Measure the contact resistance of the thermostat contacts using Kelvin connections.
6. Perform thermal sweeps in a thermal bath or environmental chamber to determine switching temperatures and the on/off state of the contacts.
7. Carefully disassemble the thermostat to expose the contacts.
8. Photograph the disassembly process looking for signs of contamination, contact arcing, loose hardware and contact material splattering and other abnormalities.

9. Remove the contacts for further examination under a stereo microscope.
10. Document the condition of the contacts and contact mounting assemblies.

As previously described there are many reasons that a thermostat may fail to adequately control the temperature of a closed environment. The following is a compilation of photographs demonstrating what contacts should look like in both satisfactory and unsatisfactory conditions.

Disassembly of a typical contact switch

An example of a good contact that should have good contact resistance and perform well in switching operation is shown in Figure 6.

The area in which the mating surface has made contact is small (red arrow and box) and that there is no discoloration in the area around the contact (Figure 7). The area of contact will vary with electrical loading.

Disassembly of failed thermostat

An example of a contact that has reached the end of its serviceable life is indicated in Figure 8 and Figure 9.

Yet another common failure mode for thermostats is found when contacts are not tightly

(Continued on page 7)

Figure 5. Typical test set-up of the environmental chamber

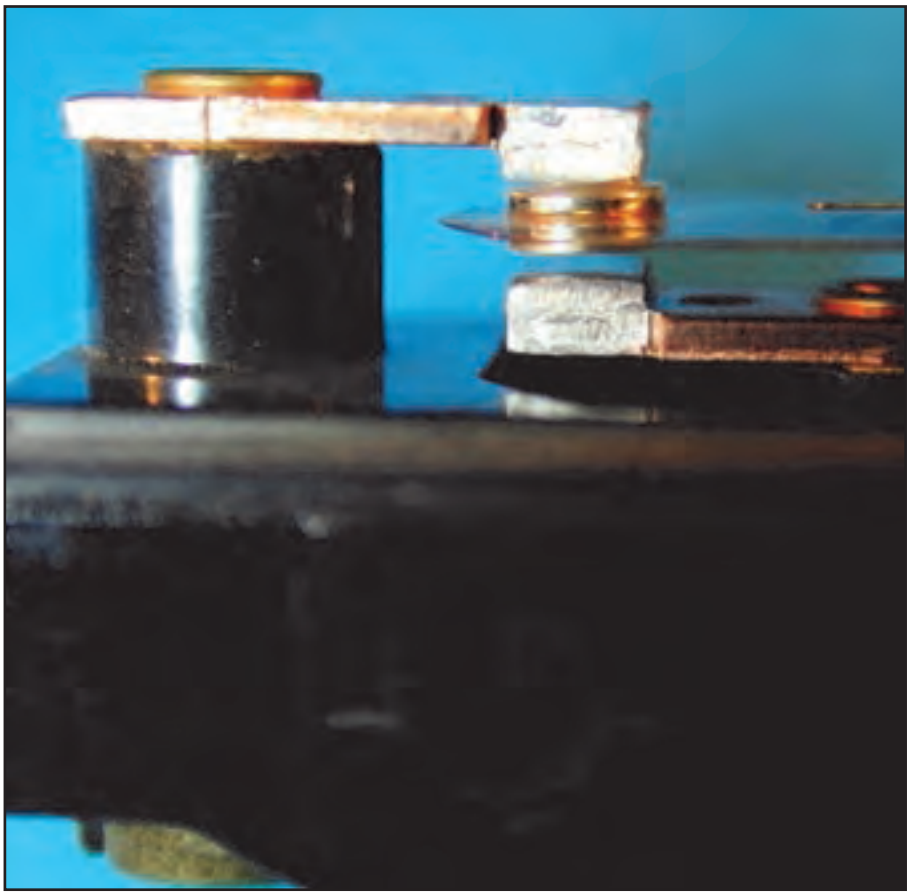

Figure 6. Side view of contact mating surfaces

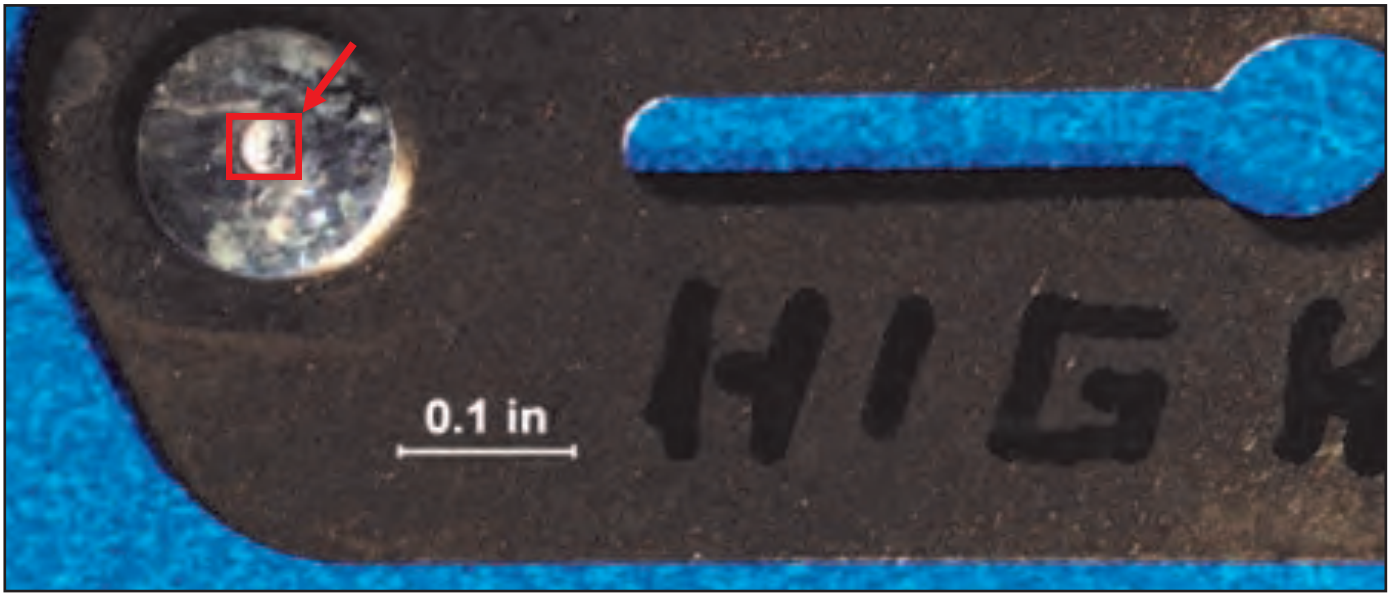

Figure 7. The good contact face showing small contact area

Letter to the Author

The question below was received from one of our readers in response to the article entitled *Dew Point Corrosion—A Case Study* from our Vol. 13, No. 2 issue of *the Conduit*. It has been answered by the author, Oscar Quintero, Metallurgical and Materials Engineer.

Q ***In the section on Mitigation, you list a number of things that can be done to alleviate the problem, all of which basically deal with changes on or to the process side of the unit. Are there any material solutions, e.g., more resistant material such as a duplex stainless steel or nickel alloy, coatings, etc. that can be used to solve the problem?***

A There are several material options out there but they would increase the cost significantly. CorTen (carbon steel) is pretty resistant to such environments as long as the humidity and temperature are controlled. That's why CorTen is good. It's cheap and works for the environment as long as the process is controlled. Some materials that can be used are 316L stainless steel, which is useful in weak sulfuric acid at low temperatures. Alloy 904L is also useful when concentrations are a bit higher. Alloy 20 is another material that may be useful for this application. Inconel 625 will also help, but this alloy is expensive (since it is used mainly for high temperature applications). Using the alloys described above will definitely assist in mitigating the dew point corrosion, but it will come at a higher price. Out of the alloys described above, the 316L stainless steel would be the least expensive to use. Keep in mind that using the alloys above will mitigate the dew point corrosion to a certain extent. If the process is not controlled adequately and the acidity levels increase significantly, you might still see corrosion attack on these higher corrosion resistant materials. It might take a while for them to corrode completely, but they will still be attacked by the acidic environment. That is the reason that mitigation of dew point corrosion is more process oriented than a materials issue.

(Continued from page 5)

attached to the electrical current carrying elements of the device. An example of a loose contact is shown in Figure 10.

Discoloration on carrier arm (Figure 11) indicates high resistance heating. Also note that the contact will no longer be co-planar with the mating contact (one side of the loose contact will touch the mating contact at an odd angle).

The top side of the carrier arm is shown below indicating an insufficient swage as the culprit resulting in loose contact (Figure 12).

The expected result of a loose contact is show in Figure 13, a mating contact with significant asymmetrical arcing damage.

The design and application of switch contact technology is complex and detail oriented. The science of alloy selection for electrical contacts is an important aspect in the design process as well as a complete understanding of the mechanical systems needed to ensure reliable trouble free thermostat function.

Great designs have provided many companies with years of reliable service from thermostats. As with any failure analysis, the goal is to cost effectively improve the process to eliminate unexpected failures.

It could be something as simple as a routine scheduled maintenance, checking for loose

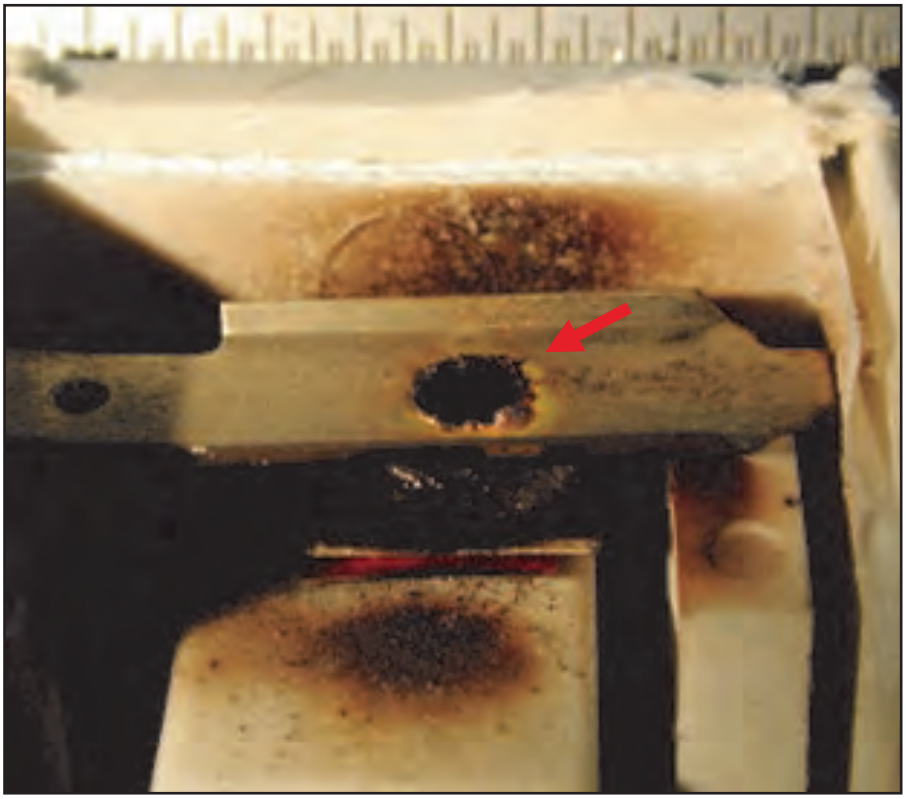

Figure 8. Discoloration and missing upper contact of failed thermostat (white arrow)

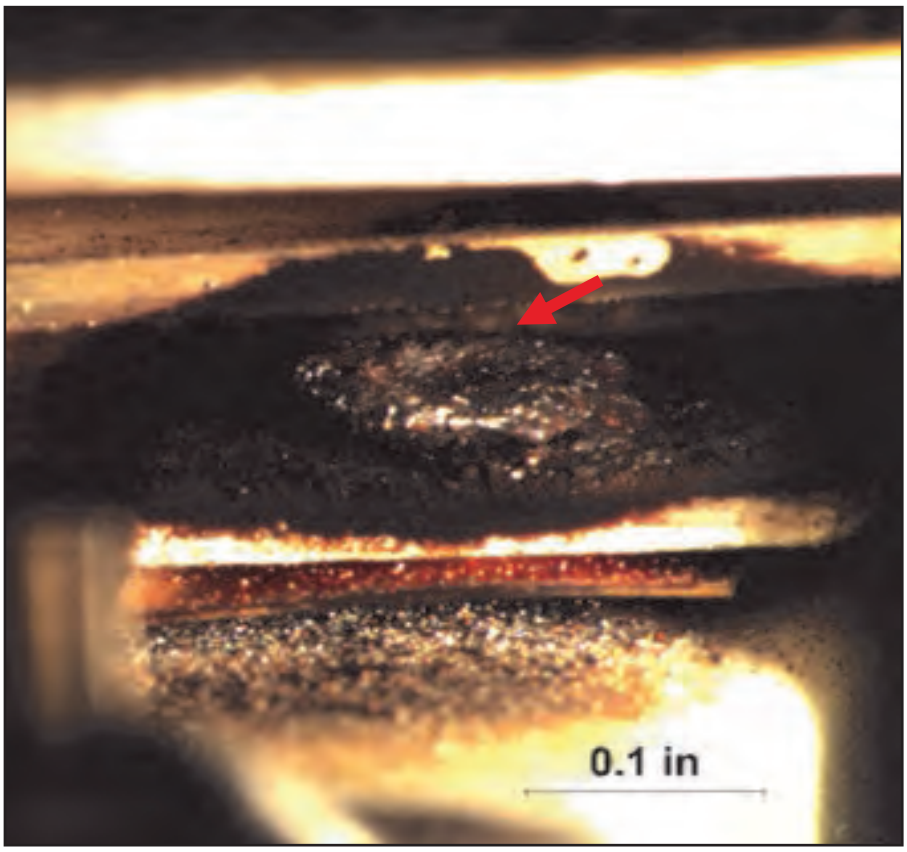

Figure 9. Contact face showing evidence of high energy arcing, contact degradation, contact material lost, and high contact resistance.

connections, blocked air vents or inaccurate temperature control. Scheduled maintenance based on an understanding of the useful life of the components involved in a controlled thermal environment may also be important.

At times, millions of dollars of customer product may be at risk because of a lack of simple process controls used to make sure the mechanical and electrical systems are functioning as designed.

In conclusion, with careful recording of the conditions of failure and following a specific test sequence, it is possible to obtain a clear analysis of the failure mechanisms involved in a controlled temperature system.

We at M&M Engineering Associates are constantly striving to expand our thermostat analysis knowledge base and capabilities.

We welcome your requests for information and look forward to providing a quotation for analysis of your temperature controller issues.

Contact the Author:

Henry Kight

Metallurgical Technician
512-407-3774
Henry_Kight@mmengineering.com

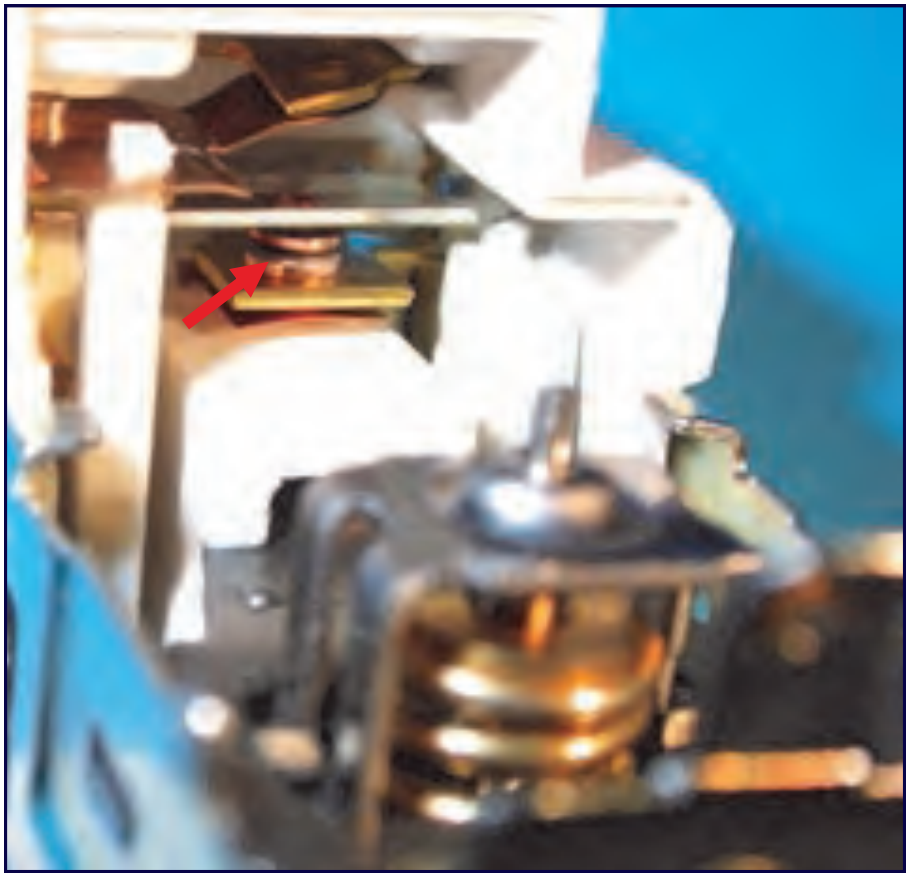

Figure 10. Loose contact at center.

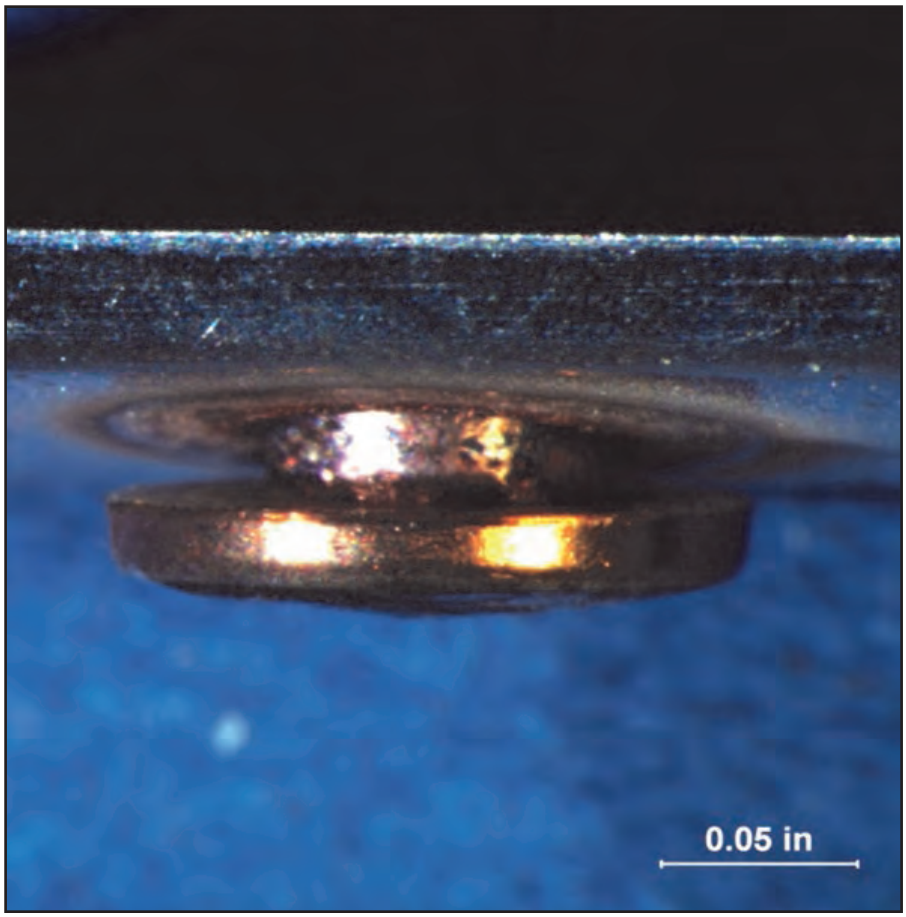

Figure 11. Contact loose in carrier arm

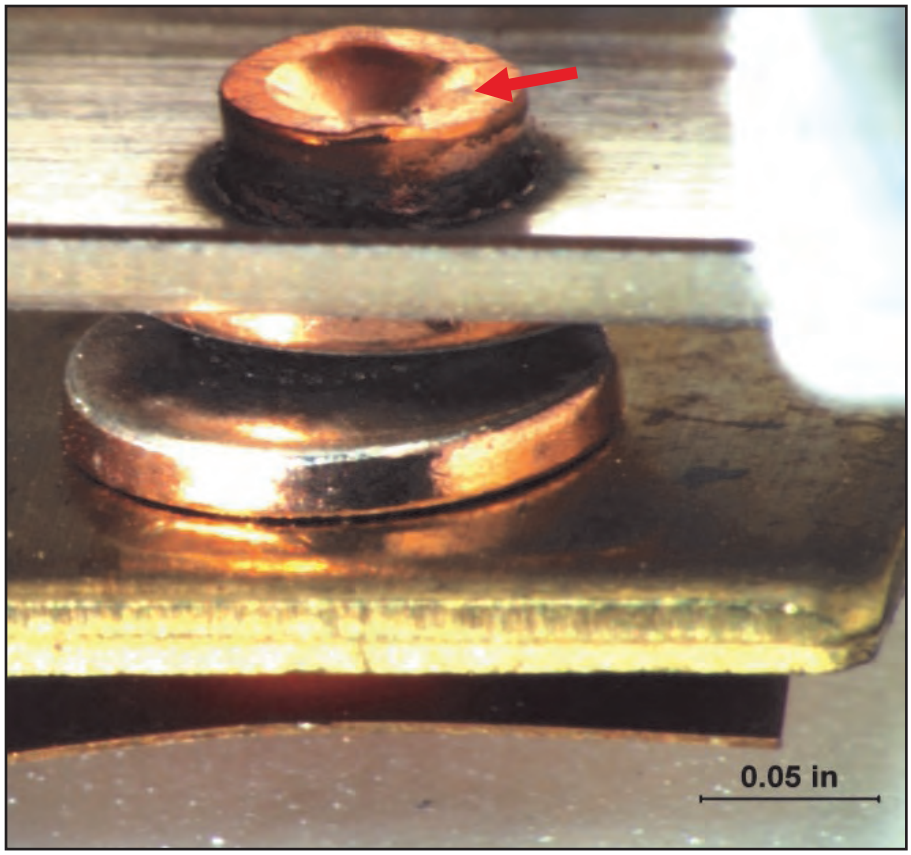

Figure 12. Incomplete swage and loose contact

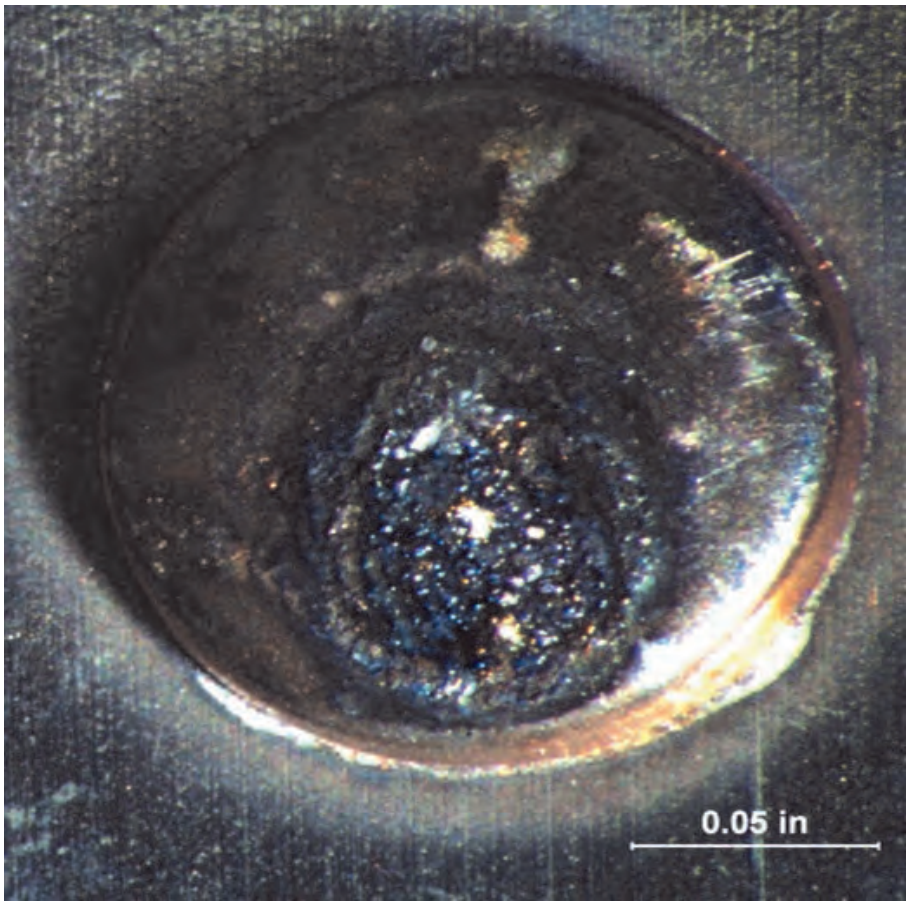

Figure 13. Example of mating contact to a loose contact damaged by high energy arcing.

The Truth About Descalers

By: David Daniels
Principal Scientist

The condenser tubes in chiller units are occasionally cleaned with descaling chemicals to remove calcium carbonate scale that accumulates on the chiller tube surface and hurts the efficiency and capacity of the chiller. These same chemicals are used to clean inter-coolers on air compressors and lube oil coolers. Occasionally these chemicals are even used to clean small fire- and water-tube boilers.

It should be noted first, that the accumulation of scale condenser tubes on a chiller represents a failure of the cooling water treatment program. If you frequently have to de-scale cooling-water touched heat exchanger tubes, it is time to seriously revisit your cooling water treatment program and make changes.

All common industrial descalers for dissolving calcium carbonate contain hydrochloric acid with additional additives. Often the vendors of these products will try to claim that their product is safe, biodegradable, etc., but regardless of the claims the

most common and least expensive way to remove calcium carbonate scale is with hydrochloric acid. That is why it is used.

Beside the acid, the descalers contain:

- Corrosion inhibitor – The inhibitor is a blend of amines and other chemicals that protects the surface of the bare metal but allow the oxidized metal (i.e., rust) and calcium carbonate to be attacked and put into solution. This is the key ingredient that allows hydrochloric acid to be in contact with metal copper or steel without destroying it.
- Surfactants – Surfactants helps clean the surface and lets the acid do its work. It also removes dirt and oils that could otherwise inhibit scale removal.

The corrosion inhibitor concentration is critical when you are using the descaler in your system. Too low and the acid begins to attack the metal; too high and it can slow the cleaning process. It is counterintuitive to think that the more concentrated the solution, the less likely it is to corrode the underlying metal, but that is the power of the corrosion inhibitor in these descalers.

It is when the corrosion inhibitor gets diluted or destroyed while there is still acid present in the system that the acid starts to attack the steel or copper tubing in the chiller, which quickly can result in a complete failure of the chiller.

The Truth Behind Some Descaler Claims

Claim: You can pour it into your skin.

Fact: Hydrochloric acid is about the least aggressive acid to the skin; far less than nitric or sulfuric acids. However, hydrochloric acid will still destroy clothes and it would be very painful and dangerous if it got into the eyes. Always wear chemical goggles and the proper Personal Protection Equipment (PPE) when handling descalers.

Claim: It is biodegradable.

Fact: Biodegradable does not necessarily mean safe or not harmful. Biodegradable means that the chemical can be broken down by bacterial action. Hydrochloric acid is an inorganic acid and does not need to be broken down biologically. The surfactants and corrosion inhibitors that are in the product will break down once they are diluted.

Claim: You can throw it down the drain.

Fact: If you are sending a lot down the drain at once, you can bet the pH of the wastewater will be less than 2 or characteristically hazardous according to the Resource Conservation and Recovery Act (RCRA). You can get into trouble if you have a pH restriction on your discharge or if the wastewater plant is not expecting acid. However, the waste is simple enough to neutralize to a non-hazardous pH by adding soda ash or sodium bicarbonate solution as it is draining.

Helpful Tips When Using Descalers

1. Before starting the use of the descaler, any highly stressed stainless steel parts (like bellows), need to be removed. Hydrochloric acid causes chloride stress corrosion cracking in stainless steels.
2. Galvanized metal (steel parts with a zinc coating), as found in cooling towers will be damaged by these cleaners. The protective coating that gives galvanized metals its corrosion resistance (zinc carbonate), will be removed. If the cooling tower has galvanized components, these components will need to be re-passivated after the cleaning is done. Failure to do so, will cause white rust to form and eventually will result in corrosion of the underlying carbon steel. Discuss the special re-passivating treatment that needs to be applied to your cooling water with your water treatment vendor. If the cleaning removes white

rust and exposes bare steel , a zinc-rich primer will be needed after cleaning and before returning the tower to service.

3. Use the cleaner for the shortest amount of time required to remove the deposit. In most cases this is 2 to 4 hours. It is much better to clean for 2 to4 hours, drain, flush, inspect and clean again than to leave the acid in the equipment overnight; or worse, over the weekend.

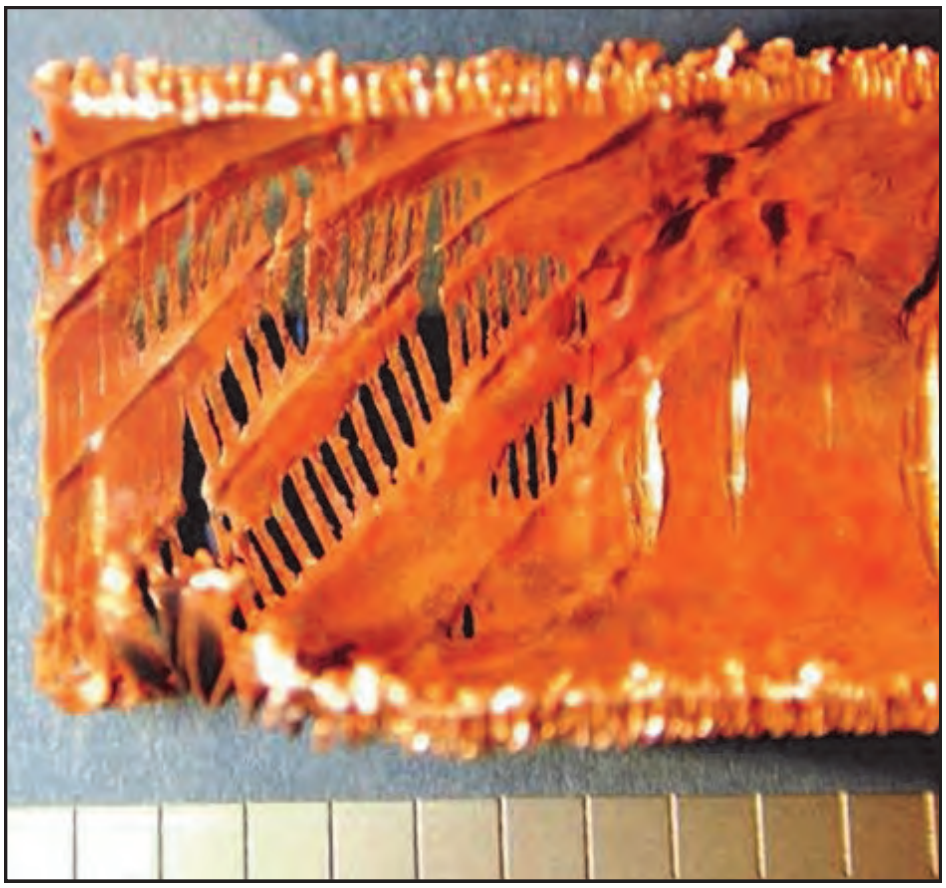

Figure 1. Improperly used descalers can result in severe corrosion and erosion corrosion.

4. Heavily scaled equipment is much more likely produce corrosion issues and tube failures. The acid gets between the scale and the metal and sits in the crevice or creates an eddy that can result in localized corrosion. Any remaining scale can have acid trapped underneath it and it will continue to corrode. Heavy scale often comes off in large pieces that can plug or partially plug tubes or drains. This can create problems when flushing out the acid and returning the equipment to service. With heavily scaled equipment, it is better to remove as much of the scale as possible by physical removal methods (high pressure washing or flushing) first, before using the chemical. Even better: clean more frequently before the scaling gets too heavy. Best: optimize the cooling water chemical treatment program to prevent scaling all together.
5. Once the cleaning is finished, drain the acid completely. Make sure to drain and flush out all dead legs and any pockets where acid could have entered. Clean and flush any blocked tubes and low points. Then rinse and circulate (and repeat) until the pH of the water in the system is close to the pH of the water going in and certainly well above acidic levels.
6. Do not treat a cooling tower/ chiller that is operating. Often the chemical vendor will claim that it can be done, but we have seen too many examples that prove that this is very risky. There are at least two reasons why adding descalers to operating chiller can be dangerous. First, the heat on the tube surfaces from the process can speed up the breakdown of the inhibitor and promotes attack. Secondly, the aeration across the tower creates ferric iron which can be corrosive and result in attack of the carbon steel in spite of the inhibitor.
7. Never apply less than the recommended dosage of the cleaner or allow the solution to become diluted during the cleaning by adding water.

The inhibitor will be diluted to the point where it becomes ineffective faster than the acid concentration will be diluted to a non-corrosive level. More descaler can be added to the system (and should be if the acid is consumed to the point where it stops working), or better yet, drain the used solution out, refill with water and retreat with the prescribed concentration of fresh descaler to remove any remaining scale.

8. Never add air (a bubbler or air lance) to "stir up" the solution. As mentioned above, aeration will accelerate corrosion of the carbon steel.
9. Hydrochloric acid based cleaners are for removing calcium carbonate scale. They will not remove silica-based deposits. If the deposit has a lot of silica you may need to use a different cleaner or resort to mechanical cleaning methods. In some cases, the acid will dissolve the calcium carbonate that is holding the silica deposit on the tube, but the silica deposits will lie in the bottom of the tube or in the cooling tower basin. It is important that these are removed before restarting the equipment.
10. Plan to mechanically clean out the tubes and associated piping after using the

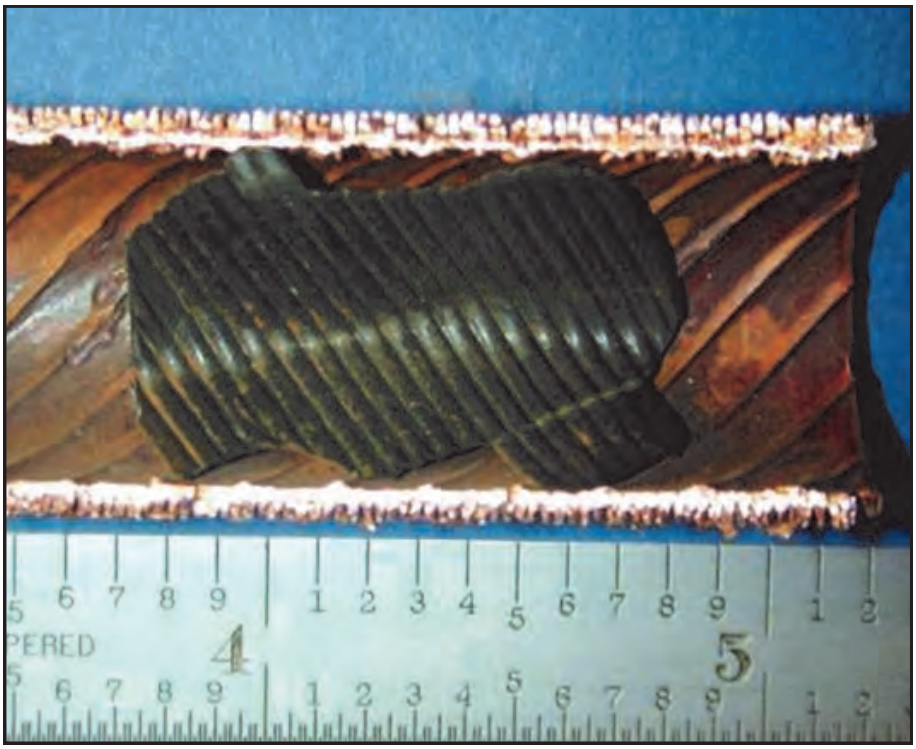

Figure 2. Section of tube with a piece of the cooling tower fill wedged in it. Arrow points to corrosion pit next to the fill caused by the descaler attacking the area adjacent to the fill.

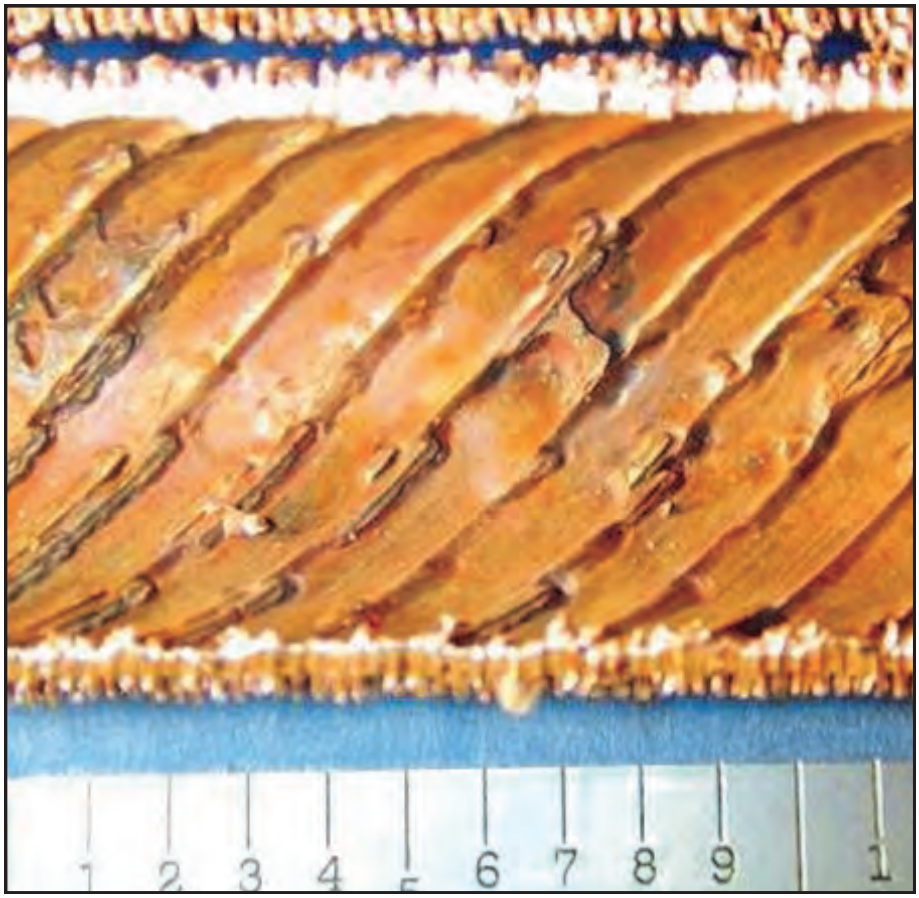

Figure 3. Another example of corrosion/erosion corrosion in a condenser tube associated with improper cleaning practices.

descaler. Not all the deposit will be dissolved and what remains can hide acidic components and produce localized corrosion. This may be done with a high volume flush or with tube brushes. Don't forget to clean out the cooling tower basin too.

The recommendations listed above are the result of seeing failed equipment in our materials laboratory and from the investigations that followed. Just because in the past someone in your organization or at another site got away with ignoring one of these recommendations, doesn't mean that it is okay. You will be putting your equipment at risk, which could lead to a catastrophic event that requires the complete replacement of the equipment.

Contact the Author:

David Daniels
Principal Scientist
512-407-3752
David_Daniels@mmengineering.com

Attending & Presenting at Seminars & Workshops

Presented by the ASME International Gas Turbine Institute
TE2013 ASME Turbo Expo 2013
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Oscar Quintero attended the ASME Turbo Expo Workshop on June 1st, 2013 in San Antonio, TX.

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Dave Daniels, Principle Scientist with M&M Engineering will be presenting:

HRSG and High Pressure Boiler Water Treatment Operation

The morning of Thursday, November 21, 2013

This workshop will cover the water quality required for high pressure (>900 psig/60 bar) steam boilers including the various treatments being used and new developments relative to protection from scale and corrosion. The course will also cover treatment issues related to pre-boiler systems and the condensate systems and a discussion of controls and troubleshooting techniques. Operators, utility plant supervisors, managers, and engineers can all benefit greatly from the practical information provided in this course.

Early Registration for the conference is open through October 18, 2013.

Preventing Failures in Steam Generating Equipment

February 19-20, 2014

Austin, Texas

M&M Engineering is hosting its 3rd annual training class for producers of steam, be it used in power or process applications. The two day workshop will focus on the issues most common in steam generating systems and will be applicable to multiple industries including: pulp and paper, refining, petro-chemical, and power generation.

Day 1	Day 2
• Steam Generating Equipment – A Primer • Feedwater Heaters and Damage Mechanisms • Water Touched Boiler Tube Failure Mechanisms • Steam Touched Boiler Tube Failure Mechanisms • High Energy Piping: Damage Mechanisms and Corrections • Overview of Gas Turbine Failures	• Introduction to Failure Analysis • Introduction to Non-Destructive Testing & Inspection Contracting • Basic Steam Turbine Failures • Condenser and Cooling Water Failures • Damage Mechanisms in Deaerators • Water and Steam Chemistry-Influenced Failures

Tour of M&M Engineering Laboratory and Facility during the class

Workshop Registration:

$750.00 (continental breakfast and lunch provided)

Please call or email Lalena Kelly to register.
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For technical information please contact:

David Daniels
(512) 407-3752
david_daniels@mmengineering.com

Mark Tanner
(512) 407-3777
mark_tanner@mmengineering.com

Karen Fuentes
(512) 407-3778
karen_fuentes@mmengineering.com

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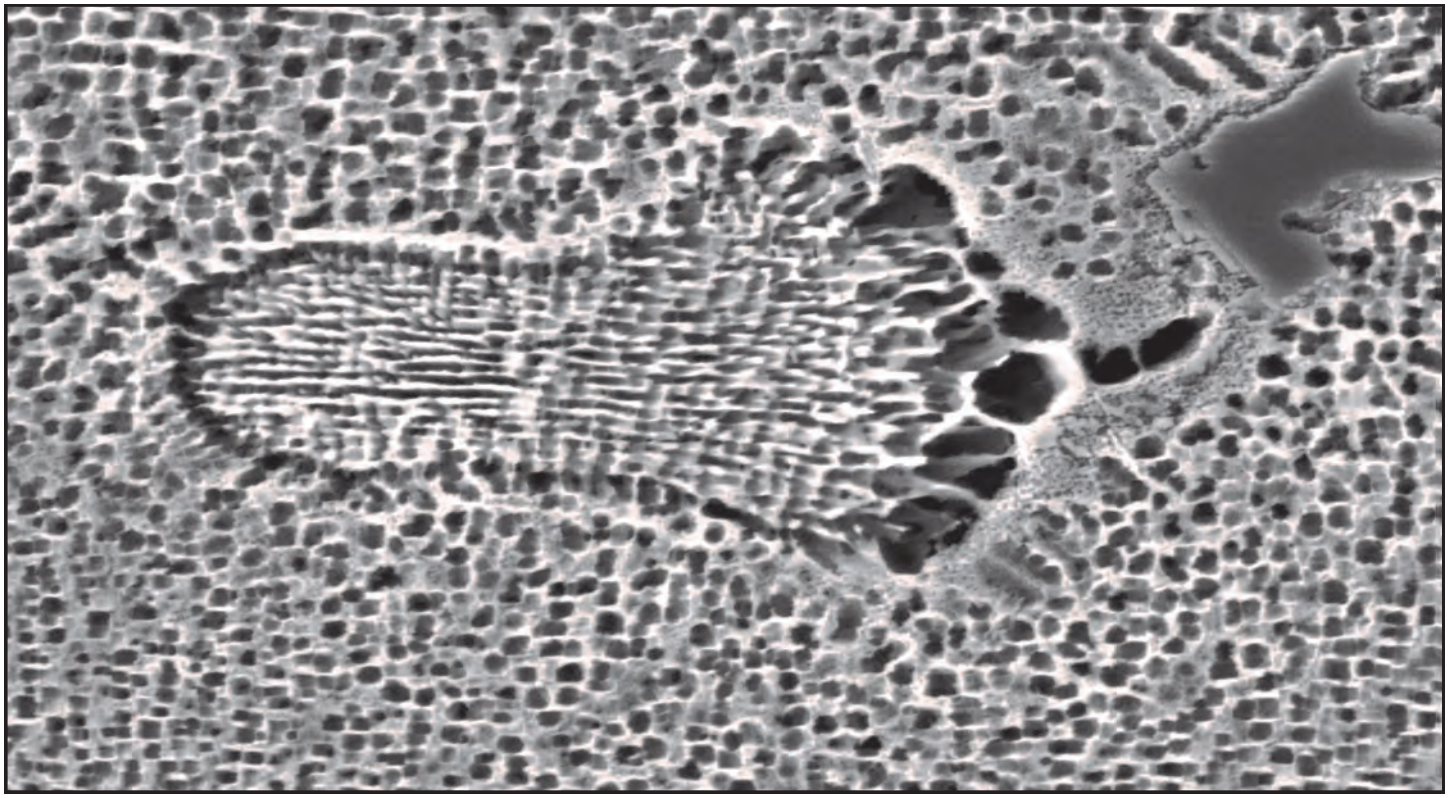

Gamma Primate appears to have stubbed his big toe on a blocky carbide (2600X)