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Subject: Alcatel-Lucent, Murray Hill, NJ – Cooling Tower, Hydrogen Peroxide Trial

I. Executive Summary

The study to evaluate the use of hydrogen peroxide was initiated on the site cooling tower system in May 2007. The cooling tower consisted of ten (10) cells with a common sump and a total circulation rate of 55,000 gpm. The goal was to replace the conventional chemical treatment scheme of bromine/chlorine biocide, corrosion inhibitor and organic dispersants with 35% hydrogen peroxide. The driving force behind this effort was to reduce the cost of the tower chemical treatment.

The Murray Hill, NJ site utilizes predominantly NJ American (City) water makeup with smaller amounts of well and DI waste streams. Please see the cooling tower data spreadsheet containing the makeup and cooling tower chemistry information throughout the trial.

The study lasted from May 14, 2007 to November 7, 2007 or approximately six (6) months. The peroxide was fed by shot feeding with higher residuals achieved periodically by design to fully assess the peroxide effectiveness.

The technical evaluation encompassed assessment in several areas:

- Biological Control – Ability to control growth of living material
- Fouling – Ability to avoid fouling through proper chemistry and biological control
- Scaling – Ability to avoid build-up of calcium salts on heat exchange surfaces due primarily to water chemistry and bio-fouling control
- Corrosion – Ability to control corrosion rates on system metallurgy to below 3 mils per year

The assessment methods used were biostrips (Biosan, Sani-check BF), test coupons, chemistry testing and visual inspections. The biological control, fouling and scaling did not appear to present a concern with the various evaluation methods employed during the study. The biostrip results were consistently below 100 cfu/ml which approached sterility in terms of biocontrol. The scaling and fouling control has been excellent in the past and continued to be excellent throughout the evaluation. As a result, the peroxide effectively controlled all biogrowth and fouling. This control was demonstrated during the #2 and #1 chiller inspections. This control was also apparent during the inspection of the tower fill with no biofilm or fouling observed. Some nuisance algae developed on the non-wetted areas during the evaluation. This was not an operational concern and was most effectively addressed with topical application of the hydrogen peroxide.

a. Corrosion Results

Corrosion studies were initiated for both mild steel and copper metallurgies from the onset of the peroxide evaluation in May 2007. Longer corrosion studies over (120 days) are considered to be more representative. This is due to the fact that metals require a period of time to form protective oxide barriers to system corrodents. Copper requires a longer period of stabilization than mild steel.

Three sets of coupons were used to evaluate corrosion during this trial. The corrosion runs demonstrated rates of less than 3.0 mils per year on mild steel and less than 0.10 mils per year on copper metallurgy. (See **III. Corrosion Report** for further detail)

b. Corrosion Mechanism

The mechanism of corrosion inhibition with hydrogen peroxide is centered around the repair of the protective oxide layer that will naturally form on the copper and mild steel metallurgies. The peroxide provides the environment for this inhibition to occur. This is covered in more detail in the discussion section.

c. Economics

The economics of the peroxide application are very favorable compared with the conventional treatment scheme. Although some information was not provided regarding prior conventional treatment costs, it appears that the cost of the peroxide application will be 20-25% of the prior treatment cost. The labor and other treatment costs are equivalent or less than with the conventional chemistry. The testing required is a function of the tower water control and should be comparable to other treatment programs. The LSI testing and monitoring of the bulk water should be performed to maintain the desired parameters for the treatment program. The peroxide treatment program should required less operational time maintain compared to conventional treatment since only the level of one material (peroxide) is to be controlled in the system.

d. Control

The present evaluation utilized shot-feed addition for control, in the absence of an in-line monitoring system. The permanent operation will attempt to incorporate an in-line peroxide residual sensor with the capability of shot-feeding and possibly pump feeding for winter operation. The effectiveness of the peroxide during the cooling season requires addition of a significant volume over a short period of time. The reasons it is necessary to achieve peroxide residuals in this manner are covered in detail in the discussion section of this report.

II. Discussion - Peroxide Evaluation Details

a. Function as a Biocide and Corrosion Inhibitor

Peroxide is a very strong oxidizing agent. It is the third strongest oxidizing material next to ozone and fluorine. It functions by oxidizing or "burning" anything it contacts. In the oxidation process, the peroxide is reduced to water and oxygen.

The contact of peroxide with any organic will reduce the organic to carbon dioxide and water with any inorganic portion reduced to ash or a silt. It is in this manner that peroxide functions as a most effective biocide. It will oxidize animal life (bacteria) by destroying the cell walls resulting in sterilization. In the case of plant life, (algae, fungus and molds) it will again oxidize the cells and convert to carbon dioxide and water with some inorganic silt (suspended solids). In all cases, the driving force is the level of residual peroxide.

The contact of peroxide with a metal surface will cause an oxide to form on that surface. This is the principal basis for peroxide acting as a corrosion inhibitor. The maintenance of the barrier oxide layer on the metal surface is the mechanism of protection with peroxide. The tendency in the system environment is for suspended solids fouling, biological fouling and scaling to act as deterrents to maintain the oxide barrier. The peroxide serves most effectively for control of the biological aspect. Suspended solids must be controlled through filtration and system blowdown. Other chemistry factors like calcium hardness, alkalinity, conductivity and pH must be balanced for scale control.

b. Filtration

The action of hydrogen peroxide in the cooling tower environment is as an oxidizing agent. In this capacity, the peroxide will react with all organic matter entering the tower from the air or generated within the operation. This reaction results is the oxidation of the organics to form carbon dioxide and water. The inorganic matter within the organic substances remains as an ash, or a silt. This must be removed on an ongoing basis with filtration. If not, it will ten to find a "home" in undesirable locations and can form breeding areas for biogrowth.

The tower system at Murray Hill contains a side stream filter system. This system is a backwashable 25 micron cartridge filter. It backwashes on pressure differential and has proven to be effective based on the condition of the tower sump, water clarity and the heat transfer equipment.

c. Control Guidelines

The overall key to the successful application of hydrogen peroxide is system cleanliness. This starts with complete biocontrol. The achieve biocontrol in the 100 cfu.ml range, high levels of peroxide must be reached in the tower water. These volumes of peroxide are significant in a system with a circulation rate of 55,000 gpm. Therefore, the shot feed method is most effective. This is most important during the summer time operation when the peroxide is very active and will not remain as residual very long in the system.

Shot feeding, during this evaluation, was performed by feeding directly from 310-gallon portable bins. Peroxide was fed directly into the sump by gravity using a stainless line and the valve at the bottom of the tank. In this manner, residuals of 40-50 ppm were achieved within minutes.

The ultra low biostrip levels (cfu/ml), maintained during the evaluation, resulted in the lack of formation of biofilm on any metal surfaces. Due to the lack of biofilm, heat transfer surfaces remained clean and clear of any deposit formation. Thus, the oxidizing effect of the peroxide functions as a repair mechanism to the protective oxide layers on the metal surfaces. Similarly, scaling tendencies are inhibited since precipitated salts in the bulk water are not agglomerated in the absence of biofilm.

The following chemistry control guidelines were employed during the peroxide evaluation:

- LSI = +2.00 to +2.50
- pH = 8.0 – 9.0
- Calcium Hardness ≤ 800 ppm
- Conductivity ≤ 2,200 micromhos
- Total Alkalinity ≤ 450 ppm
- Suspended Solids < 50 ppm
- Peroxide = 10 – 40 ppm (intermittent shot feed)
- Biostrip < $10^{\wedge 3}$ cfu/ml

Table 1 located in **Appendix 1** includes the results of the weekly testing of cooling tower and city water parameters throughout the trial period. (see Appendix 1)

III. Corrosion Report

a. Mechanism of Corrosion

Corrosion studies were initiated for both mild steel and copper metallurgies from the onset of the peroxide evaluation in May 2007. Longer corrosion studies over (120 days) are considered to be more representative. This is due to the fact that metals require a period of time to form protective oxide barriers to system corrodents. Copper requires a longer period of stabilization than mild steel.

The corrosion runs demonstrated rates of less than 3.0 mils per year on mild steel and less than 0.10 mils per year on copper metallurgy. **Table 2** below includes the corrosion data from the trial. In general, corrosion results from the trial were excellent.

Table 2

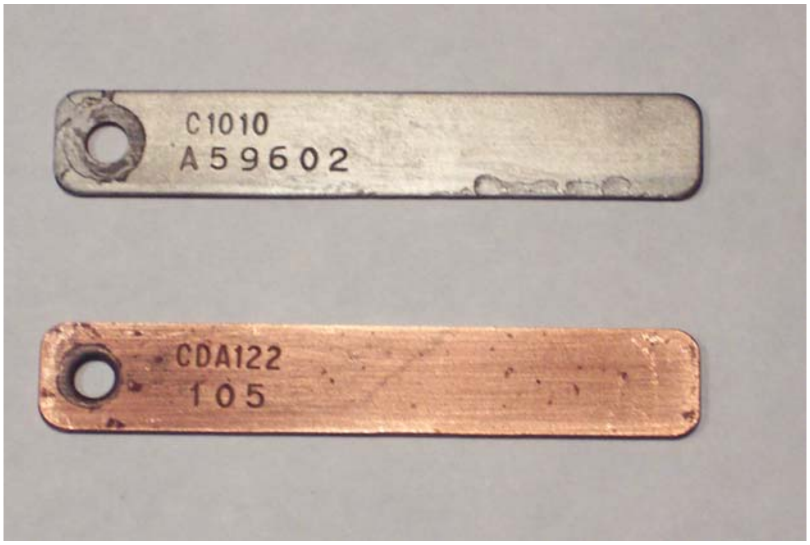
Cooling Tower Corrosion Results									
Coupon Location	**Type**	**Coupon #**	**Initial Weight (grams)**	**Final Weight (grams)**	**Loss (grams)**	**Date Installed**	**Date Removed**	**Exposure Time (Days)**	**Corrosion Rate (mils/yr)**
Pump House	Mild Steel	A 59602	10.51550	10.40675	0.1087	5/14/2007	8/8/2007	87	1.250
Pump House	Copper	105	13.23305	13.22261	0.0104	5/14/2007	8/8/2007	87	0.120
Pump House	Mild Steel	A 59616	10.51490	10.38280	0.1321	8/8/2007	10/9/2007	63	2.097
Pump House	Copper	106	13.34677	13.33380	0.0130	8/8/2007	10/9/2007	63	0.206
Pump House	Mild Steel	A 59601	10.51550	10.18766	0.3278	5/14/2007	10/17/2007	157	2.088
Pump House	Copper	104	13.30194	13.29706	0.0049	5/14/2007	10/17/2007	157	0.031

Notes:

1 All of the "W" series coupons are mild steel.
2 All of the "A" series coupons are copper.

The first set of coupons was removed on 8/8/07 and were exposed for 87 days. Since this is a short term for corrosion evaluation, the corrosion rates are normally higher than for a longer term. However, both of these coupons were very clean and contained no pitting or surface deposit. The corrosion rate for the mild steel was 1.25 mils per year and the copper was 0.12 mils per year. Both are considered excellent by any measurement of corrosion. (See **Photo 1** below)

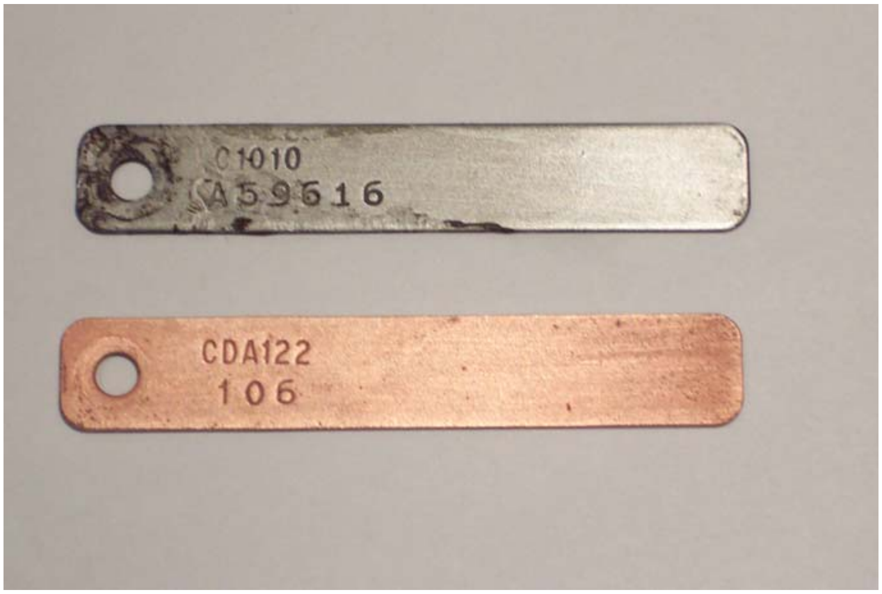
Photo 1: Coupons – 87 Days Exposure - After Cleaning



Short term coupons were removed on 10-9-07 for total exposure period of 63 days. The initial weight of the mild steel coupon (A-59616) was 10.51490 grams and the post exposure weight was 10.38280 grams. This resulted in a corrosion rate of 2.09 mils per year for the mild steel. This result is excellent, especially for short term exposure. The copper coupon (106) initial weight was 13.34677 grams and after exposure weight was 13.33380 grams. This resulted in a corrosion rate of 0.21 mils per year. This result is also excellent, especially for short term exposure. (See **Photos 2 & 3** below)

Photo 2: Coupons – 63 Days Exposure - Before Cleaning

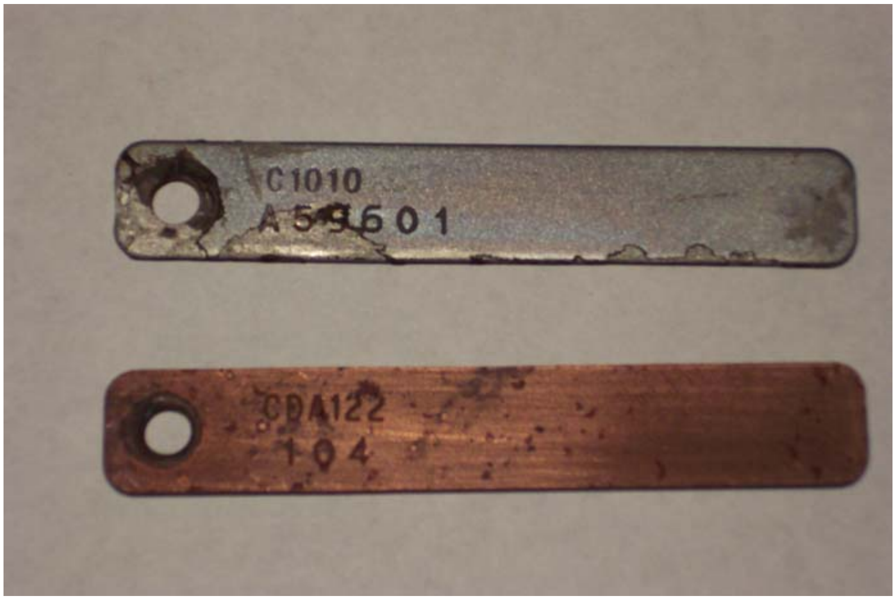
Photo 3: Coupons – 63 Days Exposure - After Cleaning



Long term coupons were removed from the corrosion rack. The exposure time for these specimens was 157 days. The mild steel coupon (A-59601) initial weight was 10.51550 grams and post exposure weight was 10.18766 grams. The copper coupon (104) initial weight was 13.30194 grams and post exposure weight was 13.29706 grams. After processing, the mild steel rate was 2.08 mils per year and the copper was 0.03 mils per year. Both are considered excellent. Of significance, was the fact that no pitting was observed on either coupon. Furthermore, most all of the corrosion on the mild steel occurred under the deposit of iron on the upper edge of the coupon. This deposit is the result of fine iron oxide initially attracted to the mild steel surface by magnetic forces. None of this activity was observed during the inspection of the chiller during the summer. (See **Photos 4, 5 & 6** below)

Photos 4 & 5: Coupons – 157 Days Exposure - Before Cleaning

Photos 6: Coupons – 157 Days Exposure - After Cleaning



IV. Chiller Inspection Reports

Two chillers were opened for inspection during the trial period. The #2 chiller was opened on August 15th after three (3) months on the peroxide treatment. The visual inspection yielded no deposit on the tubes, tube sheet or water box areas. The cursory, digital examination showed no scaling within the tube ends. The site "white glove" test (a piece of white cloth on a rod passed through the entire length of a tube) showed no sign of anything in the tube length. The lack of any corrosion activity in the inspected areas was also very positive and in line with the corrosion coupon analyses. (See **Photos 7&8** below)

Photo 7: Chiller #2

Photo 8: Chiller #2

On November 7th, chiller #1 was inspected. This unit had the most run hours during the trial period. The tubes, tube sheet and water box areas appeared the same as the other chiller inspected in August. Again, the “white glove” test was performed with the same result as the #2 chiller. Also, during this inspection, no signs of corrosion were revealed. (See **Photos 9&10** below)

Photo 9: Chiller #1

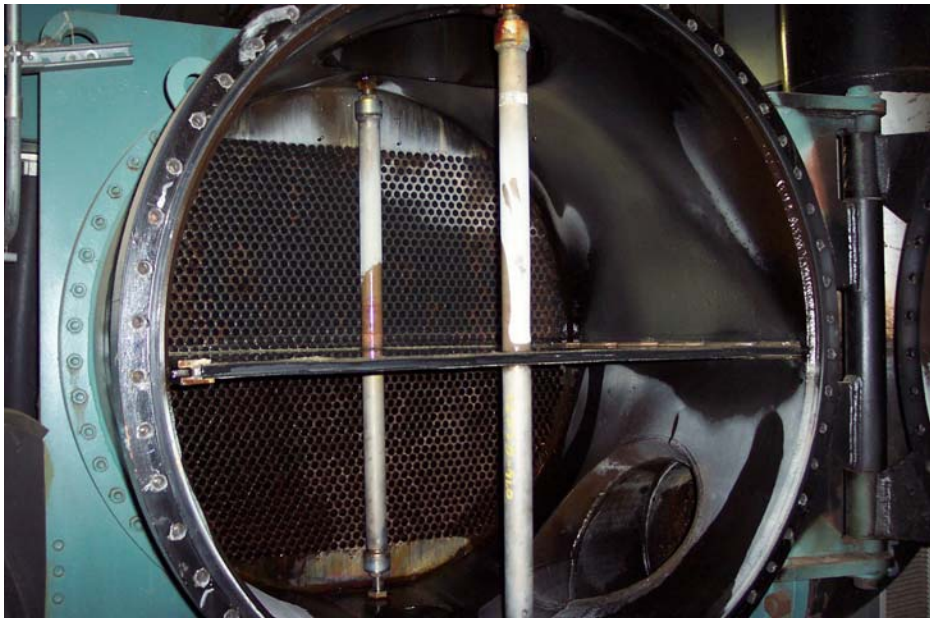
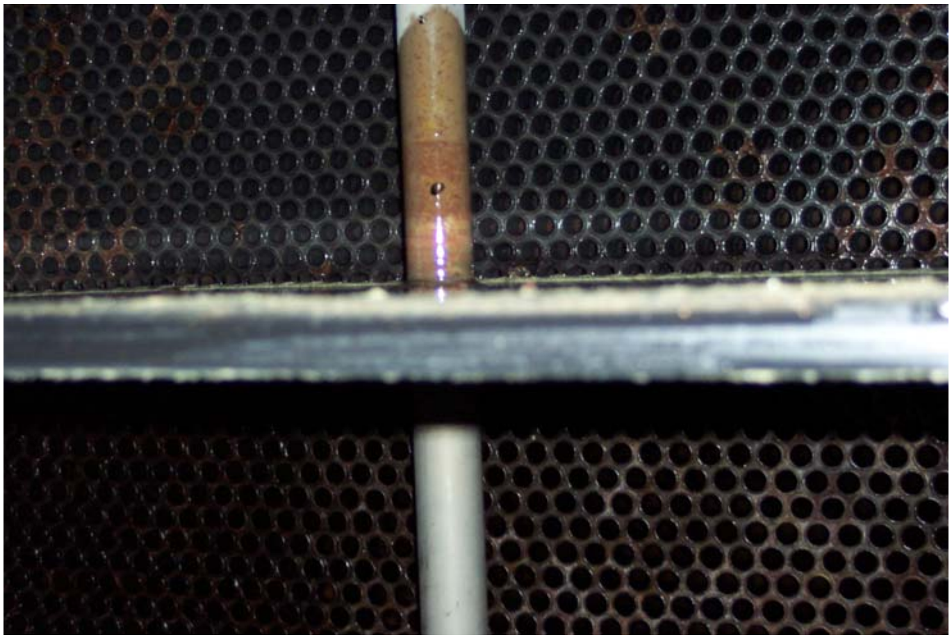


Photo 10: Chiller #1



The heat exchange equipment at this site is maintained with impeccable results. Therefore, the challenge during this evaluation was to duplicate those results. The appearance of both pieces of equipment monitored and reported above indicated that the peroxide treatment was able to maintain this high standard in the heat exchange equipment.

V. Cooling Tower Condenser Water Chemistry – Trial Operation Instruction

1.0 Procedure

1.1 Peroxide Testing (Manual)

  1.1.1 Peroxide levels in bulk tower water should be monitored using a Hach titration testing kit or equivalent.

  1.1.2 Prior to addition of peroxide to the system, peroxide level should be recorded using tower water and Hach testing kit. Follow instructions. The target system range is 10-20 ppm. (Higher ranges were employed during the evaluation to assess the full effectiveness at high demand periods).

  1.1.3 If peroxide level is 10 ppm or below, peroxide should be added using manual addition valves on the bottom of the bin.

1.2 Peroxide Addition (Manual)

  1.2.1 To add peroxide, the manual ball valve, on the bottom of the peroxide bin, must first be opened. The addition time will vary depending on the level of the bin. The peroxide will be entering the sump, during this time, via gravity feed.

  1.2.2 The operator should wait by the feed location until addition is over.

  1.2.3 The peroxide should be allowed to circulate for 15-20 minutes and the level should be tested following the procedure in (1.1).

  1.2.4 If the level is still not in the range of 10-20 ppm, follow procedure (1.2) for addition. Procedure (1.2) should be repeated as necessary to achieve desired range.
  Note: Varying system parameters and operating conditions including load and water sources will vary peroxide demand. During most of the study period, two daily additions of peroxide were employed.

1.3 System Monitoring

  1.3.1 Bio-monitoring

    1.3.1.1 Biostrips should be taken twice per week May through October and once per week November through April to monitor bio-control of system water.

      1.3.1.1.1 Sample water should be taken from the sample port in the pump house

      1.3.1.1.2 Sani-check BF or equivalent should be used and included directions followed.

      1.3.1.1.3 System results should be less than 10^3 (cfus/ml) or colony forming units per milliliter.

  1.3.2 Site Data to be recorded

    1.3.2.1 The parameters in the above section **c. Control Guidelines** should be tested and recorded during each testing period

1.3.3 Corrosion Coupons

- **1.3.3.1** There are provisions for 2-sets of corrosion coupons to monitor tower water (1 set = 1 mild steel and 1 copper). Two sets can be installed in the rack in the pump house.
- **1.3.3.2** Short term – 1 set of short term coupons should be installed in the rack (less than 60 days)
- **1.3.3.3** Long term – 1 set of long term coupons should be installed in the rack for over 120 days.
  Note: All coupons should be inspected periodically and appearance noted in the logs. Coupons should be processed and weighed correctly at the end of the test periods.

VI. Future

If the peroxide application is continued at the site, the following should be considered:

1. Development of a feed system that would facilitate operator control and management. This would incorporate either an effective peroxide probe to initiate chemical feed and/or a timer to periodically feed peroxide by gravity.
2. The incorporation of a peroxide bulk tank to facilitate storage, feed and cost optimization.
3. In conjunction with bulk storage, the site should also consider using 50% peroxide instead of the current 35%. This will benefit the site with decreased cost and increased effectiveness.
4. During the next cooling season, the site should continue to optimize the peroxide residual levels in order to minimize usage. This optimization should occur while maintaining control of bio-growth, corrosion, scaling or fouling.

If any questions exist on the above discussion or the attached results, please contact me.

Sincerely yours,

Nelson Brown
Nelson Brown III