White Paper

Laboratory Test Report
The Effect of Scale Formation on Heat Transfer Coils

Background

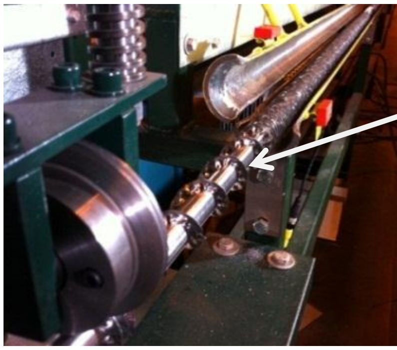
EVAPCO, Inc. recently introduced new Evaporative Condensers and Closed Circuit Coolers which utilize extended surface coils. For decades extended "fin" surfaces have been used on heat transfer coils, often referred to as "finned coils" primarily in an effort to increase dry capacity. However, in the past the fin material was limited to carbon steel tubes with a "round profile" prior to hot dip galvanizing. In most cases, the fin material was applied to a few rows of the heat transfer coil as opposed to the entire coil, due to the significant increase in airside pressure drop generated by the fins. Consequently, there was either no gain or a loss in thermal performance in the evaporative mode as a result of trying to increase dry capacity through the application of fins due to higher water and airside pressure drop.

Consistent with its mission to be a market leader in product innovation, EVAPCO commenced a rigorous Research & Development program to develop a new finned coil product that would improve upon the existing technology. EVAPCO's efforts included determining the optimum fin profile, height and spacing, as well as the optimum tube spacing required to maximize coil heat transfer efficiency. The goal was to offer a significant increase in Closed Circuit Cooler and Evaporative Condensers when operating wet (evaporative mode) and dry in the *same unit footprint* while utilizing *less fan motor horsepower.*

EVAPCO's efforts succeeded as EVAPCO released the *NEW* eco-ATW Closed Circuit Coolers and eco-ATC Evaporative Condensers, which feature a new, patent pending coil technology called "Ellipti-*fin*™." This technology is unique in that the fin material is applied to tubes with an "elliptical profile." This inherently allows for greater water and /or air over the coil while minimizing pressure losses. The result of the Ellipti-*fin*™ coil heat transfer technology is increased thermal performance in both the wet and dry modes.

In addition, EVAPCO's revolutionary Ellipti-*fin* ™ Coil Technology leads the industry by finning all rows of the "elliptical" tube coil resulting in significant Energy and Water Savings compared to conventional closed circuit coolers and evaporative condensers with bare round tubes.

EVAPCO Ellipti-*fin*™ Manufacturing Process



EVAPCO's Finning Line Precisely and Efficiently Applies the Fin Material to the Thermal-Pak™ tube.

Another key aspect of EVAPCO's development efforts included developing a manufacturing process to precisely and consistently apply fins to the Thermal-Pak™ elliptical tube. EVAPCO succeeded with this effort as well, and the new finning line ensures that EVAPCO is well prepared to meet the demand for these exciting new products.

Laboratory Test – Impact of Scale on Thermal Performance

EVAPCO anticipated that the industry would have questions about whether scale formation would inhibit the performance of the Ellipti-*fin*™ coils. As such, EVAPCO commissioned an amibitious research project aimed at quantifying the effect scale formation could have on thermal performance of both finned and bare tube heat exchangers. Product Development embarked on this rigorous test program in one of the company's six (6) Environmental Test Laboratories located in Taneytown, Maryland.

The purpose of this program was twofold:

a. *Meaure and compare the thickness of scale formation between a bare tube coil and an Ellipti-fin*™ coil.

b. *Measure and compare the thermal performance loss for a bare tube coil and an Ellipti-fin*™ *coil after scale has formed.*

Scale Formation Test Protocol

● EVAPCO manufactured a custom model ATWB 4-5G6 Closed Circuit Cooler. This unit incorporated four (4) individual galvanized steel heat transfer coils – two (2) Thermal-Pak™ bare tube coils and two (2) Ellipti-*fin*™ finned coils. The four (4) coils were physically identical in terms of tube rows, width and length. The only difference was the addition of fin material on the Ellipti-*fin*™ coils.

● All four coils were exposed to the same thermal operating conditions with identical make-up water and recirculating spray water chemistry for 45 days.

● The design load supplied to the unit was 316 gpm of water with 120°F entering the coils and a 78°F entering wet bulb temperature over the 45 day test period. The leaving water temperatures varied based on coil type.

● To promote scale formation, the unit was operated under continuous load with NO WATER TREATMENT and MINIMAL BLEED. See **Addendum A** Water Chemistry Report.

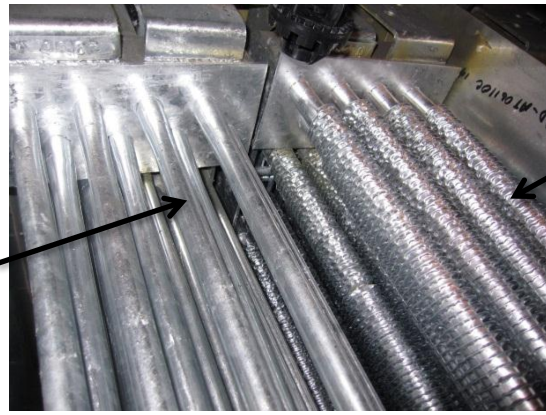
● The sequence of operation during the test was 100% fan speed operation with spray pump on at full operating heat load.

● At the end of each test day, the unit pump was turned off and the fan operated at full speed to dry the coil for approximately half an hour.

● Temperature sensors were placed at the inlet and outlet of each coil to measure entering and leaving water temperatures as scale accumulated on the surface of the tubes.

● The two (2) bare tube Thermal-Pak™ coils and two (2) Ellipti-*fin*™ coils were installed side by side, under a high and low flow spray header. The high flow spray header was designed for approximately 6.0 gpm/ft2 and the low flow header at 3 gpm/ft2. The coils were arranged so that each would see a high and low water loading.

Scale Formation Test Protocol (continued)



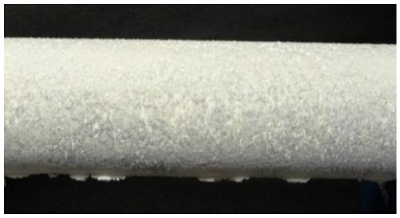
Two (2) Coil Design Prior to Commencement of Scale Formation Test

● To facilitate scale build up on the coils of the closed circuit cooler, the bleed rate was reduced and the cycles of concentration were allowed to increase dramatically. The final water chemistry reading was 8.49 pH with a conductivity reading of 20,770 μS. See **Addendum A** for the results of several water chemistry samples taken during the test.

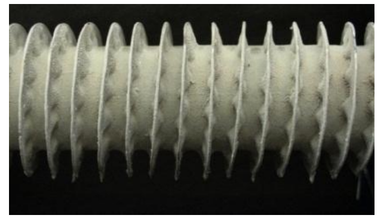
Commencement of Scale Formation on Both Coils

Laboratory Test Results

First, with respect to scale formation, at the end of the 45 day test, the Ellipti-*Fin*™ and Thermal-Pak™ coils had formed a measured scale thickness of 0.010 inches. That is, the scale formation was the same on both coils. The close up images below show the bare tube Thermal-Pak™ and Ellipti-*fin*™ samples after they were removed from the cooler following the 45 day test.



Thermal-Pak™ Coil Sample



Ellipti-*fin*™ Coil Sample

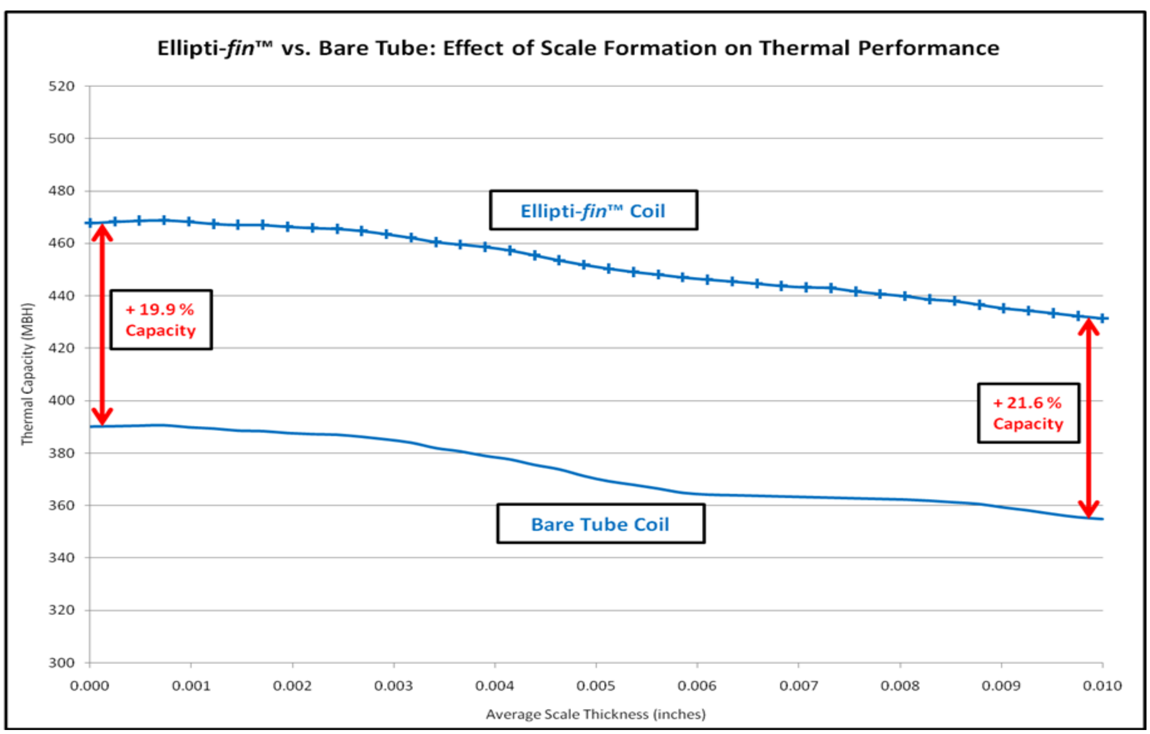
The thermal test data that was collected over 45 days, which included fluid temperatures, heat load and thickness of scale build, was plotted and analyzed to show the relationship of performance between both the bare and finned coil. Notably:

● *The thermal performance of the Ellipti-fin™ coil was **19.9%** higher versus the bare tube coil prior to scale formation.*

● *The thermal performance of the Ellipti-fin™ coil when measured at the end of the test with the 0.010 inch scale formation was **+21.6%** higher than the bare tube coil.*

The graph below shows the change in thermal performance for each coil during the 45 day test program as scale formed on the tube surfaces.

Graph 1



Conclusions

The test results prove that the rate of scale formation on a heat transfer coil is independent of bare tubes or finned tubes. In this test, the scale formation was the same on both coil technologies.

The Ellipti-*fin*™ Coil Heat Transfer Technology offers a significantly higher thermal performance over the conventional bare tube coil when no scale is present.

The thermal performance of Ellipti-*fin*™ Coil Heat Transfer Technology is greater than that of a conventional bare tube coil when operating with an equal amount of scale formation on the coil's surface.

The Ellipti-*fin*™ heat transfer coil retains a higher percentage of its thermal performance rating with scale formation when compared to a bare tube Thermal-Pak™ coil!

Summary

The *scaled* Ellipti-*fin*™ coil was proven to be thermally more resistant to scale effects versus a bare tube Thermal-Pak™ coil over similar operating conditions including load, ambient wet bulb temperature, water quality, water loading and fan speed.

The higher performance efficiency of this technology, when subjected to scale producing water chemistry, is due to the fact that as heat is transfered from the tube surface, to the fin and then to atmosphere, the fin surface temperature gradually diminishes from tube to the outer edge of the fin.

The rate and thickness of scale formation is a function of water chemistry and surface temperature. Scale will form more readily on higher temperature surfaces. Therefore, less scale is formed at the tip of the fin where the surface temperature is cooler. This allows for a more efficient heat exchange to occur on the finned coil versus the bare tube coil, thus improving its thermal performance.

Historically, EVAPCO has successfully provided finned round tube coils on hundreds of closed circuit coolers and evaporative condensers without adverse thermal performance degradation due to scaling. However, the key to maximizing the performance of all evaporative cooling equipment is to establish a water treatment program which minimizes the potential for scale formation on heat transfer surfaces. For more information on scale prevention, refer to Addenda B & C attached or contact EVAPCO directly at 1-410-756-2600.

Addendum A

EVAPCO Water Chemistry Samples

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Facsimile: 410-756-6450

5/3/2011

Sample ID: 3237
Sample Date: 7/20/2010

Subject: RD Labs
Location: Taneytown, MD
SN: Lab B

Attribute	Make-Up	07/20/10	07/30/10	08/13/10	10/08/10	Units
Conductivity	575	1482	2195	4710	8770	umho/cm
pH	7.7	8.6	8.8	8.5	8.8	
Total Hardness	217.6	353.4	564.1	1,301.2	2,614.1	ppm as $CaCO_3$
Ca Hardness	159.9	117.6	123.5	123.7	176.1	ppm as $CaCO_3$
Mg Hardness	57.7	235.8	440.7	1,177.5	2,438.0	ppm as $CaCO_3$
Alkalinity	162	219	305	275	449	ppm as $CaCO_3$
Silica	20	62	120	180	105	ppm
Chlorides	45.7	209.4	418.4	1081.4	2050.6	ppm
Sulfate	27.5	113.8	202.6	572.2	1048.4	ppm
Fluoride	0.1	0.2	0.7	0.6	<0.1	ppm
Phosphate	<0.1	<0.1	<0.1	<0.1	<0.1	ppm
Sodium	33.5	155.4	245.1	691.1	1031.0	ppm
Iron	<0.1	<0.1	<0.1	<0.1	<0.1	ppm

NOTE:

The water chemistries generated for this test were for the purpose of accelerated scale development only. The measurements posted above fall outside the recommended parameters of EVAPCO's Operation and Maintenance Guidelines.

Addendum B

Scale and Recommended Water Chemistry Guidelines

Managing the water chemistry of the recirculating water in evaporative cooling equipment to prevent scale formation is essential. Scale formation will reduce the thermal efficiency of this equipment whether it is a bare tube coil or Ellipti-*fin*™ coil technology.

Therefore, it is important to understand what scale is and how it forms on heat exchanger surfaces. The most common form of scale deposited on piping and heat exchangers is calcium carbonate (CaCO3). Calcium hardness and carbonate alkalinity are naturally dissolved in water typically used for evaporative cooling make-up. However, the amount of calcium carbonate in a given water supply can vary widely depending on water source.

The terms "Hard Water" and "Soft Water" typically refer to the amount of calcium and magnesium found in the water. Hard water is high in calcium and/or magnesium while soft water is low in these minerals. The image below shows severe scale formation on heat transfer coils in the form of calcium carbonate.

External Scale Formation

Scale forms on the external surfaces of a heat exchange coil because it is the hottest part of the system. Calcium carbonate has an inverse solubility in water. This means that the warmer the water becomes, the less calcium carbonate can be held in solution. The outside surface of the heat exchanger is the interface point where calcium carbonate is the least soluble and where scale tends to form first when the water becomes supersaturated with calcium carbonate.

Scale build on a tube can range in thickness from fractions of a millimeter to fractions of an inch or more. Studies have shown a scale thickness of only 1/32" (0.03125") will reduce the heat transfer coefficient of an evaporative condenser by approximately 16%! Water high in calcium and alkalinity is more likely to leave behind deposits that lead to scale.

The amount of scale that builds on a coil is dependent on the make-up water quality supplied to the cooler or condenser, cycles of concentration, water treatment and tube surface temperature. EVAPCO's recommended water chemistry guidelines (Appendix C) are designed to minimize scale formation when implemented in conjunction with an effective water treatment program.

Addendix C

EVAPCO's Recommended Water Chemistry for Coil Products, excerpts Page 20-21 from Bulletin 116b

For a Complete Operation and Maintenance Manual go to:

http://www.evapco.com/sites/evapco.com/files/om_bulletin_116b_12.pdf

Operation and Maintenance Instructions

Water Treatment and Water Chemistry

Proper water treatment is an essential part of the maintenance required for evaporative cooling equipment. A well designed and consistently implemented water treatment program will help to ensure efficient system operation while maximizing the equipment's service life. A qualified water treatment company should design a site specific water treatment protocol based on equipment (including all metallurgies in the cooling system), location, makeup water quality, and usage.

Bleed or Blowdown

Evaporative cooling equipment rejects heat by evaporating a portion of the recirculated water into the atmosphere as warm, saturated discharge air. As the pure water evaporates it leaves behind the impurities found in the system's makeup water and any accumulated airborne contaminants. These impurities and contaminants, which continue to recirculate in the system, must be controlled to avoid excessive concentration which can lead to corrosion, scale, or biological fouling.

Evaporative cooling equipment requires a bleed or blowdown line, located on the discharge side of the recirculating pump, to remove concentrated (cycled up) water from the system. EVAPCO recommends an automated conductivity controller to maximize the water efficiency of your system. Based on recommendations from the water treatment company, the conductivity controller should open and close a motorized ball or solenoid valve to maintain the conductivity of the recirculating water. If a manual valve is used to control the rate of bleed it should be set to maintain the conductivity of the recirculating water during periods of peak load at the maximum level recommended by the water treatment company.

Galvanized Steel – Passivation

'White Rust' is a premature failure of the protective zinc layer on hot dip or mill galvanized steel which can occur as a result of improper water treatment control during the start-up of new galvanized equipment. The initial commissioning and passivation period is a critical time for maximizing the service life of galvanized equipment. EVAPCO recommends that the site specific water treatment protocol includes a passivation procedure which details water chemistry, any necessary chemical addition, and visual inspections during the first six (6) to twelve (12) weeks of operation. During this passivation period, recirculating water pH should be maintained above 7.0 and below 8.0 at all times. Since elevated temperatures have a harmful effect on the passivation process, the new galvanized equipment should be run without load for as much of the passivation period as is practical.

The following water chemistry promotes the formation of white rust and should be avoided during the passivation period:

1. pH values in the recirculating water greater than 8.3.
2. Calcium hardness (as $CaCO_3$) less than 50 ppm in the recirculating water.
3. Anions of chlorides or sulfates greater than 250 ppm in the recirculating water.
4. Alkalinity greater than 300 ppm in the recirculating water regardless of pH value.

Changes in water chemistry control may be considered after the passivation process is complete as evidenced by the galvanized surfaces taking on a dull gray color. Any changes to the treatment program or control limits should be made slowly, in stages while documenting the impact of the changes on the passivated zinc surfaces.

- Operating galvanized evaporative cooling equipment with a water pH below 6.0 for any period may cause removal of the protective zinc coating.
- Operating galvanized evaporative cooling equipment with a water pH above 9.0 for any period may destabilize the passivated surface and create white rust.
- Re-passivation may be required at any time in the service life of the equipment if an upset condition occurs which destabilizes the passivated zinc surface.

For more information on passivation and white rust, please download a copy of EVAPCO's Engineering Bulletin 36 at www.evapco.com.

Addendix C (cont.)

EVAPCO's Recommended Water Chemistry for Coil Products, excerpts Page 20-21 from Bulletin 116b

For a Complete Operation and Maintenance Manual go to:

http://www.evapco.com/sites/evapco.com/files/om_bulletin_116b_12.pdf

Water Chemistry Parameters

The water treatment program designed for evaporative cooling equipment must be compatible with the unit's materials of construction. Control of corrosion and scale will be very difficult if the recirculating water chemistry is not consistently maintained within the ranges noted in Table 4. In mixed metallurgy systems, the water treatment program should be designed to ensure protection of all the components used in the cooling water loop.

Property	G-235 Galvanized Steel	Type 304 Stainless Steel	Type 316 Stainless Steel
pH	7.0 – 8.8	6.0 – 9.5	6.0 – 9.5
pH During Passivation	7.0 – 8.0	N/A	N/A
Total Suspended Solids (ppm)*	< 25	< 25	< 25
Conductivity (Micro-mhos/cm) **	< 2,400	< 4,000	< 5,000
Alkalinity as CaCO3 (ppm)	75 - 400	< 600	< 600
Calcium Hardness CaCO3 (ppm)	50 - 500	< 600	< 600
Chlorides as Cl (ppm) ***	< 300	< 500	< 2,000
Silica (ppm)	< 150	< 150	< 150
Total Bacteria (cfu/ml)	< 10,000	< 10,000	< 10,000

* Based on standard EVAPAK® fill
** Based on clean metal surfaces. Accumulations of dirt, deposits, or sludge will increase corrosion potential
*** Based on maximum coil fluid temperatures below 120°F (49°C)

Table 4 – Recommended Water Chemistry Guidelines

If a chemical water treatment program is used, all chemicals selected must be compatible with the unit's materials of construction as well as other equipment and piping used in the system. Chemicals should be fed through automatic feed equipment to a point which ensures proper control and mixing prior to reaching the evaporative cooling equipment. Chemicals should never be batch fed directly into the basin of the evaporative cooling equipment.

Evapco does not recommend the routine use of acid due to the destructive consequences of improper feeding; however, if acid is used as part of the site specific treatment protocol, it should be pre-diluted prior to introduction into the cooling water and fed by automated equipment to an area of the system which ensures adequate mixing. The location of the pH probe and acid feed line should be designed in conjunction with the automated feedback control to ensure that proper pH levels are consistently maintained throughout the cooling system. The automated system should be capable of storing and reporting operational data including pH reading and chemical feed pump activity. Automated pH control systems require frequent calibration to ensure proper operation and to protect the unit from increased corrosion potential.

The use of acids for cleaning should also be avoided. If acid cleaning is required, extreme caution must be exercised and only inhibited acids recommended for use with the unit's materials of construction should be used. Any cleaning protocol, which includes the use of an acid, shall include a written procedure for neutralizing and flushing the evaporative cooling system at the completion of the cleaning.