# MONITORING CALCIFICATION IN RIGID WET COOLING MEDIA USED IN DIRECT EVAPORATIVE COOLING OF DATA CENTERS

by

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May 04, 2018

Abstract

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Rigid wet cooling media is a key component of direct and indirect evaporative cooling systems. Evaporation is the process of a substance in a liquid state changing to a gaseous state. When water evaporates only $H_2O$ molecules gets evaporated and the other chemicals in the water is left behind on the surface as residue. Soul concentration is to determine how calcium scale affects the overall performance i.e. saturation efficiency and pressure drop across the media pad. An Accelerated Degradation Testing by rapid wetting and drying on the media pads at elevated levels of calcium was planned on the media pad. This research focuses on monitoring the degradation that occurs over its usage and establish a key maintenance parameter for water used in media pad. It was clearly found that scale deposition on media pads does not affect the media pad performance. Water conductivity is the key maintenance parameter for monitoring sump replenishing cycles which will result in reduced water usage.

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# Chapter 1

## Motivation

Alternative cooling solutions such as cold plate liquid cooling , single phase immersion cooling and evaporative cooling provide an energy efficient alternative to chiller-based cooling for the data center industry [1]–[4]. With air cooling being the pervasive cooling method, evaporative cooling stands to gain more and more acceptance and implementation. However, for mission critical facilities like data centers it is vital to fully understand the risks of cooling failure and the cost of maintenance. Operational efficiency of any cooling system plays a crucial role in design, control algorithm development [5], [6] and eventual operational expenditure.

The research focus was to study how water quality affected cooling media pads. That involved the cost of water bleed-off vs. replacing evaporative media. While water is a precious resource, the need for diluting sump/reservoir water salt concentration is an important financial decision. Lime scale build-up reduces cooling capacity of the evaporative media. Increases pressure drop of air through the evaporative media increasing fan energy/electrical cost. Typically, when calcium or lime scale has fouled the surface area of the evaporative media, the cost of new evaporative media is paid for within a brief time from the savings on fan energy. Secondly, focus was on monitoring the scale deposition on media pads. A monitoring parameter should be assigned in direct correlation with scale deposition or media pad life. This will help both the manufacturers and customers in understanding the degradation of media pad. Finally, in this study to treat water as a commodity, water management is very important. The amount of water used in direct evaporative cooling on large scale industries is very high. If this water usage is not monitored properly we might lose lot of water without knowing.

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Scaling on media pads

Rigid wet cooling media is a key component of direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) systems. Evaporation is the process of a substance in a liquid state changing to a gaseous state. When water evaporates as shown in Figure 1, only $H_2O$ molecules gets evaporated and the other chemicals in the water is left behind on the surface as residue. The residue accumulates on the surface of the pad and tends to deteriorate the performance of media pad.

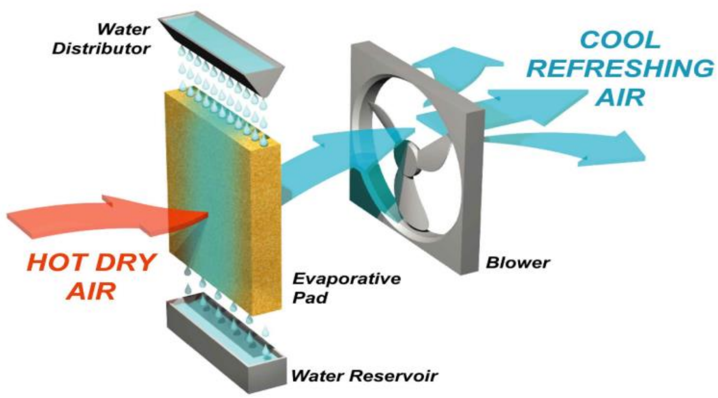


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Figure 1 Pictorial representation of DEC

Impact of scaling on media pads

Scale built up on all surfaces inside and outside cooling pads tends to prevent the pads from getting wet. This greatly reduced the system’s cooling efficiency. Scale build-up on edges of the pads was also hard and difficult to remove. This builds up the pressure drop across the media pad.

Different types of scale:

1) Calcium Carbonate

2) Calcium Sulphate

3) Magnesium Salts

4) Silica

The above stated salts are commonly found scales on media pads. Extensive research to identify the kind of chemical being deposited on media pads has been performed. It was pretty clear from reviews that calcium carbonate is the main component that affects media pad. It has the highest probability to form as a scale on media pads when compared to other salts. Hence in the following segments the concentration will be on how calcium carbonate affects the media pad life.

## Industrial Problems faced by manufacturers

Firstly, let us look at an industrial example to know the large-scale impact of scaling on media pad and water used for cooling. For every 50 gallons of spring water with 150 ppm of dissolved salts that is fully evaporated, one ounce of salts is left behind. This is the compound that forms scale on your evaporative media. In this case of 160,000 CFM of air-flow, the 312 gallons per hour of evaporated water would produce 6.64 oz. of salts per hour. These salts will accumulate in concentration within the recirculation water found in the sump/reservoir. To deal with this accumulation, a process known as “bleed-off” is required. Bleed off dilutes this salt concentration to a point that prevents scale build-up. Removing, or bleeding-off, some of the highly concentrated water and replacing it with weaker 150 ppm fresh make-up water will aid in scale build-up prevention. The main problem for the manufacturers is they have a lot of criteria’s available to them, but all those criteria are not incorporated into a maintenance guideline. If this guide can exist for the manufacturers and customers using the manual it will really help in maintaining a very high performance of media pad.

The amount of water bleed-off needed is dependent on the chemistry of your make-up or supply water. You will need to know the following about your water: -

The pH of your water

The calcium salt concentration in ppm

The hardness of your water in $CaCO_3$ ppm

The alkalinity of your water in $CaCO_3$ ppm

The TDS conductivity of your water in ppm.

This maintenance guideline will also help in regulating the water usage because it will include all the above details incorporated. It is mandatory to have a monitoring parameter attached with scale deposition.

## Chapter 2

## Accelerated Degradation Testing

High reliability systems generally require individual system components having extremely high reliability over extended periods of time. Short product development times require reliability tests to be conducted with severe time constraints. Frequently few or no failures occur during such tests, even with acceleration. Thus, it is difficult to assess reliability with traditional life tests that record only failure times. For some components, degradation measures can be taken over time. A relationship between component failure and amount of degradation makes it possible to use degradation models and data to make inferences and predictions about a failure-time distribution. This article describes degradation reliability models that correspond to physical failure mechanisms. Acceleration is modeled by having an acceleration model that describes the effect that accelerating variable has on the rate of a failure-causing chemical reaction. Approximate maximum likelihood estimation is used to estimate model parameters from the underlying mixed-effects nonlinear regression model.

Since the study is related to media pad degradation it is important to get the analogous parameters set according to our requirement.  Various parameters must be identified and related with the failure of the pad. Media pad degradation falls under soft failure. This means that media pad will not stop performing completely once it fails. The performance of media pad will drop drastically once the failure level is reached.

The acceleration factor and elevated stress levels were identified after proper literature review for the degradation test. If these two parameters are not selected with a proper relation with degradation, then the tests have to be repeated and will lead to wastage of time.

Literature review

To accelerate calcium deposition on media pads the mechanism of calcium carbonate formation was studied. Study on calcium carbonate scale deposition by Hasson [7] helped in understanding the mechanism of $CaCO_3$ formation. Effect of parameters like temperature and flow rate on calcium carbonate scale deposition was reported in that study. A knowledge base was established on what affects calcium scaling on media pads. [8] discusses different ways of conducting an accelerated test. Important step in an accelerated test is to define the type of failure and choosing the critical factor to be accelerated and establishing a monitoring parameter. Media pad degradation is a soft failure, it suggests that the pad will not come to a point where it fails completely but the performance drops drastically, and it is not on par with the recommended standards. [9]This recommendation helped in choosing the critical factor as rapid wetting and drying of media pad. [10]Evidence based guidelines for defibrillation pads by Drury used accelerated testing for establishing maintenance guide. In this paper they perform an accelerated test and reach a failure point. After reaching a failure point they create a maintenance criterion for changing the pads. Prudent use of water as a resource is a key factor when operating evaporative cooling units in regions of strained water availability [11]. Calcification occurs due to how media pads are currently operated. The effect of wetting/drying cycles on the media performance is seldom given consideration during operation and the primary monitoring parameter at the water sump is the water itself. From the different media pad manufacturers maintenance guide, it was quite clear that calcium carbonate is the scale forming component on the media pad.

Objective: This research focuses on monitoring the degradation that occurs over its usage and establish a key maintenance parameter for water used in media pad.

To determine how calcium scale affects the overall performance i.e. saturation efficiency and pressure drop across the media pad.

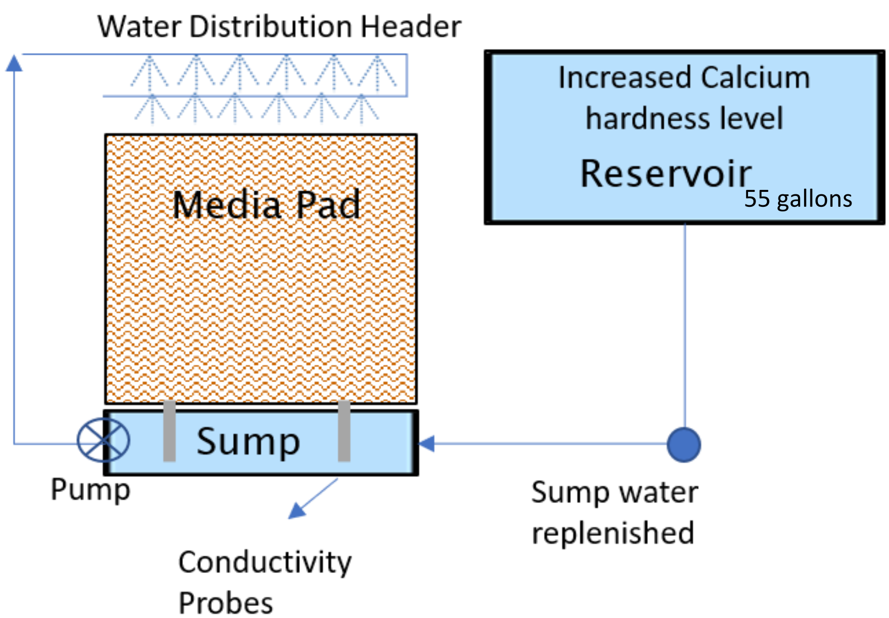



Figure 2 Schematic of the test setup

Test Procedure

Before every ADT the sump was cleaned thoroughly. Sump must be very clean before the start of any test because any chemical present in the sump can change the test results drastically. The test set up model was similar to Figure 2.

Desired calcium concentration in sump water was achieved by adding calcium hardness increaser and verified by using digital conductivity meter. The air flow bench conditions were set according to test conditions[12]. A constant airflow face velocity is achieved using the airflow test bench equipped with a blower. The pump ON/OFF cycles were controlled by Arduino using a relay switch. All the monitoring parameters will start recording once the first wetting cycle starts. Water conductivity, pressure, temperature was monitored on a continuous basis. pH was measured at regular intervals. This same procedure was followed for all the tests. A reservoir of 55gallons capacity was setup to provide continuous supply of water to the sump at the required calcium hardness level. Finally, after the completion of test all the data was analyzed. This was done in python. Any data processing software can be used as per your compatibility.

Characteristics of the parameters

Table 1 Idea behind the parameter analysis

| Parameter | Equipment used | Properties | Role in ADT |
|---|---|---|---|
| Air flow measured in FPM | Air flow bench with blast gate | Desired flow rates can be achieved by using desired nozzles. | Maintained constant throughout the test |
| Elevated Calcium level in water in ppm | Calcium hardness increaser | 5lbs of $CaCO_3$ in 10000 gallons of water increases hardness by 10 ppm. | Adjusted according to our requirement. |
| Water Conductivity in sump micro siemens/cm | Conductivity meter operated with Arduino | Output Signal: 0-5V; Range: 0-5000microsiemens/cm | Monitored continuously |
| Temperature in F and RH | RF code sensors | 18 RF code sensors were used. 9 at inlet and 9 at outlet. | Monitored continuously |
| pH | Digital pH meter | Range:0-14. | Monitored at regular intervals |
| Pressure drop inches of Water | Dwyer A-302F-A | 8 pressure taps were used. | Monitored continuously |
| Water Temperature in degree | T type thermocouple | Directly recorded in Agilent | Monitored continuously |
| Water flow rate in GPM | Submersible pump | Flow rate can be adjusted according to our requirement | Maintained constant |

Preliminary tests on water quality

Since it is a novel study, preliminary tests were mandatory because there were no established standards for media pad degradation testing. For accelerated degradation, elevated levels of water hardness can be utilized. The acceleration factor is the rate of wetting/drying of the media pad where a higher water flow rate is set for complete wetting of the pad in a short duration. Pump on cycle is shorter than the off cycle as longer drying time results in maximum evaporation off the wet media pad. Therefore, several The local water which will be used for future testing was put under a test to know its calcium content and to find the basic conductivity of tap water as shown in below Table 2 & Table 3.

Table 2 Water quality test

| Type of water | Type of test | Ca level in ppm |
|---|---|---|
| **Tap water** | Dip test | 60-120 |
| **Tap water** | Titration | 110 |
| **Drinking water** | Dip Test | 60-120 |
| **Drinking water** | Titration | 80 |
| **Few pellets of $CaCO_3$ added to tap water** | Dip test | >180 |

Table 3 Conductivity data of water

| Type of Water | Conductivity |
|---|---|
| **Tap water** | 325 microsiemens/cm |
| **Conductivity of water washing old pad** | 1143 microsiemens/cm |

*Test case 1: Short period ADT*

**Test Conditions**

Type of water used: Tap water.

Test time: 300 minutes.

Total number of cycles: 30.

Wetting time: 3 minutes; Drying time: 7 minutes.

Time between measurement:10 minutes.

Rate of wetting:2GPM.

Air flow rate:600FPM

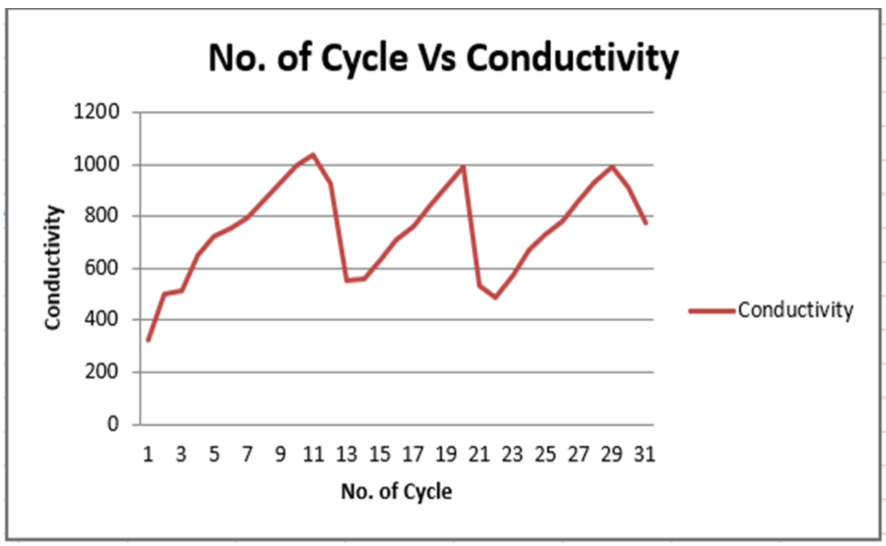



Figure 3 Variation of conductivity with change in volume

As shown in Figure 3 Variation of conductivity with change in volume, the sump water conductivity varies in accordance with sump water levels.

Inference: Constant volume should be maintained at sump level for conducting ADT or else it will create a new variability in test results.

*Test Case 2: Short period ADT*

**Test Condition:**

Type of water used: Tap water.

Test time: 300 minutes.

Total number of cycles: 60.

Wetting time: 2 minutes; Drying time: 3 minutes.

Time between measurement:5 minutes.

Rate of wetting:2GPM.

Air flow rate:600FPM.

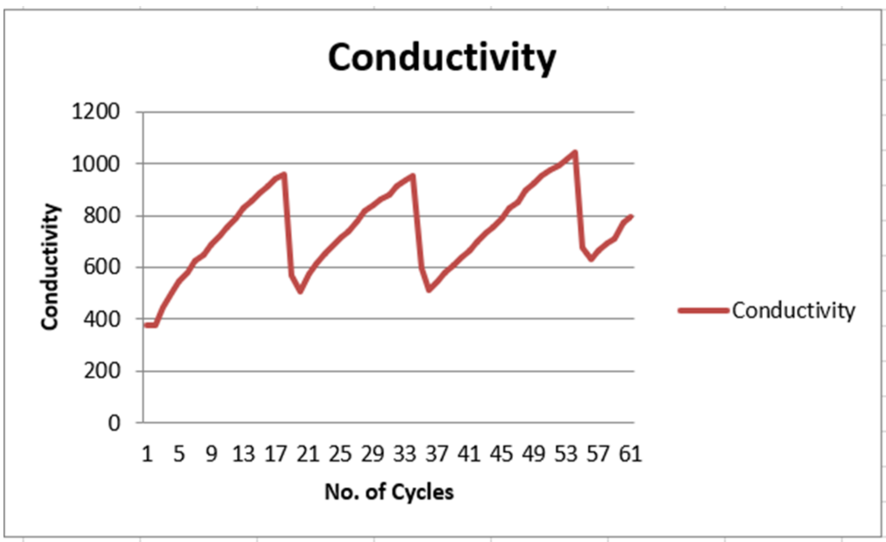



Figure 4 Variation of conductivity for 2minutes wetting and 3minutes drying

This test was conducted to find optimum wetting and drying time for ADT.

It was found that 3minutes wetting and 7 minutes drying is the optimum time for a cycle because there was complete wetting of media pad in 3 minutes. In this test the water volume in sump was varying. In future tests sump volume will be maintained constant and wetting time will be 3 minutes and drying time will be 7 minutes.

*Test Case 3: Short period ADT*

**Test Conditions**

Type of water used: 5grams of calcium carbonate was added initially in the sump and tap water was supplied to the sump.

Test time: 280 minutes.

Total number of cycles: 28.

Wetting time: 3 minutes; Drying time: 7 minutes.

Time between measurement:10 minutes.

Rate of wetting:2GPM.

Air flow rate:600FPM

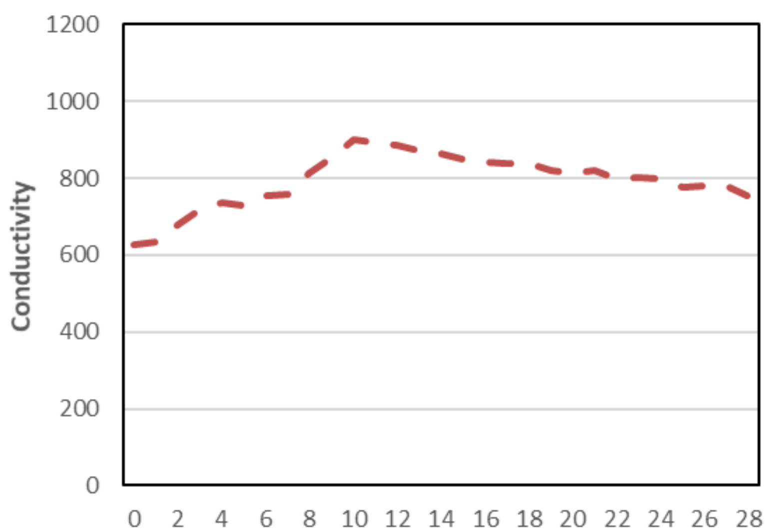



Figure 5 Variation of conductivity with continuous supply of water

To determine the effect on conductivity with continuous supply of water to the sump to maintain a constant volume at sump level. Until this point of testing conductivity was measured periodically after each cycle using a digital conductivity meter. After analysing the results from this test, it was clear that for better understanding of the scale deposition on the pads conductivity should be monitored continuously instead of periodic measurements.

## Effects of ADT on media pads

In order to check the amount of scale deposition on media pads. EDS test was performed on media pad samples after the three tests. An EDS (Energy dispersive spectroscopy) test was conducted to quantify the chemical composition of the scaled media pad. A sample from the media pad, pre-used and utilized again for preliminary testing, was analysed under a Hitachi 3000N SEM machine.

SEM Test set up: Vacuum Pressure Range: 10Pa to 270Pa. 30Pa was used for testing.

Working Distance: 15mm.

Beam current: 25kV.

Two samples were scanned in EDS. One sample was taken from the face of the pad where a deposition was visible. Another sample was taken from a completely new pad to compare the amount of calcium deposition on both the pads. Even though this EDS results gives us the idea about calcium deposition on the pads it does represent clear picture of total deposition on the media pad. Since the tested sample size is very small it is tough to relate the results with deposition on the whole pad. The EDS results are discussed in the following sequence.

EDS Results

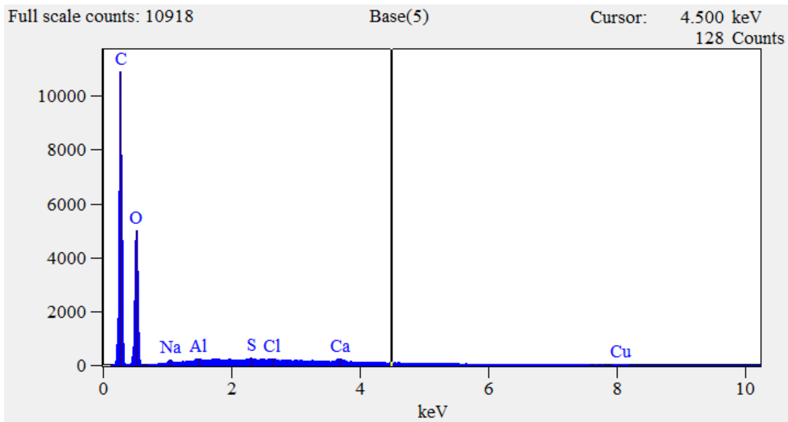



Figure 6 Calcium level in new media pad

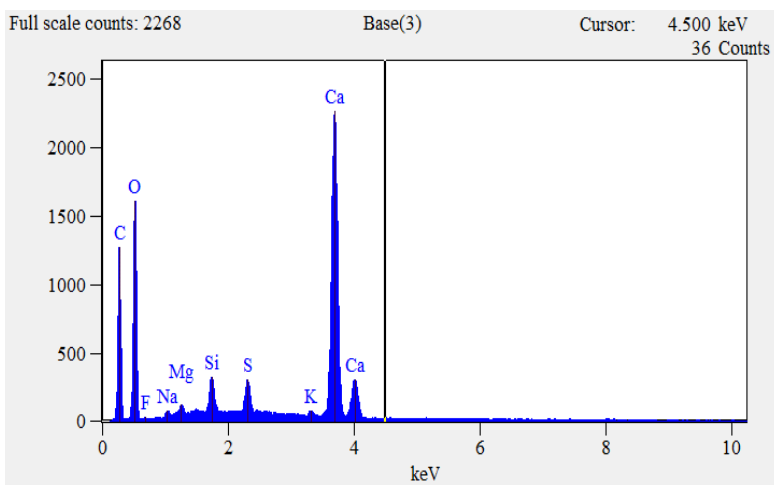



Figure 7 Calcium level in used media pad

From the above graphs **Error! No bookmark name given.** Figure 7 & Figure 6, it is clear that amount of calcium on the used media sample is very high when compared with unused media sample. The significance of this result is it clearly shows an increase in calcium deposition on the pads due to rapid wetting and drying cycles performed on media pads. Based on these test results and inferences from short period ADT new tests were planned and executed.

Table 4 Test plan

| S.No | Test | Type of water used | Type of pad used | Number of cycles |
|---|---|---|---|---|
| **1.** | Elevated level acceleration testing | 300ppm of calcium maintained in sump water | KUUL 12in cellulose media Pad that was used for preliminary testing previously | 288cycles. (2 days) |
| 2. | Elevated level acceleration testing | 300ppm of calcium maintained in sump water | Munters CELdek 12in pad | 720 cycles. (5 days) |

The tests were performed with the same test procedure as mentioned previously in the report. For the ADT test we used the media pad made up of same material and same dimension but only difference is the manufacturer. The first test was conducted only for 2 days because the test was performed on an already used pad whereas the second test is performed for 5 days because enough time should be provided for the new pad to get degraded.

Observations from test 1

After a thorough data cleaning and data processing session, a trend was observed in the conductivity of water in the sump. When the average conductivity during wetting cycle was plotted a decreasing trend, value was clearly found. The trend is represented below in a plot.

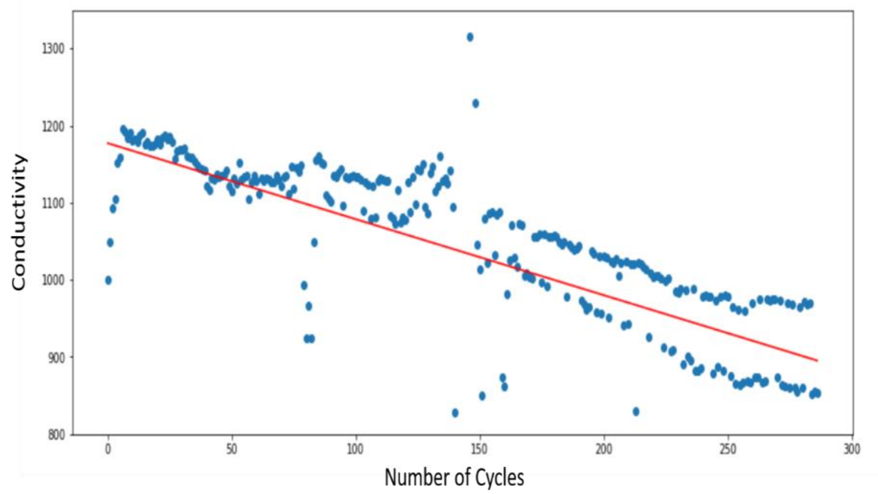



Figure 8 Average conductivity during wetting cycle

The equation of line plotted as shown in Figure 8 is Average conductivity during wetting cycle= -0.9854434*(No of cycles) +1177.25177983. This result was obtained after testing on already used media pad. There were also irregular drops in conductivity in between wetting and drying cycles. The conductivity would on some instance once the wetting cycle ends and stay at the lower value for the entire drying cycle. On some other instance it would fall after the wetting cycle and gradually increase to a higher value during the drying cycle. There was no trend to be found in drying cycles. During wetting cycles, the conductivity will change in a given range there was no drastic variation. This is the reason the observation was mainly shifted to wetting cycle and the above trend was plotted.

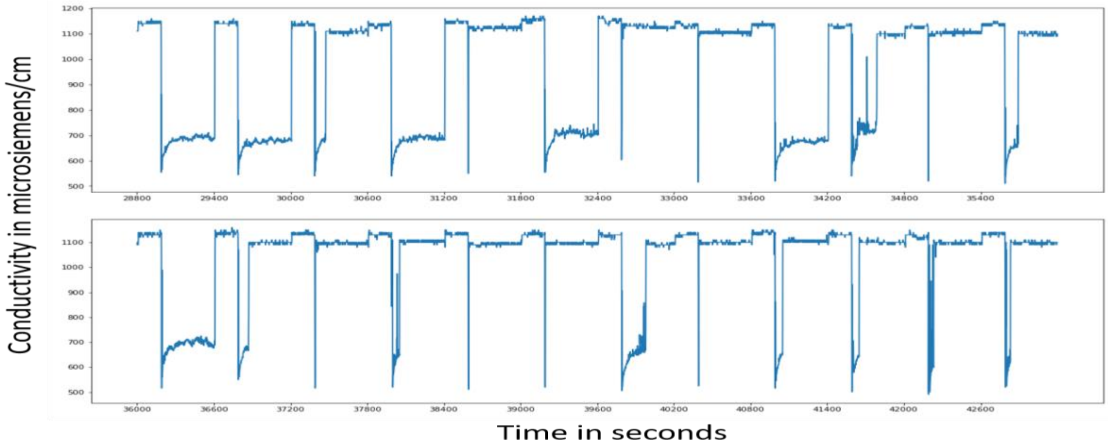



Figure 9 Sample of conductivity plot with respect to time

There was a good increase in scale deposition on the media pad especially on the face of the pad where the hot incoming air meets the dripping water. When the change in temperature was analysed at both the upstream and downstream side of the pad. There was no significant change in temperature or humidity or pressure drop. This result was a surprise but there will be a good change in the performance factors if the total test time was increase.

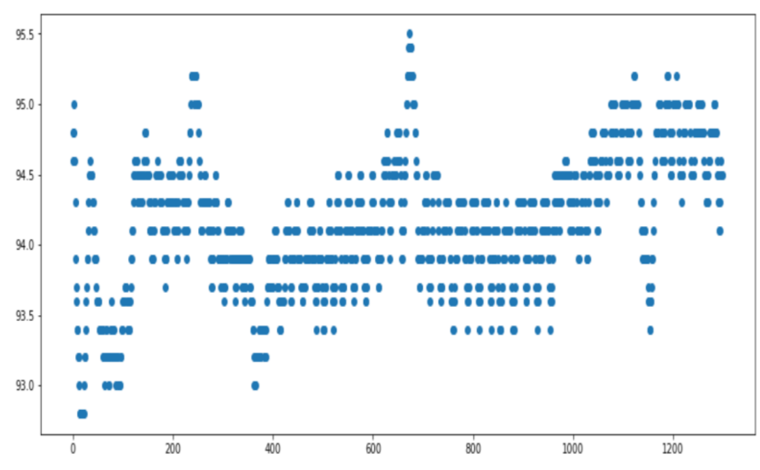


Figure 10 Inlet temperature

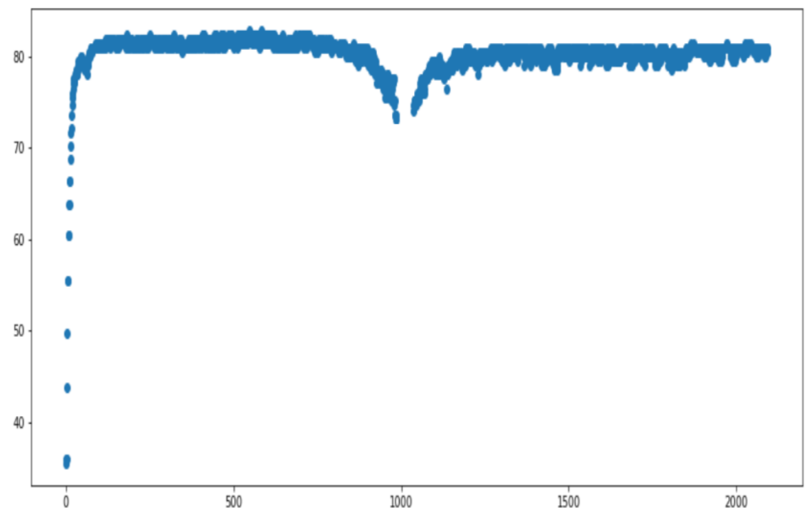



Figure 11 Outlet temperature

Scale formation on the pads were clearly visible to naked eyes as shown below in Figure. Scale formation was very high on the inlet face of the media, where upstream hot air meets the water and almost negligible at outlet face of the pad.

The weight of the pad increased from 2880 grams to 3487 grams after the test.

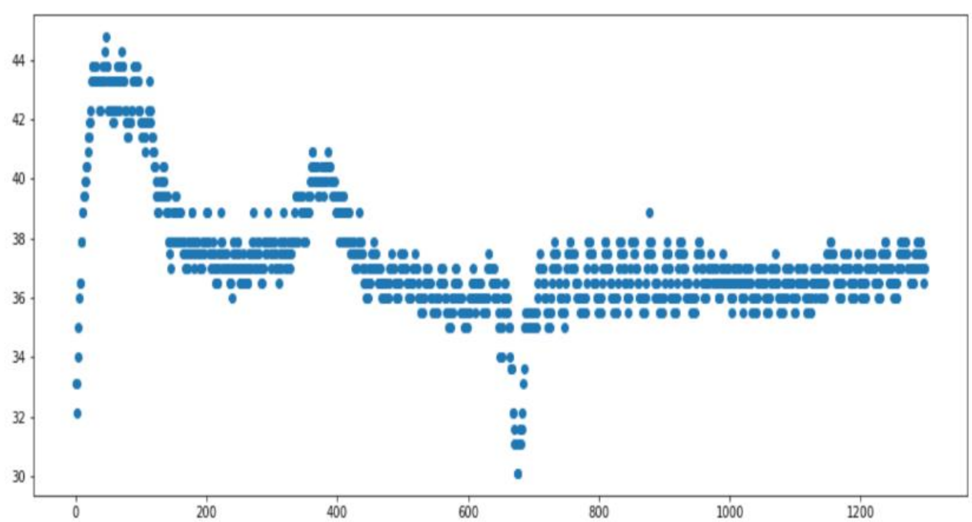



Figure 12 Inlet RH

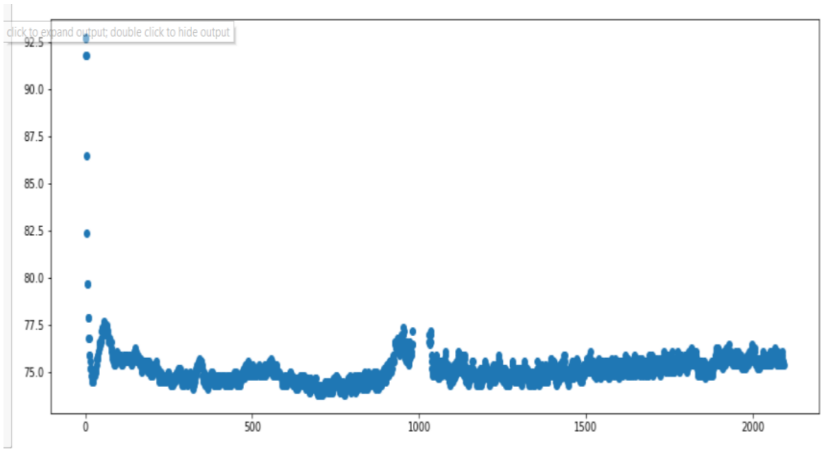



Figure 13 Outlet RH

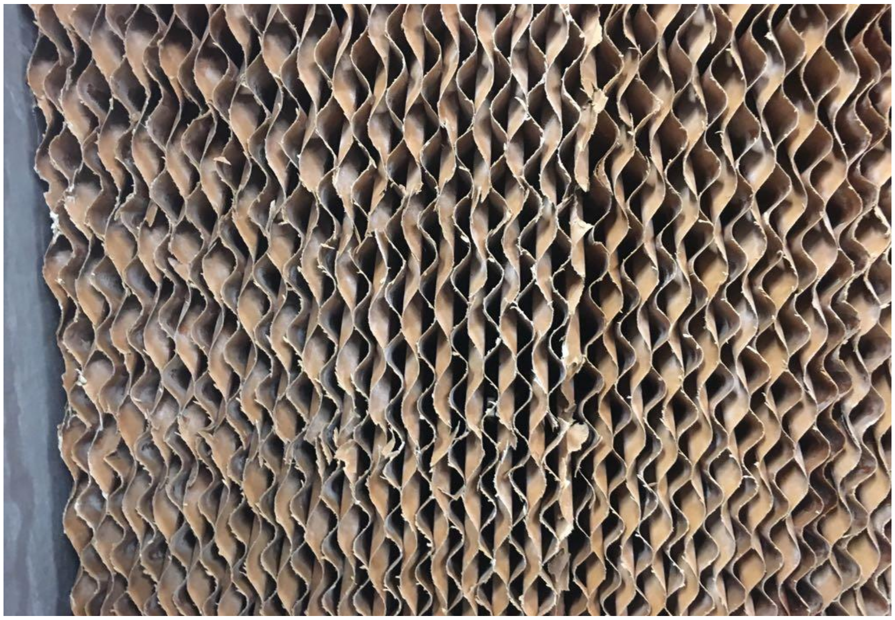
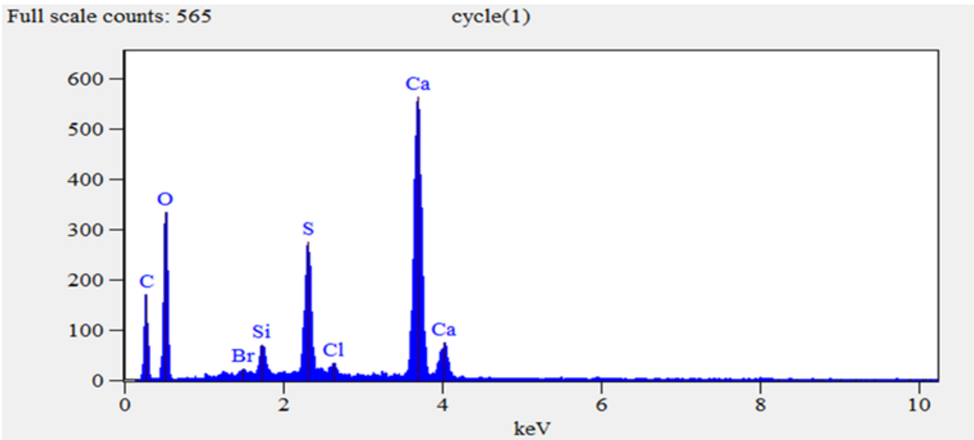


Figure 14 Picture of scaled media pad

EDS result after Test 1




| Element Line | Net Counts | ZAF | Weight % | Norm. Wt.% | Atom % |
|---|---|---|---|---|---|
| ***C K*** | 934 | 3.616 | 29.45 | 29.45 | 40.97 |
| ***O K*** | 1942 | 8.071 | 45.96 | 45.96 | 48.00 |
| ***Si K*** | 564 | 1.557 | 1.22 | 1.22 | 0.73 |
| ***S K*** | 2889 | 1.233 | 5.64 | 5.64 | 2.94 |
| ***Cl K*** | 311 | 1.292 | 0.68 | 0.68 | 0.32 |
| ***Ca K*** | 6855 | 1.134 | 16.75 | 16.75 | 6.98 |
| ***Br K*** | 9 | 1.398 | 0.29 | 0.29 | 0.06 |
| ***Total*** | | | 100.00 | 100.00 | 100.00 |

Figure 15 Calcium level after first test

The spike in calcium in the graph Figure 15 clearly shows the deposition on the pad. In the graph above two calcium can be seen on the x axis. It represents the amount of two valence states of calcium present in the sample tested.

Observations from Test 2

In this test we had additional facilities to measure water temperature at the sump level and pH of the water was measured at regular intervals. In this 5day test there was no big variation in pressure drop across the pad. The water temperature at the sump level did not have a big variation. The slight variation that can be seen on the plot below Figure 16 with water temperature was in relation with day and night temperatures.

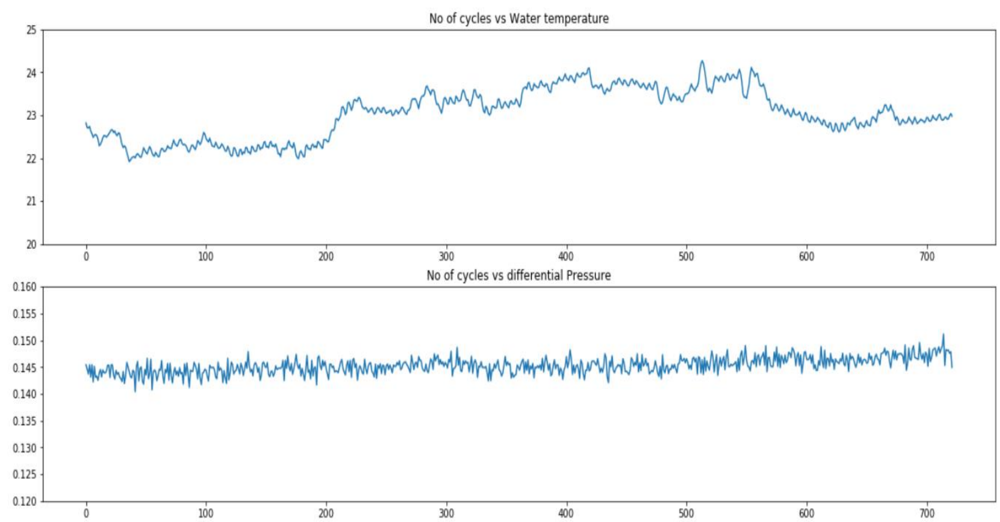



Figure 16 Change in water temperature and pressure drop with time

The pH of the water at sump level was measured after each day of test. The data is represented below in table. There was a steady increase in pH values. The reason behind this increase was there was no bleed off system installed with sump. Hence with the increase in scale deposition on the pads and with the same water being continuously used for wetting the pad.

Table 5 pH data during the test

| Day | pH of the sump water |
|---|---|
| **Before testing** | 7.5 |
| **After day 1** | 7.75 |
| **After day 2** | 7.96 |
| **After day 3** | 8.23 |
| **After day 4** | 8.46 |
| **After completion of test** | 8.65 |

Based on the previous results of conductivity a similar plot was plotted between average conductivity during wetting cycles and number of cycles. Initially there was very slight variation in conductivity change at sump level since it was new media pad. Once the induction time was provided for the pad to adjust to the chemical conditions the conductivity of the water started increasing steadily as shown in figure.

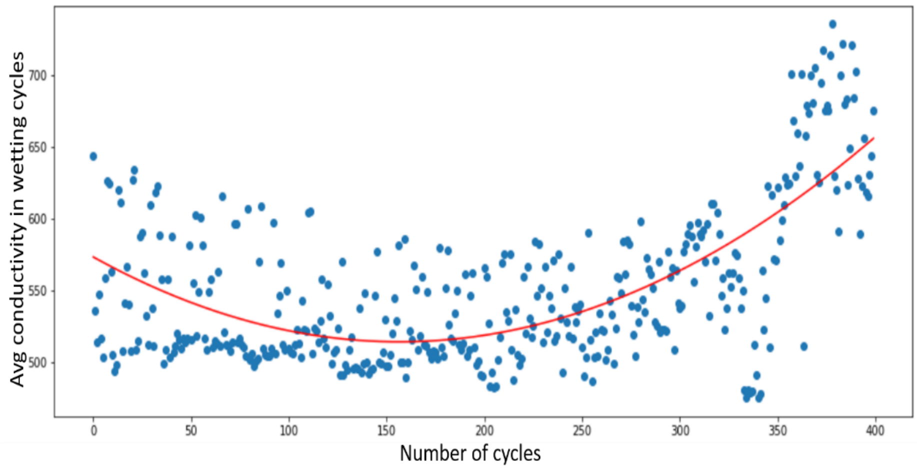
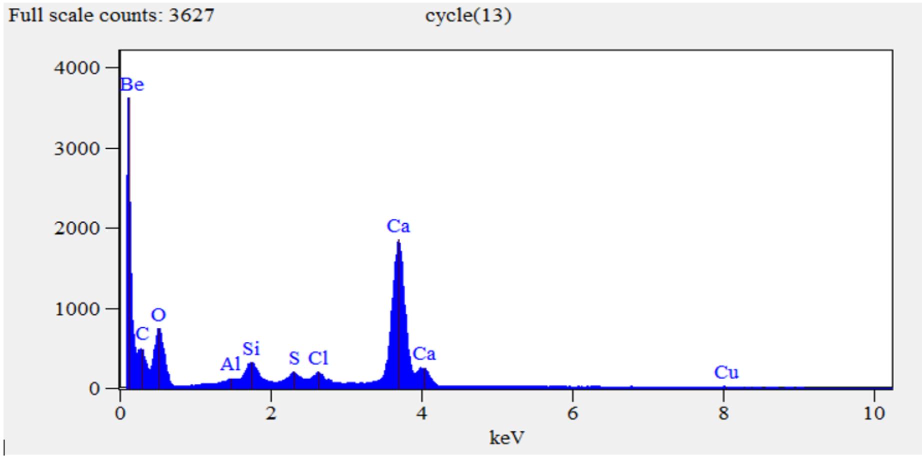



Figure 17 Average conductivity during wetting cycles

The equation of the plotted curve in Figure 17 is Average conductivity during wetting cycle = 0.0024*(number of cycles ^2) -0.7539*number of cycles + 573.246.

By using the above equation when the average conductivity was extrapolated to ASHRAE limits the number of cycles required to reach the value was found out.

On the basis of above equation, it will take 1272 cycles to reach 3500 micro siemens/cm. Even though its an extrapolated value it is just a step in right direction. This kind of empirical relation when provided to media pad manufacturers and customers will help them in understanding the level of degradation of media pad. It will also help in maintaining purge cycles and replenishing cycle. This empirical relation will also help in monitoring water usage. In order to get an idea of calcium deposition on new media pad an EDS test was performed on a sample.




Quantitative Results for: cycle(13)

| Element Line | Net Counts | ZAF | Weight % | Norm. Wt.% | Atom % |
|---|---|---|---|---|---|
| Be K | 3124 | 3.970 | 19.38 | 19.38 | 27.51 |
| C K | 15125 | 4.055 | 47.47 | 47.47 | 50.56 |
| O K | 10086 | 8.795 | 23.28 | 23.28 | 18.62 |
| Al K | 719 | 1.673 | 0.14 | 0.14 | 0.07 |
| Si K | 4236 | 1.366 | 0.73 | 0.73 | 0.33 |
| S K | 2628 | 1.159 | 0.44 | 0.44 | 0.17 |
| Cl K | 2490 | 1.163 | 0.45 | 0.45 | 0.16 |
| Ca K | 36845 | 1.102 | 7.95 | 7.95 | 2.54 |
| Cu K | 263 | 1.301 | 0.17 | 0.17 | 0.03 |
| Total | | | 100.00 | 100.00 | 100.00 |

Figure 18 Calcium content on new media pad after ADT

## Degradation model

Degradation model can be created by using various methodologies. In our case since the degradation of the media pad is due to rapid wetting and drying of the pad at elevated levels.

Usability rate will be the key parameter and it can be used as a degradation parameter. Usability rate: Industrial requirement/ Known time. The Known time is 10minutes as per our testing. Elevated Calcium concentration in water will be second parameter. Baseline test will help us in defining the boundaries. Baseline test should be performed using tap water and this should be conducted at least for a fortnight. This baseline should be conducted for a long time for providing the media pad enough time to degrade. [13]ASHRAE allowable water conductivity limits: 350-3500microsiemens/cm. These limits can be used provide maximum and minimum value of conductivity of water in the sump to be used for designing the degradation model. Aim of this project is to create a platform for degradation model and provide a maintenance guide for both the manufacturers and customers to help them deal with the degradation.

# Chapter 3

## Conclusion

1. The accelerated degradation testing performed by rapid wetting and drying clearly proved that it leads to scale deposition on the pads.
2. However, the performance of the media pad i.e. the efficiency of the media pad does not drop drastically with scale deposition.
3. This ADT leads to better understanding of maintaining a media pad based on water quality. Based on the conductivity of water in the sump, water can be replenished accordingly.
4. By this way water is treated as a commodity and use of water can be controlled with better understanding.

## Future Works

Bleed off cycles can be introduced in the sump for better results. This will enhance the value of the results because it will be more relatable for industries. Degradation model can be established for all the cities in US. The water quality report for any city in U.S can be obtained from internet. If tests can be conducted for the maximum and minimum ranges of the calcium content present in water for different cities. A detailed degradation model can be derived based on those results. Calcium sensor should be installed for future testing. This will help in understanding the variation in calcium level at sump after each cycle. Continuous Data Logging of pH will be very helpful in understanding the chemistry. Different media pad materials can be put through the same testing procedures and results can be compared. Different replenishing cycles can be used on media pad to calculate the amount of deposition removed from the pads.

Test timing should be increased for future testing because it creates better understanding of degradation. Baseline cases should be run for the degradation model without increasing the calcium level of normal tap water.

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