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ACCELERATED DEGRADATION TESTING OF RIGID WET COOLING MEDIA TO ANALYSE THE IMPACT OF CALCIUM SCALING

Hemanth N. Dakshinamurthy
University of Texas at Arlington
Arlington, TX, USA

Ashwin Siddarth
University of Texas at Arlington
Arlington, TX, USA

Abhishek Guhe
Mestex
Dallas, TX, USA

Rajesh Kasukurthy
University of Texas at Arlington
Arlington, TX, USA

James Hoverson
Mestex
Dallas, TX, USA

Dereje Agonafer
University of Texas at Arlington
Arlington, TX, USA

ABSTRACT

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 water molecules get evaporated and the other chemicals in the water are left behind on the surface as residue. Many studies have been conducted on how the change in air flow velocity, media depth, porosity and water distribution affect performance of the cooling system. The operational efficiency of the cooling media varies over its life cycle and depends primarily on temperature and speed of inlet air, water distribution system, type of pad and dimension of the pad.

Although evaporative cooling when implemented with air-side economization enables efficiency gains, a trade-off between the system maintenance and its operational efficiency exists.

In this study, the primary objective is to determine how calcium scale affects the overall performance of the cooling pad and the water system. Areas of the pad that are not wetted effectively allow air to pass through without being cooled and the edges between wetted and dry surface establish sites for scale formation. An Accelerated Degradation Testing (ADT) by rapid wetting and drying on the media pads at elevated levels of calcium is designed and conducted on the cellulose wet cooling 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.

As a novel study, preliminary tests were mandatory because there were no established standards for media pad degradation testing. Sump water conductivity is identified as the key maintenance parameter for monitoring sump replenishing and draining cycles which will result in reduced water usage. The average water conductivity in the sump during wetting cycles increases monotonically when ADT was performed on a new media pad. An empirical relationship between sump water conductivity and number of wetting cycles is proposed. This information will be very helpful for the manufacturers to guide their customers for maintenance of the media pad and sump water drain cycles.

NOMENCLATURE

ADT	Accelerated degradation testing
DEC	Direct evaporative cooling
EDS	Energy dispersive spectroscopy
FPM	Foot per minute
GPM	Gallon per minute
SEM	Scanning electron microscope
RH	Relative humidity

INTRODUCTION

Prudent use of water as a resource is a key factor when operating evaporative cooling units in regions of strained water availability [1]. 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. The common suggestion from all the cooling media pad manufacturers is to avoid rapid wetting and drying cycles for a long period of time but the effect of this operation was not studied [2]. Study on Calcium Carbonate ($CaCO_3$) scale deposition by Hasson [3] helped in understanding the mechanism of $CaCO_3$ formation on heat transfer surfaces.

Furthermore, the effect of parameters like temperature and flow rate on calcium carbonate scale deposition was reported in that study. An important step in an accelerated test, before choosing the critical factor to be accelerated and establishing a monitoring parameter, is to define the type of failure [4]. 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. Evidence based guidelines for defibrillation pads by Drury [5] used accelerated testing for establishing a maintenance guide.

DEGRADATION MODEL

An accelerated degradation test involves choosing a proper degradation model to correlate the critical factor and the performance factor to define the thresholds of the failure condition. The testing involves two parameters i.e. the elevated calcium hardness of water, primarily to increase the rate of scale deposition, and the rate of wetting and drying to track the usability rate of the media pad. These models will be crucial for establishing a maintenance criterion for cooling media pads. This usability rate can be used as a factor based on the timing of wetting and drying cycles i.e. actually in use. The degradation based on usage rate is well explained in [6]. Analogous model based on the literature review was created for this degradation model.

$$\boldsymbol{Usability\ Rate} = \frac{\boldsymbol{Actual\ Wetting\ Time}}{\boldsymbol{Wetting + Drying\ Time}} \quad (1)$$

The elevated hardness test results and usability rate can be used to establish an empirical relation between conductivity and number of cycles. This empirical relation can then be used to control replenishing rates for media pad washing. This can control water usage and create better understanding of sump drain water cycles.

METHODOLOGY

Preliminary tests are run to estimate the rate of wetting and drying for a fixed water flow rate over the media pad. The sump water is set to elevated Calcium hardness level. The water flow rate from the water distribution header is set at 2GPM as per media manufacturer's recommendation. Wetting and drying duration in the experiment is 3 minutes and 7minutes respectively and together they compromise a cycle. Complete media pad wetting can be achieved during the wetting cycle and longer drying time is provided for water in the pad to get evaporated. Rapid wetting and drying of media pad is the critical factor to accelerate calcium scale deposition.

As shown in Figure 1, when the sump water is not replenished continuously, the sump water conductivity varies in accordance with sump water levels. The water level in the sump is 10gallons. When the water level goes down during the wetting cycle in the sump, the conductivity starts increasing. The variation in conductivity of sump water in Figure 1 is due to the wetting cycle and the continuous loss of sump water due to evaporation. However, as shown in Figure 2, with continuous supply of water to the sump, the eventual drop in conductivity is primarily due to the dilution of the sump water as the water being replenished is tap water. To perform an accelerated test for long period, it is important to maintain a continuous supply of water to the sump and use water with same elevated levels of Calcium hardness to be maintained in the sump.

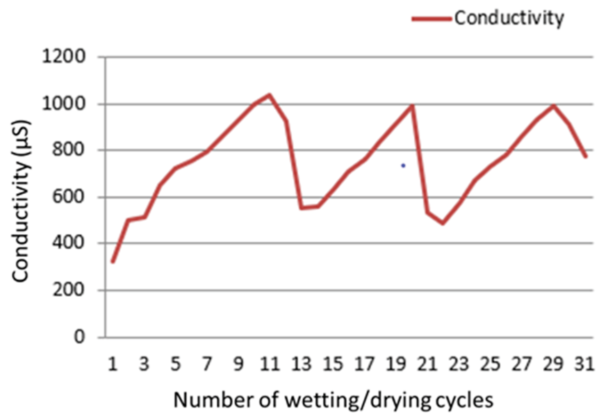


Figure 1: Conductivity of water without continuous supply of water to the sump.

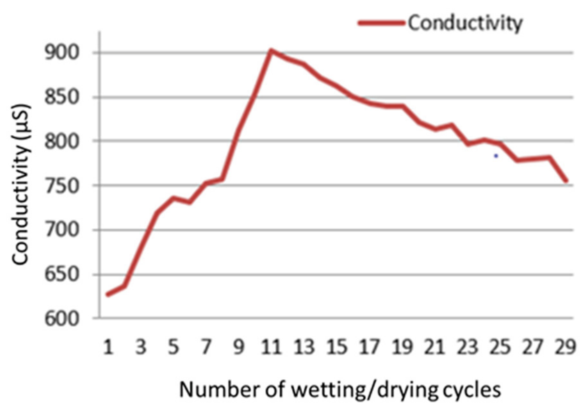


Figure 2: Conductivity in sump water with continuous tap water supply to the sump

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 analyzed under a Hitachi 3000N SEM machine. SEM Test set up: Vacuum Pressure Range is between 10Pa to 270Pa. 30Pa was used for testing with a working distance of 15mm. Beam current: 25kV.

It is clear from the Figure 3 and Figure 4 that there is a stark difference in calcium level. This result proves that rapid wetting and drying cycles on media pad at elevated Ca levels results in significant deposition of calcium on the pads.

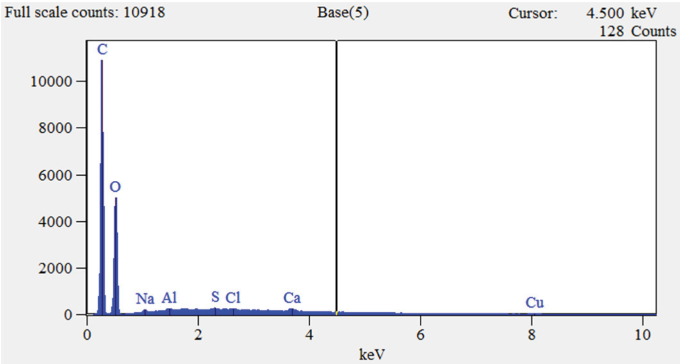


Figure 3: Calcium content in an unused/new media pad

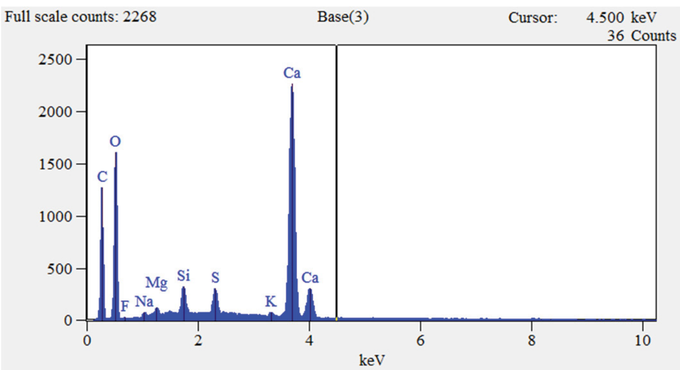


Figure 4: Increased Calcium deposits evident in an used media pad

EXPERIMENTAL TEST SETUP

An airflow test bench with suitable ductwork, equipped with a sump and a water distribution header, is designed to operate the wet cooling media pad. Further details of the test up involving the airflow bench is detailed in [7].

The model of the test setup is depicted in Figure 5. Before every ADT the sump was cleaned thoroughly. The air flow bench conditions were set according to the requirement. Pump was controlled using Arduino. All the monitoring parameters will start recording once the first wetting cycle starts. Table 1 lists the parameters of significance and the design of experiment (DOE) in the degradation testing due to the elevated Calcium hardness levels of the sump water. Preliminary testing of regional water is conducted to establish the elevated level of calcium hardness to be considered for the degradation test. Table 2 lists the Calcium levels of the regional tap water.

A reservoir of 55 gallons capacity was setup to continuously replenish water supply to the sump at the required calcium hardness level. Desired calcium concentration in sump water was achieved and verified. Finally, after the completion of test all the data was analyzed. Dip test was performed using calcium hardness testing strip. It will give us the range of amount of calcium present in the sample when compared with the provided chart. The titration gives us the exact amount of calcium present in the water. Both the titration and dip test were performed by using a Calcium testing kit. The second result from Table **3** shows that the conductivity of water increased after washing the media pad.

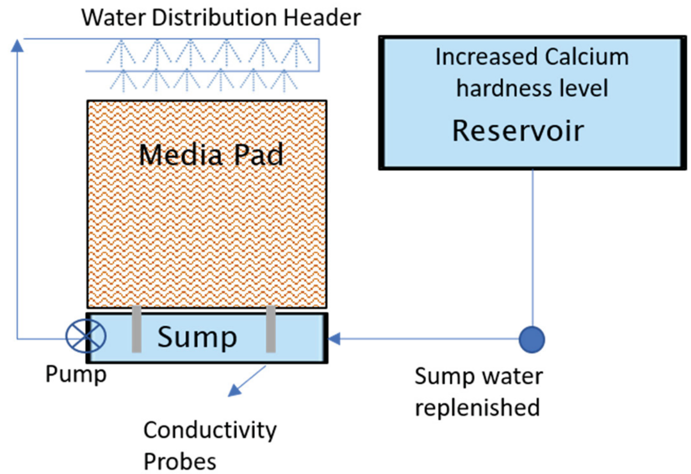


Figure 5: Test setup used for accelerated degradation testing

Table 1: Characteristics of the parameters

Parameter	Equipment used	Properties	Role in ADT
Airflow measured in Cubic Feet per minute (CFM)	Air flow bench with blast gate	Desired flow rates can be achieved by using desired nozzles and blower fan speeds	Maintained constant throughout the test
Elevated Calcium level in water in parts per million (ppm)	Calcium hardness increaser	5lbs of $CaCO_3$ in 10000 gallons of water increases hardness by 10 ppm.	Adjusted according to testing requirement
Sump Water Conductivity in micro Siemens/cm	Conductivity meter operated with Arduino	Output Signal: 0-5V; Range: 0-5000 micro Siemens/cm	Monitored continuously
Temperature (^oF) and Relative Humidity (%)	RF code sensors	18 wireless sensors were used. 9 at inlet and 9 at outlet.	Monitored continuously
pH	Digital pH meter	Range: 0 to 14	Monitored at regular intervals
Pressure drop (inches of Water)	Dwyer A-302F-A	Pitot tubes, 4 upstream and 4 downstream of pad	Monitored continuously
Water Temperature (^oC)	T-type thermocouple	Directly recorded in Agilent	Monitored continuously
Water flow rate in gallons per minute (GPM)	Submersible pump	Flow rate can be adjusted	Maintained constant throughout the test

Table 2: Preliminary testing of regional water

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 of tap water and sump water

Type of Water	Conductivity
Tap water	325 micro Siemens/cm
Conductivity of water washing old pad	1143 micro Siemens/cm

RESULTS AND DISCUSSION

The test conditions for the degradation test is shown in Table 4. The cooling performance of the media pad did not degrade even though there was good deposition on the pad. Temperature across the media pad just changed slightly according to the diurnal temperature variation as shown in Figure 6. However, in practice the scale deposition can build up in areas where dry-streaks exists and significantly reduce saturation efficiency of the media pad [8]. This can be attributed to the DOE as the experimental setup ensured proper distribution of water over the pads and the increased water flow rate for rapid wetting also ended up washing down the media pad. However, scale deposition on the pad is clearly visible as shown below in Figure 7. Scale formation is more pronounced on the inlet face of the media, where upstream hot air meets the wetted media pad and results in higher evaporation rate.

Table 4: Degradation testing with elevated Calcium hardness levels for extended period

Type of water used	Type of pad used	Number of cycles
300 ppm of calcium maintained in water reservoir	Munters CELdek 12in media pad in new condition	720 cycles (5 days)

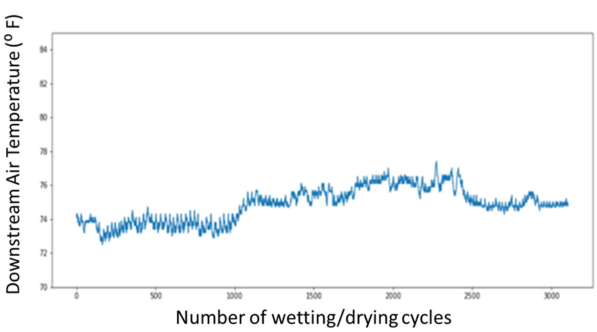
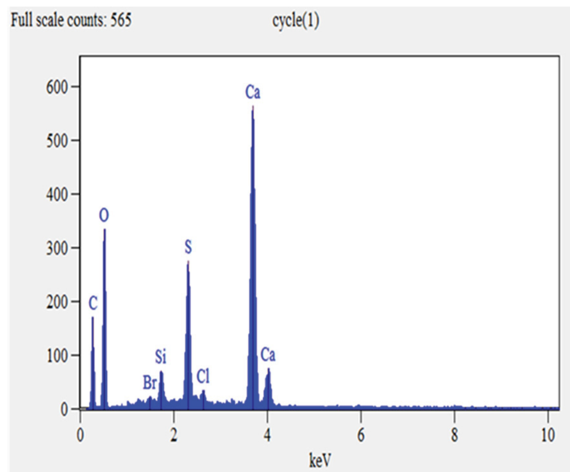


Figure 6: Variation of outlet temperature during the ADT test.

Again, a sample was taken from the media pad for EDS test. The testing conditions was same as previous SEM test setup. The results are represented in Figure 8. The spike in calcium content shows the clear deposition of calcium on the media pad. The pressure drop across the media pad varied between the 0.10-0.18 inches of water. Water temperature varied in the range between 22-25 ºC as shown in Figure 9. A significant change is observed only in Conductivity and the pH of the sump water and this justifies using water conductivity as the monitoring parameter.

Front Back

Figure 7: Scale deposition more pronounced at the inlet of the media pad



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 8: EDS results of media pad sample after accelerated degradation test

Table 5: pH data after each day of testing

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

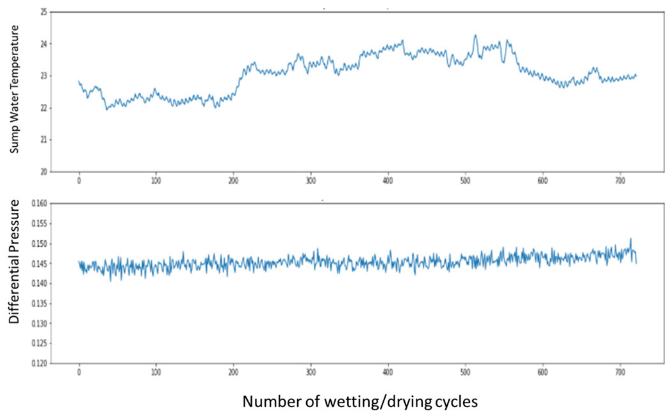


Figure 9: Variation of sump water temperature (°C) and pressure drop (inH_2O) across the media pad

As there was no bleed off cycle maintained, the pH of the sump water kept increasing with increase in scale formation on the pad. During the initial stages of testing the conductivity remained in the 500-600 µS (micro Siemens/cm) range with slight variation. After the 300th cycle there was an increase in conductivity of the water from 600 and started moving to 700. This rate of increase was plotted using a second-order curve. Equation of the curve plotted in Figure 10 is Equation 2.

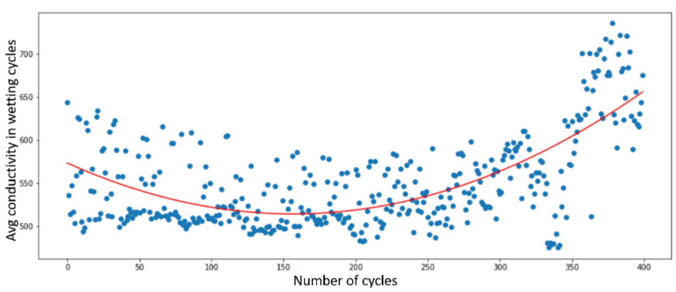


Figure 10: Conductivity plot for the initial 400 cycles.

$$\mho av = 0.0024\,(n^2) - 0.754\,(n) + 537.25 \qquad (2)$$

where $\mho$av is the average conductivity of sump water during wetting of media pad and n is the number of wetting/drying cycles.

When Equation (2) was extrapolated to the ASHRAE limits the number cycles required to reach the extreme value can be found out. As per the [9] ASHRAE, allowable range is 350-3500 µS. Based on equation 3, it will take 1272 cycles to reach 3500 µS.

CONCLUSION

In the water system of an evaporative cooler using a rigid wet cooling media, it was shown that a balance needs to be established between the total evaporation rate and the rate of scale deposition. The accelerated degradation testing performed by rapid wetting and drying clearly proved that it leads to scale deposition on the pads. Sump water needs to be drained periodically and the media pads require a periodic washing to avoid scale build-up [8]. The empirical relationship, given in Equation (2), between a monitoring parameter and number of wetting cycles will be very helpful for the manufacturers to guide their customers for maintenance of the media pad and sump water bleed-off rate or drain cycles. Such information is invaluable for maintenance-oriented monitoring in direct evaporative cooling units. 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 or drained accordingly. By this way water is treated as a commodity and use of water can be controlled.

ACKNOWLEDGMENTS

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