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Corrosion Management for Data Centers

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Abstract

The recent interest in air-side cooling and the spread of data centers into geographies with higher levels of atmospheric contamination is requiring more attention towards air quality management in data centers. One concern of air side economization is an increase in contamination levels potentially leading to more failures and outages of the IT equipment. In this paper we describe a corrosion measurement and management technology that enables high accuracy and real time monitoring of the gaseous contamination. The synergistic effects of indoor air temperature and relative humidity on corrosion rates are investigated and the spatial and the temporal variations of the corrosivity are established. Filtering of the outside air, both for particulate and gaseous contamination can mitigate air contamination in data centers. Implementing a facility wide air quality monitoring system promises the safe use of air-side economizers and would establish appropriate filtering, which enable early prevention of critical situations for information technology (IT) equipment operations.

Keywords

corrosion, risk management, relative humidity, dew point, data center

1. Introduction

The desire of operating data centers (DCs) more energy efficient has resulted in two trends: (1) environmental operating parameters for IT equipment have been significantly expanded and (2) air side economizers are increasingly used to offset cooling energy consumption, which can be substantial fraction of the total DC power. These two trends can have significant implications for the corrosion risk of a DC.

a) Expanded DC environmental operating conditions

Traditionally DCs are operated in highly controlled environments where strict temperature, humidity and air quality parameters are maintained. Recently the temperature and humidity operating envelope was expanded by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in collaboration with IT equipment manufacturers. [1] The recommended temperature and humidity levels for air inlets in IT equipment are summarized in Table 1.

ASHRAE recommendations	IT equipment environment (2008)
Low end temperature	**18° C**
High end temperature	**27° C**
Low end moisture	**5.5° C** dew point
High end moisture	**60%** RH and **15°** C dew point

Table 1 ASHRAE recommended environmental parameters for data center operations. [1]

The ASHRAE guidelines are designed to minimize the physical failure risks of the IT equipments while achieving higher energy efficiency. [2-7] For example it is suggested that humidity levels below 20% can increase the probability of electrostatic discharge (ESD) and implicitly the failure of integrated circuit components. [2] High humidity levels (above 70%) may increase the probability of PCB board delamination, anodic filament growth, zinc whisker growth and corrosion. [3-6] Furthermore the recommended operating boundaries are considering the combined effect of temperature and relative humidity to avoid condensation and static charge buildup.

Extended operation outside of the recommended environmental ranges exposes the IT equipment to higher failure risks. Many studies have been dedicated to investigate the effect of temperature and humidity on integrated circuit (IC) reliability. Predictive models of "mean time to failure" for IC components were developed based on first principle models and/or on data driven models of failed components in the field. [7] While these models apply to discrete IC components they can be extended to system levels as discrete component failure will affect IT equipment operation.

b) Air-side Economizer: One of the most straightforward approaches to drive down cooling energy cost in a data center is air side economizer. [8] Its main advantage is that it can be adapted using existing infrastructures and has a proven track of successful deployment in buildings and industrial facilities. Enabling free air cooling in high energy demand facilities like data centers can reduce cooling energy consumption by up to ~50%. The period of time in a year when air side economizer can be used is dependent on the outside air temperature and humidity levels and can vary with geographical locations and weather conditions. Based on local weather data the numbers of hours a data center can utilize outside air for cooling for three cities are summarized in the graph below:

Representative Cities	Potential Hours of air side economizer	Potential percent of "free" cooling
San Francisco, CA	**8,563**	**98%**
New York, NY	**6,634**	**76%**
Dallas, TX	**4,470**	**51%**

Table 2: Potential availability for airside economizer in three US cities, using a target supply air temperature of 20^{o} C at a dew point temperature set point of 12º C .

For IT equipment operated at high temperatures and increased humidity combined with high level of air contamination can lead to corrosion risk in data centers. As we will discuss in this paper only a comprehensive monitoring and management technology addressing the corrosion risk in real-time promises to enable the full leverage of both the expanded range of environmental parameters for operating IT equipment as well as air side economizer.

There are two types of contamination that were identified to impose risk on IT equipment; particulates and gaseous contaminations. [9] Recent investigation of the particulate contamination levels in data centers established that proper filtering can reduce the concentrations to acceptable levels. [10] For gaseous contamination monitoring, the ASHRAE publication [9] states that reactivity should be measured both for copper and for silver. The study recommends that copper and silver corrosion rates should be maintained less than 300 Å/month for a non contaminated environment. Furthermore the ASHRAE publications suggest that in situations where atmospheric contamination is high, proper filtration should be used to reduce the corrosion levels below 300 Å/month. [9]

Based on ANSI/ISA-71.04-1985 the corrosivity in data centers can be classified according to 4 severity levels: G1 level-Mild with copper reactivity rate below 300 Å/month; G2 level-Moderate with reactivity levels between 300 to 1000 Å/month; G3 level-Harsh with reactivity levels between 1000 to 2000 Å/month; and G4 level-Severe with reactivity levels above 2000 Å/month. [11]

In this article we present the development of a high sensitivity real time corrosion sensor technology and initial corrosion results from a data center with known corrosion problems. We investigate the indoor air parameters (temperature and relative humidity) impact and their synergistic effect on the corrosion rate. Spatial and temporal variations of the corrosion rate are established in this data center and corrosion rate changes are correlated with temperature and relative humidity variations. We are also comparing two corrosion monitoring techniques, one based on real time corrosion sensing and a second based on Coulometric detection of metal coupons.

High sensitivity corrosion rate measurements enable the development of corrosion management strategies in data centers. With corrosion sensors installed both inside the data centers and outdoor, the corrosion management enables real time monitoring of the pollution levels of the outside air for cooling purposes. Such a strategy can prevent polluted air being used for cooling purposes and enable air side economizer utilization when outdoor contamination levels are low. With contamination (corrosion) sensors distributed in the data center, the continuous monitoring will assure that year long air quality specifications are maintained in the data center including the effectiveness of gaseous filters. Having contamination control monitoring is critical in areas with higher corrosion risks (such as CA, NY, NJ) where previous measurement of the gaseous contamination of the outdoor air established that the corrosion rates can be higher then the recommended upper levels (300 Å/month). [12]

2. Corrosion monitoring and management

Corrosion caused failures of discrete electronic components and PCB boards have been reported in literature. [13-15] Studies since the 1980's reveal that atmospheric corrosion is a concern for telecom facilities, avionics and nuclear plants. Concomitantly corrosion management strategies have been developed for nuclear plants and for avionics. [16-19] These management models include prognostics to asses the mean time to failure and useful lifetime for components, circuits and systems. Similar strategies may become feasible for data center operations, where risk factors like increased operating temperature, very high and very low relative humidity, rapid temperature and humidity cycling and air contamination could be quantified by standard metrics that allow comparison of the risk levels between data centers.

An emerging risk factor is the air contamination in data centers that can lead to corrosion related failures. There are two main goals of a corrosion management strategy: establish the risk levels for IT equipment operated in contaminated atmosphere and propose strategies to mitigate corrosion effects. A successful corrosion management approach should integrate correlation of the corrosion rate levels with mean time to failure for electronic component and IT equipment and should use prognostic tools to estimate the remaining useful lifetime. Since corrosion is a synergistic result of gaseous contamination, temperature, and humidity variations in data centers, the corrosion has to be analyzed in the context of data center operating conditions. A full scale deployment of temperature, humidity, and air flow sensors combined with corrosion sensors enables the development of predictive risk models for data centers.

Gaseous contamination can be monitored by (1) measuring the composition of the air in the data center or (2) metal reactivity monitoring. For reactivity monitoring, a clean metal surface is exposed to the contaminated atmosphere and the growth rate of contamination product is measured. Gas composition monitoring in data centers can measure contamination levels directly. However, relating gas concentration levels to corrosion rate turn out to be a challenging task. [20] The reactivity method is a more direct and preferred characterization of the corrosion rates in data centers over gas concentration measurement. [21]

For atmospheric contamination monitoring it has been established that silver and copper are reactive to atmospheric pollutants including sulphur bearing gases. Furthermore silver is more reactive in the indoor atmosphere while copper is a better monitor of the outdoor air. [12]

The reactivity of the contaminated atmosphere with metal surfaces can be measured by passive and real-time means. Passive methods expose metal foils to the environment and measure the thickness of the corrosion product by Coulometric reduction or by weight gain. The real-time sensing on the other part, measures the transformation of metal films into corrosion products. There are two real time detection approaches: electric measurements of the resistance change of a thin metal film or weight gain measurements. [22] Both these methods measure cumulative corrosion over the exposure time.

We developed a very sensitive atmospheric contamination sensor with a corrosion rate sensitivity of 1 Å/day and sensor lifetime of over 2 years. In other corrosion sensor implementations there is a tradeoff between (1) the corrosion rate sensitivity that is limited by smallest corrosion caused change detectable by the recording equipment and (2) the lifetime of the sensor that is limited by the film thickness that gets consumed by corrosion. In our approach, to maintain the sensitivity while preserving sensor lifetime, multiple sensors having increasing film thicknesses are monitored simultaneously. Once the thinnest film is consumed by corrosion, the detection circuit monitors the second sensor having a larger film thickness, and when the second sensor is consumed the circuit monitors the third sensor. The sensor consists of thin metal film structures deposited on glass or silicon surfaces. The width and the length of the metal film are much larger than the film thickness assuring that any change in resistance is fully due to film thickness change. Once the metal film is exposed to the corrosive environment the silver and copper film get transformed into non conductive corrosion products like Ag_2S, Cu_2O, Cu_2S etc. This change in chemical composition of the film results in a change in film thickness and an increased resistance of the thin film structure. The resistance change is converted to film thickness loss and the change over a period of time gives the corrosion rate. Furthermore both silver and copper sensors are located on the same substrate such that corrosion rates for both metals are investigated simultaneously under similar environmental conditions.

The detection electronics is a Wheatstone bridge circuit where the exposed silver and copper film elements are resistors of the bridge arm. Bridge circuits have been used in the past for strain sensing where small changes in resistance can be detected. The corrosion sensor and the detection electronics are shown in Fig 1a. A 1-wire communication protocol is used for sensor inquiry and the data is recorded using IBM's Measurement and Management Technologies (MMT). [23] MMT is an established technology for optimizing energy efficiency in data centers. MMT entails an analytic platform to monitor and to integrate sensor data in physical models for full scale modeling of the environmental conditions of the data centers (Fig 1a). [24] The corrosion data complement temperature and humidity information acquired by MMT for a holistic assessment and modeling of the atmospheric conditions in data centers.

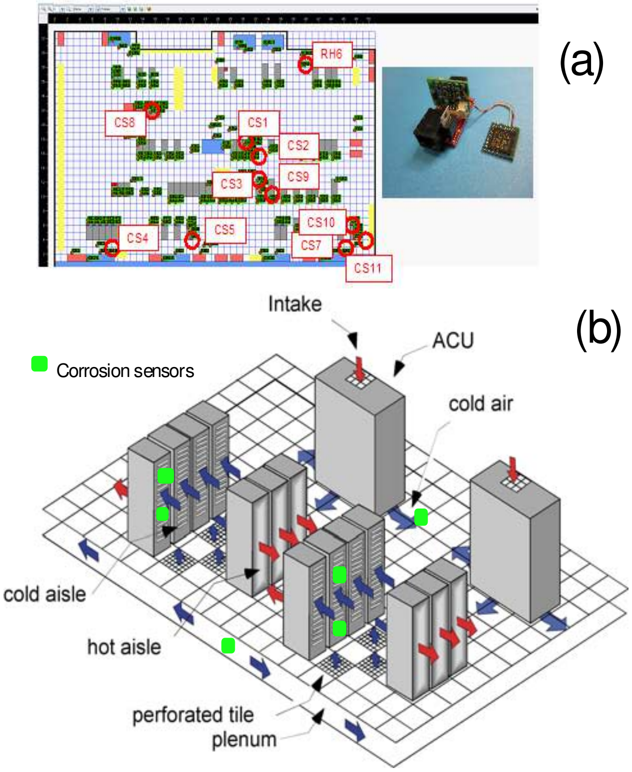


Fig 1 The data center layout (a) with sensor positions marked on the MMT map and a picture of the corrosion sensor with the electronic circuit. Schematics (b) of sensor placement under the raised floor and in front of racks at a height of 0.5 m and 1 m.

Real time silver corrosion sensors were placed in a DC with raised floor that utilize air cooling. The sensors were mounted at the outlet of ACUs (2 sensors), in front of computer racks at 0.1 m above the ground (4 sensor), at a height of 1 m front of rack (4 sensors) and at a height of 2 m front of rack (1 sensor). To compare the corrosion measurement methods, besides real time sensors additional silver and copper coupons were installed in front of two racks for a period of 1 month. Additional reference coupons enclosed in a plastic bag were deployed to establish the reference levels for corrosion product calculations. In the case of the reference copper coupon, after being deployed in the DC, sealed in protective bag, a thin Cu_2O oxide film (16± 2 Å) was formed while the control silver coupon had no corrosion product. Copper interacting with the moisture in the air oxidizes over a short period of time.

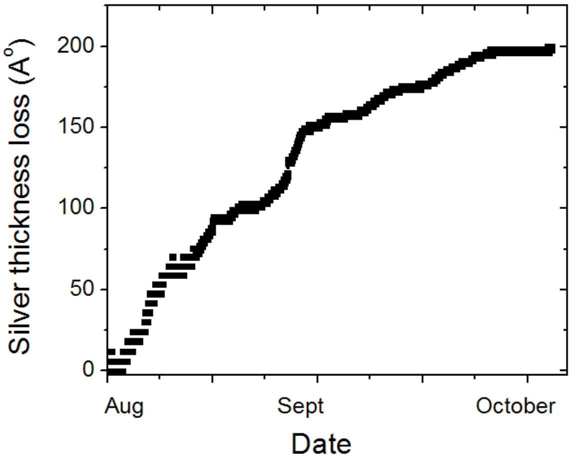


Fig 2 Silver film loss as function of time for a corrosion sensor positioned at front of rack at 0.1 m height.

Real time corrosion sensors located under the raised floor, at the outlet of ACU, detected small corrosion (<10 Å/month). We note that in these locations the temperature was maintained constant at 15° C during the time of measurement. For other sensors located above the raised floor at a height of 0.5 m in front of racks, the average corrosion rate was ~160 Å/month. For sensors located at 1 m height the corrosion rate was ~140 Å/month. Sensors located above the raised floor, the air temperature was 23° ±2 ° C as the cold air coming from the raised floor is mixed with air that backflow from the fans that cool the IT equipment. The other corrosion sensors placed at same height but different racks measured a corrosion rate of 150 Å/month.

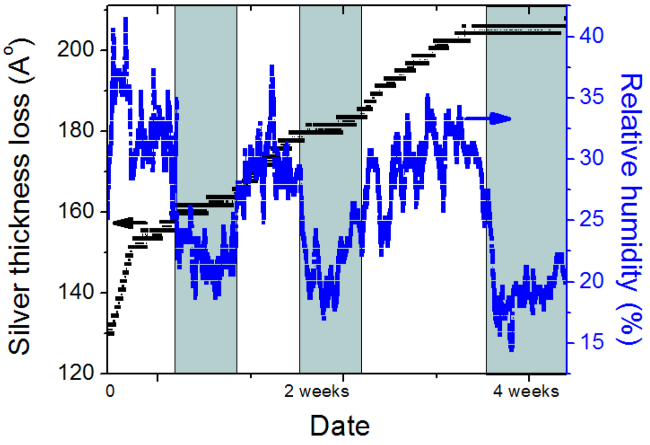


Fig 3 Silver thickness loss and simultaneous variation of the relative humidity in the data center. When the relative humidity goes below 27% (shaded regions) the metal loss became constant.

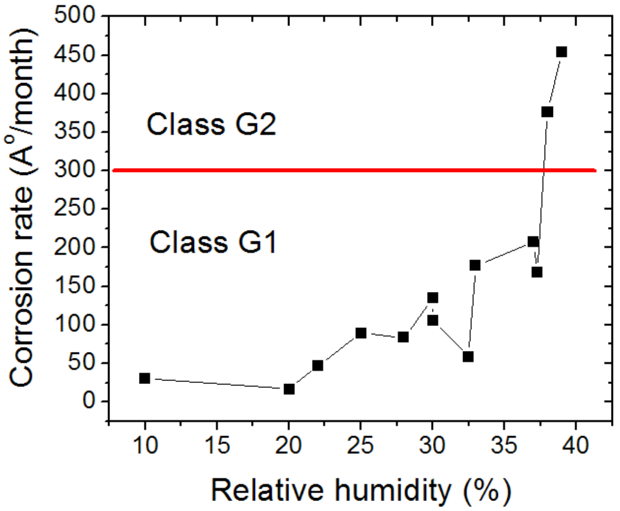
The variations in the corrosion rate are due to the different micro-environmental conditions that sensors are placed. Different humidity and air flow rates have their influence on the corrosion rate.

The silver film loss for a 2 month time period is shown in Fig 2. The silver film loss increased with time, as the silver gets consumed once reacting with the polluted atmosphere. There are periods of time when the metal loss is constant (plateaus in the curve), the corrosion rate of the silver film is very small. A section of Fig 2 is shown in Fig 3 where the metal loss and the relative humidity changes are plotted on the same graph. The silver film loss is strongly influenced by the relative humidity measured in the same locations (Fig 3). When the relative humidity was below 27% the metal loss became constant. The shaded regions are the periods when humidity is below 27 % and the metal loss is constant. When the relative humidity was above 27%, the silver thickness loss is accelerated.

The silver thickness loss data from Fig 3 were converted to corrosion rates (i.e. by determining the slope of metal loss for segments where the relative humidity was constant). For every segment the corrosion rate was calculated as the ratio of metal loss divided by the time period. The corrosion rate as function of relative humidity and also as function of temperature is shown in Fig 4.

The corrosion rate detected by the same sensor changed from 50 to 500 Å/month with an averaged corrosion rate of 150 Å/month. These changes of the corrosion rate are due to temperature and humidity variation during the study period. The change in corrosion rate as function of relative humidity and temperature in the data center is shown in Fig 4. The silver corrosion rate, for this particular data center, is mainly driven by relative humidity variations; as the relative humidity increases above a certain threshold the corrosion rate also increases. Previous studies suggested that silver corrosion rate is independent of humidity while other studies measured a humidity dependence on corrosion rates. [12, 25] For the 60 nm silver sensors used in this study the corrosion rate increases with relative humidity. Since the temperature variations are less than 3°C, the corrosion rate is not strongly influenced by temperature in this particular data center. Further studies are necessary to establish the corrosion rate dependence on temperature in data center environments.

Copper and silver coupons were deployed in the same data center for a period of 1 month. There were 2 silver and 2 copper coupons positioned at 0.5 m and 1.5 m height. The coupons were analyzed using Coulometric reduction for corrosion rate measurements: the corrosion rate was 121± 35 Å/month for silver and 48±13 Å/month for copper. The same analysis established that the main corrosion products were Ag_2S for the Silver foil and mainly Cu_2O and a small amount of CuO for the Copper foil. Both real time corrosion sensors and coupon measurement indicates that the atmosphere is G1 level (corrosion rate <300 Å/month) suitable for data center operations as per ASHRAE recommendations. The corrosion rate measured by the real-time sensors varied significantly over the study period and there were periods of time when the corrosion rate was >300 Å/month indicating a G2 environment.



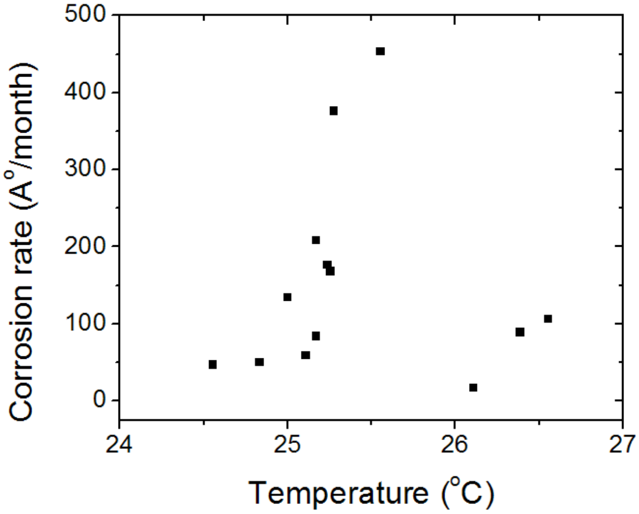


Fig 4 Corrosion rate for a Silver corrosion sensors and its dependence on relative humidity and temperature variation in the data center.

It must however be noted that gaseous contamination has seasonal variations and measurements should be taken over an extended period of time to establish the contamination level in the data center. We also note that the indoor atmosphere of this particular data center was strongly influenced by the outdoor dew point temperature. While the dew point inside the data centers was maintained in the ASHRAE recommended range, the indoor dew point temperature varied up to 14° C during the study period. The indoor dew point was tracking the outdoor dew point temperature during the study period. Data centers that are strongly influenced by the amount of "fresh air" make up and where indoor dew point temperature tracks the outdoor dew point temperatures are exposing IT equipment to weather variability. Ideally both temperature and humidity should be maintained constant and within the ASHRAE recommended range avoiding exposure of IT equipment to large dew point variations.

3.Discussion and Conclusion

Using outside air for cooling can have a large energy saving potential but may pose a risk of air contamination entering in data centers. It is documented that corrosion level of the outside air can have corrosion rates much larger than 300 Å/ month in some parts of the US (NY, NJ, OH, AR and CA). [12] In places where air contamination may pose a risk, gaseous and particulate filtering should be integrated with air side economization. Pollution and air contamination have spatial and temporal variations and these variations should be considered when outside air may be used for cooling purposes. The air contamination should be measured both for the indoor and outdoor air to establish when the outdoor air meets the required specifications to be used for air side economization.

Since the corrosion is a complex function of temperature, relative humidity, and contamination concentration, a facility wide monitoring of air quality parameters is highly beneficial to prevent corrosion failures. To enable gaseous contamination monitoring, an ultra sensitive corrosion sensor technology was developed and was characterized is a data center environment. This case study demonstrated the usefulness of corrosion monitoring and the future applicability of the same technology in air side economized data centers. Besides the effort to monitor the atmospheric contamination in data centers, a parallel effort should focus on characterizing the electronics components and circuits that should become more robust to withstand harsh atmospheric environments. [26, 27]

One risk parameter that appears with free air cooling is the corrosion of IC components and circuits. These risks should be quantified and build into prognostics models to manage and establish strategies to mitigate their effect. The corrosion rate is not uniform across a data center and there are locations where its value can be significantly lower than in other locations. A facility wide environmental sensor network would pinpoint regions with high risk and management models can be developed that relate the risk factors to data center operations. Such models can be extrapolated to provide a three dimensional visualization and prognostics of equipment failure risks in a data center.

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