RELIABILITY CHALLENGES IN AIRSIDE ECONOMIZATION AND OIL IMMERSION COOLING

By

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Abstract

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The Datacom facility which comprises rooms or closets used for communication, computers/servers or electronic equipment requires cooling unit which consumes 31% (23% HVAC cooling + 8% HVAC fans) of overall energy. The ASHRAE TC9.9 subcommittee, on Mission Critical Facilities, Data Centers, Technology Spaces, and Electronic Equipment, has suited the data center’s executives by permitting brief period outings of the environmental conditions outside the prescribed temperature-humidity range, into passable extents A1-A4. To comprehend the expanding server densities and the required cooling vitality costs, data center operators are falling back on cost cutting measures. For instance, they are not firmly controlling the temperature and humidity levels as per ASHRAE recommended envelope and as a rule turning to air side economizers with the related danger of bringing particulate and gaseous contaminants into their data centers. This thesis is a first attempt at addressing this challenge by studying the cumulative corrosion damage to Information Technology equipment in a real world data center. This study serves several purposes: including the correlation of equipment reliability to levels of airborne corrosive contaminants and the study of the degree of reliability degradation, when the equipment is operated, outside the recommended range, in the allowable temperature-humidity range in geographies with high levels of gaseous and particulate contamination. The study is taken place at the modular data center which uses air-side economizer located at Dallas Industrial area which falls under ISA 71.04-2013 severity level G2.

Full submersion of servers in dielectric oils offers an opportunity for significant cooling energy savings and increased power densities for data centers. The enhanced thermal properties of oil can lead to considerable savings in both the upfront and operating costs over traditional air cooling methods. Despite recent findings showing the improved cooling efficiency and cost savings of oil as a cooling fluid, this technique is still not widely adopted. Many uncertainties and concerns persist regarding the non-thermal aspects of an oil immersion cooled data center. This study reviews the changes in physical and chemical properties of information technology (IT) equipment and compatibility of materials like polyvinyl chloride (PVC), printed circuit board (PCB) and switching devices with mineral oil to characterize the interconnect reliability of materials. The study proposes a testing methodology which can be adopted by all for evaluating the reliability of electronic packages and components when immersed in mineral oil. The study indicates the effect of mineral oil on IT equipment reliability and reliability enhancements for oil cooled data centers. This thesis also includes Cup Burner Experiment as per ISO 14520/NFPA 2001 standard to determine the minimum design concentration of fire extinguishing agent for the class B hazard of heavy mineral oil and the class C hazard of electronic equipment as a part of the safety concerns for oil cooled data centers.

Table of Contents

List of Illustrations

List of Tables

Chapter 1

Introduction

To comprehend the expanding server densities and the required cooling vitality costs, data center operators are falling back on cost cutting measures like they are not firmly controlling the temperature and humidity levels as per ASHRAE recommended envelope and as a rule turning to air side economizers with the related danger of bringing particulate and gaseous contaminants into their data centers.

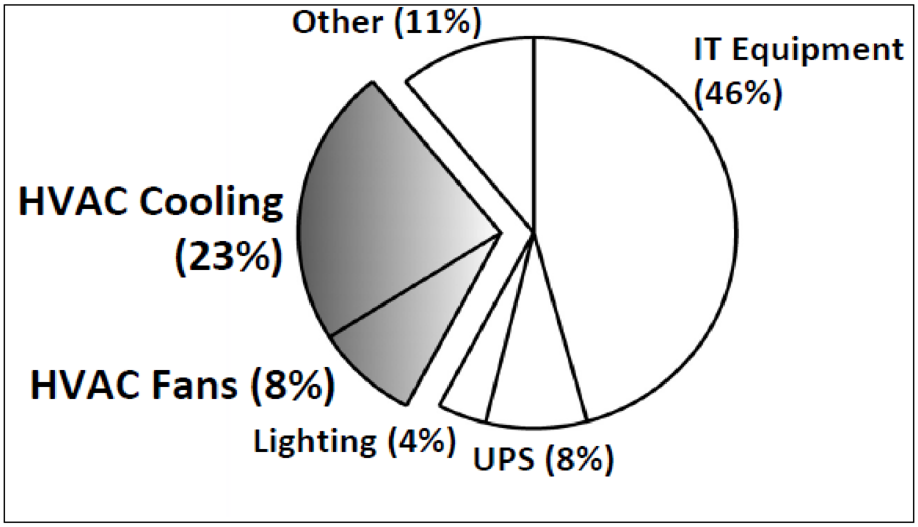

Figure 1: A common data center power allocation [20]

Figure 1 shows power allocation usually found in data centers. The Datacom facility which comprises rooms or closets used for communication, computers/servers or electronic equipment requires cooling unit which consumes 31% (23% HVAC cooling + 8% HVAC fans) of overall energy. With the radical change in data center operational temperature and 100% utilization of economizer, operators can save up to 74% of mechanical energy. [20]

1.1 Energy usage and cooling alternatives

Increasing dependence on computer based application led to the demand for faster and improved communication. The desire to store, recover and control the data has led to use of microelectronic devices (MCD) integrated with microelectromechanical systems (MEMS). To match with the rising demands, better and efficient servers are needed for information processing which has eventually led to the growth of datacenters. A significant amount of energy is utilized for the continuous air-conditioning of the servers with high internal heat loads and to maintain the indoor temperatures within recommended operating. Rising energy costs and ever growing needs for power supplies worldwide has led to increasing efficient use of energy. Due to the recent climatic changes and the greenhouse effect has generated focus on energy savings and use of alternate sources of energy.

The data reported by Koomey mentions that the server electrical use alone represents 1.2% of U.S. electrical use and close 2% for overall electrical use of data center in US [2]. His study stated that the server electrical use has doubled from 2000 to 2005 and will grow by 15% annually from 2006 to 2010. Other articles and references have detailed similar growth rates at individual firms. This rapid increase in energy usage has attracted the attention of environmental agencies in the U.S., European Union, China and other countries. In order to meet with the rising computing costs for the data centers, practices are implementing for cost-cutting measures like operating slightly above the recommended envelope and using the outside ambient air.

The ASHRAE TC9.9 subcommittee, on Mission Critical Facilities, Data Centers, Technology Spaces, and Electronic Equipment, has accommodated the data center administrators by allowing short period excursions outside the recommended temperature-humidity range, into allowable classes A1-A4. Under worst case conditions, the ASHRAE A3 envelope allows electronic equipment to operate at temperature and humidity as high as 24˚C and 85% relative humidity for short, but undefined periods of time [3]. Any choice outside of the recommended region will be a balance between the additional energy savings of the cooling system versus the deleterious effects that may be created in reliability, acoustics, or performance [4]. Various cost-cutting alternatives such as not tightly controlling the temperature and relative humidity levels or using an Air-Side Economizers is implemented, keeping in mind the associated risk of allowing the particulate and gaseous contaminants into their data centers.

Power usage effectiveness (PUE) has become the new metric to measure data center efficiency which creates a measurable way to see the effect of data center design and operation on data center efficiency. To improve PUE, air- and water-side economization have become more commonplace with a drive to use them year round. To enable improved PUE capability TC 9.9 has created additional environmental classes along with guidance on the usage of the existing and new classes. Expanding the capability of IT equipment to meet wider environmental requirements can change reliability, power consumption and performance capabilities of the IT equipment and guidelines are provided herein on how these aspects are affected [5].

As mentioned above, an alternate source to air-conditioning, air-side economizers are used to reduce power consumption. The air-side economizers work on the principle of free air cooling which implements outside ambient air as the working fluid.

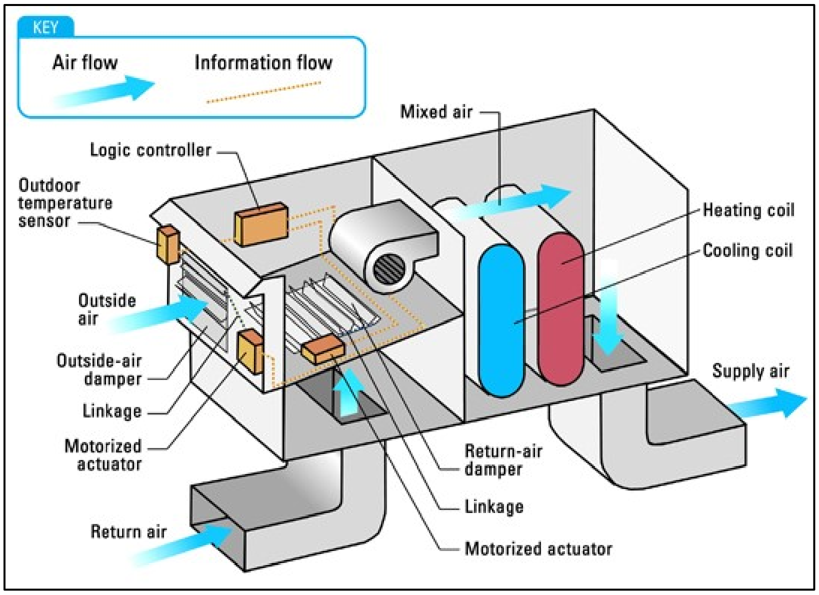

Figure 2: Air-side Economizer

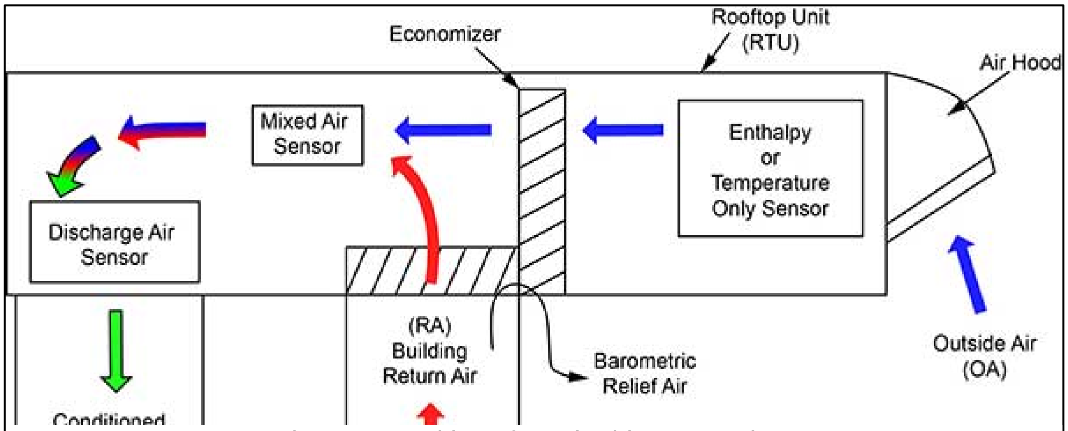

Figure 3: Working of an air-side economizer

Air-side economizers get a lot of the outside free air to cool internal loads, when climate conditions are positive, sparing a lot of vitality by lessening chiller operation. Rather than cooling the recycled air, the hot air from the servers is just coordinated to the climate. At the point when the outside air is at a lower temperature than the recycled inside air, the economizer blends it with the hot air to reach the desired range of temperature and moistness. With legitimate filtration and conditioning, the blended air is then supplied to the datacenter. When the outside air is both adequately cool and dry, the measure of enthalpy noticeable all around is acceptable and no extra conditioning is required. This part of the air-side economizer control plan is called free cooling.

Data centers are usually placed in relatively cleaner environment with suitable filters to eliminate the amount of particulate matter entering the unit. From air side free cooling map, it is clearly noticeable that many data centers across the US take the advantage of free air cooling in terms of usage of air side economizers in hours of operation. Air side economizers are installed in central air handling system with suitable filters to take maximum benefits of the inlet and exhaust air for the datacenters.

The air-side economizer is introjected into the central air handling system for intake and exhaust air, with suitable filters to reduce the particulate matter or contaminants entering the data center. Many datacenters across the U.S. take the benefit of this free cooling which is shown in Figure 3 in terms of the usage of air-side economizers in hours per year.

1.2 Contamination in Datacenters

Datacenters are well designed and are placed in a suitable and relatively clean environments. Hence they do not experience any particulate and gaseous contamination, and if experienced, it is relatively benign. The work presented here is focused on those small fraction of datacenters which have harsh and harmful environmental conditions that is mainly due to particulate and/or gaseous contaminants.

Intel IT conducted a proof-of-concept test that used an air-side economizer to cool servers with 100% outside air at temperatures of up to 90°F. A survey conducted by them estimates that a 500kW facility will save $144,000 annually and that a 10MW facility will save $2.87 million annually [8]. However, this technology is not widely adopted because of many factors like the class of environment (temperature variations) in which economizers are placed, climatic conditions (exg. humid to dry air conditions). The reluctance in using this technique is due to the undetermined equipment reliability due to introduction of outside air pollutants which over time could cause failures. It should be even noted that the reduction of circuit board feature sizes and the miniaturization of components, necessary to improve hardware performance, also makes the hardware more prone to attack by the corrosive particles and gases in the data center environment. This develops the need to study the detrimental effects of using free cooling on the IT equipment reliability.

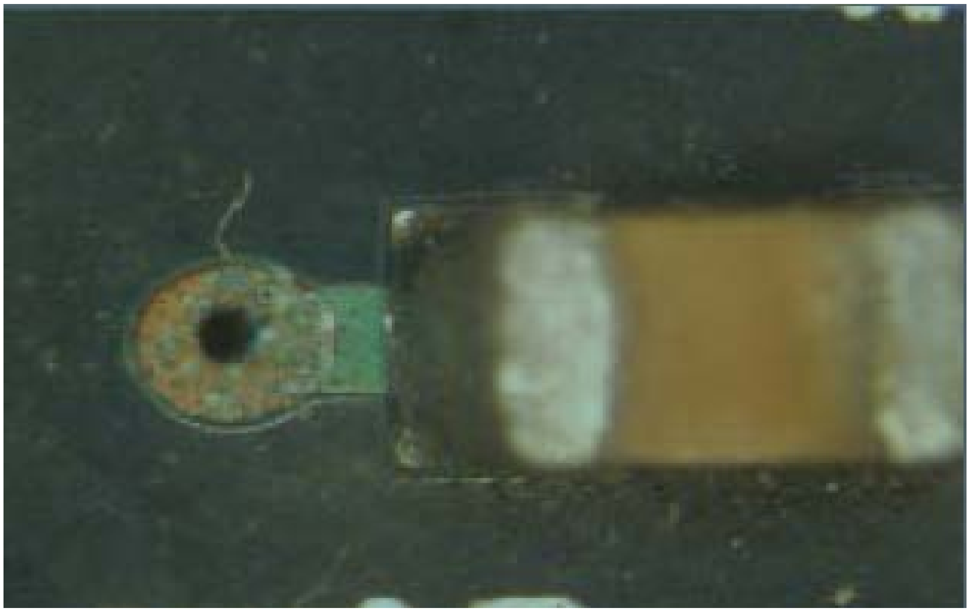

Figure 1: Corrosion of a plated through hole because of wetted ionic dust

Expansion in the ASHRAE's guidelines for data center safe operating temperature-humidity envelopes generates the need to know the potential risk or predicting the failure rates of hardware that is involved in operating outside the envelopes. The recommended range for temperature as given by ASHRAE is 18ºC to 27ºC and for humidity is up to 60% [1]. These conditions are conducive enough for corrosion to occur on the IT equipment. Thus, the air entering the datacenter via the economizers pose a potential threat to electronics of the IT equipment. Hence, any choice outside of the recommended region should be a balance between the additional energy savings of the cooling system versus the deleterious effects that may be created in reliability, acoustics, or performance [4].

Various particulate matters like pollen, dust, debris, automobile emission, carbon dust, smoke, etc. are known to enter the datacenter. Specially designed MERV filters are used to filter the particulates but the ones with diameter < 2.5µm are reported to be unfiltered. These particulate matter (PM) is known to become wet under the influence of moisture present and therefore becomes conductive. When the deliquescence relative humidity (DRH) of the particulate matter is lower than that of the datacenter, the PM gets wet by absorbing water and becomes corrosive in nature [9]. Figure 4 is an example of copper corrosion caused by dust settled on a printed circuit board.

While the PM is wet results in electrically bridging closely spaced features on printed circuit boards, resulting in current leakage eventually leading to their electrical failure [3]. According to ISA-71.04-1985, “Failures attributed to particulate matter have even been observed in data centers where the gaseous contamination levels are low enough to meet the ANSI/ISA-71.04-2013 G1 severity level” [10] . Thus with the miniaturization of electronic components, the reduction of feature spacing on PCBs along with the loosening of the data center temperature and humidity envelope to save energy is making electronic hardware more prone to failure due to particulate matter [3]. The role of gaseous contamination is discussed in next chapter.

1.3 Gaseous Contamination

With the increase in the rate of hardware failures in data centers high in sulfur-bearing gases, led to the study of dust and gaseous contamination. Corrosion induced failures is common in electronics due to higher levels of gaseous contaminations. Common modes of corrosion failures due to gaseous contamination is are the corrosion of silver terminated surface mount resistors and the creep corrosion on printed circuit boards (PCBs) [11]. The corrosion of silver terminations in the Surface Mount Technology (SMT) resistors has been brought largely under control by improving the packaging of the resistors. The creep corrosion of PCBs is believed to be more susceptible to RoHS complaint circuit boards [12] [13]. RoHS is the European Union of Restriction of Hazardous Substance (RoHS) directive issued in February 2003 that took effect on 1 July 2006, banning the use of lead in solder joints [14].

The silver and copper solder contained the lead tin (PbSn) solder has two shortcomings: One is its higher melting range that necessitates the change of PCB laminate epoxies to ones with higher glass transition temperatures; the second is the poor wetting of the copper metallization on the PCBs by the lead-free solder, necessitating the use of various surface finishes on the copper metallization to enhance wetting by the lead-free solder. The net result is that the RoHS compliant PCBs are more prone to creep corrosion as shown in Figure 5 [11]. Picture courtesy 2011 “Gaseous and Particulate Contamination Guidelines for Data Centers”.

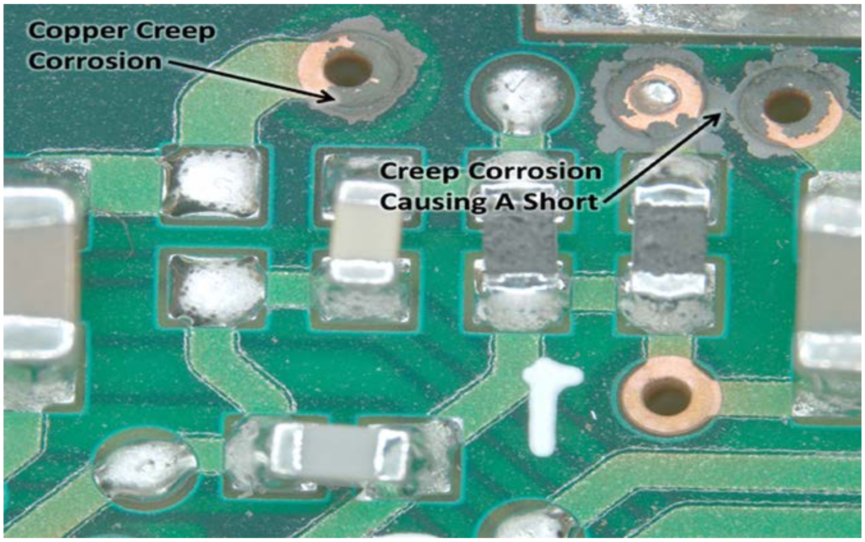

Figure 2: Example of copper creep corrosion on a lead-free circuit board

Creep corrosion is the corrosion of copper (and sometimes silver) metallization on PCB and creeping the corrosion product, mainly the sulfides, resulting in the electrical shorting of PCBs. From the survey by Fu, H., Zhou, Y. et al, the challenge still remains to develop a reliable qualification test for creep corrosion, though progress has been made developing the mixed flowing gas (MFG), the Chavant clay and the flowers of sulfur tests [12] [13] [15]. The gaseous contaminants when enters the datacenter, under the influence of temperature and humidity, undergo a chemical reaction with the elements of PCB resulting in the surface deposition of products like oxides, sulfides or chlorides. These products gradually increase and short circuit the adjacent buses or solder joints as shown in Figure 6 and 7.

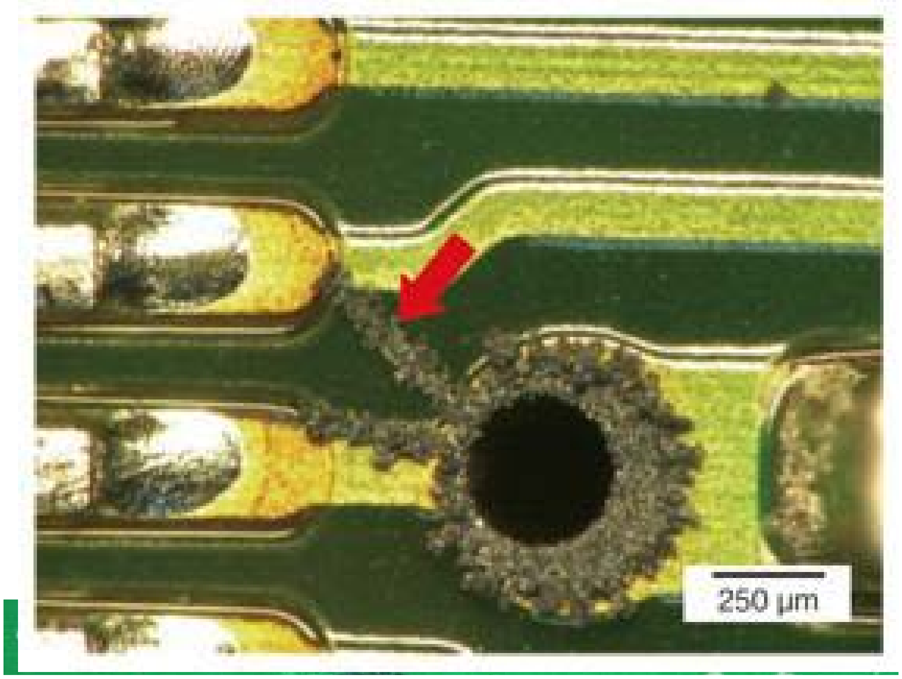

Figure 3 Short in adjacent solder hole and bus line as a result of surface deposition

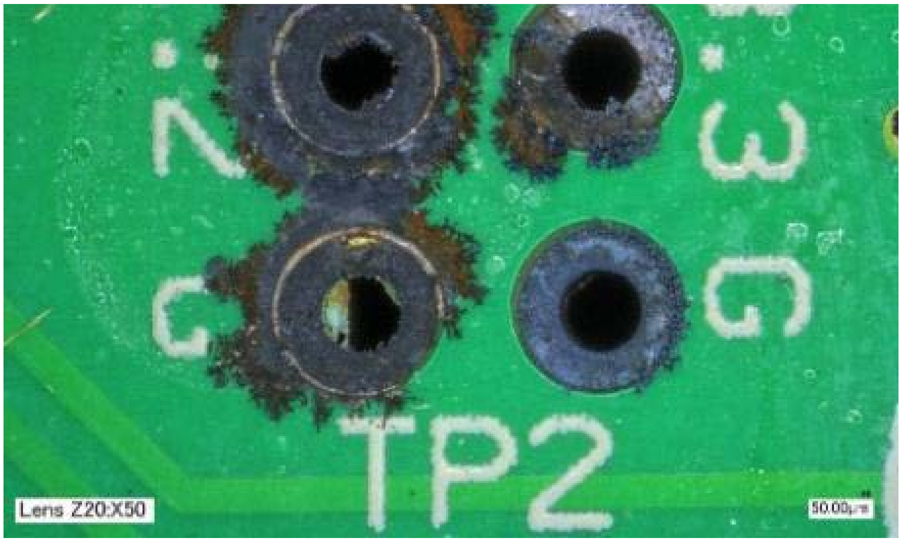

Figure 4 Short Due to the Mixture of Gaseous Contaminants

Sulfur bearing gases, such as Sulfur dioxide (SO_2) and Hydrogen sulfide (H_2S), are the most common gases in the datacenter causing hardware corrosion [16]. Other harmful gases like, Nitrogen dioxide (NO_2) and Chlorine (Cl_2) are also considered to have the most influence on the corrosion of copper and silver. Gaseous composition environmental limits have been published in ANSI/ISA-71.04-1985 [17]. Determination of gaseous composition is not trivial. The gaseous composition present in the air can be determined using a gas analyzer. Predicting the rate of corrosion from the synergy of various gases becomes a complicated task. A low-cost, simple approach to monitoring the air quality in a data center is to expose copper and silver foil coupons in the data center for 30 days followed by coulometric reduction analysis in a laboratory to determine the thickness of the corrosion products on the metal coupons [18]. From a survey of ASHRAE literatures and whitepaper, it observed that a very strong relationship for the frequency of corrosion related hardware failures to the copper and silver corrosion rates [17].

With the fast growth of Information Technology Equipment, the concern for removing heat out is constantly increasing. The world is looking for cheaper and reliable sources to meet the need [1] [2]. In the vast expansion the use of Mineral Insulating oil for cooling IT equipment expanded a lot and now it becomes essential to monitor and maintain the reliability of cooling oil along with the durability concerns. To explore and develop a deeper understanding with the concept of oil Immersion cooling this paper provides the insight for current challenges.

The reason in choosing mineral oil for cooling purpose is its production and availability at a cheaper cost throughout the world. Also to mention here oil emersion cooling has an edge over water or air in terms of thermal properties which is the key in cooling microelectronics. The main resource of mineral oil is fossil fuel which contributes to 85% of the energy used in the world.

Ever since we now have set up that mineral oil would have been a lot more effective to use for eliminating temperature by personal computers, let's have a look at how a program could be manufactured to take advantage of this simple fact [3] [4] [5] [9], also the Operational efficiency with respect to the properties of fluid, compatibility of components, safety and serviceability.

This report reviews Electronic Performance and Reliability Impacts of Elevated and Harsh Environments – Implications of Free Air Cooling of Data Centers by studying the impacts of free air cooling. The report provides the study on effect of relative humidity, temperature and gaseous and particulate contaminants on IT equipment reliability. It also provides the case studies on power distribution unit failure analysis and hard disk drive failure analysis. The second part of the report focuses on effects of mineral oil immersion cooling on it equipment reliability, reliability enhancements to data center operations and critical non-thermal design considerations for oil cooled data centers.

Note: The majority and important part of the research has not been included in this report as the research is in a process of getting published as a technical paper.

1. Qualitative Study of Cumulative Corrosion Damage of IT Equipment in a Real Data Center Environment Utilizing Air-side Economizer – IMECE 2016
2. Critical Non-Thermal Factors for Oil Immersion Cooled Data Center – IMECE 2016

Chapter 2

Effect of Relative Humidity, Temperature and Gaseous and Particulate Contaminations on Information Technology Equipment Reliability

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Abstract

The energy used by information technology (IT) equipment and the supporting data center equipment keeps rising as data center proliferation continues unabated. In order to contain the rising computing costs, data center administrators are resorting to cost cutting measures such as not tightly controlling the temperature and humidity levels and in many cases installing air side economizers with the associated risk of introducing particulate and gaseous contaminations into their data centers. The ASHRAE TC9.9 subcommittee, on Mission Critical Facilities, Data Centers, Technology Spaces, and Electronic Equipment, has accommodated the data center administrators by allowing short period excursions outside the recommended temperature-humidity range, into allowable classes A1-A3. Under worst case conditions, the ASHRAE A3 envelope allows electronic equipment to operate at temperature and humidity as high as 24oC and 85% relative humidity for short, but undefined periods of time. This paper addresses the IT equipment reliability issues arising from operation in high humidity and high temperature conditions, with particular attention paid to the question of whether it is possible to determine the all-encompassing x-factors that can capture the effects of temperature and relative humidity on equipment reliability. The role of particulate and gaseous contamination and the aggravating effects of high temperature and high relative humidity will be presented and discussed. A method to determine the temperature and humidity x-factors, based on testing in experimental data centers located in polluted geographies, will be proposed.

INTRODUCTION

Since the dawn of the computer age, it has, up until recently, been the universally accepted paradigm that the environmental conditions for mission-critical IT equipment err on the cold and the dry side and be strictly controlled. The 1st edition of the ASHRAE Thermal Guidelines for Data Processing Environments, Datacom series book, published in 2004, defined the temperature-humidity range in which IT equipment manufacturers guarantee their equipment to operate reliably [1]. The 2nd edition of the book, published in 2008, expanded the recommended range to allow an increase in the number of hours data centers can operate in air side economizer mode worldwide. It defined the recommended temperature-humidity range as 18-27oC dry bulb temperature range, 5.5-15oC dew point range and relative humidity less than 60% [2]. In the interest of data center energy saving, in addition to the expanded recommended range, there are allowable ranges to which the IT equipment may be allowed to be exposed for short periods of undefined duration and frequency. Figure 1 shows the ASHRAE recommended and allowable ranges defined in the 3rd edition of the ASHRAE Thermal Guidelines for Data Processing Environments, Datacom series book, published in 2012 [3]. IT equipment manufacturers do state that the equipment will suffer some reliability degradation depending on the extent of deviation and duration outside the recommended limits. With the proliferation of IT equipment and the associated increase in energy consumption, there is relentless pressure from data center administrators to expand the recommended and allowable limits. More details on the temperature and humidity limits are available in the ASHRAE Thermal Guidelines book of which the 4th edition will soon be published.

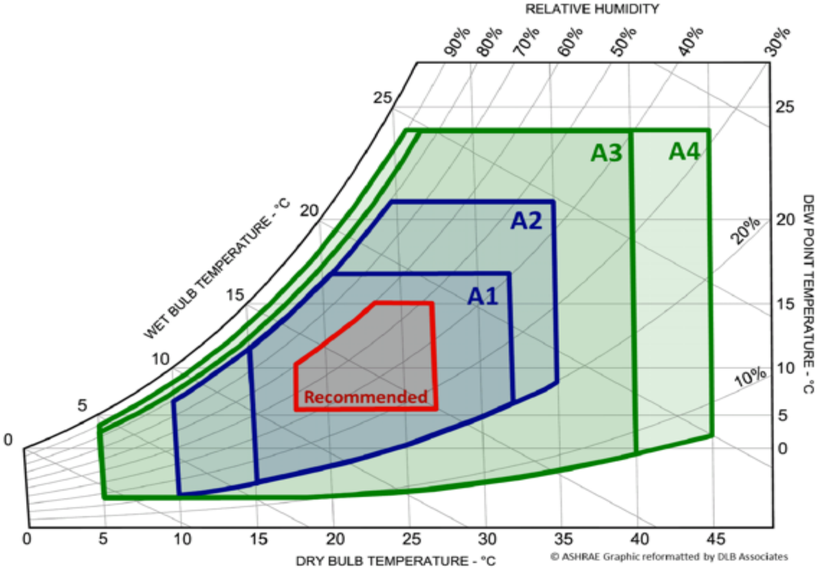


Figure 1: ASHRAE psychometric chart showing the IT equipment manufacturer recommended and the allowable ranges **[2]**

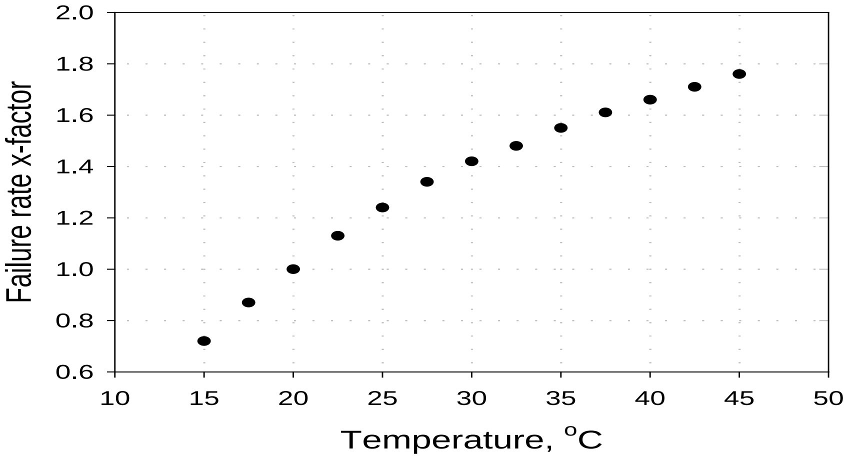


Figure 2: Failure rate temperature x-factor as published in the ASHRAE Thermal Guidelines **[2].**

The physical environment surrounding IT equipment is defined by the temperature, the relative humidity and the gaseous and airborne particulate contamination. Based on field experience, we know that environmental factors can cause IT equipment to fail in two major ways: .

First, electrical open circuits can result from corrosion, such as the corrosion of silver terminations in surface mount components. The IT equipment manufacturers have learned to make their hardware robust against this failure mode, which used to occur predominantly in geographies with high levels of sulfur bearing gaseous contamination [4].

Second, electrical short circuits can be caused by the following mechanisms:

− Copper creep corrosion on PCBs: In 2006, the European Union's RoHS directive banning the use of lead in solders led to changes in PCB finishes and the elimination of lead from solders [5]. These changes dramatically increased the PCB failure rates due to creep corrosion [6, 7].

− Electrochemical reactions such as ion migration and cathodic-anodic filamentation [8].

− Settled, hygroscopic particulate matter contamination reducing the surface insulation resistance between closely spaced features on PCBs: The failure mode that is much more difficult to deal with and eliminate is that of the electrical short circuiting caused by the accumulated particulate matter in humid environments. The difficulty arises from the intermittent electrical nature of these particles and the fact that the failure leaves no visible evidence besides the presence of deposited particulate matter [9, 10].

The IT equipment manufacturers are experienced in the design, manufacture and maintenance of their equipment in the ASHRAE recommended temperature-humidity range. They have learned to mitigate the corrosion-related hardware failures in high gaseous and particulates pollutions levels common in the rapidly expanding markets of Asia. Their field-based experience is, however, limited to environments within the ASHRAE recommended range of temperature and relative humidity.

As more data center environments operate in the allowable ranges for longer periods with higher frequency, the understanding of the roles of temperature and humidity, outside the ASHRAE recommended temperature-humidity range, on equipment reliability, will become more important, especially in the presence of gaseous and particulate contaminations.

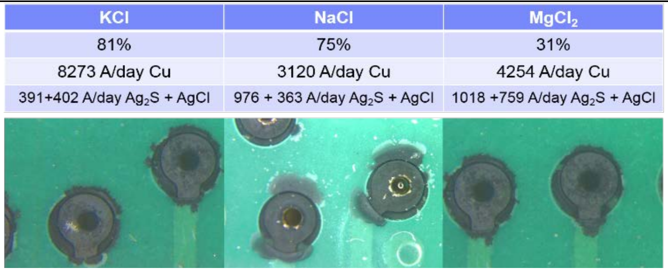
The 3rd edition of the ASHRAE Thermal Guidelines book has a table of temperature x-factor, developed by IT equipment manufacturers, that describes the effect of temperature on equipment reliability [3]. The x-factor at 20oC is assigned an arbitrary value of 1. The x-factor is less than 1 below 20oC and greater than 1 above 20oC. Just as there is x-factor for the effect of temperature on equipment reliability, there is a strong motivation to determine an x-factor for humidity. To develop the x-factor for humidity, the first step is to determine the influence of humidity on the known corrosion-related failure modes of surface mount resistor corrosion and the creep corrosion on PCBs. In addition, there are most probably other corrosion-related failure mechanisms unknown to us that we must somehow take into account in our determination of the x-factor for relative humidity.

The roles of each of the four factors (temperature, humidity, particulate and gaseous contamination) will be examined and discussed in this paper relative to the temperature and relative humidity x-factors.

ROLE OF TEMPERATURE

Temperature can influence equipment reliability may ways, the major ones being as follows:

Temperature coefficient of expansion differences between individual electronic components and their assemblies can effect hardware reliability. Higher temperatures lead to higher mechanical stresses which cause mechanical disintegration of the



KCl	NaCl	$MgCl_2$
81%	75%	31%
8273 A/day Cu	3120 A/day Cu	4254 A/day Cu
391+402 A/day Ag_2S + AgCl	976 + 363 A/day Ag_2S + AgCl	1018 +759 A/day Ag_2S + AgCl

Figure 3: Creep corrosion at various humidity levels at 50°C in chamber with flowers of sulfur and Clorox. The test PCBs are from a lot that suffered creep corrosion in the field.

components or subassemblies even under static conditions. In dynamic conditions involving cyclic temperature fluctuations, the differences in the temperature coefficient of expansion can lead to mechanical fatigue failures.

Rapid temperature fluctuations can also lead to higher corrosion rates of metals. The differences in the temperature coefficients of expansion between the base metal and its corrosion product can generate mechanical stresses at the metal-corrosion product interface that may be high enough to flake off the corrosion products exposing the underlying metal to vigorous attack by the corrosive environment.

Temperature can accelerate mechanisms involving activation energies such as thermo- and electro-migration in metals [11].

Temperature's direct influence on metal corrosion is relatively insignificant compared to the influence of relative humidity. Relative humidity, not the absolute humidity, is the primary factor influencing metal corrosion. Temperature and relative humidity are inversely related. Higher temperature reduces relative humidity and therefore may lead to lower metal corrosion rates. Increasing temperature can reduce the corrosion rate of metals by decreasing the monolayers of water adsorbed on metal surface. Graedel showed that above 0oC, the number of monolayers of moisture adsorbed on silver surface decreased with increasing temperature [12]. The reduced relative humidity will also reduce the detrimental effects of settled particulate matter as explained in a latter section

The 3rd edition of the ASHRAE Thermal Guidelines book addresses the question of the role of temperature on IT equipment reliability by combing through and consolidating the field failure data from multiple IT equipment manufacturers that participated in the ASHRAE Technical Committee 9.9, Mission Critical Facilities, Technology Spaces and Electronic Equipment. A baseline failure rate (x-factor) of 1.00 was chosen to reflect the average probability of failure under a constant IT equipment inlet temperature of 20°C [3]. The x-factor represents a relative failure rate compared to the baseline of a constant IT equipment inlet temperature of 20°C. Figure 2 presents the x-factor over a range of temperature, with equipment operating in constant temperature, steady state condition. The information for the x-factor was from manufacturers' reliability data that included all components within the volume server package. The ASHRAE Thermal Guideline book does not present the raw data or give any information on how the x-factor table was generated [3]. No information is provided on the failure modes involved. As explained earlier in this section, there are some failure modes, such as those associated with mechanical stresses that will be aggravated by increased air inlet temperature; while, there will be others, such as ion migration on PCBs surfaces that will be reduced by increased air inlet temperatures. The effect of temperature on reliability is therefore dependent on the dominant failure mechanism that can vary from product to product and environment to environment. It is highly improbable that there can be a well-defined and monotonic relationship between reliability and temperature as shown in Figure 2.

ROLE OF RELATIVE HUMIDITY

Relative humidity can influence IT equipment in the following major ways:

(a) Degraded performance through increased PCB epoxy dielectric constant and dissipation factor.

(b) Enhanced corrosion in presence of gaseous contamination.

(c) Reduced surface insulation resistance in presence of particulate contamination.

Each of these failure modes is discussed in turn.

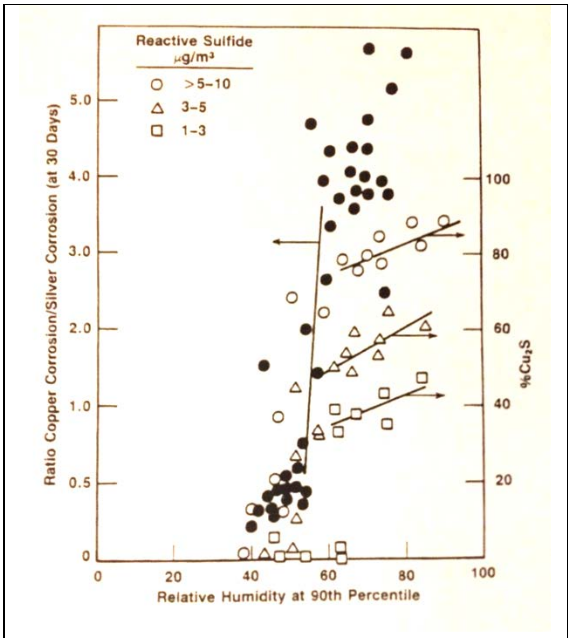


Figure 4a: Open data points are the ratio of copper to silver corrosion rate as a function of relative humidity. The solid data points are the %Cu2S in the corrosion product as a function of relative humidity [**17**].

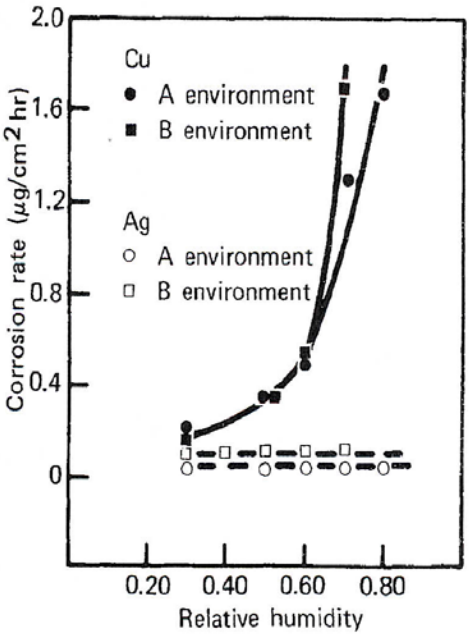


Figure 4b: Copper and silver corrosion rate as a function of relative humidity [**14**].

PCB dielectric constant and dissipation factor:

The two properties of PCB epoxies that affect high-speed circuit design, in terms of signal propagation delay and dissipation factor are

Dielectric constant and

Dissipation factor or loss tangent.

The propagation delay in ns/m is given in terms of effective dielectric constant by the relation:

$$t_{pd} = 1.017\sqrt{\varepsilon_{eff}}$$

where ε_{eff} is the effective dielectric constant of the PCB epoxy. The increase in the dielectric constant due to water absorption increases propagation delay, that is, it slows down the speed at which the signal travels down the wire [13].

Dissipation factor or loss tangent ($\tan(\delta)$ affects the insertion loss (attenuation) a, in terms of dB/inch, of the signal as per the following relation:

$$\alpha = 2.3 \cdot f \cdot \tan(\delta) \cdot \sqrt{\varepsilon_{eff}}$$

where f is the frequency in terms of GHz [13].

As the frequencies move up the GHz scale, more attention has to be paid to dielectric constant and the dissipation factor of the PCB epoxies. As the PCB epoxies absorb moisture, the values of both the dielectric constant and the dissipation factor increase, degrading signal speed and increasing the insertion loss. Fortunately, the moisture take up by the PCB epoxies is slow and there are ample copper planes in PCBs to further slow the moisture uptake. Still, further studies are warranted to study the effect of exposure to high humidity on circuit performance.

Relative humidity enhanced corrosion in presence of gaseous contamination:

As-manufactured, new IT equipment is clean. Its surfaces have high insulation resistance. If there is no trapped contamination in the PCBs, even exposure to high humidity for extended periods of time will not lead to any corrosion-related failures. IT equipment manufactures routinely test their equipment at the four corners of the allowable temperature-humidity envelope without experiencing any corrosion or leakage current failures.

Corrosion-related failures can occur in the field when the equipment is exposed to environments high in gaseous contamination. The role of particulate contamination will be dealt with in a latter section. The two common modes of gaseous contamination induced corrosion related failures that IT equipment is currently suffering are the corrosion of silver terminated surface mount resistors and the creep corrosion on printed circuit boards (PCBs). The corrosion of silver terminations in surface mount technology (SMT) resistors has been brought largely under control by improving the packaging of the SMT resistors and by developing a flowers of sulfur test consisting of exposing the resistors to dry flowers of sulfur in a chamber at 105oC for 20 days [4]. The flowers of sulfur chamber is kept dry by not intentionally introducing moisture in

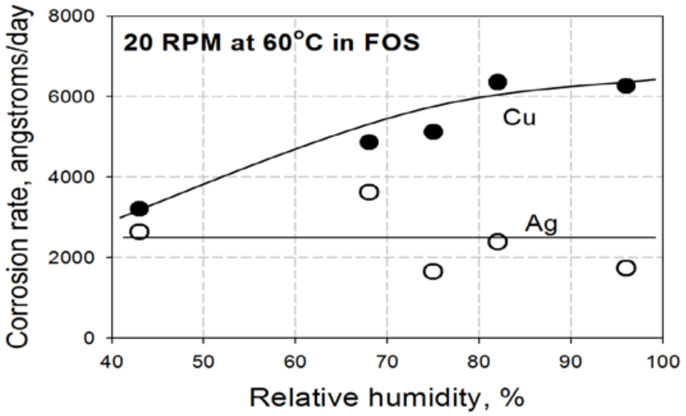


Figure 5: Copper and silver corrosion rate as a function of humidity in a flowers of sulfur paddle wheel camber at 60^{o}C [**15**].

to the chamber; the reason for not introducing moisture is that silver corrosion has little dependence on humidity and, anyway, adding and controlling humidity to a chamber at 105oC would be problematic.

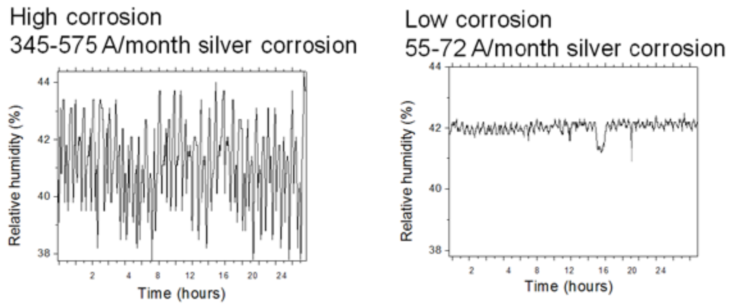


Figure 6: Effect of relative humidity fluctuations on silver corrosion rate.

The creep corrosion of PCBs is commonly believed to be mostly on RoHS compliant circuit boards [6. 7]. RoHS is the European Union Restriction of Hazardous Substance (RoHS) directive issued in February 2003 that took effect on 1 July 2006, banning the use of lead in solder joints [5]. The silver and copper containing tin solder that replaced the lead tin (PbSn) solder has two shortcomings: One is its higher melting range that necessitates the change of PCB laminate epoxies to ones with higher glass transition temperatures; the second is the poor wetting of the copper metallization on the PCBs by the lead-free solder, necessitating the use of various surface finishes on the copper metallization to enhance wetting by the lead-free solder. The net result is that the RoHS compliant PCBs are more prone to creep corrosion. Creep corrosion is the corrosion of the copper (and sometimes silver) metallization on PCBs and the creeping of the corrosion product (mostly sulfides of copper and sometimes silver) on the board surfaces which may lead to the electrically shorting of neighboring features on PCBs. The problem of creep corrosion has been largely brought under control by selecting finishes, by trial and error, that have less propensity to creep corrosion. But the challenge of a reliable qualification test for creep corrosion remains, though progress has been made developing the mixed flowing gas (MFG), the Chavant clay and the flowers of sulfur tests [6, 7, 14].

Relative humidity x-factor in presence of gaseous contamination:

The corrosion-related failures of surface mount resistors is due to the corrosion of the silver metallization in the resistors. Silver corrosion rate is generally believed to be relatively independent of relative humidity [15]. Therefore, the humidity x-factor for the resistor failure mode would be essentially flat at 1, independent of humidity.

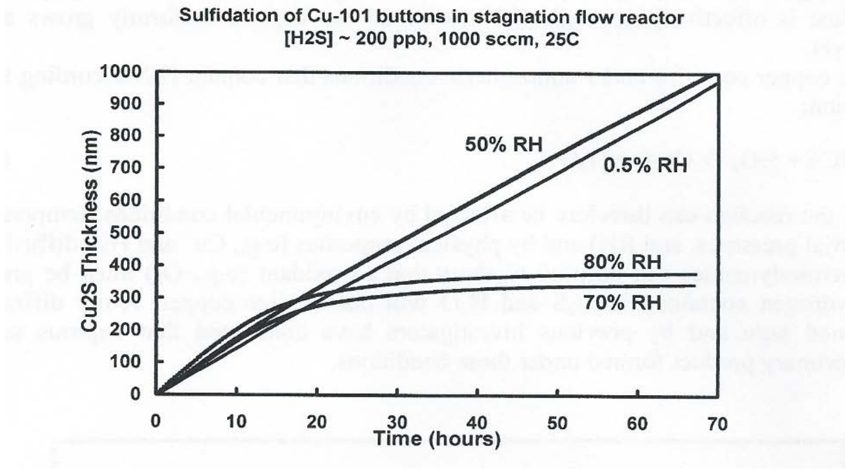


Figure 7: Copper sulfide corrosion product thickness growth as a function of time [**19**].

The creep corrosion on PCBs is a surface-related phenomenon that should probably be influenced by relative humidity. However, amongst the hundreds of creep corrosion failures in the field since the roll out of RoHS-compliant PCBs, the role of relative humidity has not been so strong as to be clearly evident. There have been no known cases of data centers in which PCBs suffered creep corrosion because of high relative humidity in the data center. There is some evidence in laboratory creep corrosion testing in flowers of sulfur chamber that indicates that creep corrosion may be quite independent of relative humidity. Creep corrosion tests have been conducted on PCBs from lots known to have suffered creep corrosion in the field. The test details have been described elsewhere [16]. A 20-RPM paddle wheel setup flowers of sulfur (FOS) chamber at 50oC with Clorox as a source of chlorine gas was used to test the PCBs. Tests were run for 5 days at three different humidity levels using KCl saturated salt solution for 81%RH, NaCl for 75%RH and MgCl2 for 31%RH. As shown in Figure 3, creep corrosion occurred at all three relative humidity levels, indicating that relative humidity may not have a strong influence on creep corrosion. Similar results showing creep corrosion occurring at relative humidity as low as 31% have been obtained in an on-going, soon to be published iNEMI study. This inference is support by Abbott, who showed that the creep of Cu2S on gold surfaces is not a strong function of humidity [17, 18]. In summary, relative humidity was not found to be factor dominating creep corrosion. Even at 31% relative humidity, the lowest relative humidity used in the study of Figure 3, the creep corrosion was found to be significant. Therefore, the humidity x-factor for creep

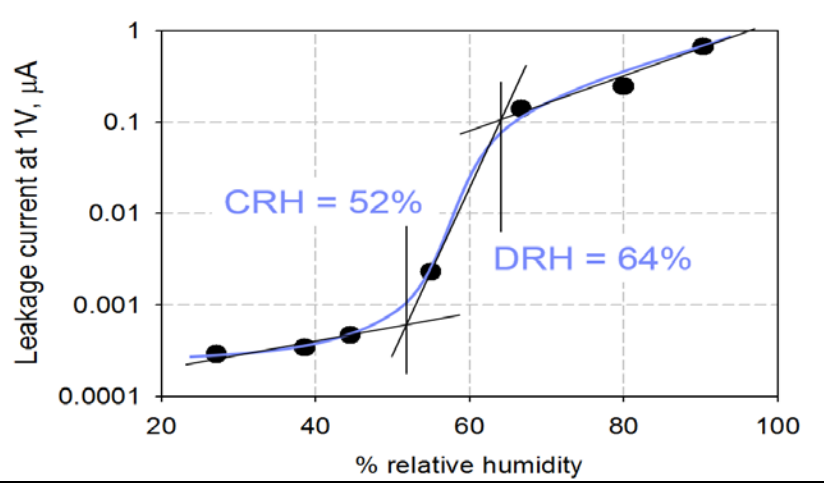


Figure 8: Leakage current through particulate, contamination collected in an Indian data center, as a function of humidity.

corrosion is essentially flat at 1, independent of humidity, though more research needs to be done to verify this conclusion.

Besides the resistor corrosion and the creep corrosion, logically there clearly have to be other, unknown modes of failure, of low significance, aggravated by high relative humidity in environments high in gaseous contamination. New corrosion-related failure modes could arise in future machines. Not knowing how to determine the effect of relative humidity on these present and future modes of failure, we can resort to assuming that the dependence of equipment failure rates on relative humidity would be similar to the dependence of the corrosion rates of copper and silver on relative humidity. The corrosion rates of copper and/or silver have been studied by many researchers including Rice [15], Abbott [17, 18], Sakai [19], Graedel [12] and Barbour [20]. Figure 4 shows the results of research by Rice and by Abbott. Rice used a mixed flowing gas chamber to show that the copper corrosion rate rose sharply above about 60% relative humidity, while the silver corrosion rate was quite independent of humidity. Abbott’s study of corrosion rate in over a thousand field sites showed that at above about 60% relative humidity, there was a sharp rise in copper corrosion rate with respect to the silver corrosion rate. Recent research by Sakai involving corrosion rate measurements of silver in a flowers of sulfur chamber showed that silver corrosion rate was quite independent of temperature.

A recent iNEMI study of copper and silver corrosion rates in flowers of sulfur chamber agrees with the results of Rice and Abbott [16]: As shown in Figure 5, the copper corrosion rate has a somewhat steep increase in the 60-70% relative humidity range; whereas the corrosion rate of silver is quite independent of relative humidity.

Abbott's work also points out, probably for the first time, the dominant role played by fluctuating relative humidity in effecting metal corrosion rate [17]. Figure 6 shows the role of humidity fluctuations on silver corrosion rate, in an actual production data center, which rose almost by an order of magnitude when the relative humidity fluctuations were present compared to when the humidity was quite constant. Figure 7 shows copper corrosion rate data collected in another production data. The copper corrosion rate was clearly proportional to the relative humidity and aggravated by relative humidity fluctuations.

Contrary to the works by Rice and Abbott which show a direct relationship between copper corrosion rate and relative humidity, Barbour showed that copper corrosion rate did not monotonically increase with relative humidity. Figure 8 shows that in an environment containing 200 ppb H2S gas, the corrosion of copper was linear with time and initially independent of relative humidity, but as the corrosion product thickened, the corrosion rate at high humidity (70 and 80% relative humidity) decreased, in a parabolic fashion, while that at low humidity (0.5% and 50% relative humidity), the corrosion rate kept increasing quite linearly.

A compressive literature search of copper corrosion rate versus relative humidity led to Figure 9 [15-18, 21-23]. The environmental conditions, including the level of air corrosivity represented in this plot are quite varied. In the spirit of the x-factor concept championed by the ASHRAE TC9.9 committee, the data were normalized at 50% relative humidity, that is, the corrosion rate was normalized at 1 for all data. The plot shows the relative humidity x-factor for copper corrosion as a function of relative humidity. The data fit from the varied sources collected under very different environmental conditions is excellent, indicating the validity of the x-factor concept for copper corrosion rate. The x-factor for copper corrosion rate would be useful to data center administrators if the IT equipment reliability is directly proportional to copper corrosion rate.

Contrary to the works by Rice and Abbott and others which show that silver corrosion rate has little dependence on relative humidity, Graedel states that silver corrosion occurs only in the presence of moisture [12]. There is a monotonic increase in water adsorption with increase in relative humidity: At 60% relative humidity, there are about 4 monolayers of water on the silver surface. The crucial role of water on metal surfaces is the absorption of atmospheric gases and the subsequent dissolution of silver. The water molecules provide the cathodic reaction that consume the electrons produced by the anodic dissolution of the solid silver. Graedel does not provide any information on the effect of relative humidity on silver corrosion rate.

Relative humidity enhanced corrosion in presence of particulate contamination:

Particulate matter contamination is known to become wet and therefore ionically conductive and corrosive if the humidity in the environment rises above the deliquescence relative humidity (DRH) of the particulate matter [24]. In wet condition, particulate matter can electrically bridge closely spaced features on printed circuit boards, leading to their electrical failure. Failures attributed to particulate matter have even been observed in data centers where the gaseous contamination levels are low enough to meet the ANSI/ISA- 71.04-2013 G1 severity level [25]. The combination of miniaturization of electronic components, the reduction of feature spacing on PCBs and the loosening of the data center temperature and humidity envelope to save energy is making electronic hardware more prone to failure due to particulate matter.

A 1993 study by Comizzoli [26] showed that, for various locations worldwide, leakage current due to dust settled on PCBs, increased exponentially with relative humidity. This study led to the conclusion that keeping the relative humidity in a data center below about 60% will keep the leakage current from settled fine dust in the acceptable sub-micro ampere range.

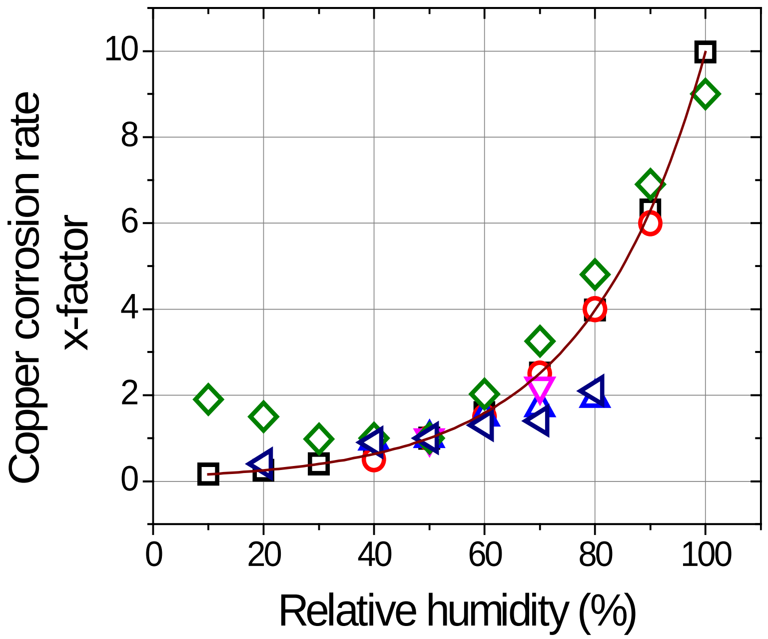


Figure 9: Copper corrosion rate as a function of relative humidity based on comprehensive literature search

A research team at the University of Maryland studied the effect of temperature and relative humidity on the impedance degradation of dust-contaminated electronics [27]. The study is cited here because it concludes that the impedance degradation rises with temperature. The impedance was measured at 90% relative humidity in the 20-60oC temperature range. While the result of this study may be valid, the temperature-humidity conditions are well outside the conditions in data centers. Under more realistic relative humidity conditions, the rise in temperature would lower the relative humidity in a data center. Higher air temperatures also lower the deliquescence relative humidity of salts.

These two effects combined would raise the surface insulation resistance of PCBs contaminated with particulate matter as the temperature is increased.

The role of particulate contamination in high relative humidity environments on hardware reliability can be best described by the plot of electrical conductivity of the particulate contamination versus relative humidity [24]. The electrical conductivity is often expressed as leakage current through the particulate matter at a constant voltage across the particulate matter. Figure 10 is an example of log (leakage current) versus relative humidity for particulate matter collected from IT equipment from a data center in India. The lower relative humidity asymptote intersects the inversion line at the critical relative humidity (CRH) of the particulate matter. This is the relative humidity at which the dust starts adsorbing enough moisture to start becoming electrically conductive. The intersection of the inversion line and the upper asymptote is the deliquescence relative humidity (DRH) of the particulate matter. This relative humidity corresponds to the beginning of the formation of saturated salt solution from the dust.

If the relative humidity in a data center is higher than the deliquescence relative humidity (DRH) of the particulate matter in the data center, the hardware has a high probability of failure due to degraded surface insulation resistance, between closely spaced features on printed circuit boards, especially if the electric field between the features is high [24]. To be more conservative, the upper limit of relative humidity may be specified at the critical relative humidity (CRH) of the particulate matter.

Relative humidity x-factor in presence of particulate contamination:

The effect of relative humidity on surface insulation resistance in the presence of settled particulate matter is a step function: When the data center air relative humidity is below the DRH of the particulate matter, the equipment is reliable; above the DRH, the lowered surface insulation resistance will degrade the equipment reliability.

Since settled particulate matter covers a wide range of chemistries and therefore a wide range of DRH values, there cannot be a reasonably well-defined relative humidity x-factor for settled particulate matter.

DETERMINING TEMPERATURE AND HUMIDITY X-FACTORS

To study the effect of temperature and humidity on IT equipment reliability, particulate and gaseous contamination must be present. Without the contaminants, equipment generally operates reliably in ASHRAR A1-A3 allowable environments. Contaminants limit the temperature-humidity envelope in which equipment can operate reliably. Mixed flowing gas and flowers of sulfur are two corrosive environments available in laboratories. Neither of these tests are ideal for testing IT equipment reliability because they do not represent the environments in data centers. In the laboratory environments, copper corrosion rates are much higher than the silver corrosion rates; whereas, in data centers, silver corrosion rates are generally much higher than copper corrosion rates.

It is strongly recommended that the testing be done in real world field conditions. Testing should be conducted in experimental data centers located in polluted geographies. The copper and silver corrosion rates should be measured as per the AHSRAE location requirements of ¼ and ¾ heights in front of the rack. Corrosion rates should also be measured in other locations in the data centers to help determine the gaseous contamination distribution. Corrosion rates should be determined two ways: (1) Exposing metal coupons for 2 week periods and determining the corrosion product thickness via coulometric reduction: (2) Exposing thin metal films and tracking the real-time corrosion rates by measuring the resistance change of the films. The corrosion rates should be measured at predetermined temperatures and humidity ranging from 20 to 50oC and 30 to 90%RH.

The effect of temperature and humidity on IT equipment reliability should be determined using test hardware consisting of fully populated test printed-circuit boards representing the state of the art technology. The test PCBs should be of convenient size, say, 100x150 mm, assembled on current production lines using the current PCB materials, finishes, solders and fluxes and components. Some features of the test boards may be powered on using batteries for convenience. The advantages of using test hardware rather than actual hardware are cost, size and breadth of technology. The test boards can be manufactured in conveniently large quantity to afford statistically valid sample size. The test boards should be contaminated with dust consisting of equal parts of ammonium nitrate, ammonium sulfate and ammonium hydrogen sulfate to simulate the dust in the polluted geographies of Asia. Dust should be deposited on the test boards by spraying the salt solution using a nebulizer. The test boards should be exposed to the experimental data center air sequentially set at various temperature and humidity conditions ranging from 20 to 50oC and 30 to 90%RH.

In addition to the test boards, we should find and test PCBs from lots known to have suffered creep corrosion in the field. And we should test surface mount resistors from weak lots populated on PCBs.

Interdigitated combs coupons with and without ammonium salt contamination should be placed in the racks and the resistance between the combs monitored on a real time basis to study the effect of temperature, humidity and contamination conditions on the surface insulation resistance (SIR) of PCBs.

The above work should be repeated at one or more experimental data centers located in polluted geographies, preferably in Asia.

Such a project will for the first time relate reliability of current and future technology hardware to the temperature, humidity, dust and gaseous contamination under real world data center conditions in an ANSI/ISA Standard 71.04-2013 severity level G2 or higher environment. Temperature and humidity x-factors can, thus, be determined.

CONCLUSIONS

The temperature x-factor cannot be reasonably well-defined due of the complex and unpredictable nature of the following competing failure mechanisms:

- Failure mechanisms involving temperature coefficient of expansion differences and chemical mechanisms involving activation energies are aggravated at higher temperatures.
- Failure mechanisms dominated by relative humidity are suppressed at higher temperature.

The humidity x-factor cannot be reasonably well-defined due to the complex and unpredictable nature of the following competing failure mechanisms:

- The effects of humidity on SMT resistor corrosion and on creep corrosion may be insignificant.
- In the presence of settled particulate dust, the effect of humidity on equipment reliability would be step wise: very little at low relative humidity and high above the critical relative humidity (CRH) of the particulate matter.

The best way to determine the temperature and humidity x-factors is to conduct tests using copper and silver corrosion coupon and state-of-the-art test PCBs in experimental data centers with ASHRAE severity level G2 or G3. The copper and silver corrosion rates and the test PCB failure rates should be determined as a function of temperature and humidity, in real world data centers in polluted geographies, to obtain the temperature and humidity x-factors.

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Chapter 3

Effects of Mineral Oil Immersion Cooling On IT Equipment Reliability And Reliability Enhancements To Data Center Operations

Abstract

This paper reviews the changes in physical and chemical properties of information technology (IT) equipment materials like polyvinyl chloride (PVC), printed circuit board (PCB) and switching devices due to mineral oil to characterize the interconnect reliability of materials. By submerging all of a server’s heat-generating components in a dielectric liquid, creates the attack on reliability issues at the device level. The improved efficiency of mineral oil may offer simplicity in facility design compared to traditional air cooling and provide a means for cost savings. In spite of its improved cooling efficiency and cost savings, a mineral oil immersion cooling technique is still not widely implemented and suppliers are reluctant to jeopardize sales of existing air-based cooling system equipment. Only compelling physics regarding direct immersion cooling is not enough for data center operators. Many uncertainties and concerns persist regarding the effects of mineral oil immersion cooling on information technology equipment reliability. The paper presents useful information regarding the influence of mineral oil on the mechanical properties as well as chemical properties of a material. The changes in properties of mineral oil like kinematic viscosity and dielectric strength are also cited as an important factor and discussed briefly. The changes in mechanical properties like elasticity, hardness, swelling, and creep are being shown in the paper for thermoplastic materials. The chemical reaction between material and mineral oil as a function of time and temperature is also conferred. These are significant factors which are responsible for the reliability and compatibility of a material. The changes or modifications in materials of important parts in physical and chemical manner are also indicated. The relations between different dielectric oils and different materials provide us a comparative analysis for reliability and performance.

Oil immersion cooling of data centers offers opportunities for enhanced reliability with even temperature conditions in operations as it minimizes common operational issues like: overheating and temperature swings in the system, fan failures in servers, noise, dust, air quality, corrosion, electrochemical migration, and whiskers will also be addressed. The reliability improvements are comprised of the reduction in corrosion & electrochemical migration like corrosive exposure and moisture reduction, reduction in environmental contamination like dust, debris and particulate reduction, stable and even thermal environment and tin and zinc whisker mitigation. These may lead to infer the significance of oil cooled data centers towards performance and savings in operating cost as per reliability aspect. The literature gathered on the subject and quantifiable data gathered by the authors provide the primary basis for this research document.

Keywords— information technology equipment; reliability; compatibility; reliability enhancements

INTRODUCTION

Submerging servers and IT equipment in a mineral oil, a dielectric liquid, for cooling purposes, enables substantial energy savings today and accommodates growing load densities of future facilities. In the current scenario, the lack of extremely high load densities that would make traditional air cooling inadequate has forced the discussion to focus on just the efficiency merits of this technology. The existing proprietary submersion cooling solutions [1], [3], [4] and numerous case studies [2], [3] have established the effectiveness and energy savings for a new construction or a retrofit from device to the facility level. For mission critical operations of a data center, a comprehensive study of reliability and availability is necessary for widespread adoption of this disruptive technology.

This study focuses on the reliability of servers and IT equipment when submerged in a mineral oil at the device level. Prolonged immersion of servers in mineral oil will onset a wear-out mechanism and upon cumulative damage can lead to component failure. Degradation of material property or component functionality is a result of fundamental mechanical, chemical, electrical and thermal phenomena introduced due to changes in the typical operating environment. The superior heat carrying capacity of a mineral oil compared to air eliminates hot spots and produces less variation in temperature spatially and in time. The chemical interactions between the coolant and various components for an extended amount of time introduce lifecycle loads not observed in traditional air cooling. The components considered in this investigation are cables, printed circuit boards, packages and passive components. When we deal with immersion cooling it attacks to the reliability at device and component level. With the concern of critical performance, cost, safety and operating environment, the study of the reliability of these four categories of components becomes significant. The study of the change in the properties of a mineral oil like kinematic viscosity, flash point, and dielectric strength is also the subject of anxiety for the data center operators. These properties have the direct relation with the coolant efficiency, servicing costs, pumping power, operating cost and facility design. It becomes critical to know about these changes as it keeps data centers functioning. Some standard methodologies have already been derived from measuring the change in properties of important components submerged in a mineral oil. But sometimes, it becomes hard to follow those standards because of following limitations [19.]:

(1.) The Joint Electron Device Engineering Council (JEDEC) and the American Society of the International Association for Testing and Materials (ASTM) standards won't be relevant due to the significant difference in the ramp rates of air and oil.

(2.) Failure Mechanisms and Models for IT equipment established by these standards are not directly applicable in the reliability analysis of oil immersed components as oil immersion cooling has different operating conditions than the air cooled data centers for which these standards have been derived.

(3.) IEC and ISO test methods might not have the direct applicability to determine the real degradation in the properties of a mineral oil as the oil cooled data center has different parameters affecting the operation such as temperature, flow rate, varied surfaces, different materials etc.

(4.) The air cooled system has a high fluctuation in operating conditions such as temperature and relative humidity. The standard also indicates such variations in thermal cycling with high temperature differences. In oil cooling, the temperature profile is more stable and even. So the standard also needs to be developed for such conditions and parameters should be modified accordingly.

This paper also leaves a scope for instituting design of experiments for determination of modeling parameters and a methodology which should be analogous to accelerated thermal cycling and accelerated thermal aging, so that it can be accepted as a standard methodology to provide the reliability analysis of oil cooled data center components and the coolant. The methodology should be proposed and adopted which can provide the reliable data to determine the failure in oil cooling technology. The assumptions should be made for all the parameters which are important in the case of oil immersion cooling. The parameters like heat load, flow rate, inlet temperature, placement and power levels of the components and volume of the oil should be considered in order to fix the temperature for the thermal overstress experiment.

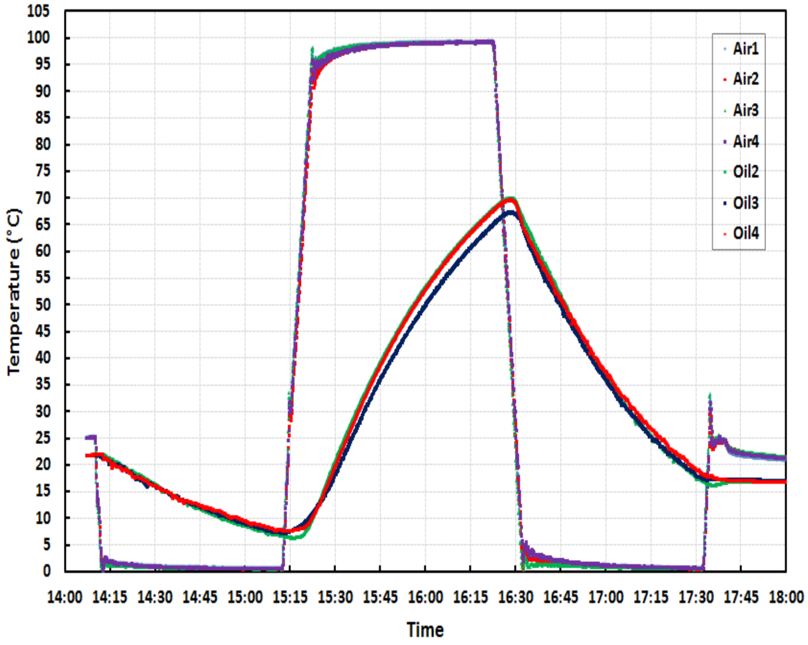

Figure 1: Plot for Temperature Vs Time for Air and Oil [20]

Figure 1 shows the results of the trial test which was conducted to determine the feasibility of performing ATC tests on oil in the environmental chamber. Clearly, the ramp time and dwell times between air and oil are going to be significantly different. Since it seems unlikely that accelerated cycling will be able to be tested in a timely manner, an alternative test is sought. Elevated temperature tests (Thermal Aging) can be used to gather some results of plastic materials for PVC, PCBs, and passive components. In this proposed method, we need to maintain a temperature above typical operating temperatures for an extended duration. This type of test is common in capacitor degradation tests.

Oil immersion cooling technology of data centers extends the prospects for improved reliability in operations as it minimizes common operational issues and eliminates the root causes of failure like reduction in solder joint failures, lower operating temperatures for board & components, no oxidation/corrosion of electrical contacts, no moving parts, like fans, within the device enclosure, no exposure to electrostatic discharge (ESD), no sensitivity to ambient particulate, humidity, or temperature conditions. The reliability advances include a reduction in corrosion & electrochemical migration, lessening of environmental contamination like dust, debris, and particulates, and mitigation of tin and zinc whisker [5], [12] and [13].

EFFECT OF A MINERAL OIL ON PRINTED CIRCUIT BOARDS AND PACKAGES

A primary concern by data center industry professionals regarding mineral oil immersion techniques is the impact of the fluids on the long-term reliability of components and systems. By fully immersing a server in oil, a company may be voiding the warranty on their equipment, and expose themselves to potential failure costs. Current industry data regarding the reliability of server systems after immersion in mineral oil suggest that there is no detrimental impact to components [6] [8]. However, the remarks made in literature are anecdotal, not providing detailed information or data, limiting their utility to the industry at large.

The study was undertaken and discussed below presents a look at the impact of mineral oil on server components. This includes high-level visual observations, microscopic observations made by sectioning server components, and a more detailed study of the change in material properties that result from exposure of printed circuit boards (PCBs) to mineral oil. Similar observations of air cooled servers were taken as a basis for comparison.

A sample of three servers that were immersed in mineral oil for a six-month period during thermal testing were taken apart, photographed and sectioned for imaging to document the effects of oil on server components. Figure 2 shows the fading off screen printed component markings on the memory chips of the DIMM modules. Although not a direct impact on mechanical reliability, this fading of markings may impact identification of components, servicing should be needed.

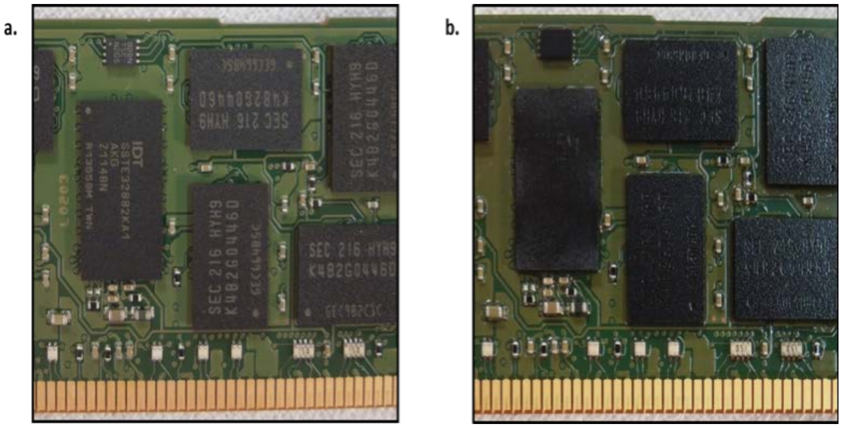

Figure 2: Fading component identifies as a result of oil exposure was seen in (a) an air-cooled server and (b) an oil immersed server [21]

A more detailed visual study was carried out by taking cross sections of various components to determine the microstructure of electronic packages. Key components were placed in molding compound, sectioned, and polished. Control samples of servers that were not exposed to oil and used in traditional air-cooled based testing underwent the same testing. The details of the package structure were observed under microscopes.

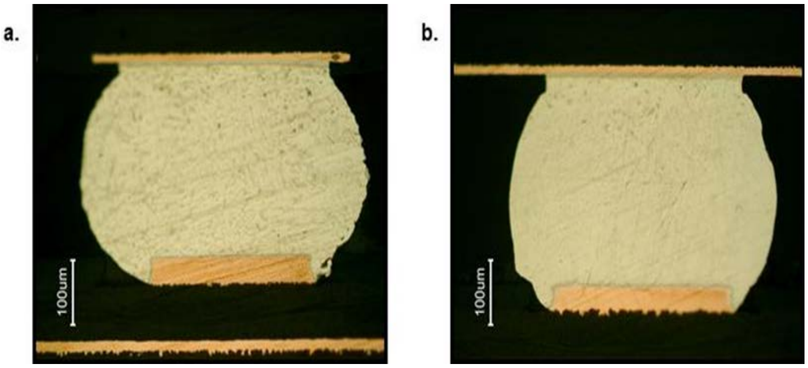

Figure 3: Comparison of microstructure of solder balls taken from (a) an air cooled server and (b) an oil immersed server [21]

Figure 3 offers a comparison of solder balls from the backside of the memory module attached to the DIMMs. As can be seen, there are no noticeable deformations, change in size, or cracking of solder balls. In addition, the intermetallic compound (IMC) layers which provide the mechanical and electrical connection between PCB-solder balls and solder ball-substrate interfaces showed no change in thickness between air cooled and oil cooled samples. The chip under fill material, which strengthens the mechanical connection between a flip chip package and substrate, also showed no detectable variation between air and oil cooled samples. In Figure 4, it is seen that there are no size variations in the metal layers of the packaging a substrate. The trace thickness does not change or alter after exposure of the server in an immersive environment.

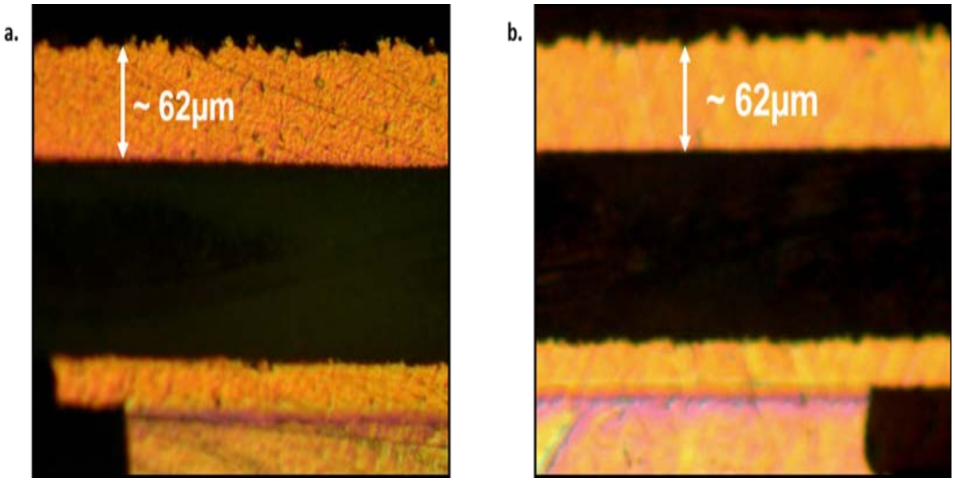

Figure 4: Comparison of substrate layer of BGA package taken from (a) an air cooled server and (b) an oil immersed server [21]

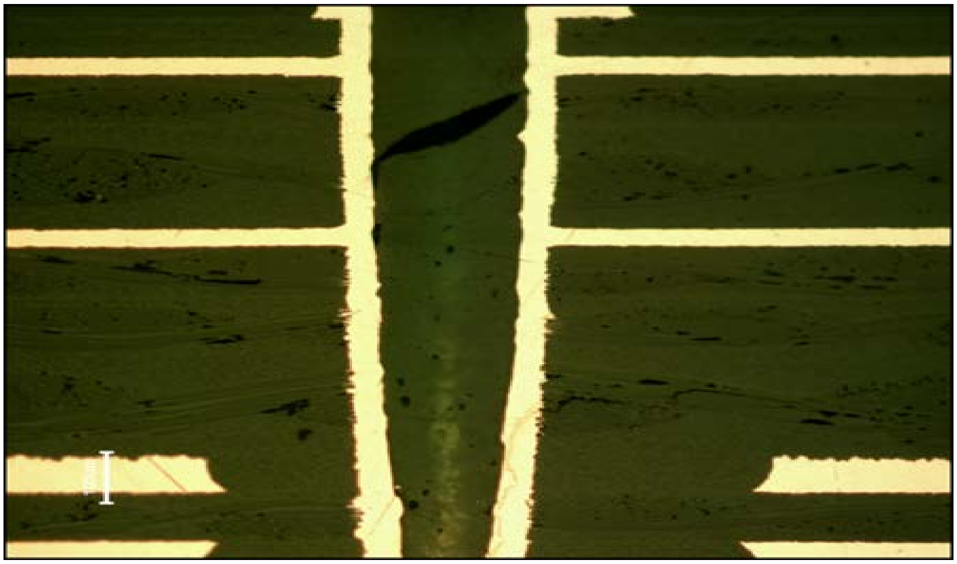

Figure 5: Cross section of PCB plated through-hole on oil exposed server [21]

Figure 6: Edge of oil exposed PCBs maintain structural integrity and show no indication of delaminating [21]

Additional samples of PCB boards showed no delaminating, swelling, or warpage of layers after extended periods of submersion in mineral oil. In Figure 5, a cross section at a plated through hole location on the motherboard has maintained its structural integrity. Similar observations can be made from Figure 6 at an edge location on the PCB.

The images and results gathered here provide a more detailed account to support the anecdotal claims made in the literature. In terms of component reliability, when submerging servers over the six-month duration, there is not any indicated reason for concern. However, typical servers operate in a data center for longer durations, anywhere from three years up to 10 years. A larger sample size of components and materials tested over extended periods or with the aid of accelerated thermal testing can help strengthen the conclusions made here. An observation made when handling servers after submersion in mineral oil for extended periods is that some materials become noticeably stiffer. This includes the primary PCBs, as well as, the plastic and insulating materials used for connection cords for power, networking, and hard disk drives (HDD). A concern amongst industry professionals is that this hardening may lead to cracking of insulators, exposing wiring or full failure of connectors. A study was initiated to determine the extent to which oil exposure alters the material properties of PCBs.

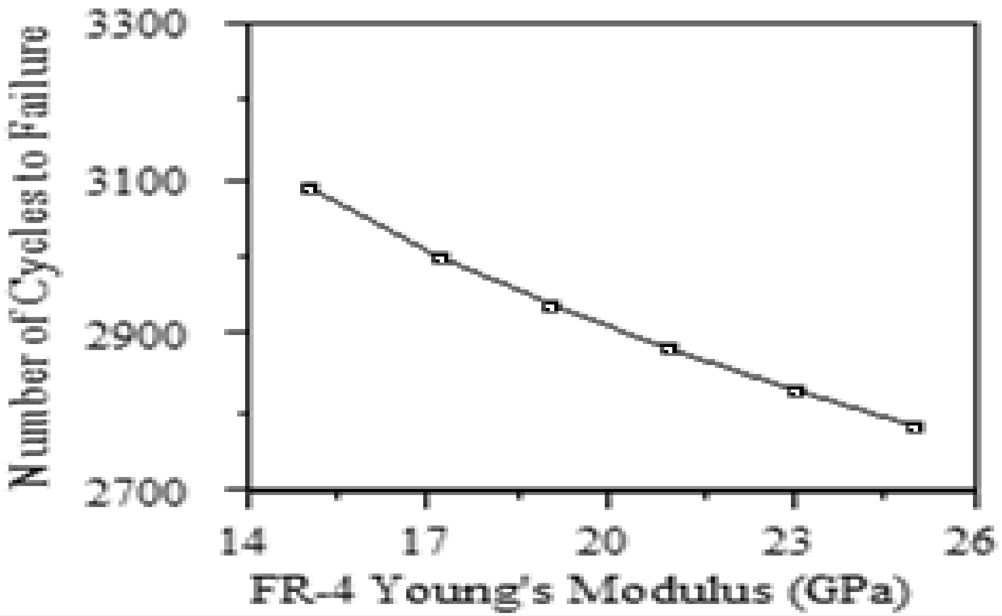

Figure 7: Typical relationship between circuit board stiffness and cycles-to-failure [3]

Samples of motherboard PCBs from air cooled and oil immersed servers were taken and prepared for mechanical testing using the Instron micro-tester. Preliminary stain measurements showed a significant increase in the Young's modulus of PCB material from 27.2GPa to 38.1GPa for servers that had been immersed in oil for an eight month period. An increase of this type may severely limit the reliable life a motherboard based on the trend discussed by Cheng et. al. [3] and shown in Figure 7. The results from this study may be input to Finite Element Models (FEA) to further simulate the impact of changes in material properties on the component and solder ball fatigue life.

PCB dielectric constant and dissipation factor:

The properties those define any dielectric material of PCB epoxies that have an effect on high-speed circuit design, in terms of signal propagation delay and dissipation factor are

•Dielectric constant and

•Dissipation factor or loss tangent.

The propagation delay in ns/m is given in terms of effective dielectric constant by the relation:

$$t_{pd} = 1.017\sqrt{\varepsilon_{eff}} \tag{1}$$

where, ε_{eff} is the effective dielectric constant of the PCB epoxy. The increase in the dielectric constant due to water (available in the form of relative humidity, water and gas contamination in a mineral oil) absorption increases propagation delay, that is, it slows down the speed at which the signal travels down the wire.

Dissipation factor or loss tangent tan(δ) affects the insertion loss (attenuation)α, in terms of dB/inch, of the signal as per the following relation:

$$\alpha = 2.3 * f * \tan(\delta) * \sqrt{\varepsilon_{eff}} \tag{2}$$

where, f = frequency (GHz)

As the frequencies rise up the GHz scale, more consideration has to be paid to dielectric constant and the dissipation factor of the PCB epoxies. The PCB epoxies absorb moisture and will lead towards in an increment in the values of both the dielectric constant and the dissipation factor, degrading signal speed and increasing the insertion loss. Fortunately, the moisture take up by the PCB epoxies is slow and there are ample copper planes in PCBs to further slow the moisture uptake. As well as, oil cooling technology provides more protection to the PCBs with the direct exposure to humidity in the atmosphere. Still, further studies are warranted to study the effect of exposure to oil immersion cooling on circuit performance.

EFFECT OF A MINERAL OIL ON CABLES AND SWITCHING DEVICES

The properties of insulation materials can be characterized as extruded primary insulations, which are applied directly over the conductor and also are used for jackets. Those are mainly polyvinyl chlorides (PVCs), polyethylenes, fluorocarbons, and silicones. While PVC insulation has desired mechanical and electrical properties and low cost, those make it a stronghold of the wire and cable industry, it presents environmental concerns. PVC contains halogen. PVC releases toxic gasses, smoke, and acids while burning that can be harmful to health and equipment. XLPE is halogen-free but is not highly recyclable. These two materials are abundantly being used in the cable industry. Using newly developed polyphenylene ether [mPPE] alloy insulating material is halogen-free and recyclable, yet remains cost-effective and robust. [9]

Figure 8: Electrical Cables and Wiring

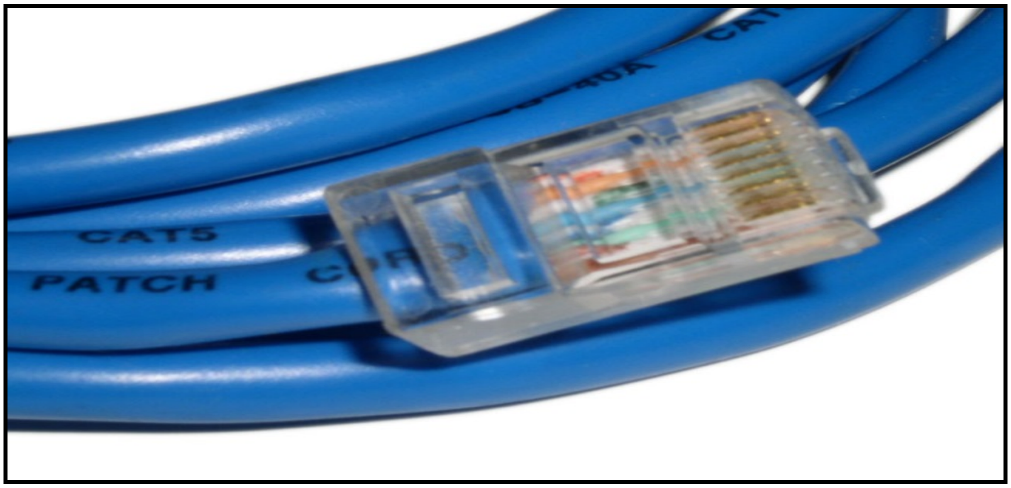

Figure 9: Network Cables

There are different formulations of Polyvinylchloride which show extremely high or low-temperature properties of PVC. Some PVC formulations have –55°C to 105°C rating. The regular PVCs have –20°C to 60°C. The dielectric constant is in between 3.5 to 6.5. XLPE is having 150°C ratings. Cross-linking converts polyethylene to a thermosetting material which enhances the properties of a material.

Rubber can be categorized as natural rubber and SBR compounds. These materials can be used for both insulations and jackets purposes. Some formulations are suitable for –55°C minimum, while others are suitable for 75°C maximum.

Table 1 provides information regarding the properties of general insulation and jacket materials like oil resistance, resistant to heat and dielectric strength based on the test results provided by different esteemed laboratories.

Properties	**PVC**	**PE Cable**	**XLPE**	**mPPE**	**Rubber**
Oil Resistance	Fair	Excellent	Excellent	Excellent	Poor
Heat Resistance	Good	Poor	Good	Good-Excellent	Fair
Dielectric Strength (kV/mm)	15-20	20	20	Not Available	Not Available

Table 1: Rating chart

For a Mineral oil immersed rack or tank, the cabling architecture could comprise of a top of rack or end of row design like all modern data centers [7]. The servers are connected to the switch generally by an unshielded twisted pair (UTP) cable for up to 10 GB/s for short distances. Off the shelf Category 5E, 24 AWG UTP local area network cable was considered for testing the impact of mineral oil. The cable is plenum rated and has a low smoke PVC jacket and FEP insulation. As the thickness of the jacket specimen was less than 0.76mm, tubular specimen was prepared and tested in accordance with UL 2556. The specimens were 6 cm long and immersed in mineral oil for 48 hours at 100°C. The mechanical testing of the cable jacket specimen (the test setup has been shown in Figure 10) was performed to determine the percentage change in elongation and to compare the change in Young's Modulus.

From Figure 11, it can be inferred that there is a drastic increase in Young's Modulus. Due to aging in mineral oil the specimen shrunk in length and loss of plasticizers could be attributed to its reduction in weight.

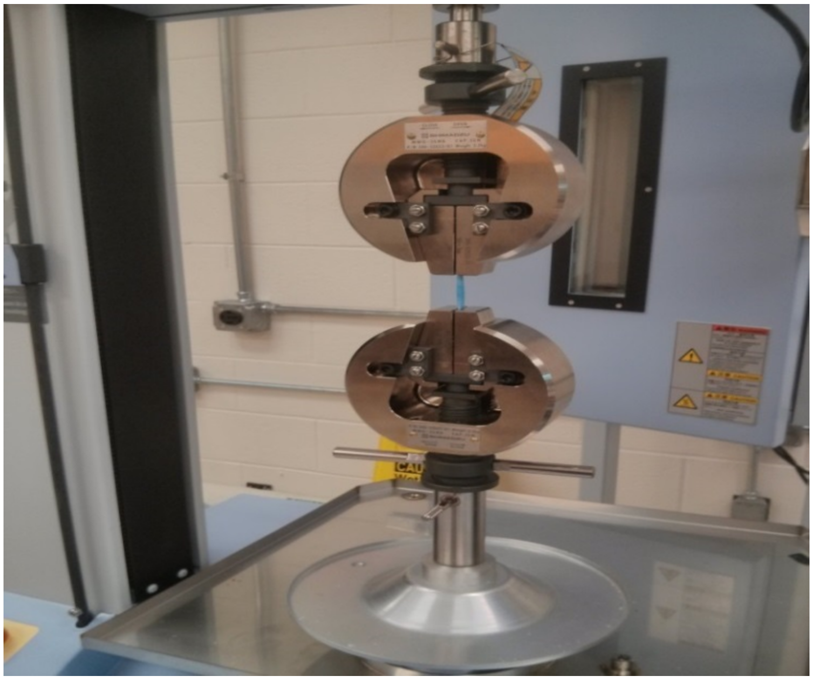

Figure 10: Test setup to measure mechanical properties of cable specimen

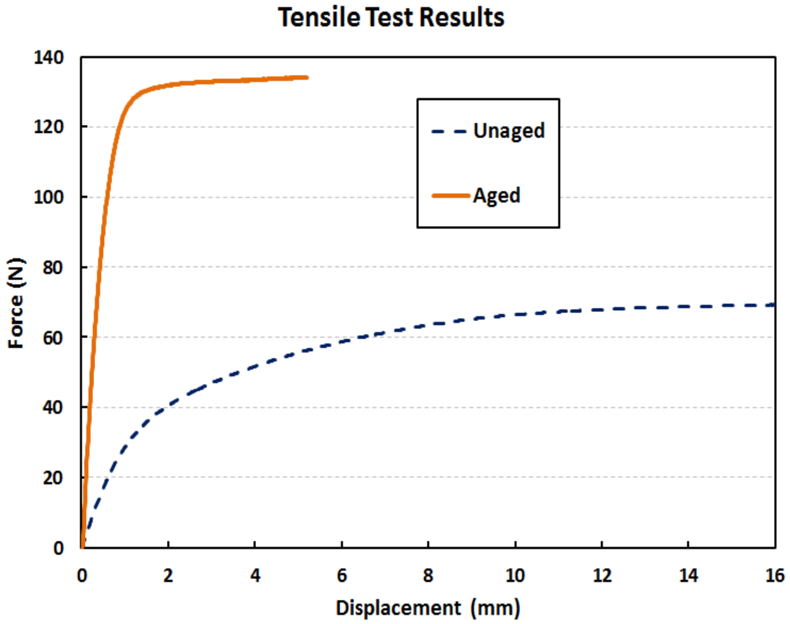

Figure 11: Load versus extension for a Low smoke PVC jacket tubular specimen without aging and aged in mineral oil

Figure 12: Ethernet switches immersed in oil [13]

No performance impact of a mineral oil on RF components and switching devices has been found yet. No considerable analysis has been carried out yet. Operators have not detected any issues, but to predict the life of materials and performance, the study should be acted upon.

EFFECT OF A MINERAL OIL ON PASSIVE COMPONENTS LIKE CAPACITORS

Electrolytic capacitors, prominently the Aluminum Conductive polymer capacitor, are generally used in servers. Degradation of performance in electrolytic capacitors can be caused by various factors like electrical, thermal and environmental stresses. Upon electrical overstress, the increase in internal temperature in turn increases the electrolyte evaporation rate. Similarly, when the capacitor is operating or is stored in the high-temperature environment the heat travels from the body of the capacitor thereby increasing the internal temperature.

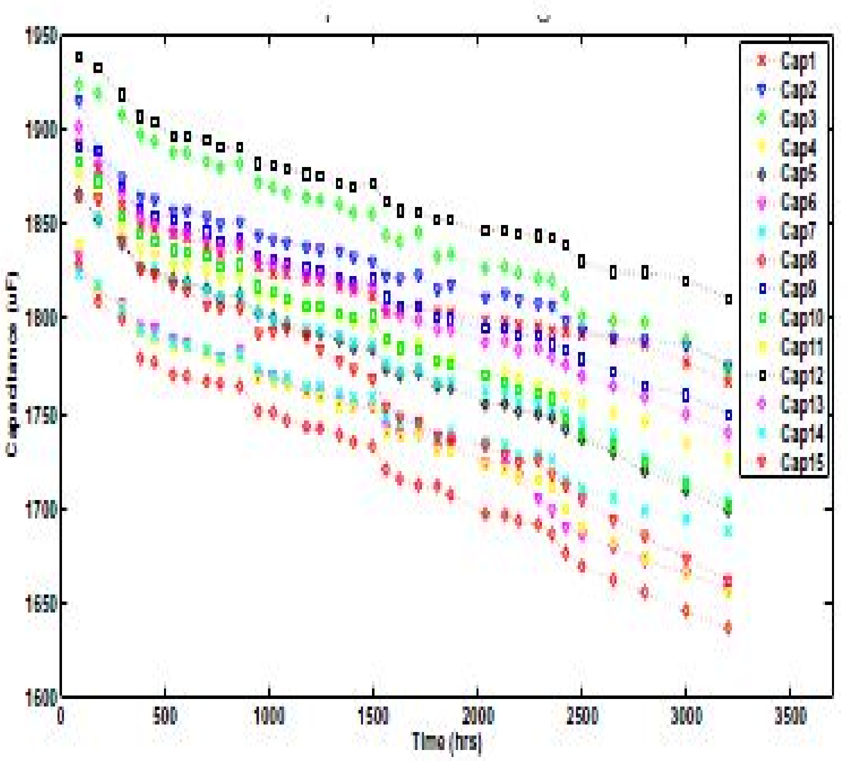

Figure 13: Capacitor degradation data in a thermal overstress experiment from air cooling testing [16]

Figure 13 describes capacitor degradation data in a thermal overstress experiment at 105°C and humidity factor of 3.4% for 3500 hours shown below. Electrolytic capacitors and Polymer capacitors are mainly used in the data center industry and should be tested in Mineral oil at elevated temperatures as provided for air cooling testing in figure 13 [16].

Degradation of Capacitors in turn leads to an implication in two main electrical parameters of the capacitor:

1. Equivalent Series Resistance (ESR), and

2. Capacitance (C).

The temperature profile of a server, when immersed in mineral oil, reduces hot spots and ΔT across the servers and, therefore, provides a better operating environment for capacitors. The concern in mineral oil is about the dissolution of the electrolyte in mineral oil causing degradation in performance. Rubber bungs at the bottom and plastic capacitor sleeve should be avoided due to incompatibility with mineral oil. A degradation of capacitance should indicate any decrease in electrolyte volume of the capacitor. Liquid electrolyte capacitors that produce hydrogen gas when it fails due to the chemical reaction inside can be a cause of concern as well.

CHANGES IN PROPERTIES OF A MINERAL OIL

The standard properties of mineral oil as per Data sheets/MSDS from STE Oil Company Crystal Plus Tech Grade Mineral Oil are:

Density (kg/m3) : 849.3
Specific Heat (kJ/kg·K) : 1.670
Thermal Conductivity (W/m·K) : 0.13
Thermal Expansions Coefficient (1/K) : 0.0007
Thermal Diffusivity (m2/s) : 9.166E-08
Prandtl Number (at 40°C) : 134.4

NOTE: Some of these properties may be temperature dependent (i.e. density). The changes in properties of a mineral oil are mainly concerned with the changes in kinematic viscosity and dielectric strength.

The viscosity of oils has a relationship with temperature and time and it affects system pressure directly. So that pumping power becomes critical. A standard correlation between viscosity and temperature for transformer oils is given in [10] as:

$$\mu = C_1 * Exp\left[\frac{2797.3}{T+273.2}\right] \qquad (3)$$

where, µ = dynamic viscosity (centipoise),

T = temperature (°C), and C = coefficient for scaling

Oil Temperature (°C)	***Dynamic Viscosity µ (kg/m·s)***	***Kinematic Viscosity v (m^2/s)***
30	**0.01405**	**1.65E-05**
35	**0.01209**	**1.42E-05**
40	**0.01046**	**1.23E-05**
45	**0.00909**	**1.07E-05**
50	**0.00794**	**9.35E-06**
55	**0.00696**	**8.19E-06**

Table 2: Analytical calculation of Viscosity with respect to Oil Temperature

The direct proportionality of viscosity with Reynolds Number (Re), Reynolds number with friction factor (f), and friction factor with pressure drop (Δp) for laminar flow is given below as [10],

$$Re \propto f \propto \Delta p \tag{4}$$

That results in the relation with the pumping power,

$$P_{pump} = \Delta p * \bar{V} \tag{5}$$

where, $\bar{V}$= volumetric flow rate [10].

Figure 14 infers that the change in viscosity is having the direct impact on pumping power that may be useful to derive the flow rate and operating conditions. It has a direct relation with operating cost too.

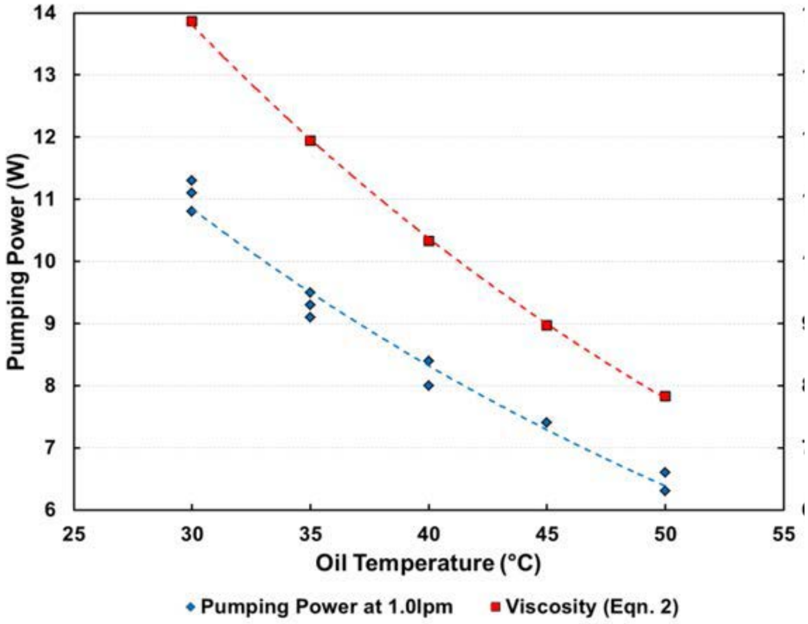

Figure 14: The relationship between pumping power and temperature dependent dynamic viscosity [10]

Since pumping power and flow rate are directly related to the operating cost, critical performance and efficiency of facility equipment, to study the phenomena regarding the change in viscosity of a mineral oil for data center operators becomes significant. Temperature, oxygen availability, and presence of a catalyst (Thermal Aging) are the main factors that influence the chemical stability of oil. The hydrocarbon molecules in oil start decomposition at high temperature and that may cause the oil degradation process. The oxygen contents in cooling oil might lead to a rise of the acidity number and to sludge formation. Catalysts such as copper and iron are dissolved in oil during aging and might accelerate the aging process [17].

During an accelerated thermal aging process, It is also important to analyze the dielectric properties of mineral oil, such as the breakdown voltage, dielectric losses (tan A), and relative permittivity. There is some analysis carried out for transformer oil. The study of aging test and dielectric property analysis for the transformer (mineral) oil concludes that there is a chance of a leak during the operation and its less biodegradable property leads towards pollution. It has a low flash point and high pour point for transformer operations. At the end of the aging process, the mineral oil demonstrated lower breakdown voltages rather than at the starting. The tan δ of the mineral oil showed the significant variation during the different stages of aging test process. The effect of humidity should also be considered during the oil aging test [17].

Figure 15 indicates the dielectric strength of transformer oil (mineral oil) remains fairly consistent across the temperature range of interest for data center applications and Figure 16 shows the study of change in the dielectric property of oil in transformers which shows some degradation over time. The literature states breakdown voltage depends on water content, suspended particles, and cleanliness.

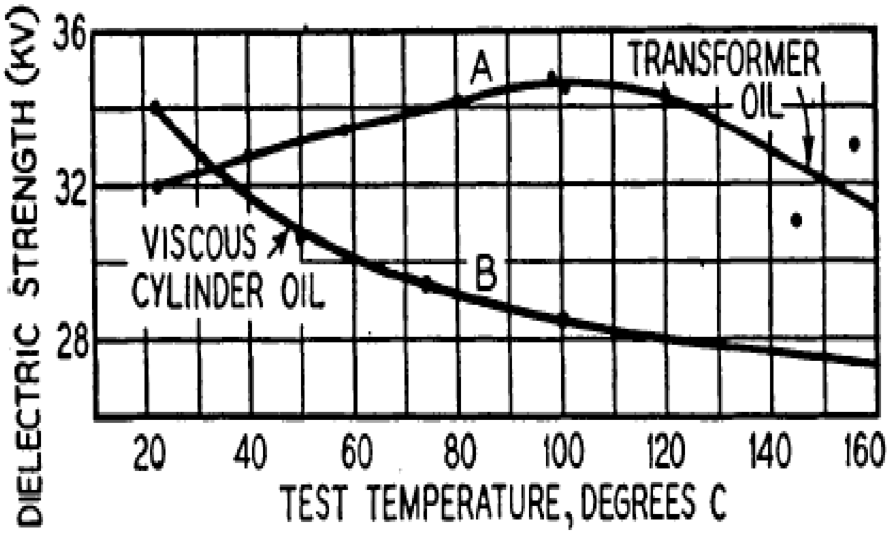

Figure 15: Temperature Dependence **[11]**

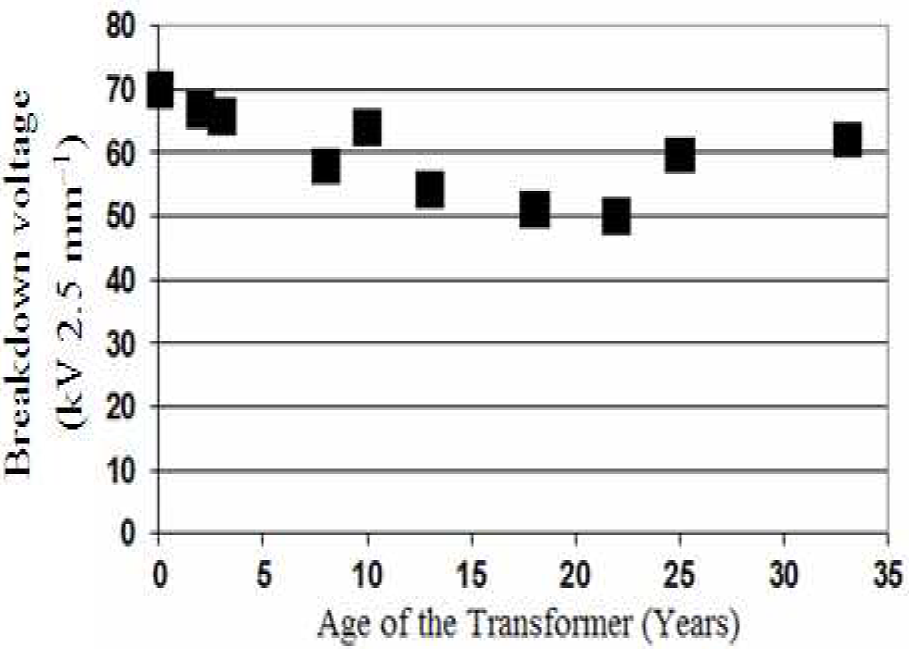

Figure 16: Breakdown over Time **[11]**

Thus, the dielectric property analysis for data center cooling mineral oil should be carried out by proposing an aging testing methodology to provide the data for variation in properties to operators for advancements in oil cooling technology and to increase its applicability. It would be an interesting study to observe the change in kinematic viscosity and thermal conductivity of a mineral oil during the actual operation as a function of temperature and time. The comparative study of different engineered fluids should also be performed to provide more options to industries.

POTENTIAL RELIABILITY ENHANCEMENTS

Oil cooling technology offers minimization in common operational issues and removal in failure modes like [18], [20]:

- Overheating
- Temperature swings
- Failures of server fan
- Solder joint failures
- Air quality
- Dust
- Corrosion
- Whiskers

Figure 17 provides the glance of the working of oil cooled data centers, which eliminates the root causes of failures, improves the operating conditions and reliability and advances in cooling technology for data center industries. This technology paves the path for the retrofitting of air cooled data centers and efficient performance with high load capacities. Figure 17 is an experimental setup that gives the understanding of the working environment of oil cooled data centers that may encourage its adoption by operators with its simplicity in implementation.

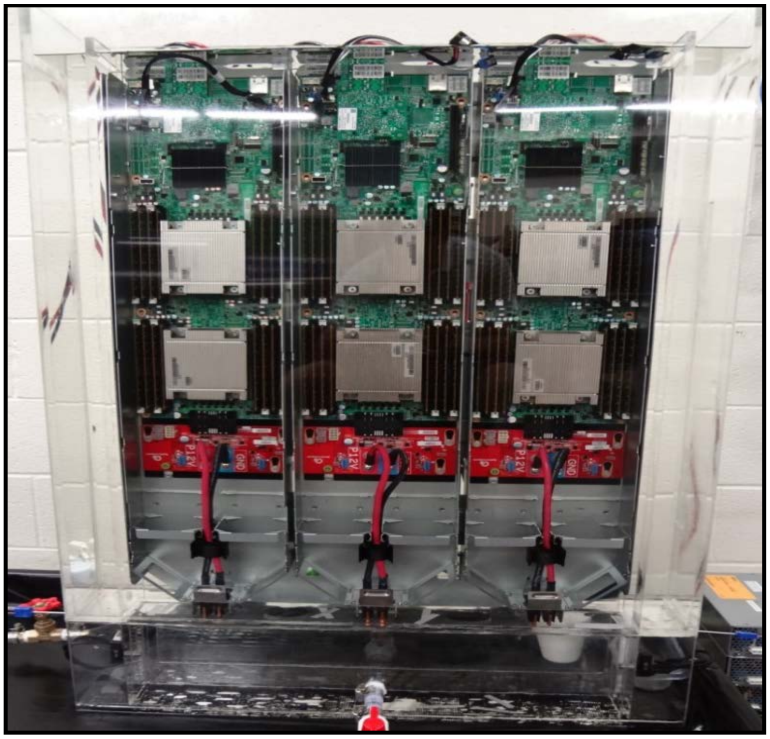

Figure 17: Experimental Setup providing the glimpse of oil cooled data center [21]

The reliability upgrading of data center operations is mainly [12], [18]:

1. Lessening the Electrochemical Migration
    - Reduction in corrosive exposure
    - Reduction in moisture
2. Reduction in Contaminants
    - Efficient handling and cleanliness prevent accumulation of particulates and dust
3. Temperature stability
4. Mitigation of Tin and Zink Whisker

Electrochemical Migration is a movement of metal through an electrolytic solution under an applied electric field between conductors which are insulated. Electrochemical migration (ECM) is a common reliability issue that can be found in the electronic packaging industry, including different materials and components like dies surface, epoxy encapsulates, PCB and passive components etc. The major ECM drivers are temperature, moisture, contamination and voltage/electrical field. Immersion oil cooling reduces and/or eliminates temperature, moisture, and contamination aspects [14], [13].

The main sources of contamination are storage and environment. The concerns of storage include cleaning chemicals, outgassing and polymeric materials. Operating environments include dust, debris, zinc whiskers, moisture, evaporated sea water and industrial pollutants like sulfur, etc. Oil immersion cooling prevents contamination accumulating. Efficient handing methods and cleanliness should be implemented and filtration of oil lessens the risk of particulate and dust contaminants [14].

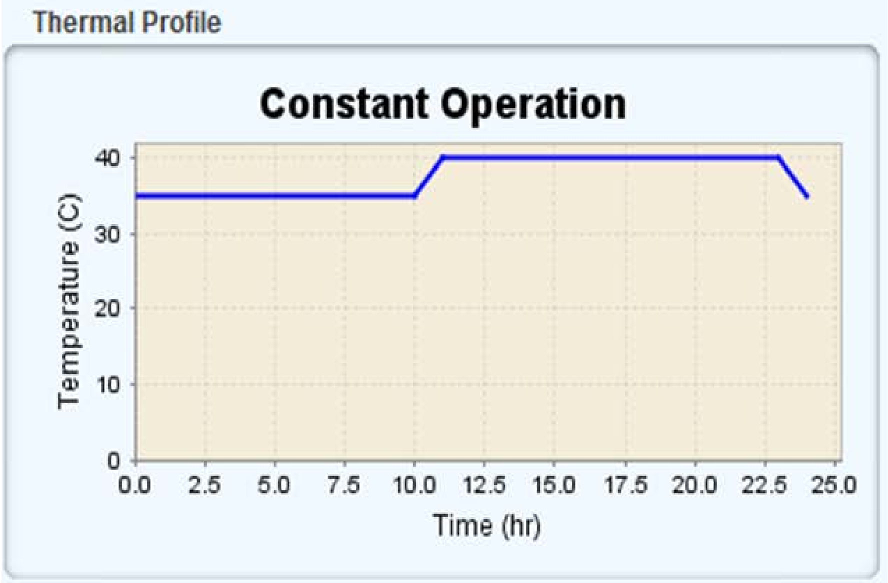

Figure 18: Thermal profile of operation for oil cooled data center

Figure 18 shows the thermal profile for a temperature cycle with 24-hour server uptime. The results show the constant operation that proves the thermal stability of oil cooled data centers. It is expected to see a hot spot reduction and improved thermal uniformity using immersion oil cooling [12] [13].

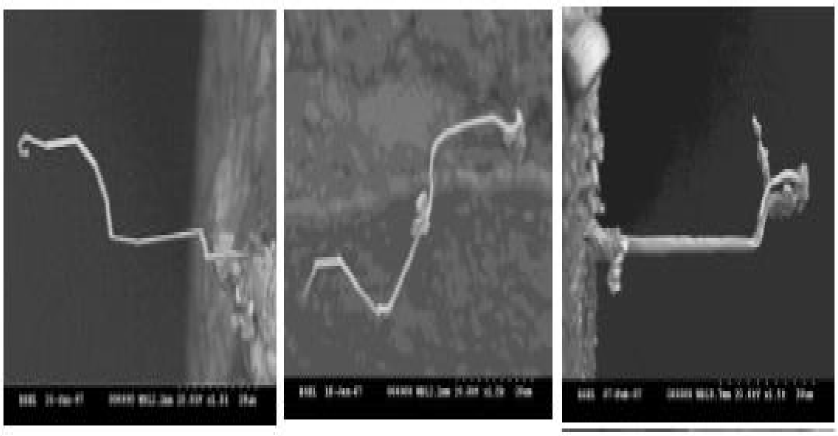

Figure 19: Tin whiskers

Figure 19 describes the phenomenon of Tin whiskers, hair-like single crystal metallic filaments that grow from Tin films. The potential failure modes are direct contact that causes an electrical short (arching) and requires growth of adequate length and in the correct direction. Electro-magnetic (EM) Radiation which releases or receives EM signal and noise at higher frequencies and deterioration of signal for frequencies above 6 GHz, which is independent of whisker length and debris like whisker breaks off and shorts two leads (primarily during handling). These can be mitigated by immersion oil [12], [13].

The occurrence of Zink whiskers is shown in figure 20.

“Unfortunately, accelerated techniques do not currently exist to predict if, when, and to what extent a zinc-coated surface will produce zinc whiskers.”[15]

“If you manage a data center, especially one that sits on a raised floor, zinc whiskers might eventually have an impact on your operations.”[15]

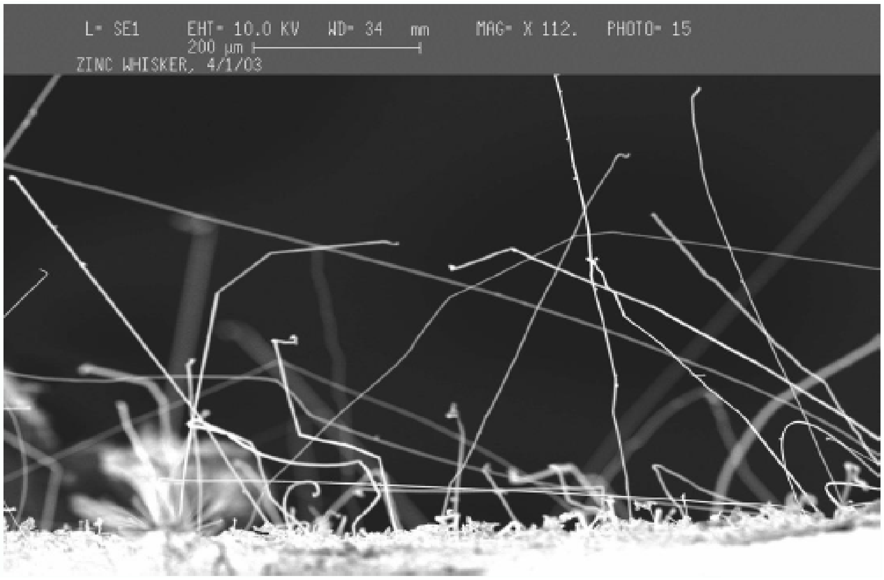

Figure 20: Zink Whiskers **[15]**

For Zink whiskers, there is some uncertainty persist regarding the prediction of whiskers and its criticality of failure modes [15]. But still, the study may provide some noteworthy information regarding its impact on data center operations.

CONCLUSION AND FUTURE WORK

The information furnished here is based on strong literature review and quantifiable data gathered for validation. The study provides a strong background for direct and indirect reliability concerns related to oil cooling technology. The operators will have trustworthy data to implement this technology.

Oil immersion cooling may offer better practices in some developing countries like India, China, etc where the environmental conditions for data centers are above ASHRAE G3 severity level and where it is hard to implement airside economizers to derive recommended environmental envelope. With the enhanced reliability, high heat dissipation and performance efficiency, oil cooling technology may serve the data center cooling technology world as a leader in the future.

As we can reiterate that the field of reliability for oil immersion cooling is having a lot of scope for future work. The effect of mineral oil on major components should be measured. The changes in mechanical and chemical properties of mineral oil should be investigated by aging test. The humidity and contaminant barriers, especially leaching out from plastics of cables and components should be checked. The temperature and heat density optimization should be carried out. Thus, the scope of studying thermal performance and reliability concerns is of all data center operators' interest and concern.

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Chapter 4

Case Studies

4.1 Case Study: PDU Failure Analysis

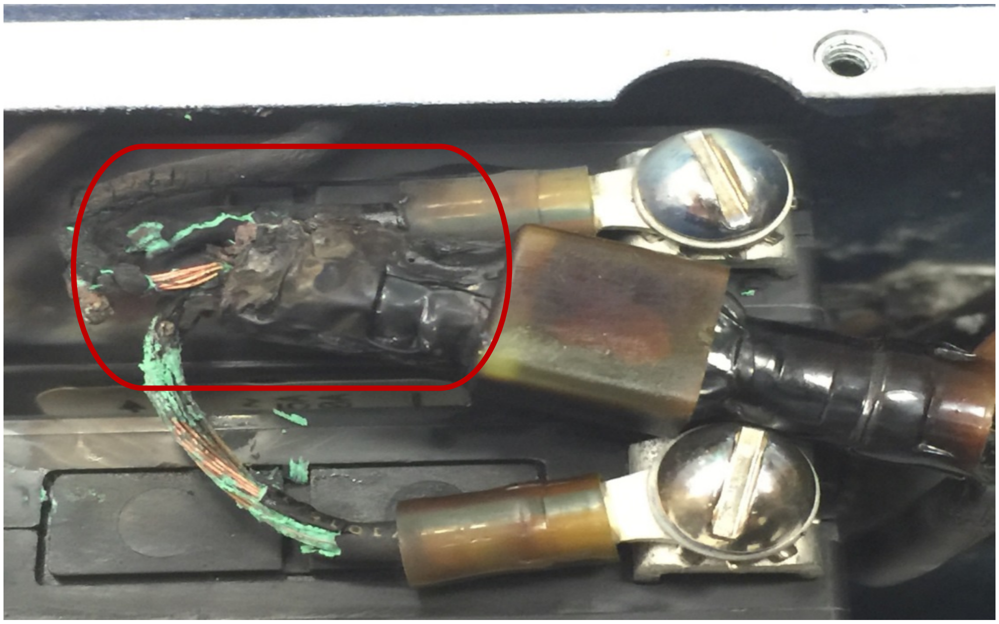

Figure 1: PDU-1 FAILURE

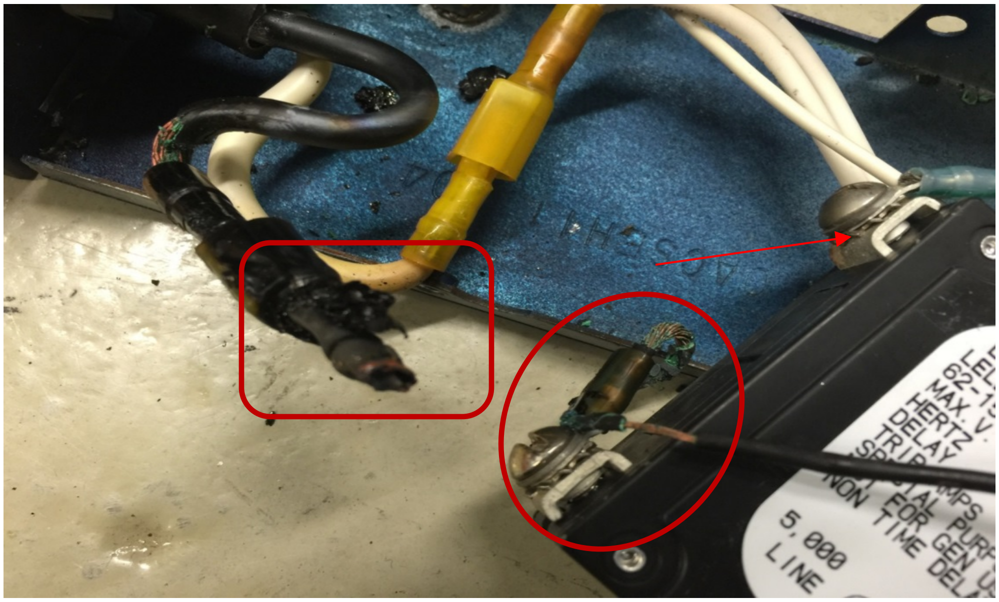

Figure 2: PDU-2 FAILURE

Figure 3: Rust on the mounting screw

Key Takeaways:

- The hot aisle/high temperature and high humidity air might have caused condensation on the chassis and on the surface of power supply components.
- Rapid change in outside air conditions based on Trend data and reaction of direct evaporative cooling towards humidity variations.
- The high temperature of hot aisle and high humidity from supply air because of evaporative cooling might have led towards shorts and damage of powered power distribution units (PDUs).

Evidence: -

- Rust on the steel screw because of moisture

 - Oxide on Connector after the short circuit

Suggestions:

- Humidity excursions in data center should be studied.

- Environment Acclimation of ITE should be identified and the documentation of ‘best practices’ for acclimation should be prepared.

4.2 Case Study: Hard Disk Drives Corrosion/Failure Analysis

Figure 4: Copper and Silver Corrosion on HDD

Figure 5: Blank Prompt

Design of Experiment:

1. I started up a server labelled as “Hard Disk while Partitioning” by the team which installed OS on each server in the rack. The label basically meant that when the OS installation reached to the point where hard disk is partitioned, it wouldn’t show any hard disk connected (didn’t detect it).

2. What I got is just a blank prompt at which point the system would freeze not even accepting Ctrl+Alt+Del

3. Then I tried to remove the hard disk and then boot the system, at that point the system displayed “Insert Boot Media” error message.

4. I took a hard disk from a different server and tried in the same machine, it started up and another machine previously working wouldn’t startup just as before, with a blank prompt.

Key Takeaways:

- The study of copper and silver corrosion rates as a function of temperature and relative humidity with respect to time should be carried out.

- The experiments performed to study the operability of data centers at high temperatures and using free air cooling have ranked hard disks as the highest failing component with such environments.

- For free-cooled data centers, the impact of environmental conditions on hardware reliability should be addressed with the meaningful dataset.

- The meaningful reliability studies require large server populations in datacenters that are monitored for multiple years.

Chapter 5

Conclusion and Future work

5.1 Physical Environment for Safe Operation

ASHRAE 2011 Gaseous and Particulate Contamination Guidelines For Data Centers recommending that gaseous contamination should be within the modified severity level G1 which meets are:

1. A copper reactivity rate of less than 300 Å/month and
2. A silver reactivity rate of less than 200 Å/month

Any corrosion within this range is considered to be not prone to hardware failure but not safe. Care has to be taken to regularly clean and filter the server room and take precautionary measures to avoid further contamination.

5.2 Conclusions

- For Contamination:
  - i. The rapid expansion of the ITE business and increasing pressure to reduce energy consumption, data centers should move their operating conditions up to ASHRAE A1 allowable environment considering the danger of short-circuit failure mode due to particulate matter.
  - ii. Both natural and anthropogenic sources of particulate matter should be controlled.
  - iii. The study for gaseous contaminants should be carried out with reliable methodology which can give us reproducible data.
  - iv. It is essential to manufacture hardware robust against PCB creep corrosion /short ckts caused by settled particulate matter in humid

environment and surface mount resistor open circuits by gaseous contamination.

    v. The corrosion testing should be done in real world field conditions with larger data as laboratory testing facility do not represent the environment in data centers.

- For Oil Immersion Cooling:
  1. The methodology to estimate the reliability of server components should be proposed. The method has already been proposed as a part of this study and in a process to get published.
  2. This method is analogous to JEDEC, ATC, ASTM thermal ageing standards.
  3. Hence this method will be feasible to perform at laboratory test facility and will give us reliable data.
  4. Single phase cooling is cheaper and offers reliability enhancements
  5. The minimum design concentration for class B hazard of heavy mineral oil of extinguishing agent Novec 1230 fluid exceeds the minimum design concentration for the class C electrical equipment, so it would both extinguish class B and C hazards.

5.3 Future Work

- For Contamination:
  1. To determine the chemical composition and temporal and spatial variation of the gaseous contamination in real world data centers with ANSI/ISA Standard 71.04-2013 severity level G2.

2. Predict the gaseous composition of the air using Gas Analyzers and simulating the same conditions in laboratory to understand the parameters affecting the corrosion rate in depth.
3. To conduct tests using copper and silver corrosion coupon and state-of-the-art test PCBs in experimental data centers with ASHRAE severity level G2 or G3.
4. These servers will be placed again to their original locations until they fail to determine the final degradation and failure mode in order to estimate the life and environment excursions by the means of quantitative approach.
5. To validate the experimental results for the corrosion rate by performing CFD simulations
6. The gaseous contamination levels in a data center are a function of location and time of year
7. To procure the real world data for corrosion from two locations to find the levels of severity of the ambient air from different geographical locations

- For Oil Immersion Cooling:
    1. To validate the methodology and analyze for more experiments with different environmental conditions.
    2. To provide the trend of accelerated degradation of components for oil cooled data centers
    3. Can these Overstress tests be used to evaluate change in fluid properties over time? (i.e. is there leaching of plastics or other materials that influence the fluid?)
    4. Change in the properties of Mineral oil because of Thermal Overstress.

5. Overall life cycle of mineral oil should be derived for the case of oil immersion cooled data center and will be considered for the prediction of sustainability of facility.

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Biographical Information

Jimil has received his Masters' Degree from the University of Texas at Arlington majoring in Mechanical Engineering. He received his Bachelors' degree with honors in Mechanical Engineering from Gujarat Technological University, India. Jimil's research interest at UTA includes Data center cooling, gaseous contaminations, electronic Packaging and Internet of Things. Presently, he is working on Operational efficiency and reliability of data center cooling technologies, estimation of the life cycle of emerging technologies such as immersion cooling and environmental effects on the reliability of wearables.

He has been a member of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the American Society of Mechanical Engineers (ASME). He was an integral part of a team which represented the UTA projects at the NSF I/UCRC IAB Meetings held in Steel Orca, NJ and Georgia Tech., GA in Spring 2015 and Fall 2015 respectively. He has received the “Best Abstract Award” at IMAPS 2015, Los Gatos, CA. He has publications on Contamination and Corrosion of IT Equipment and Reliability of Oil Immersion Cooling. He is the recipient of the 2015-2016 Electronic, MEMS and Nanoelectronics Systems Packaging Center Scholarship Award. He has three applied Patents and some publications in India. He has received “Innovative Project Award” during his Bachelors' by GTU Innovation Council. He has been very involved in Organizing Technical Symposiums and workshops from school to collegiate level. He has a practical experience in production at FIAT India Limited, Pune and as a lecturer at Parul University, Vadodara in India.

Coming from a business background, Jimil was always aspired to be an entrepreneur in the field of mechanical engineering. He would like to use this knowledge in mechanical engineering for the good of mankind and help all the public equally.