THERMAL DEGRADATION OF PASSIVE COMPONENTS FOR USE IN SINGLE PHASE IMMERSION COOLING APPLICATION

by

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Abstract

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The growth in the computing and data industry demands high-performance data centers where the thermal management issues are of greater concern. A cooling system paradigm using the immersion cooling technology is a more reliable and effective method. In immersion cooling, servers are directly submerged into a dielectric fluid. A comparative study on the reliability of the passive components cooled by air, mineral oil and EC-100 was carried out. The Accelerated Thermal Cycling test based on ATC JEDEC is applicable only for air cooling. The ASTM standards D 3455 with some suitable modification was adopted to test the material compatibility with Immersion cooling. The experiment is designed to operate at an elevated temperature of 45^{o}C and relative humidity of 35%. For every 72-hour time interval 3 samples each of thick film resistor, an electrolytic capacitor, polymer capacitor and transistors were taken out and the experiment was continued for the remaining samples. The study focuses on analyzing the change in the electrical properties, and the formation of cracks in the microstructural level of the passive components. The electrical properties such as resistance, capacitance etc. are measured using the multimeter and the microstructure study is done using the Scanning Electron Microscope (SEM). This experiment will provide with trend data of the effect of thermal aging on the electrical property of the passive components aged by air, mineral oil and synthetic fluid. This trend data provides with the comparative performance study of the passive components aged by air, mineral oil and synthetic fluid and, provides the advantages and disadvantages of each medium.

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Chapter 1

Introduction

1.1 Overview

With fast growth in computing and data industry a high effective and efficient data centers are becoming mandatory. Data Centers is called as the brain of any company that need to deal with data, computing and networking. In this current scenario all most every Industrial sector rely on data center. Depending on the requirements data center's size varies from few hundred sq. feet to over one million sq. feet. The environment in which the data centers are built is different from general environmental conditions chosen for building industries. As a hub data centers are very high in power consumption, the consumption will be 10 to 15 times that of a commercial building. Out of this power 40 % of the energy is used just to cool the data center. [1], [3], [4], [15] Data centers in common will have stack up of racks to several rows as per the requirements. [1]

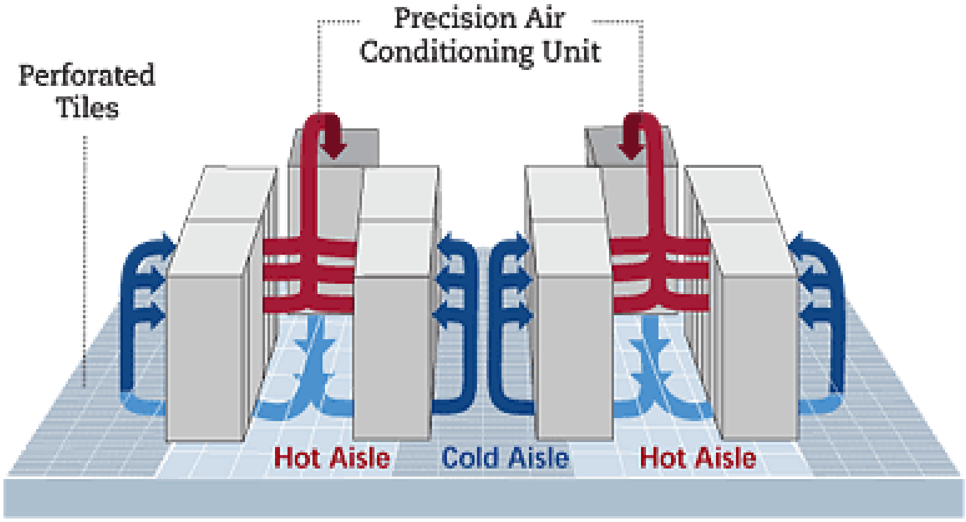

Figure 1.1 Conventional Data Center Layout [1]

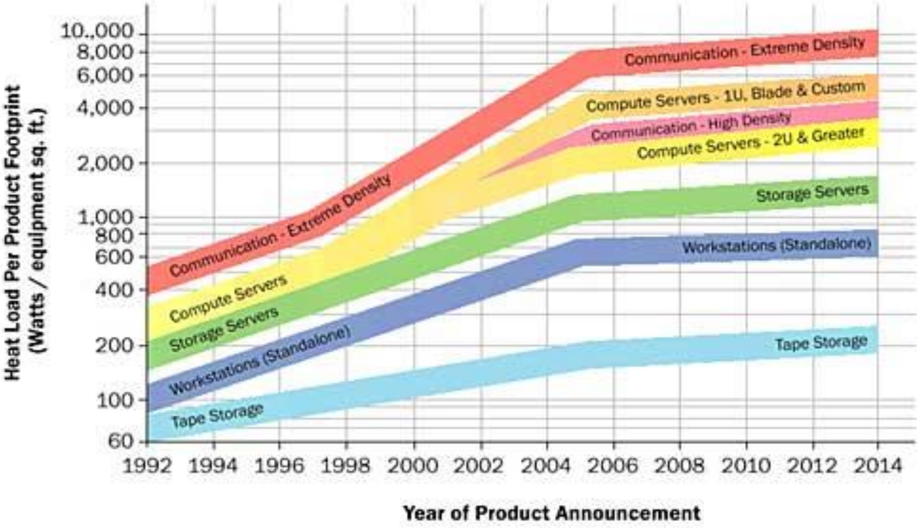

Figure 1.2 IT Heat Load Distribution

With increase in the power density the process of removing heat from the data center becomes a tough task. After a certain limit the air becomes less capable of performing effective cooling. Due to this inadequacy other unconventional cooling methods are being considered. Immersion Cooling is a type of liquid cooling in which the whole server and components to be cooled are immersed into a Dielectric Fluid. The temperature of the server is maintained constant because fluid’s heat capacity by volume is 1120 to 1400 times greater than air. [1], [2], [3] In traditional cooling method there is a chance of sedimentation of dirt and dust particles on the chassis of the computer and may lead towards the mechanical failure. In Immersion Cooling the computer is isolated from the outer environment which prevents from the deposition of dirt and dust particle. In single phase immersion cooling, the dielectric fluid coolant dependably remains in liquid state (as opposed to the two-phase coolants that change state from liquid to gas and back). The coolant fluid is dependably in contact with the equipment introduced in the bath and is pumped through the equipment towards heat exchanging system that consider the extraction of heat gathered by the coolant. This heat exchanging system for the most part pass on with a water-cooled circuit. The advantages of using single phase immersion cooling technique is the Lower Maintenance cost, Lower coolant cost, absence of coolant evaporation and reduction in noise compared with air cooled data center. [1], [2], [5], [6], [13] Along with this this the hardware benefits from the lower junction temperature with no temperature swings or hot spots and generally runs more reliable with improved performance. In this thesis we have performed experiments to determine the reliability of Immersion Cooling on Passive Components in terms of both operability and material compatibility.

Chapter 2

Instruments Used and Sample Preparation

2.1 Introduction

The passive components along with their electrical property and the instruments used in testing the components are discussed in this section. Each passive component used is described in brief about their working and uses, and the sample preparation was mentioned in here. The importance of the instruments used for measuring the electrical property and the visual analyzes is also discussed in addition to the components details.

2.2 Instruments used

The list of instruments used in this experiment are

- Environmental Chamber
- Multimeter
- Scanned Electron Microscope

Environmental Chamber:

The environmental chamber used in the experiment is Thermotron 600-10-10(Figure 2.1). The environmental chamber is used to maintain an elevated temperature and to have control over the relative humidity as desired to perform the experiment. The specification of the machine is as specified below [7]:

Humidity	10 % to 98 %
Temperature	-70^{O}C to +180^{O}C

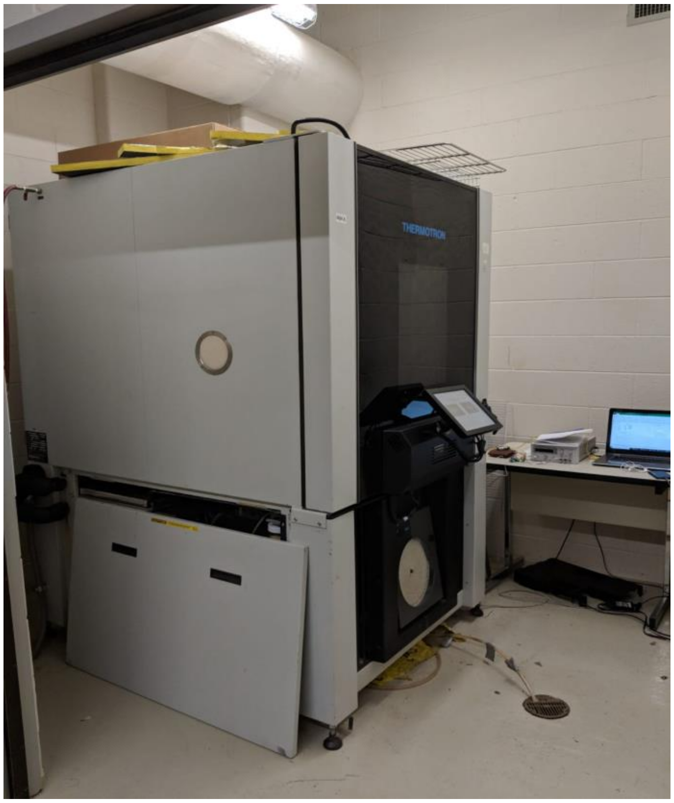

Figure 2.1 Thermotron 600-10-10

Multimeter:

Multimeter in general is used to measure the electrical properties of the components. The digital multimeter we used for the experiment as the functionality to measure resistance, capacitance, voltage and continuity with a precision of 98%. The digital multimeters are cheaper when compared with analog multimeter and high in precision. The analog multimeter is preferred for recording measurements which are continuously varying.

Figure 2.2 Multimeter

Scanning Electron Microscope:

In this a beam of electron is made to strike the surface of the specimen to be tested on hitting the solid surface different signals are generated. These signals can be used to analyze the surface morphology, chemical composition and crystalline structure. In general, these signals produce a 2 D image of the spot in a spatial system. The machine used in this experiment is Hitachi 3000N, it has the ability to switch between high vacuum and variable vacuum specification. The specification of the Hitachi 3000N system is as follows:

Accelerated Voltage Range	0.3 – 30 kV
Maximum possible resolution	25 nm
Maximum Specimen Size	150 mm.

Figure 2.3 Hitachi 3000N Scanning Electron Microscope

2.3 Passive Components chosen

The Passive Components which are chosen for the experiment upon which the proposed methodology will be applied are listed below:

- Thick Film Resistor
- Electrolytic Capacitor
- Polymer Capacitor
- NPN Transistor
- PNP Transistor

2.3.1 Thick film resistors

A thick film resistor is generally a Surface Mount Device (SMD) and typically called as chip resistor [8]. Thick film resistor is widely used in electrical and electronic industry and it is so cheap. These components are made of ceramic substrate on which a grain containing ruthenium is printed [9]. A thick film resistor in general is hundreds and thousands of times thicker than the thin film resistors. These types of resistors are cheaper on comparison with other variants.

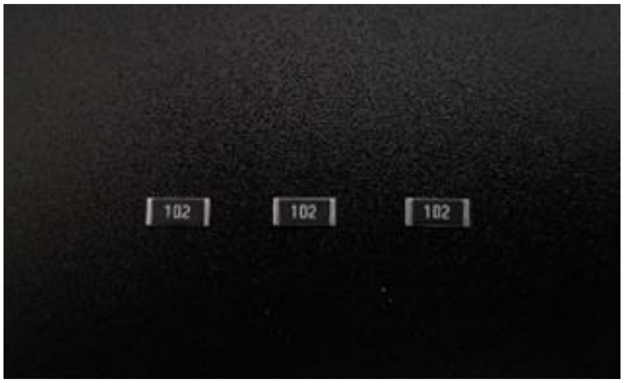

Figure 2.4 Thick film resistors

Specifications:

Resistance	1Kohms
Power rating	2W
Tolerance	5%
Temperature coefficient	100PPM/C
Voltage rating	300V
Operating temperature range	-55ºC to +105ºC
Height	0.6mm
Length	2.5mm
Width	1.2mm

The figure above represents the thick film resistors used in this experiment. The resistance of the thick film resistors will be measured using the multimeter and the SEM imaging will be done to check any penetration of fluids by making the cut section after every thermal cycle.

2.3.2 Polymer capacitors

The polymer capacitor is similar to aluminum electrolytic capacitor in construction, it as anode foil, cathode foil and different paper separator in between. Instead of a liquid electrolyte, the polymer capacitor will have a solid polymer [10]. The life expectancy of this capacitors is more when compared with electrolytic capacitors. These capacitors have a higher leakage current value on comparison with other passive components.

Figure 2.5 Polymer capacitors

Specifications:

Model 1 (16SVPF270M)

Capacitance	270µF
Voltage rating DC	16V
Tolerance	20%
Minimum operating temperature	-55ºC
Maximum operating temperature	+105ºC
Diameter	8mm
Length	6.9mm
Leakage current	864µA

Model 2 (2R5SVPC560M)

Capacitance	560µF
Voltage rating DC	2.5V
Tolerance	20%
Minimum operating temperature	-55ºC
Maximum operating temperature	+105ºC
Diameter	6.3mm
Length	5.9mm
Leakage current	300µA

These are the specifications of the 2 variants of polymer capacitors that are used in the experiment. The capacitance of the thick film resistors will be measured using the multimeter and the SEM imaging of the rubber sealing will be done by making the cut section after every thermal cycle.

2.3.3 Electrolytic capacitors

The electrolytic capacitor is a form of polarized capacitor. This type of capacitor is constructed using two thin films of aluminum foil, one layer being covered with an oxide layer as an insulator [11]. The use of the aluminum foil give rise to the fact that the capacitor is often referred to as the aluminum electrolytic capacitor. A paper sheet soaked in the electrolytic solution is place between them and then the plates are wound around one another and placed into a can.

Figure 2.6 Electrolytic capacitors

Specifications:

Model 1 (EEE-FP1C471AP)

Capacitance	470µF
Voltage rating DC	16V
Tolerance	20%
Minimum operating temperature	-55ºC
Maximum operating temperature	+105ºC
Diameter	8mm
Length	10.5mm
Height	10.2mm

Model 1 (EEE-1CA101WP)

Capacitance	100µF
Voltage rating DC	16V
Tolerance	20%
Minimum operating temperature	-55ºC
Maximum operating temperature	+105ºC

Diameter	6.3mm
Length	5.5mm
Height	5.4mm

These are the specifications of the two types of electrolytic capacitors that will be used in the experiment. The capacitance of the thick film resistors will be measured using the multimeter and the SEM imaging of the rubber sealing will be done by making the cut section after every thermal cycle.

2.3.4 Transistors

A transistor is a miniature electronic component that can do both different tasks like an amplifier and can also act as a switch. Depending on the material used for doping in transistor we can classify the terminal as N-type and P-type. The NPN and PNP junction transistors are quite commonly used in the electronic appliances [12]. We have used both NPN and PNP transistors in this experiment. The transistor can operate without flaw till the temperature range of 150^{o}C.

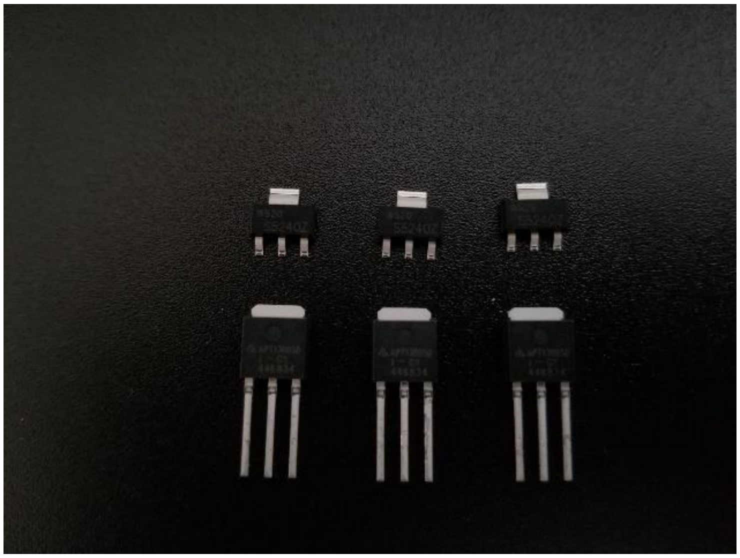

Figure 2.7 Transistors

Specifications:

Model 1 (Transistor polarity: PNP)

Configuration	single
Collector-emitter voltage	450V
Emitter-base voltage	9V
Collector-emitter voltage	900mV
Maximum DC collector current	8A
Bandwidth	4MHz
Maximum operating temp.	+150C
Mounting style	through hole

Model 2 (Transistor polarity: NPN)

Configuration	single
Collector-emitter voltage	450V
Emitter-base voltage	9V
Collector-emitter voltage	900mV
Maximum DC collector current	8A
Bandwidth	4MHz
Maximum operating temp.	+150C
Mounting style	through hole

These are the specification of both the NPN and PNP transistors that are used in the experiment. The barrier voltage will be measured for different configurations in the transistors to find the defect in it. The following table depicts the range within which the value should be on measuring with different configuration.

Table 2.1: Transistor Specification Table

	Property according to Specification	
Transistor	**NPN**	**PNP**
	Voltage (v)	
BASE TO EMITTER	0.45 to 0.9	OL
BASE TO COLLECTOR	0.45 to 0.9	OL
EMITTER TO BASE	OL	0.45 to 0.9
COLLECTOR TO BASE	OL	0.45 to 0.9
COLLECTOR TO EMITTER	OL	OL

Chapter 3

Proposed Methodology & Experimental Setup

As the standards ATC JEDEC is only applicable for air cooling a new accelerated thermal cycling test is devised based on the ASTM standards D 3455 with some modification as required. [14] Initially the dry run cycle of the environmental chamber is carried out with the following condition:

Temperature : 30^{O}C
Humidity : 10 %
Period : 8 hours

Then continued with the baking of the samples to remove the moisture content present in the components. In the baking cycle, the components are placed in a pyrex glass jar with minimal contact with each other. The glass jar is then placed in the environmental chamber with the environmental condition as follows:

Temperature : 45^{O}C
Humidity : 10 %
Period : 4 hours

Figure 3.1 Experimental Setup in Environmental Chamber for Baking Cycle

During this cycle we filled 2 of 1-liter pyrex jars with 800 ml of fluids (1 with Synthetic Fluid and 1 with Mineral Oil). Once after the baking cycle is over, 4 of each passive component are placed in the 2 jars with the fluids and in 1 empty jar. Now the 2 jars with the fluids are closed using air tight lid, and the jar with just the passive components is let open to the environment. These 3 jars are placed in the environmental chamber to perform the thermal cycling on the passive components immersed into the fluids and exposed to the air. The environmental condition maintained in the chamber for the thermal cycling is specified below:

Temperature : 45^{O}C
Humidity : 35 %
Period : 72 hours

Figure 3.2 Experimental Setup in Environmental Chamber for Thermal Cycle

Once after the cycle is completed one sample of each passive components are taken out from all the 3 jars using a pair of tongs. Then the components are placed in an aluminum cover which is labelled with all the details like cycle number and the fluid immersed. The aluminum cover is used to prevent oxidation of the components. After taking out the specimens for analysis the jar with the remaining samples are placed in the environmental chamber and the second thermal cycle is started this is repeated for 4 cycles. Once after taking the specimens from the experiment they are analyzed for their electrical properties and then SEM imaging is done to find the structural integrity. The passive components used in the experiments are Thick film resistor, electrolytic capacitor, polymer capacitor and Transistors (NPN and PNP). The electrical properties measured are resistance, capacitance and barrier voltage. The instrument used for this is multimeter. Once after measuring the electrical properties the cut section of the components is performed as per the requirements. The capacitors are made a cut exactly at the intersection of rubber sealing and the electrolytic paper to analyze the rubber sealing. The resistor is made a cut exactly at the center to scan for any penetration of oil into the polymer. For visual analyze and imaging we use Scanned Electron Microscope with the following settings:

Vacuum Pressure : 30 Pa
Beam Current : 25 kV
Working Distance : 14 mm to 24 mm.

The SEM scan is performed to find the maintenance of overall structural integrity of the components i.e., to find if there any formation of crack or penetration of the fluid on to the surface or swelling in the rubber sealant. By this methodology the reliability of the materials in the passive components with the immersion cooling technique is figured out.

Chapter 4

Results

Once after every thermal cycle the electrical properties of the passive components are recorded. Using the trend data graph is plotted to study the degradation of the electrical properties of the passive components which are cooled by immersing in the fluid and the components exposed to air.

Exposed to Air:

The change in electrical properties of the samples exposed to air are discussed below:

The trend of Thick film resistor is tabulated below:

Table 4.1: Resistance of Thick Film resistor exposed to air recorded after each Thermal Cycle

	Thick Film Resistor
	k ohms
Model	
Test 1 (72-hour Cycle)	0.996
Test 2 (144-hour cycle)	0.996
Test 3 (216-hour cycle)	0.996
Test 4 (288-hour cycle)	0.998

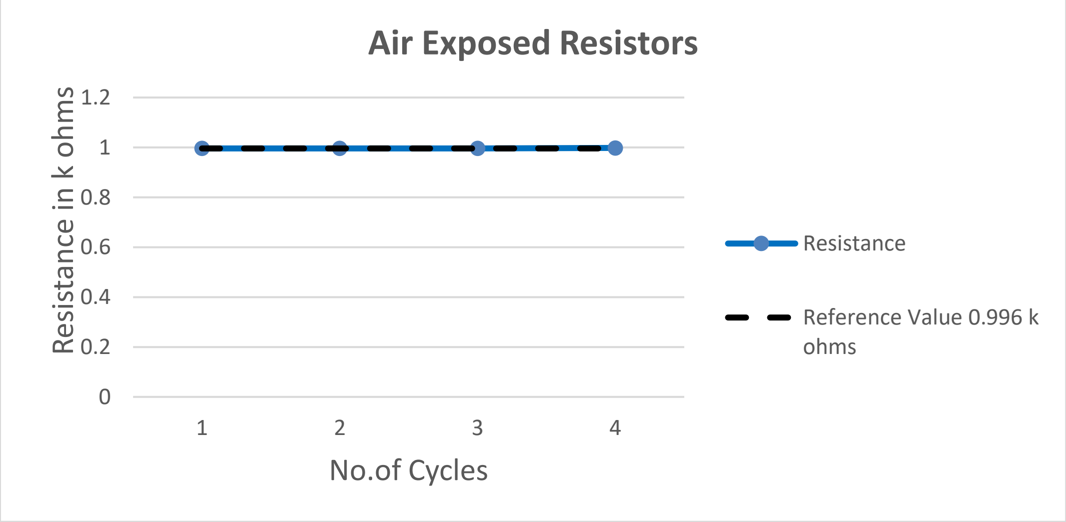

Figure 4.1: Change in Resistance vs No. of Thermal Cycle

From the Figure 4.1 the precision of the resistor is 1%. The recorded values are well within the allowable range.

The trend data of the capacitance of the electrolytic capacitor is tabulated below:

Table 4.2: Capacitance of Electrolytic Capacitor exposed to air recorded after each Thermal Cycle

	Capacitor	
	Electrolytic Capacitor	
	µF	
Model	**EEE-1CA101WP**	**EEE-FP1C471AP**
Test 1 (72-hour Cycle)	101	469
Test 2 (144-hour cycle)	101	469
Test 3 (216-hour cycle)	101	467
Test 4 (288-hour cycle)	103	469

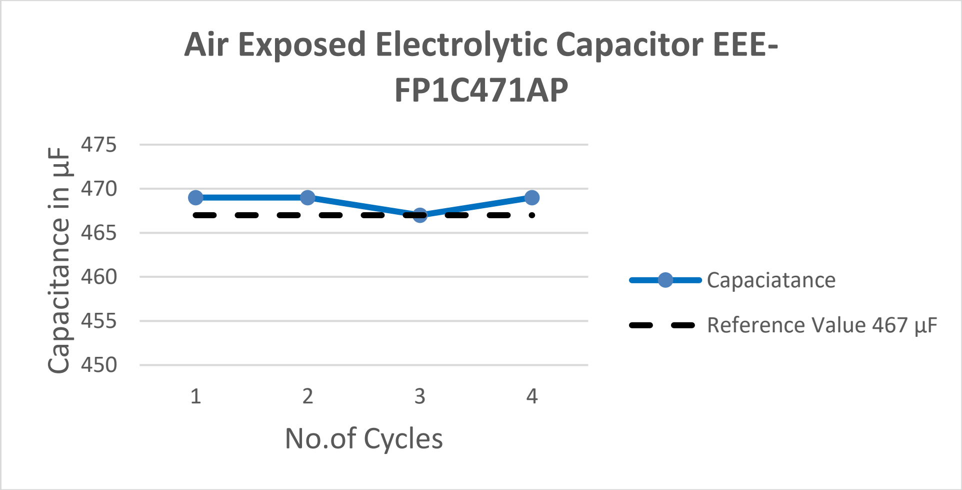

Figure 4.2(A): Change in Capacitance of EEE-FP1C471AP Capacitor vs No. of Thermal Cycle

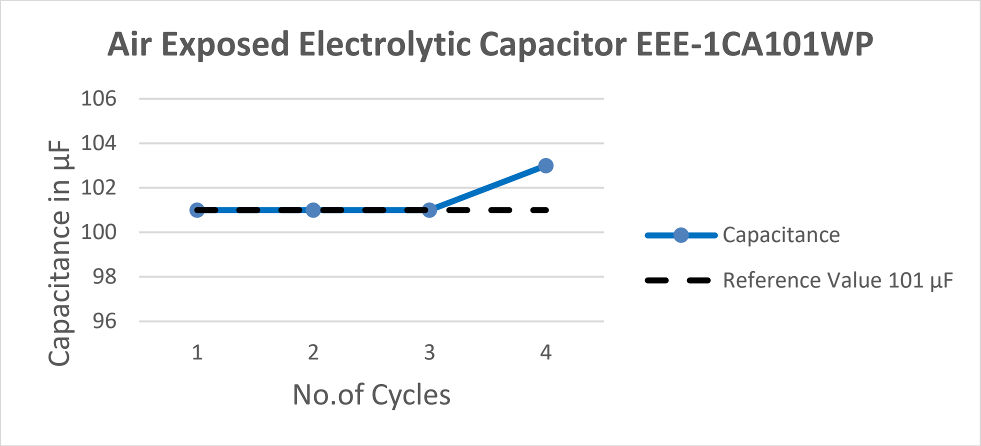

Figure 4.2(B): Change in Capacitance of EEE-1CA101WP Capacitor vs No. of Thermal Cycle

From Figure 4.2 (A) & (B) the capacitance of the electrolytic capacitors is well within the allowable range.

The trend data of the capacitance of the electrolytic capacitor is tabulated below:

Table 4.3: Capacitance of Electrolytic Capacitor exposed to air recorded after each Thermal Cycle

	Polymer Capacitor	
	µF	
Model	**16SVPF270M**	**2R5SVPC560M**
Test 1 (72-hour Cycle)	247	606
Test 2 (144-hour cycle)	261	612
Test 3 (216-hour cycle)	247	615
Test 4 (288-hour cycle)	261	615

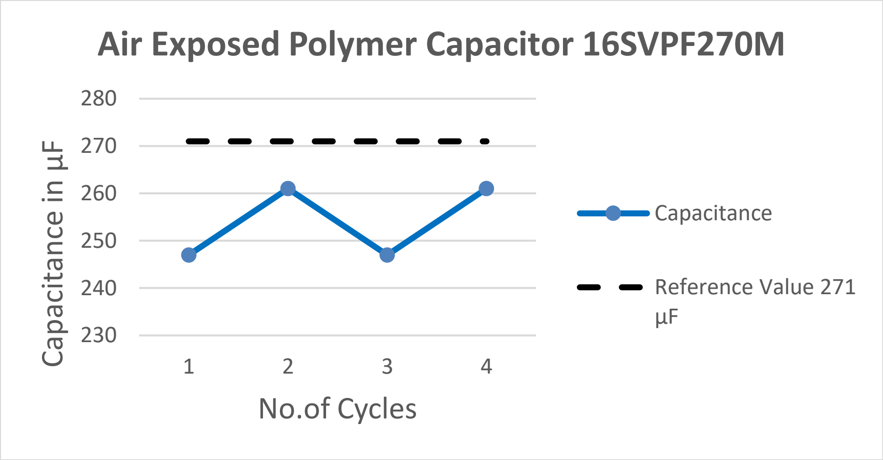

Figure 4.3(A): Change in Capacitance of 16SVPF270M Capacitor vs No. of Thermal Cycle

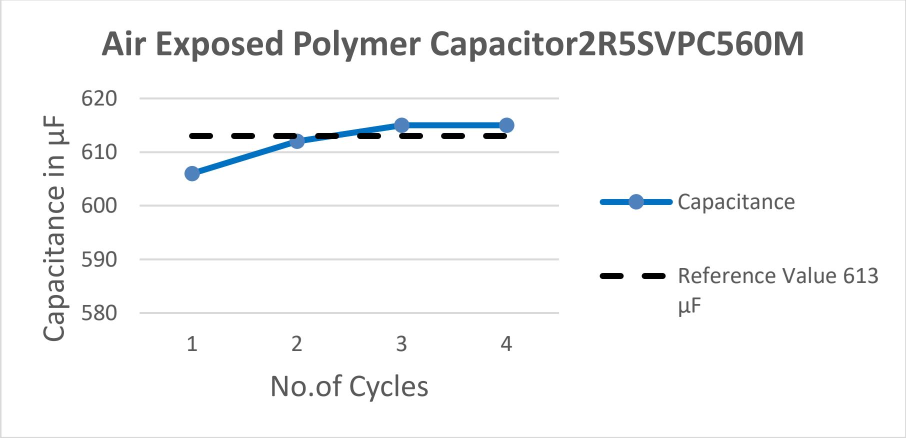

Figure 4.3(B): Change in Capacitance of 2R5SVPC560M Capacitor vs No. of Thermal Cycle

From the Figure 4.3 (A) & (B) the capacitance of the polymer capacitors is well within the allowable range.

The barrier voltage reading of the NPN and PNP transistor are recorded below:

Sample 1 represents samples taken after 72-hour thermal cycle.

Sample 2 represents samples taken after 144-hours thermal cycle.

Sample 3 represents samples taken after 216-hours thermal cycle.

Sample 4 represents samples taken after 288-hours thermal cycle.

Table 4.4(A): Voltage across junctions of transistor exposed to air recorded after each Thermal Cycle

Transistor	**NPN (**sample 1**)**	**PNP (**sample 1**)**	**NPN (**sample 2**)**	**PNP (**sample 2**)**
	Voltage (v)		Voltage (v)	
BASE TO EMITTER	0.575	OL	0.574	OL
BASE TO COLLECTOR	0.556	OL	0.557	OL
EMITTER TO BASE	OL	0.671	OL	0.671
COLLECTOR TO BASE	OL	0.67	OL	0.67
COLLECTOR TO EMITTER	OL	OL	OL	OL

Table 4.4(B): Voltage across junctions of transistor exposed to air recorded after each Thermal Cycle

Transistor	**NPN (**sample 3**)**	**PNP (**sample 3**)**	**NPN (**sample 4**)**	**PNP (**sample 4**)**
	Voltage (v)		Voltage (v)	
BASE TO EMITTER	0.576	OL	0.574	OL
BASE TO COLLECTOR	0.557	OL	0.556	OL
EMITTER TO BASE	OL	0.671	OL	0.671
COLLECTOR TO BASE	OL	0.669	OL	0.669
COLLECTOR TO EMITTER	OL	OL	OL	OL

The voltage across the junctions are well within the range.

Immersed in Mineral Oil:

The change in electrical properties of the samples immersed in Mineral Oil are discussed below:

The trend data of Thick film resistor immersed in the Mineral Oil is tabulated below:

Table 4.5: Resistance of the Thick Film Resistor immersed in mineral oil recorded after each Thermal Cycle

	Thick Film Resistor
	k ohms
Model	

Test 1 (72-hour Cycle)	0.996
Test 2 (144-hour cycle)	0.996
Test 3 (216-hour cycle)	0.996
Test 4 (288-hour cycle)	0.996

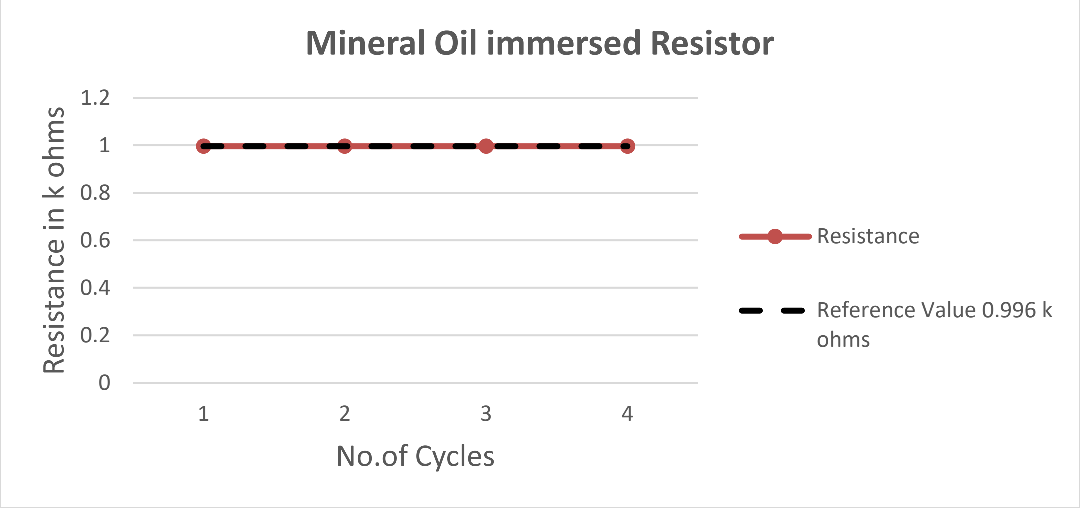

Figure 4.4: Change in Resistance vs No. of Thermal Cycle

The resistance of the thick film resistor is well within the allowable range.

The trend data of the capacitance of the electrolytic capacitor immersed in the Mineral Oil is tabulated below:

Table 4.6: Capacitance of Electrolytic Capacitor immersed in mineral oil recorded after each Thermal Cycle

	Electrolytic Capacitor	
	μF	
Model	**EEE-1CA101WP**	**EEE-FP1C471AP**
Test 1 (72-hour Cycle)	101	466
Test 2 (144-hour cycle)	101	464
Test 3 (216-hour cycle)	100	463
Test 4 (288-hour cycle)	100	464

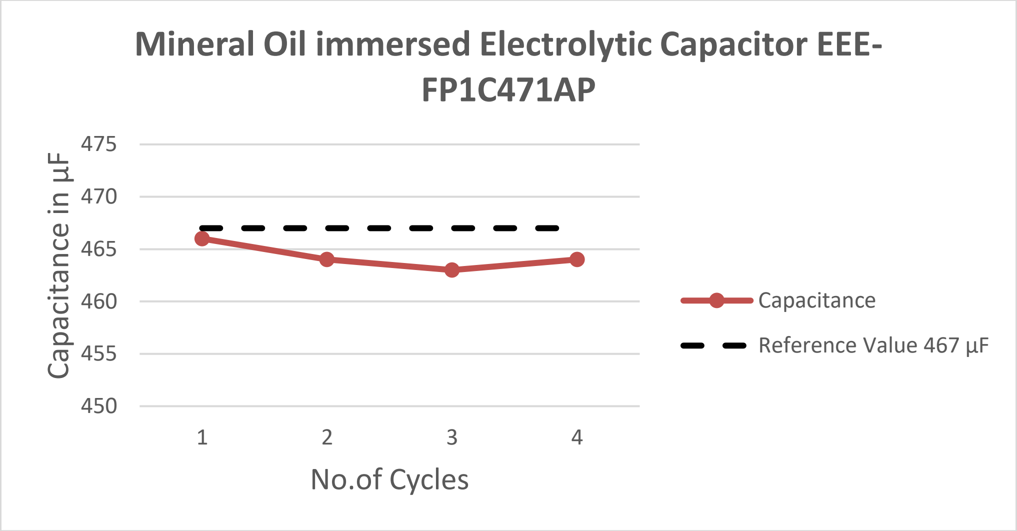

Figure 4.5(A): Change in Capacitance of EEE-FP1C471AP Capacitor vs No. of Thermal Cycle

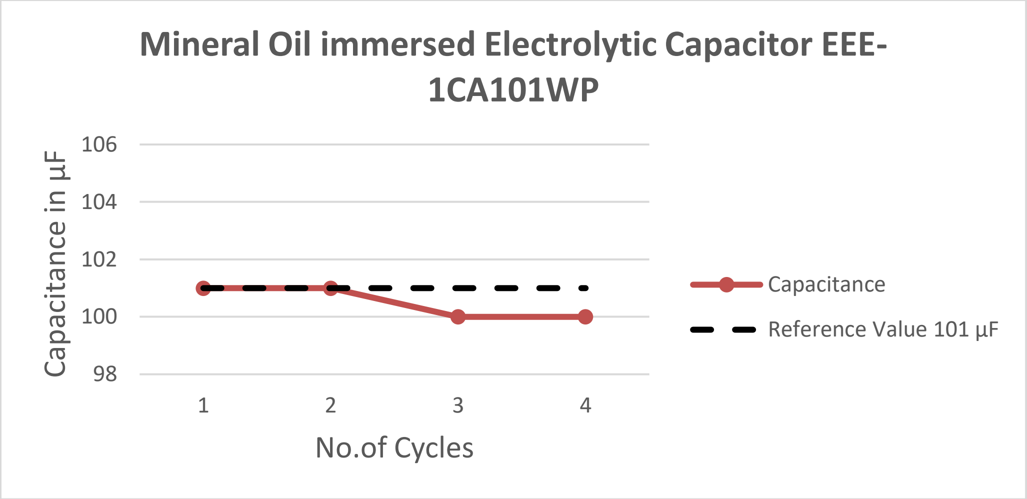

Figure 4.5(B): Change in Capacitance of EEE-1CA101WP Capacitor vs No. of Thermal Cycle

From the above figure the capacitance of the electrolytic capacitors is well within allowable range.

The trend data of the capacitance of the polymer capacitor immersed in the Mineral Oil is tabulated below:

Table 4.7: Capacitance of Polymer Capacitor immersed in mineral oil recorded after each Thermal Cycle

	Polymer Capacitor	
	μF	
Model	**16SVPF270M**	**2R5SVPC560M**
Test 1 (72-hour Cycle)	267	618
Test 2 (144-hour cycle)	267	612
Test 3 (216-hour cycle)	267	615
Test 4 (288-hour cycle)	267	615

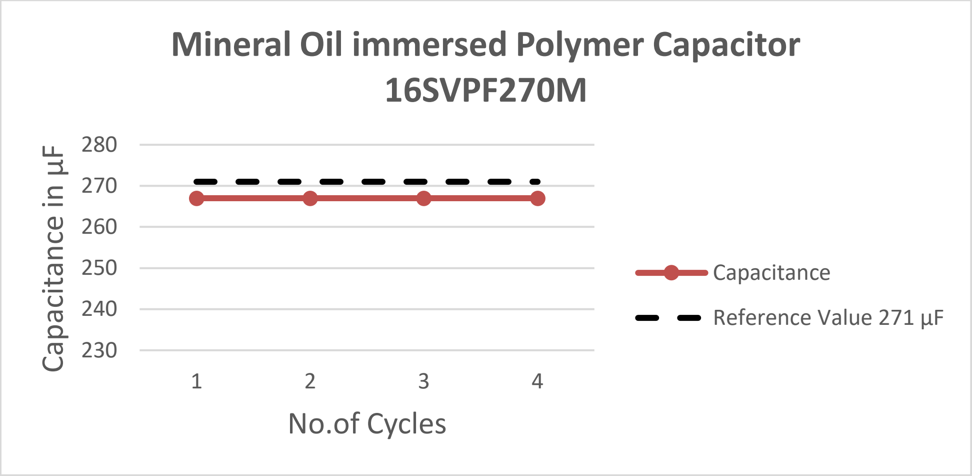

Figure 4.6(A): Change in Capacitance of 16SVPF270M Capacitor vs No. of Thermal Cycle

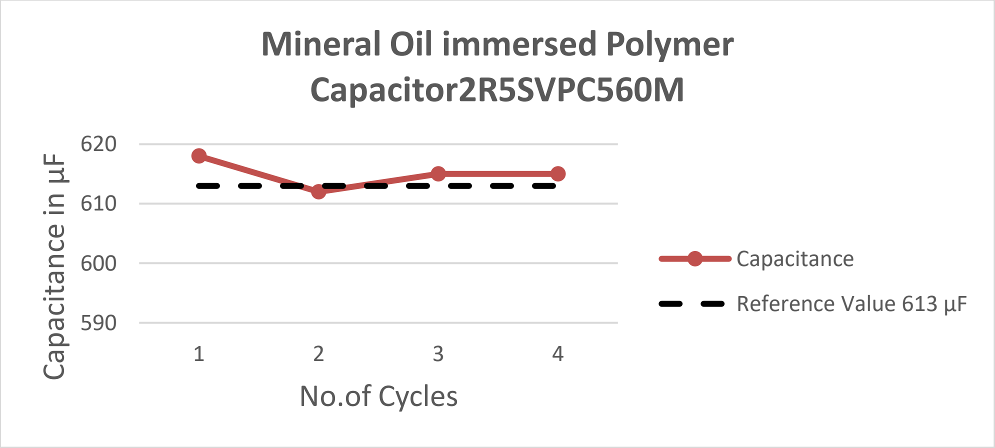

Figure 4.6(B): Change in Capacitance of 2R5SVPC560M Capacitor vs No. of Thermal Cycle

From the above figure the capacitance of the Polymer capacitor is well within the allowable range.

The barrier voltage reading of the NPN and PNP transistor immersed in Mineral Oil are recorded below:

Sample 1 represents samples taken after 72-hour thermal cycle.

Sample 2 represents samples taken after 144-hours thermal cycle.

Sample 3 represents samples taken after 216-hours thermal cycle.

Sample 4 represents samples taken after 288-hours thermal cycle.

Table 4.8(A): Voltage across junctions of transistor Immersed in Mineral Oil recorded after each Thermal Cycle

Transistor	**NPN (**sample 1**)**	**PNP (**sample 1**)**	**NPN (**sample 2**)**	**PNP (**sample 2**)**
	Voltage (v)		Voltage (v)	
BASE TO EMITTER	0.57	OL	0.574	OL
BASE TO COLLECTOR	0.554	OL	0.556	OL
EMITTER TO BASE	OL	0.671	OL	0.671
COLLECTOR TO BASE	OL	0.67	OL	0.67
COLLECTOR TO EMITTER	OL	OL	OL	OL

Table 4.8(B): Voltage across junctions of transistor Immersed in Mineral Oil recorded after each Thermal Cycle

Transistor	**NPN (**sample 3**)**	**PNP (**sample 3**)**	**NPN (**sample 4**)**	**PNP (**sample 4**)**
	Voltage (v)		Voltage (v)	
BASE TO EMITTER	0.573	OL	0.573	OL
BASE TO COLLECTOR	0.556	OL	0.556	OL
EMITTER TO BASE	OL	0.671	OL	0.667
COLLECTOR TO BASE	OL	0.669	OL	0.667
COLLECTOR TO EMITTER	OL	OL	OL	OL

The voltage across the junctions are well within the range.

Immersed in Synthetic Fluid:

The change in electrical properties of the samples immersed in Synthetic Fluid are discussed below:

The trend data of Thick film resistor immersed in the Synthetic Fluid is tabulated below:

Table 4.9: Resistance of the Thick Film Resistor immersed in Synthetic Fluid recorded after each Thermal Cycle

	Thick Film Resistor
	k ohms
Model	
Test 1 (72-hour Cycle)	0.996
Test 2 (144-hour cycle)	0.996
Test 3 (216-hour cycle)	0.996
Test 4 (288-hour cycle)	0.996

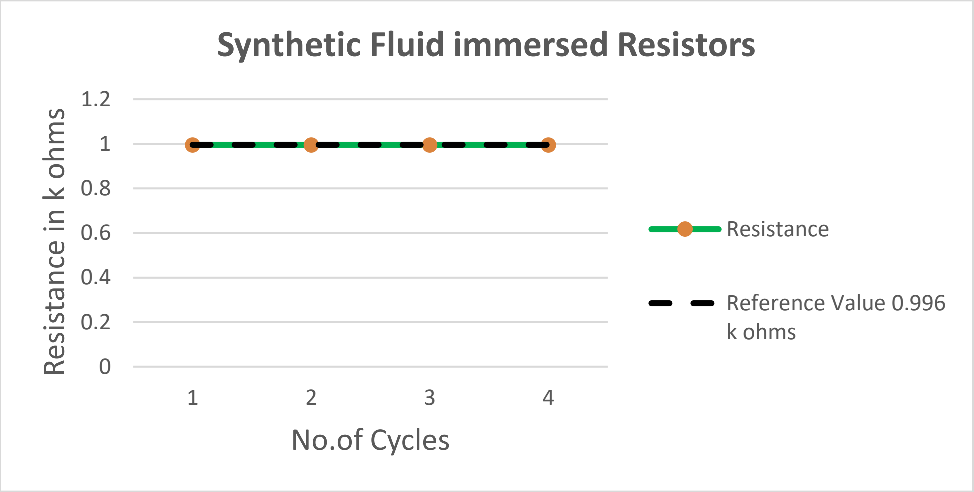

Figure 4.7: Change in Resistance vs No. of Thermal Cycle

The resistance of the Thick Film Resistor is well within the allowable range.

The trend data of the capacitance of the electrolytic capacitor immersed in the Synthetic Fluid is tabulated below:

Table 4.10: Capacitance of Electrolytic Capacitor immersed in Synthetic Fluid recorded after each Thermal Cycle

	Electrolytic Capacitor	
	μF	
Model	**EEE-1CA101WP**	**EEE-FP1C471AP**

Test 1 (72-hour Cycle)	101	470
Test 2 (144-hour cycle)	101	467
Test 3 (216-hour cycle)	99	467
Test 4 (288-hour cycle)	101	467

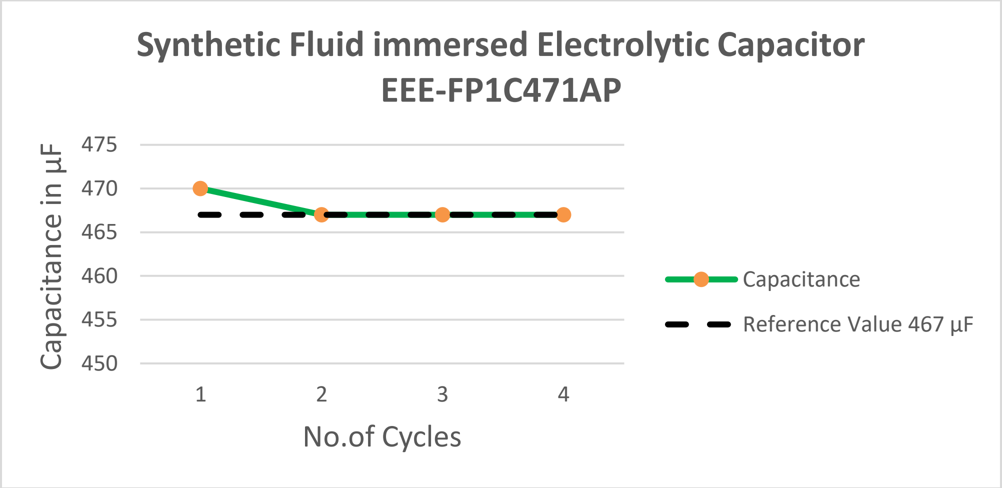

Figure 4.8(A): Change in Capacitance of EEE-FP1C471AP Capacitor vs No. of Thermal Cycle

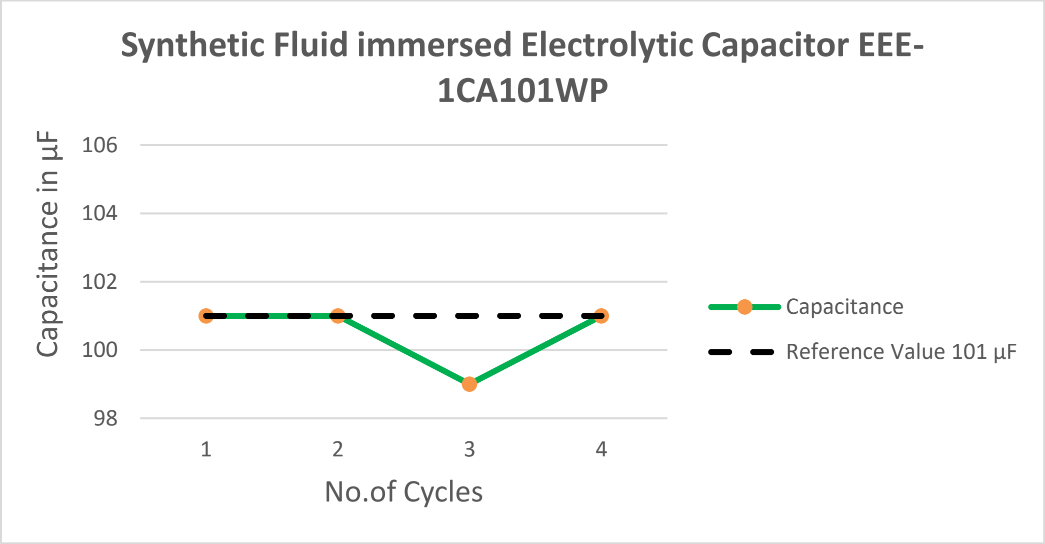

Figure 4.8(B): Change in Capacitance of EEE-1CA101WP Capacitor vs No. of Thermal Cycle

The capacitance of the electrolytic capacitor is well within the allowable range.

The trend data of the capacitance of the polymer capacitor immersed in the Synthetic Fluid is tabulated below:

Table 4.11: Capacitance of Polymer Capacitor immersed in Synthetic Fluid recorded after each Thermal Cycle

	Polymer Capacitor	
	µF	
Model	**16SVPF270M**	**2R5SVPC560M**
Test 1 (72-hour Cycle)	269	602
Test 2 (144-hour cycle)	264	610
Test 3 (216-hour cycle)	267	608
Test 4 (288-hour cycle)	267	618

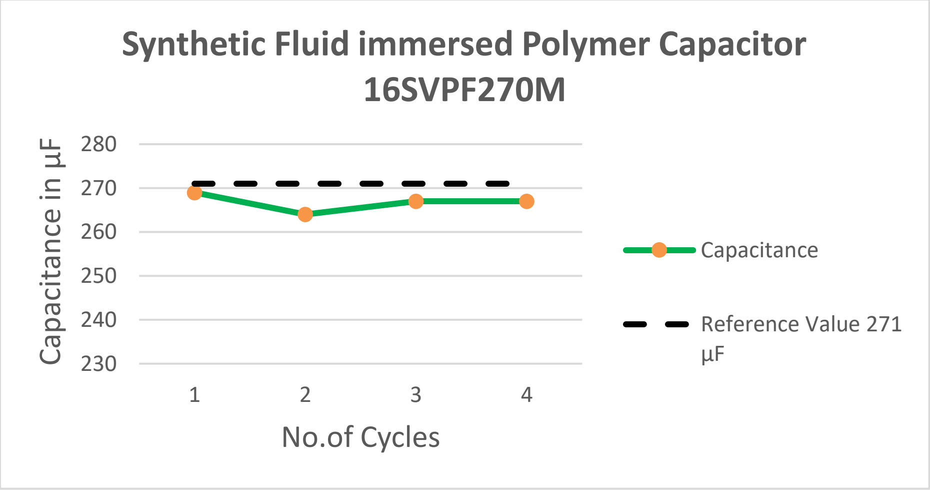

Figure 4.9(A): Change in Capacitance of 16SVPF270M Capacitor vs No. of Thermal Cycle

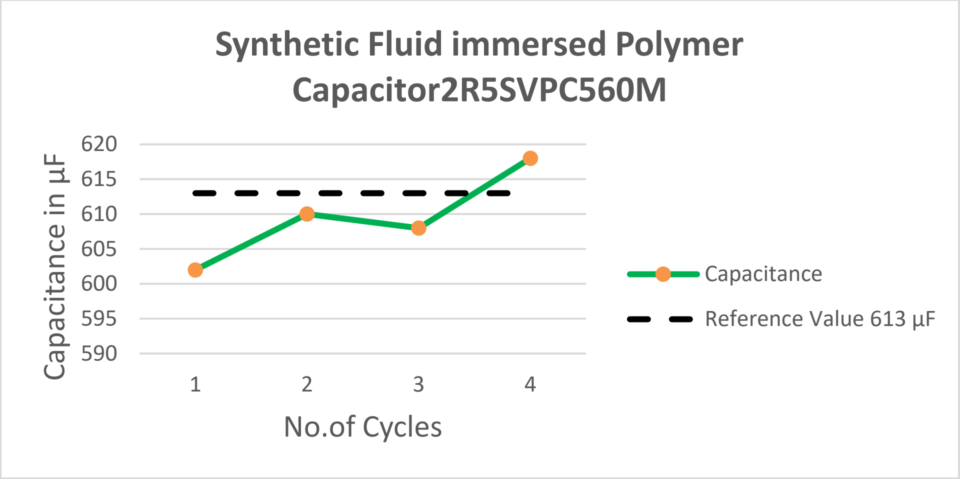

Figure 4.9(B): Change in Capacitance of 2R5SVPC560M Capacitor vs No. of Thermal Cycle

The capacitance of the Polymer capacitor is well within the allowable range.

The barrier voltage reading of the NPN and PNP transistor immersed in Synthetic Fluid are recorded below:

Sample 1 represents samples taken after 72-hour thermal cycle.

Sample 2 represents samples taken after 144-hours thermal cycle.

Sample 3 represents samples taken after 216-hours thermal cycle.

Sample 4 represents samples taken after 288-hours thermal cycle.

Table 4.12(A): Voltage across junctions of transistor Immersed in Synthetic Fluid recorded after each Thermal Cycle

Transistor	**NPN (**sample 1**)**	**PNP (**sample 1**)**	**NPN (**sample 2**)**	**PNP (**sample 2**)**
	Voltage (v)		Voltage (v)	
BASE TO EMITTER	0.571	OL	0.575	OL
BASE TO COLLECTOR	0.552	OL	0.557	OL
EMITTER TO BASE	OL	0.671	OL	0.671
COLLECTOR TO BASE	OL	0.669	OL	0.669
COLLECTOR TO EMITTER	OL	OL	OL	OL

Table 4.12(A): Voltage across junctions of transistor Immersed in Synthetic Fluid recorded after each Thermal Cycle

Transistor	**NPN (**sample 3**)**	**PNP (**sample 3**)**	**NPN (**sample 4**)**	**PNP (**sample 4**)**
	Voltage (v)		Voltage (v)	
BASE TO EMITTER	0.574	OL	0.571	OL
BASE TO COLLECTOR	0.556	OL	0.554	OL
EMITTER TO BASE	OL	0.669	OL	0.671
COLLECTOR TO BASE	OL	0.669	OL	0.669
COLLECTOR TO EMITTER	OL	OL	OL	OL

The voltage across the junctions are well within the range.

Comparative analysis of the electrical properties of the components immersed into the fluid and exposed to the air is discussed here:

Thick Film Resistance:

Table 4.13: Comparative change in resistance of the resistor in all 3 different conditions is recorded.

Thick Film Resistor	**Air Exposed Samples**	**Mineral Oil Immersed Samples**	**Synthetic Oil Immersed Samples**
Unit	**k ohms**		
Test 1 (72-hour Cycle)	0.996	0.996	0.996
Test 2 (144-hour cycle)	0.996	0.996	0.996
Test 3 (216-hour cycle)	0.996	0.996	0.996
Test 4 (288-hour cycle)	0.998	0.996	0.996

Figure 4.10: Change in resistance of samples exposed to various medium vs No.of Cycles

Resistance of the Thick Film Resistor specified by the manufacturer is 1k ohm.

The measured resistance value of the Thick Film Resistor is 0.996 k ohm.

Allowable tolerance range (1%): 0.990 k ohm to 1.001k ohm.

The performance is maintained in all the 3 conditions (immersed in Mineral Oil, Immersed in Synthetic Fluid and Exposed to Air) for the Thick Film Resistor.

Electrolytic Capacitor:

Table 4.14: Comparative change in Capacitance of the Electrolytic Capacitor in all 3 different conditions is recorded.

	Air Exposed Samples		**Mineral Oil Immersed Samples**		**Synthetic Oil Immersed Samples**	
Electrolytic Capacitor	**EEE-1CA101WP (Allowable range: 80 µF-120 µF)**	**EEE-FP1C471AP (Allowable range: 376 µF-564 µF)**	**EEE-1CA101WP (Allowable range: 80 µF-120 µF)**	**EEE-FP1C471AP (Allowable range: 376 µF-564 µF)**	**EEE-1CA101WP (Allowable range: 80 µF-120 µF)**	**EEE-FP1C471AP (Allowable range: 376 µF-564 µF)**
Unit	**µF**					
Test 1 (72-hour Cycle)	101	469	101	466	101	470

Test 2 (144-hour cycle)	101	469	101	464	101	467
Test 3 (216-hour cycle)	101	467	100	463	99	467
Test 4 (288-hour cycle)	103	469	100	464	101	467

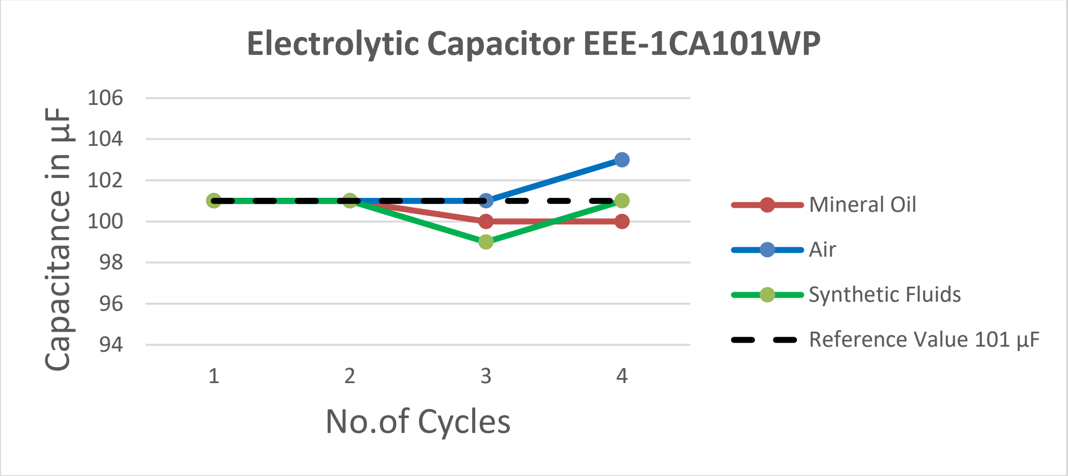

Figure 4.11(A): Change in capacitance of samples exposed to various medium vs No.of Cycles

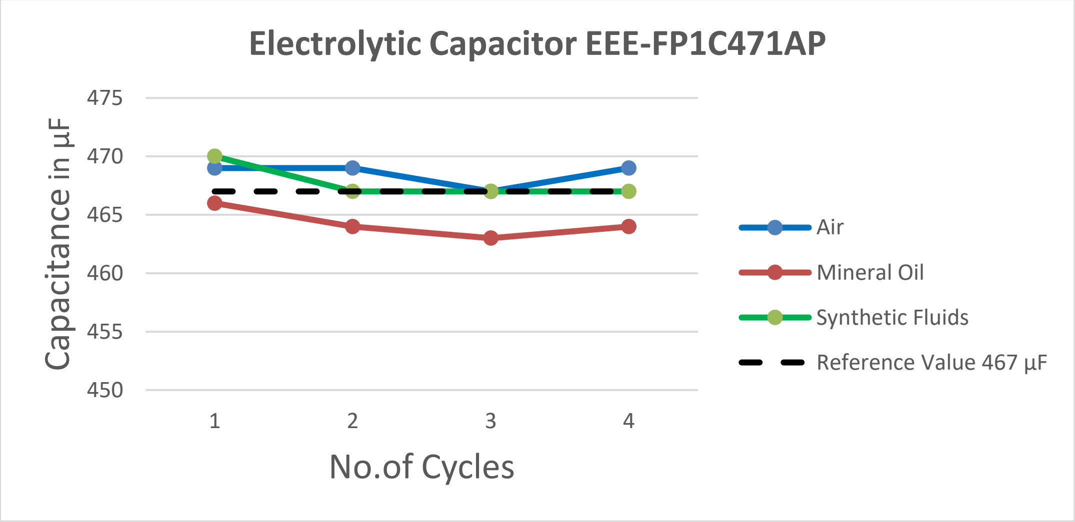

Figure 4.11(B): Change in capacitance of samples exposed to various medium vs No.of Cycles

Capacitance of the Electrolytic Capacitors EEE-1CA101WP and EEE-FP1C471AP specified by the manufacturer is 100 µF and 470 µF respectively.

The measured Capacitance of the Electrolytic Capacitors EEE-1CA101WP and EEE-FP1C471AP was 101 µF and 467 µF respectively.

The performance is maintained in all the 3 conditions (Immersed in Mineral Oil, Immersed in Synthetic Fluid and Exposed to Air) for the Electrolytic capacitor.

Polymer Capacitor:

Table 4.15: Comparative change in Capacitance of the Polymer Capacitor in all 3 different conditions is recorded.

	Air Exposed Samples		Mineral Oil Immersed Samples		Synthetic Oil Immersed Samples	
Polymer Capacitor	**16SVPF270M (Allowable range: 216µF-324µF)**	**2R5SVPC560M (Allowable range: 456µF-672µF)**	**16SVPF270M (Allowable range: 216µF-324µF)**	**2R5SVPC560M (Allowable range: 456µF-672µF)**	**16SVPF270M (Allowable range: 216µF-324µF)**	**2R5SVPC560M (Allowable range: 456µF-672µF)**
Unit	**µF**					
Test 1 (72-hour Cycle)	247	606	267	618	269	602
Test 2 (144-hour cycle)	261	612	267	612	264	610
Test 3 (216-hour cycle)	247	615	267	615	267	608
Test 4 (288-hour cycle)	261	615	267	615	267	618

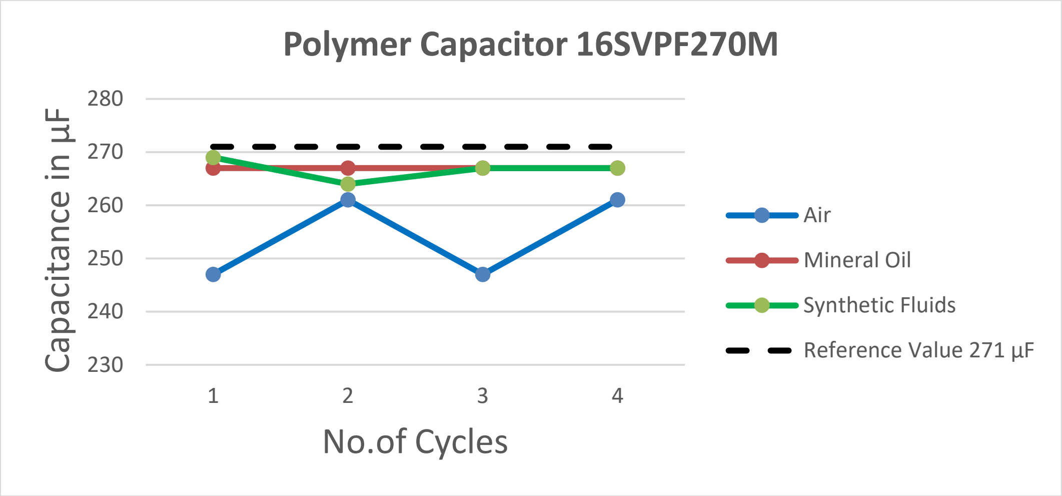

Figure 4.12(A): Change in capacitance of samples exposed to various medium vs No.of Cycles

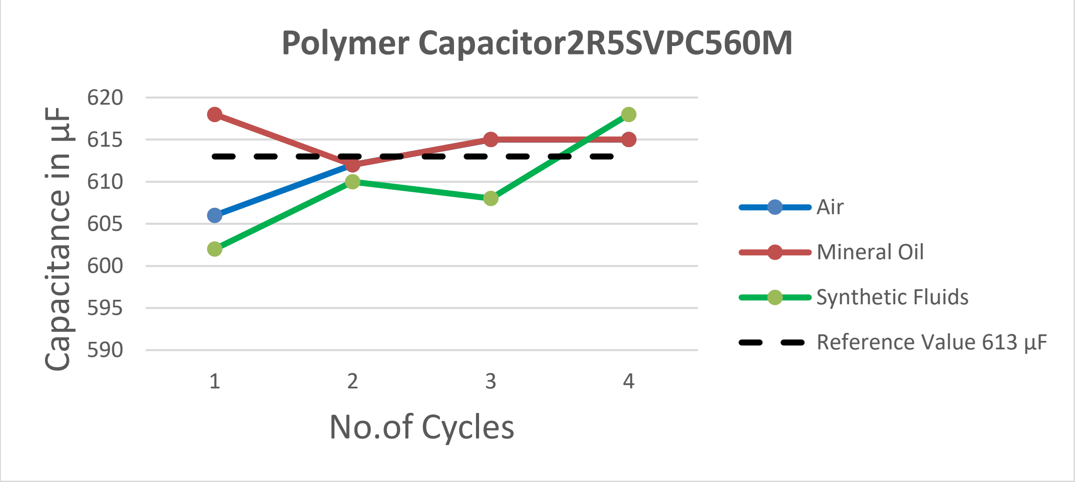

Figure 4.12(B): Change in capacitance of samples exposed to various medium vs No.of Cycles

Capacitance of the Polymer Capacitors 16SVPF270M and 2R5SVPC560M specified by the manufacturer is 270 µF and 560 µF respectively.

The measured Capacitance of the Polymer Capacitors 16SVPF270M and 2R5SVPC560M was 271 µF and 613 µF respectively.

The performance is maintained in all the 3 conditions (Immersed in Mineral Oil, Immersed in Synthetic Fluid and Exposed to Air) for the Polymer capacitor.

Scanning Electron Microscope Imaging of Immersion Cooled Samples:

Imaging after the 1st Thermal Cycling (After 72 Hour)

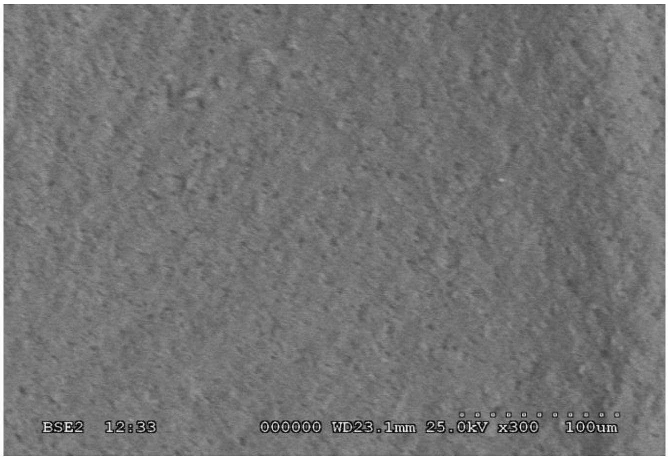

Figure 4.13(A): SEM Image of Mineral Oil Immersed Thick Film Resistor

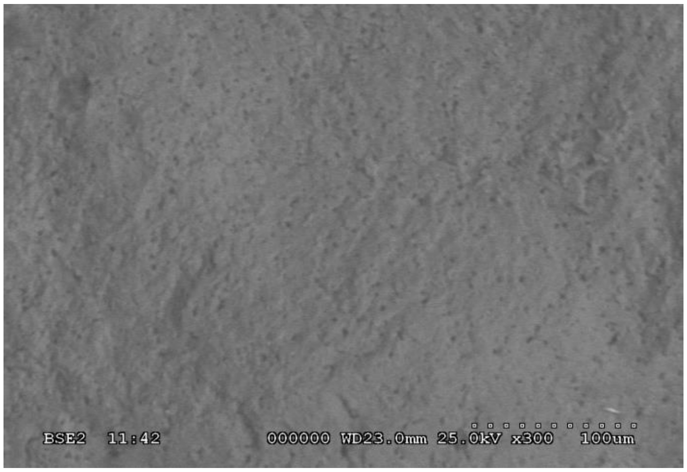

Figure 4.13(B): SEM Image of Synthetic Fluid Immersed Thick Film Resistor

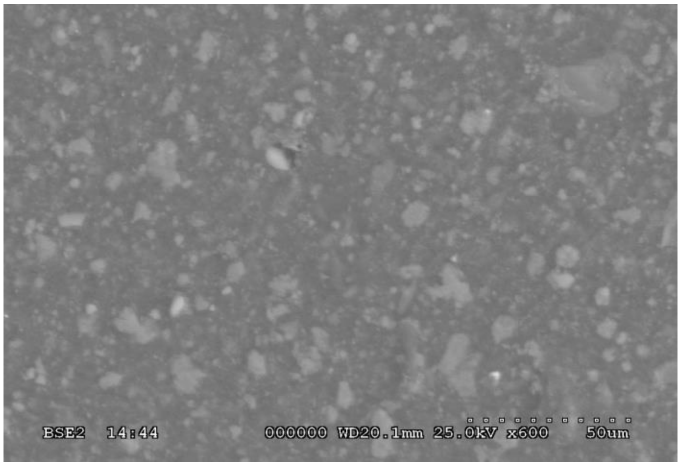

Figure 4.13(C): SEM Image of Mineral Oil Immersed Electrolytic Capacitor

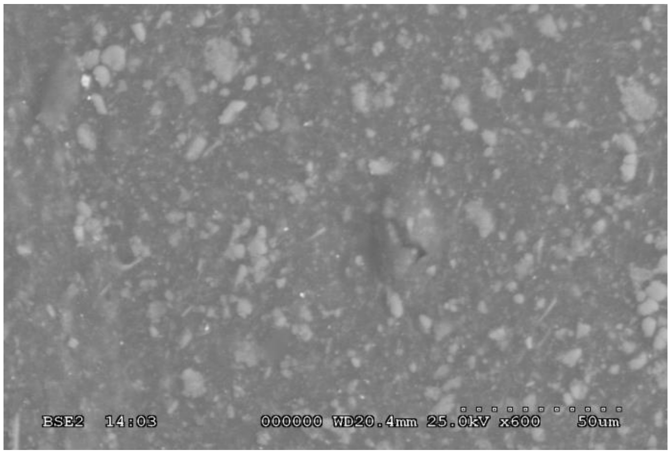

Figure 4.13(D): SEM Image of Synthetic Fluid Immersed Electrolytic Capacitor

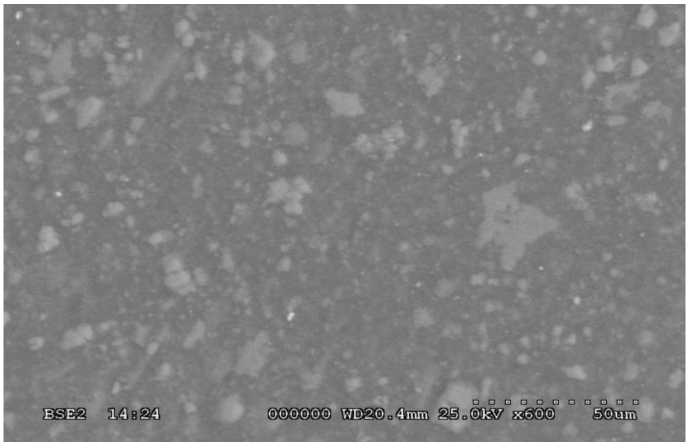

Figure 4.13(E): SEM Image of Mineral Oil Immersed Polymer Capacitor

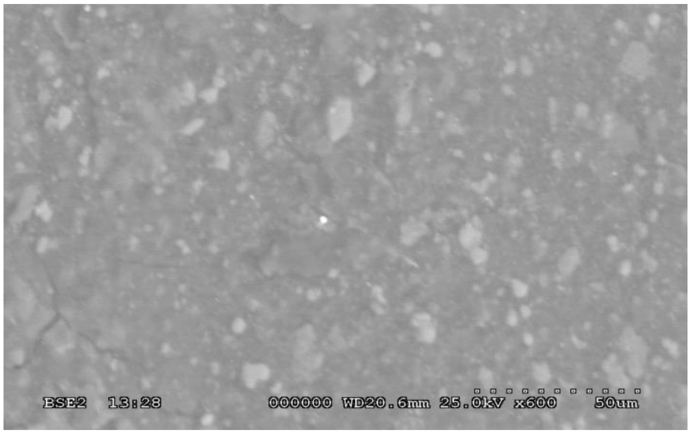

Figure 4.13(F): SEM Image of Synthetic Fluid Immersed Polymer Capacitor

The structural integrity is maintained for all the components and there is no sign of crack.

Imaging after the 2nd Thermal Cycling (After 144 Hours)

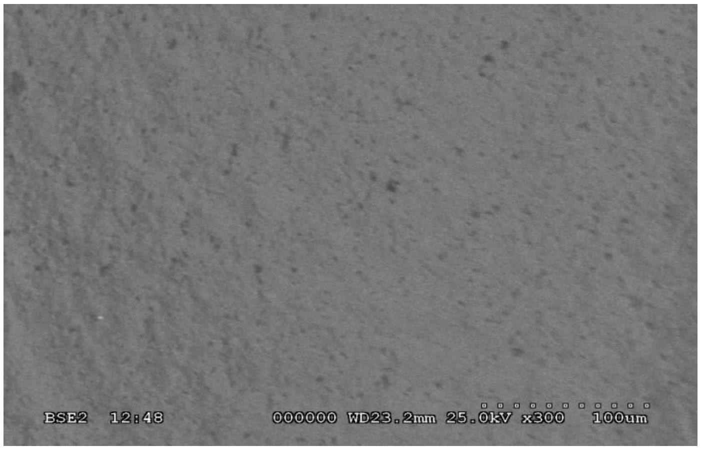

Figure 4.14(A): SEM Image of Mineral Oil Immersed Thick Film Resistor

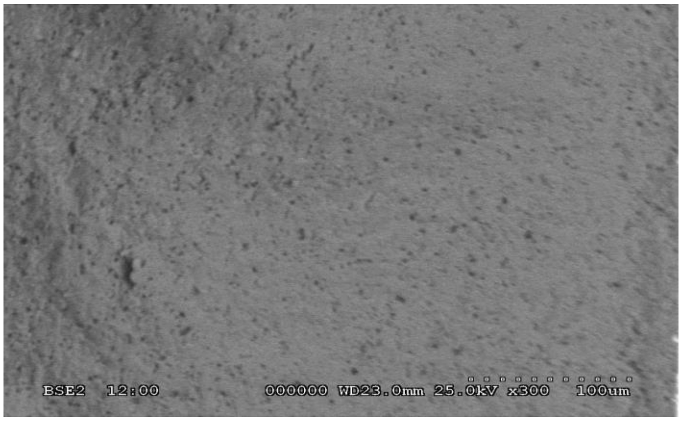

Figure 4.14(B): SEM Image of Synthetic Fluid Immersed Thick Film Resistor

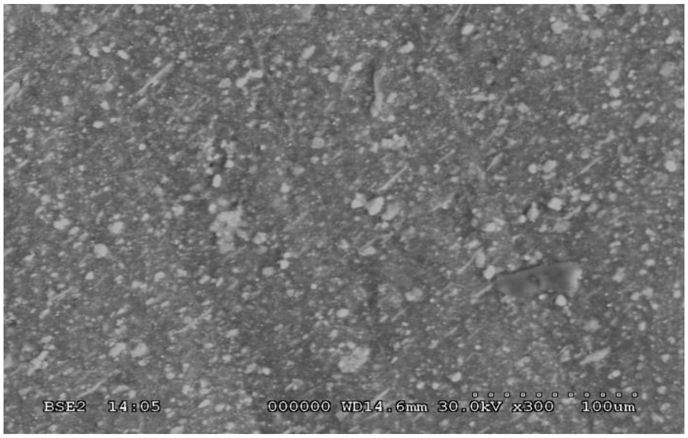

Figure 4.14(C): SEM Image of Mineral Oil Immersed Electrolytic Capacitor

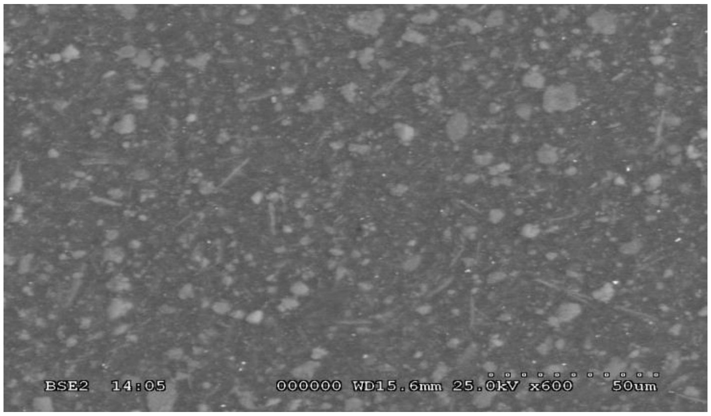

Figure 4.14(D): SEM Image of Synthetic Fluid Immersed Electrolytic Capacitor

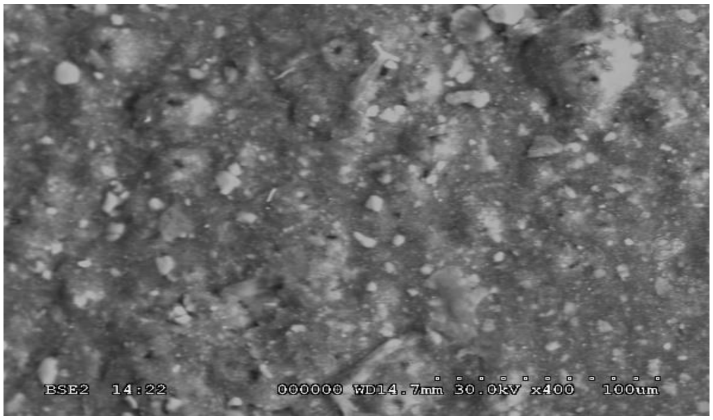

Figure 4.14(E): SEM Image of Mineral Oil Immersed Polymer Capacitor

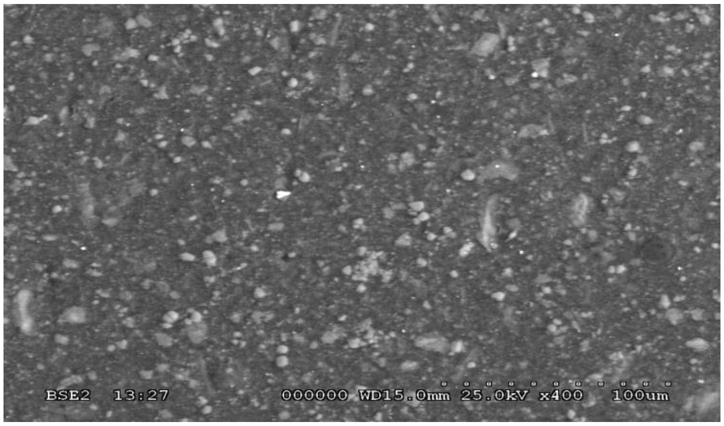

Figure 4.14(F): SEM Image of Synthetic Fluid Immersed Polymer Capacitor

The structural integrity is maintained for all the components and there is no sign of crack formation.

Imaging after the 3nd Thermal Cycling (After 216 Hours)

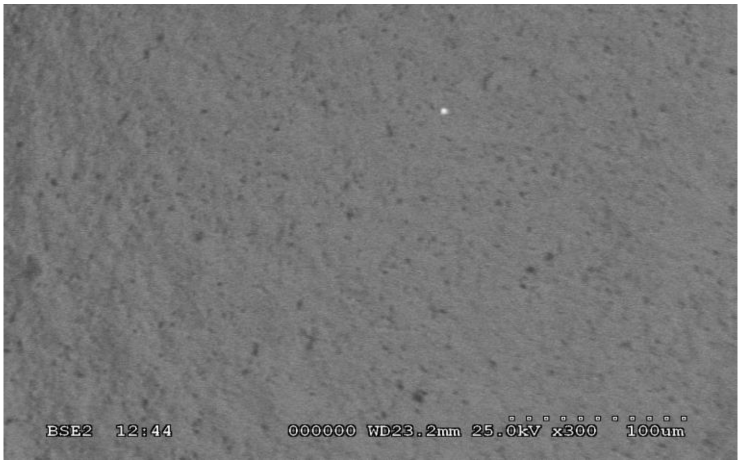

Figure 4.15(A): SEM Image of Mineral Oil Immersed Thick Film Resistor

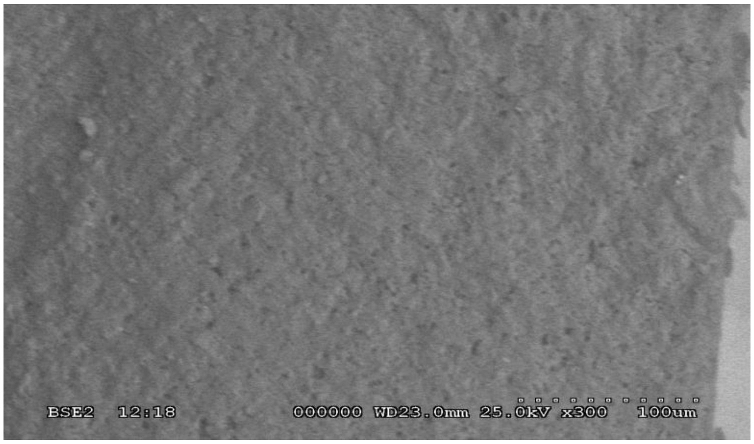

Figure 4.15(B): SEM Image of Synthetic Fluid Immersed Thick Film Resistor

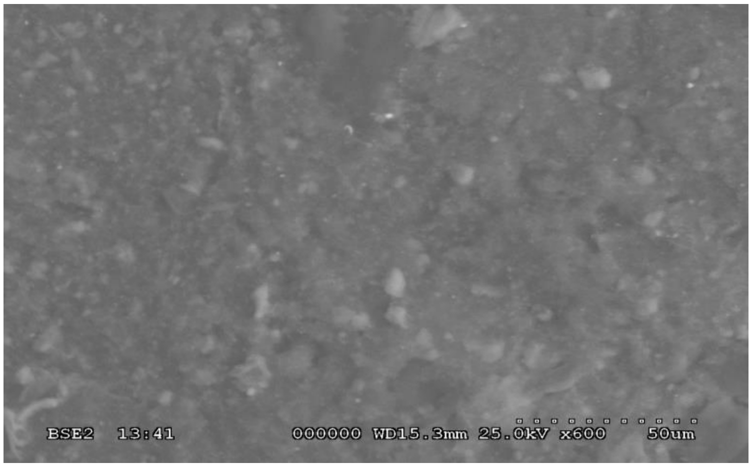

Figure 4.15(C): SEM Image of Mineral Oil Immersed Electrolytic Capacitor

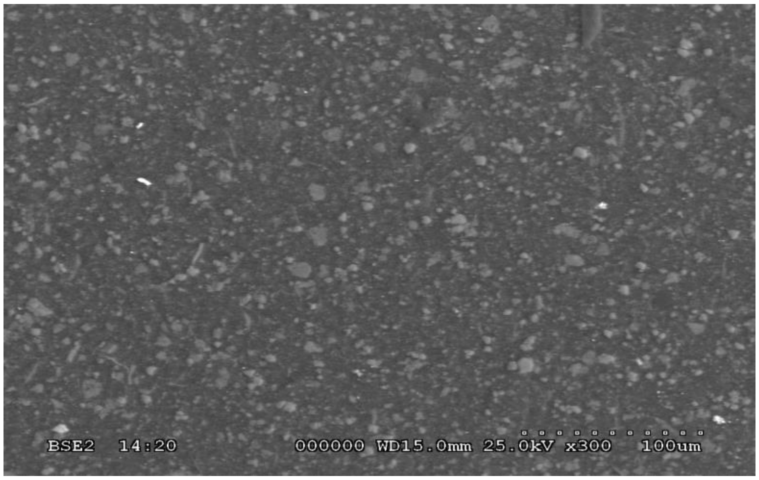

Figure 4.15(D): SEM Image of Synthetic Fluid Immersed Electrolytic Capacitor

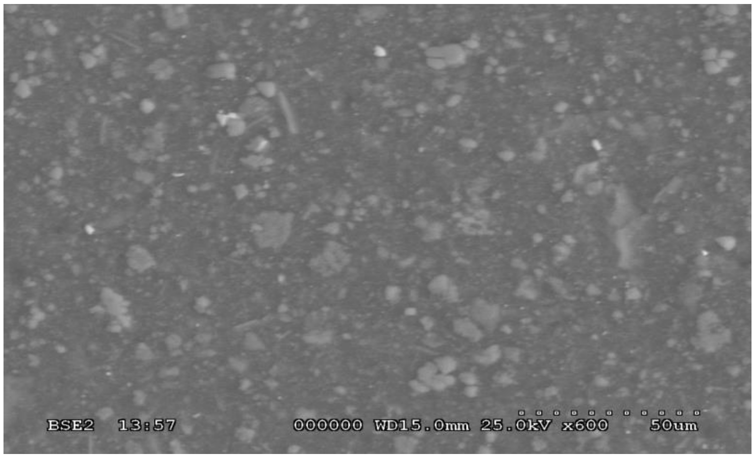

Figure 4.15(E): SEM Image of Mineral Oil Immersed Polymer Capacitor

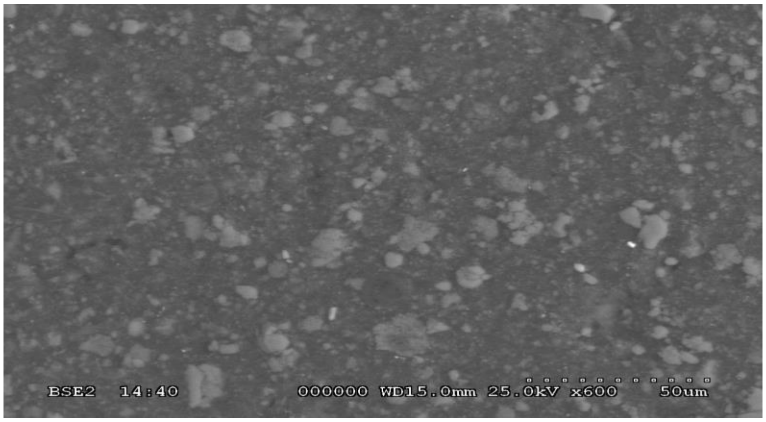

Figure 4.15(F): SEM Image of Synthetic Fluid Immersed Polymer Capacitor

The structural integrity is maintained for all the components and there is no sign of crack formation.

Imaging after the 4th Thermal Cycling (After 288 Hours)

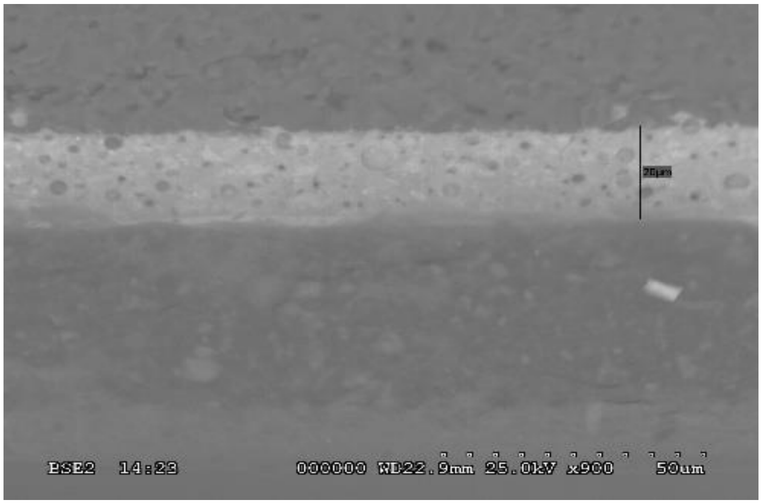

Figure 4.16(A): SEM Image of Mineral Oil Immersed Thick Film Resistor

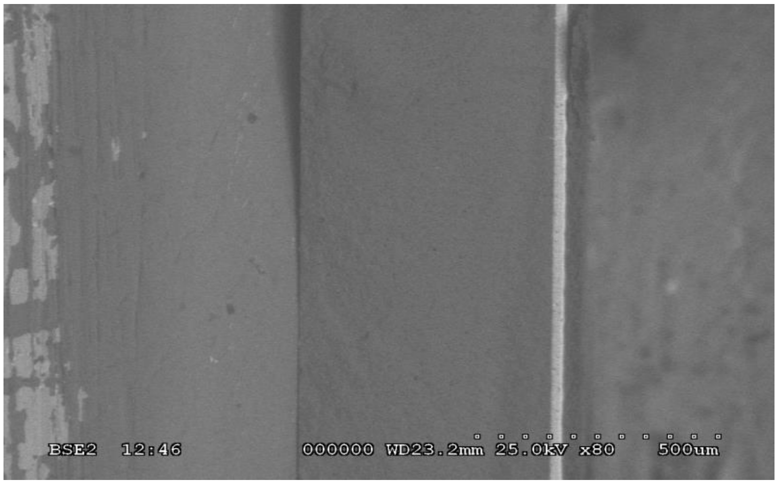

Figure 4.16(B): SEM Image of Synthetic Fluid Immersed Thick Film Resistor

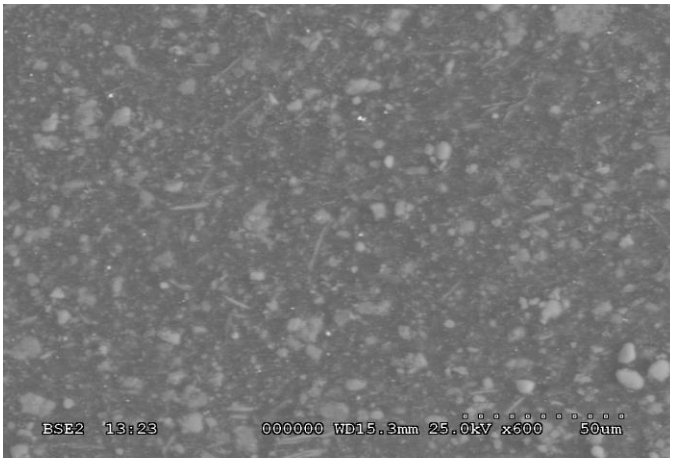

Figure 4.16(C): SEM Image of Mineral Oil Immersed Electrolytic Capacitor

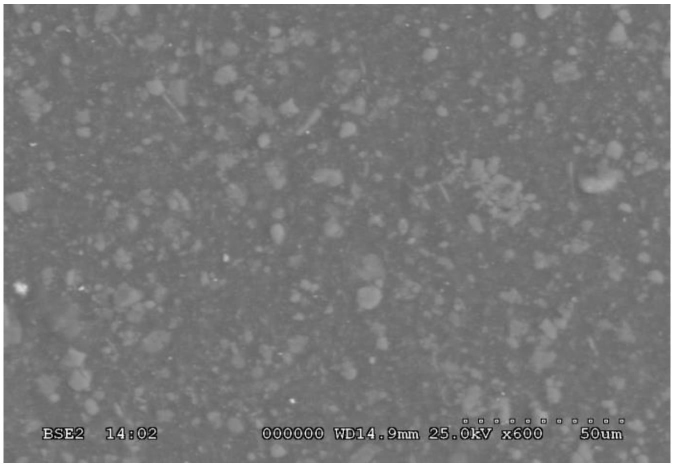

Figure 4.16(D): SEM Image of Synthetic Fluid Immersed Electrolytic Capacitor

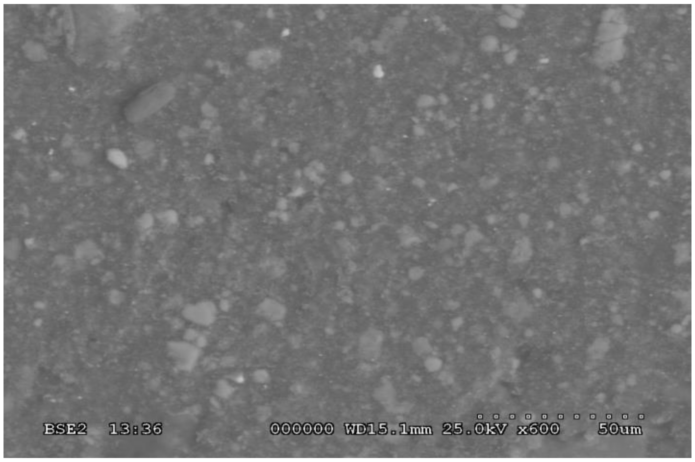

Figure 4.16(E): SEM Image of Mineral Oil Immersed Polymer Capacitor

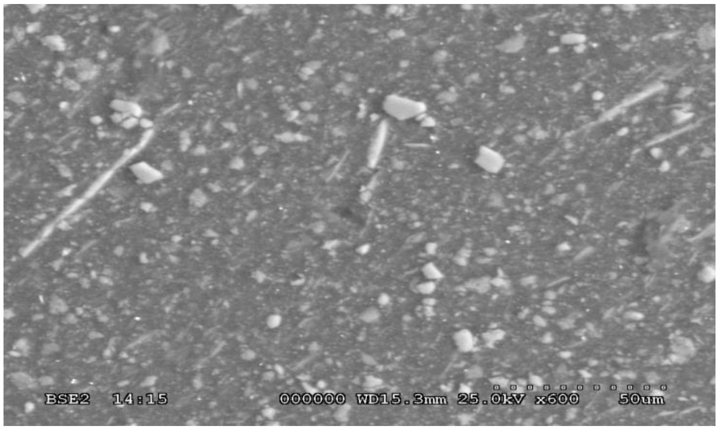

Figure 4.16(F): SEM Image of Synthetic Fluid Immersed Polymer Capacitor

The structural integrity is maintained for all the components and there is no sign of crack formation.

Chapter 5

Conclusion

From the experimental data, it can be inferred that the passive components used in the servers are reliable to use in Single Phase Immersion Cooling technique. The comparison graph of all the Passive components immersed in Mineral Oil vs immersed in Synthetic Fluid vs Exposed to air provides the evident that the electrical properties of the components are stable. This concludes that the Single-Phase Immersion Cooling of passive components doesn’t affect the desired property of the components. The Images from the Scanning Electron Microscope provides the information about structural integrity of the passive components and the crack formation on the surface. From all the images (14.13 to 14.16) we attained from the SEM Scan it is clear that the structural integrity of all the passive components are maintained and there is no sign for formation of any crack or penetration of fluid into the surface. These results conclude that the Single-Phase Immersion Cooling is on par in terms of reliability with the conventional data center cooling method. As the Single-Phase Immersion Cooling as lot of thermal advantageous it is obviously a better choice for high density data centers.

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Biographical Information

Keerthivasan Padmanaban was born in Thiruvarur, Tamil Nadu, India in 1993. Keerthivasan Padmanaban has received his Master of Science degree in Mechanical Engineering from The University of Texas at Arlington. He completed his Bachelor of Technology in Mechanical Engineering from Anna University, India. He worked in Wipro Ltd., as s Project Engineer for 11 months. He had been working in the EMNSPC Research lab at UTA on oil immersion cooling of the server and reliability of the server