IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 5 Ver. II (Sep – Oct. 2015), PP 19-28
www.iosrjournals.org

Effect of DBDS and DBPC on Paper Oil Insulation of Power Transformers

Faheem Ahmed Khan[1], Asma Tamboli[2]
[1]*(Electrical and Electronics (Associate Professor), Ghousia College of Engineering/ Visvesvaraya Technological University, INDIA)*
[2]*(Electrical and Electronics (PG Student), Ghousia College of Engineering/ Visvesvaraya Technological University, INDIA)*

Abstract: *Power transformers are the integral part of the power systems. In oil immersed transformers, oil acts as a coolant as well as an insulator. To prevent the oil from oxidation antioxidants such as Dibenzyl Disulfide (DBDS) and 2, 6 Di-tertiary Paracresol (DBPC) are added to the oil to enhance the quality of the oil. A number of failures have occurred in transformers causing great loss to power grids due to the presence of copper sulfide. The formation of copper sulfide on the insulation paper degrades the insulation strength of paper. The transformer mineral oil is one of the sources for the formation of copper sulfide. The sulfur in the insulating oil is present in the range of 0.001 to 0.5%. It was seen that the sulfur was also added intentionally to the oil in the form of antioxidant such as DBDS. The corrosive sulfur is formed by the reaction of DBDS with the copper surface. At a certain time the increase in the concentration of DBDS and DBPC increases the formation of copper sulfide. In present work, the effect of DBDS and DBPC on leakage currents and hence on dielectric characteristics have been studied.*
Keywords: *Copper sulfide, DBDS, DBPC, Transformer oil*

I. Introduction

Transformer oil is one of the very important components in oil immersed transformers. The life expectancy and satisfactory operation of transformers are mainly dependent on the oil in which it is used. The transformer oil performs two important functions. It creates an acceptable level of insulation and also acts as a coolant to extract heat from the core and the windings. The oil used in transformers is hydrocarbon mineral oil. It is mainly composed of four generic classes of organic compounds, aromatics, paraffins, napthenes and olefines. Transformer oil gives a better insulation when aromatics, paraffins, napthenes and olefines are present at the right proportion. For better insulation Transformer oil is desired to have more of saturated paraffins and less of aromatics, napthenes and olefines. For more stability, more aromatics and napthenes are necessary. To get both insulating property and stability at the same time, there must be an optimum mix of four organic components. This can be obtained by careful refining of crude oil.

Transformer oil is a mixture of paraffinic, naphthenic and aromatic hydrocarbons is Prone to oxidation. Many polar compounds such as acids, aldehydes, ketones, peroxides and alcohols are formed due to the oxidation of oil. These products affect the insulating properties of oil and heat transfer properties of oil by forming sludge type compound. This reduces the performance of power transformers, thereby reducing their life. In order to improve the stability of mineral transformer oil against oxidation and thereby to improve the life of oil, a few additives known as antioxidants and metal deactivators are added. Conventionally Dibenzyl disulfide (DBDS) and 2, 6–di-tertiary-butyl-para-cresol are used as the antioxidant [1].

A number of transformer failures have occurred due to the deposition of copper sulfide in the windings and this is a major issue of concern. Copper sulfide is formed due to the transformer mineral oil. Copper sulfide is more likely to be found on oil immersed windings and Insulation paper. The deposits vary within the windings and usually there are more deposits on the upper part of the windings. Copper sulfide covered on the metal surface leads to overheating and arching and then induces failure [2, 3].

Recent observations have shown that there are premature transformer failures in the field caused by copper sulfide deposition. Large, heavily loaded transformers and transformers with sealed oil preservation systems of different types seem to be severely affected. The external conditions which influence the copper sulfide formation are aging, heating duration, type of oil, temperature, oxygen content, electrical fields etc, except the type of paper which is used in the transformers.

Although most of the sulfur compounds cause corrosion and accelerate sludge formation and hence affecting adversely, the electrical properties of the mineral oils; there are a few sulfur compounds that are beneficial to the oils in that, they may act as retardants or passivants in the oxidation process of the oils. Passivators are also known as metal deactivators, they react with metal surfaces and dissolved metals such as copper and reduce their rate of reaction with other compounds in the oil.

Copper sulfide particles from the conductor surfaces will eventually migrate or diffuse into the porous insulating papers, thereby augmenting their conductivity and magnitude of dielectric loss. The increased dielectric losses will enhance heat generation and lead to the formation of hot spot regions. When the rate of heat generation will exceed that of heat transmission to the surrounding medium, thermal instability will result; the magnitude of the electrical current at the hot spots will increase until short circuiting current develop between the coils and cause breakdown. This scenario accounts for the charred and collapsed coils in electrical apparatus, particularly at the upper portion of the coils where oil temperature is higher.

Dibenzyl Disulfide (DBDS) is one of several sulfur compounds known to cause copper corrosion in transformers under certain circumstances. The molecular formula of DBDS is shown in Fig. 1. DBDS, in itself might or might not be corrosive. DBDS-copper complex is formed in which the copper is removed from the conductor surface and goes through a series of reactions in which copper sulfide is then formed on the copper surface. These DBDS breakdown products are very corrosive. The role played by DBDS on the corrosiveness of oil is very important because the rate of copper sulfide formation from the DBDS is about five times greater than the rate for the other aromatic sulfur compounds, for example, dihexyl sulfide, dihexyl disulfide, or dibenzyl sulfide. The thermal degradation of DBDS increased with temperature and in the presence of copper, revealing the catalytic role played by copper. The mechanism of copper sulfide deposition on the insulating paper occurs in three steps: first, the dissolution of DBDS-Cu Complex in insulating oil takes place, then the DBDS-Cu Complex is absorbed in the insulating paper and finally the decomposition of DBDS-Cu complex on insulating paper which causes copper sulfide generation [3,4].

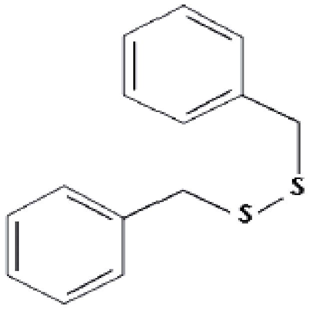

Fig. 1: Chemical Structure of DBDS

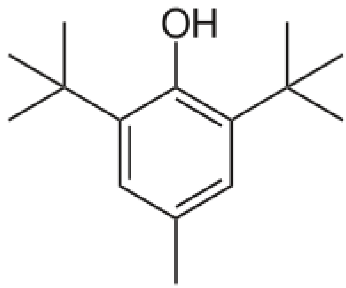

Fig. 2: Chemical Structure of DBPC

DBPC is an organic compound. Chemically a derivative of phenol that is useful for its antioxidant properties. Its molecular formula is shown in Fig. 2. The molecular formula of DBPC is $C_{15}H_{24}O$. The physical appearance of DBPC is white to yellow powder. It has a melting point of about 70°C and boiling point of about 265°C. DBPC is flammable in nature. It is one of the suitable oxidation inhibitor for transformer oil [1]. The effective life of the equipment is prolonged with DBPC inhibited oil.

The formation of copper sulfide increases with the increase in concentration of antioxidants Dibenzyl disulphide (DBDS) and 2, 6-ditertiary-butyl-para-cresol (DBPC). The DBDS concentration on oil has two effects on the formation rates of copper sulfide. The formation rates of oil are proportional to the DBDS concentration when concentration is low and the amount of copper on the Insulation papers is constant when the DBDS concentrations are more than certain values, which is the saturation of dissolving DBDS-Cu complex in the oil. Copper sulfide formed on Insulation paper can be measured by the portion of reacted copper with DBDS. While, DBPC has been established as suitable antioxidant for transformer oil, it is effective even in small concentrations. The increase in the concentration of DBPC increases the formation of copper sulfide leading to insulation failure [2]. It is seen that one molecule of DBDS gives two molecules of copper sulfide which can be illustrated by chemical reaction [5]:

$$4Cu + (C_6H_5CH_2)_2S_2 \rightarrow 2Cu_2S + C_6H_5CH_2CH_2C_6H_5 \qquad (1)$$

II. Experimental Setup

The effect of DBDS and DBPC on transformer oil is evaluated, which are leading to the insulation failures. These failures are the result of deposition of copper sulfide that is formed by the reaction of copper and these antioxidants. The experimental setup is as shown in the Fig. 3. The voltage is applied through a high voltage transformer across the electrodes placed in an oil cell shown in Fig. 4. An electrical grade paper is placed between the electrodes. The voltage is applied across the electrodes in steps and the corresponding leakage current is measured. At a certain point a spark over takes place which leads to the breakdown of the oil.

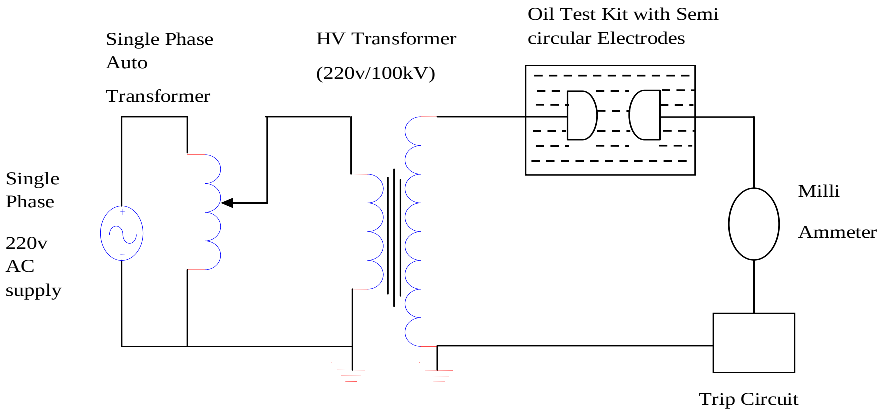

Fig. 3: Experimental Set-up

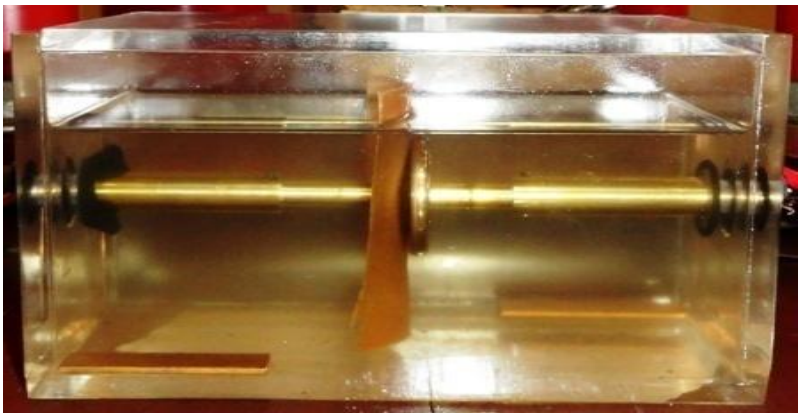

Fig. 4: Cell with insulation paper held between the plane-plane electrodes.

III. Results And Discussions

Leakage current measurement for clean oil, oil with DBDS and oil with DBPC at different concentrations are tabulated and graphically shown.

3.1: Leakage current measurement of clean oil.

The leakage current is measured for clean oil at different applied voltages when different layers of insulation papers are held between the electrodes immersed in clean oil. The results are tabulated and discussed below in the Table 1.

Table 1: leakage current at different applied voltages for clean oil with different layers of papers placed between the electrodes

Applied Voltage(kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.06	0.062	0.065	0.07	0.075
2	0.065	0.067	0.07	0.075	0.08
3	0.07	0.073	0.075	0.082	0.1
4	0.076	0.079	0.082	0.089	0.11
5	0.082	0.085	0.09	0.093	0.12
6	0.089	0.09	0.105	0.098	0.13
7	0.099	0.1	0.11	0.12	0.145
8	0.11	0.115	0.12	0.13	0.145
9	0.12	0.125	0.13	0.14	0.176
10	0.13	0.135	0.14	0.155	0.192
11	0.14	0.145	0.15	0.17	0.21
12	0.16	0.165	0.17	0.185	0.23
13	0.18	0.185	0.19	0.2	0.25
14	0.20	0.21	0.22	0.23	BD
15	0.22	0.23	0.24	0.25	
16	BD*	BD	BD	BD	

*Breakdown

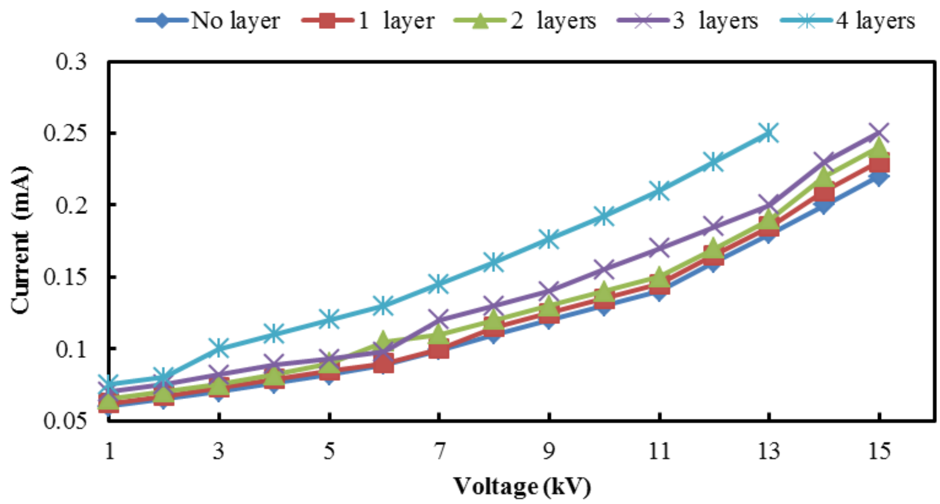

Fig. 5: leakage current versus applied voltage for clean oil having different paper layers placed between the electrodes

3.2: Leakage current measurement for oil containing different concentrations of DBDS.

Leakage current is measured for different applied voltages when different numbers of paper layers are held between the electrodes kept at a distance of 2mm immersed in the oil containing DBDS at concentrations of 25 ppm, 50ppm and 100 ppm. These results are tabulated in the Tables 2, 3 and 4 respectively.

Table 2: Leakage current at different applied voltages for oil with DBDS (25 ppm) when different layers of papers placed between the electrodes

Voltage Applied(kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.063	0.0651	0.06825	0.0735	0.07875
2	0.06825	0.07035	0.0735	0.07875	0.084
3	0.0735	0.07665	0.07875	0.0861	0.105
4	0.0798	0.08295	0.0861	0.09345	0.1155
5	0.0861	0.08925	0.0945	0.09765	0.126
6	0.09523	0.0963	0.11235	0.10486	0.1391
7	0.10593	0.107	0.1177	0.1284	0.15515
8	0.1177	0.12305	0.1284	0.1391	0.1744
9	0.1284	0.13375	0.1391	0.1498	0.18832
10	0.1391	0.1445	0.1498	0.16585	0.20544
11	0.1554	0.15805	0.1635	0.1853	0.2289
12	0.1776	0.17985	0.1853	0.20165	0.2507
13	0.1998	0.20165	0.2071	0.218	0.2725
14	0.222	0.2289	0.2398	0.2507	BD
15	0.2442	0.2507	0.2616	0.2725	
16	BD	BD	BD	BD	

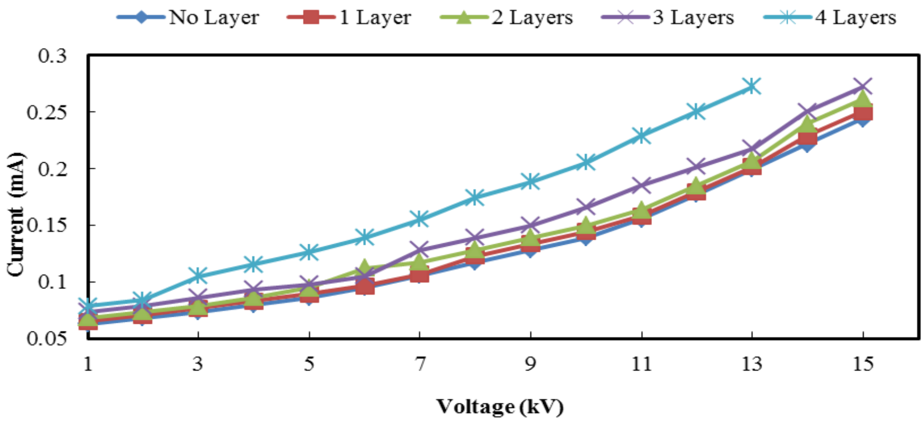

Fig. 6: Leakage current as a function of applied voltages when different layers of insulation papers are held between the electrodes in oil with 25 ppm DBDS concentration.

Table 3: Leakage current at different applied voltages for oil with DBDS (50 ppm) with different layers of insulation paper held between the electrodes.

Voltage Applied (kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.0642	0.06634	0.06955	0.0749	0.08025
2	0.06955	0.07169	0.0749	0.08025	0.0856
3	0.0749	0.07811	0.08025	0.08774	0.107
4	0.08132	0.08453	0.08774	0.09523	0.1177
5	0.08774	0.09095	0.0963	0.09951	0.1284
6	0.0979	0.099	0.1155	0.1078	0.143
7	0.1067	0.11	0.121	0.132	0.1595
8	0.121	0.1265	0.132	0.143	0.176
9	0.132	0.1375	0.143	0.154	0.1936
10	0.143	0.1485	0.154	0.1705	0.231
11	0.1582	0.16385	0.1695	0.1921	0.2373
12	0.1808	0.18645	0.1921	0.20905	0.2599
13	0.2034	0.20905	0.2147	0.226	0.2825
14	0.226	0.2373	0.2486	0.2599	BD
15	0.2486	0.2599	0.2712	0.2825	
16	BD	BD	BD	BD	

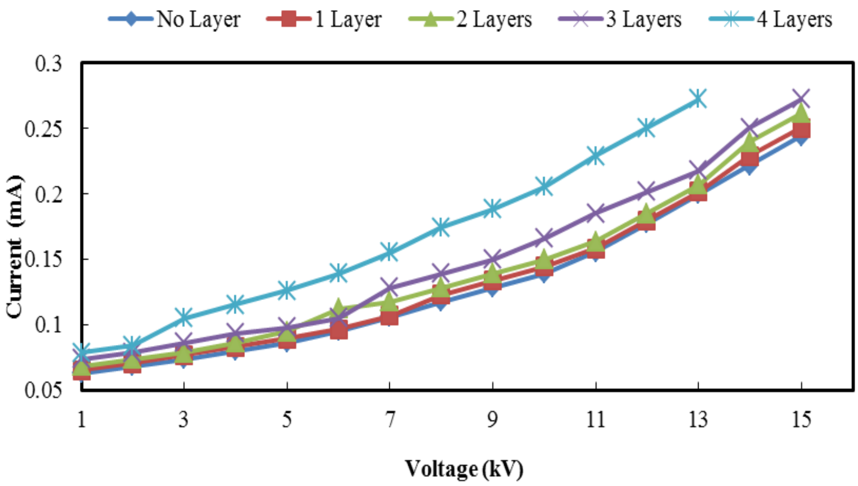

Fig. 7: Leakage current as a function of applied voltages when different layers of insulation paper are held between the electrodes in oil with 50ppm DBDS concentration.

Table 4: Leakage current at different applied voltages for oil with DBDS (100 ppm) with different layers of insulation papers placed between the electrodes.

Applied Voltage (kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.0648	0.06696	0.0702	0.0756	0.081
2	0.0702	0.07236	0.0756	0.081	0.0864
3	0.0756	0.07884	0.081	0.08856	0.108
4	0.08208	0.0853	0.08856	0.09612	0.1188
5	0.08856	0.0918	0.0972	0.10044	0.1296
6	0.10057	0.1017	0.11865	0.11074	0.1469
7	0.1187	0.1243	0.1356	0.1469	0.16385
8	0.1243	0.12995	0.1469	0.1582	0.1808
9	0.1356	0.14125	0.1582	0.161	0.1988
10	0.1469	0.15255	0.1582	0.17515	0.21696
11	0.1624	0.1628	0.179	0.1972	0.2436
12	0.1856	0.1914	0.1972	0.2146	0.2668
13	0.2088	0.2146	0.2204	0.232	0.29
14	0.232	0.2436	0.2552	0.2668	BD
15	0.2552	0.2668	0.2784	0.29	
16	BD	BD	BD	BD	

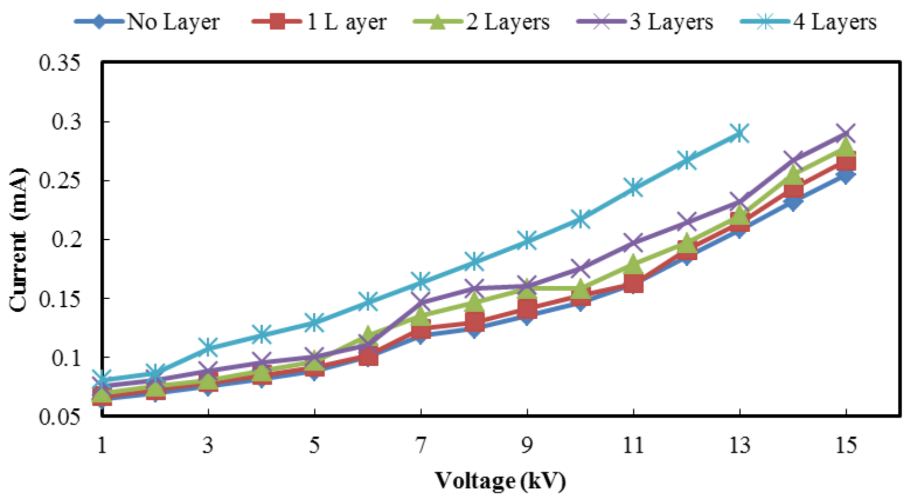

Fig. 8: Leakage current as a function of applied voltages when different layers of insulation paper are held between the electrodes in oil with 100ppm DBDS concentration.

From Fig. 6, it can be seen that the leakage current varies linearly with applied voltages when no paper layer is introduced between the electrodes. As the number of layers between the electrodes increase, the leakage current rise enters exponential growth. On an average 5 % rise in leakage current was observed for an applied voltage of 1-5kV. The rise in leakage current was found to be rising at a rate of 7% for an applied voltage of 6-10kV. Further till breakdown it was found to be 9% for a concentration of 25ppm of DBDS.

In the next case for the concentration of 50 ppm DBDS, the leakage current rises linearly when no paper is placed between the electrodes as shown in Fig. 7. The leakage current was found to be increasing exponentially as the layers of paper between the electrodes are increased. For an applied voltage of 1-5 kV there was rise of about 7%, for 6-10kV it was about 10% and for voltage till breakdown it was about 13%.

For the concentration of DBDS of 100 ppm, the leakage current rises linearly when no paper is introduced and exponentially when the insertion of paper layers are increased as shown in Fig. 8. There was an average rise of 8% for 1-5 kV, 13% for 6-10kV and 16% until breakdown.

3.3: Leakage current measurement for oil containing different concentrations of DBPC.

Leakage current is measured for different applied voltages when different numbers of insulation paper layers are held between the electrodes kept at a distance of 2mm immersed in the oil containing DBPC of concentration 25ppm,50ppm and 100 ppm. The results for these are tabulated in the Tables 5, 6 and 7 respectively.

Table 5: leakage current at different applied voltages for oil with DBPC (25 ppm) with different layers of papers placed between the electrodes

Voltage Applied (kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.0642	0.06634	0.06955	0.0749	0.08025
2	0.06955	0.07169	0.0749	0.08025	0.0856
3	0.0749	0.07811	0.08025	0.08779	0.107
4	0.08132	0.0845	0.08774	0.09523	0.1177
5	0.08774	0.09095	0.0963	0.09951	0.1284
6	0.09701	0.0981	0.11445	0.10682	0.1417
7	0.1057	0.109	0.1199	0.1308	0.15805
8	0.1199	0.12535	0.1308	0.1417	0.1744
9	0.1308	0.13625	0.1417	0.1526	0.19184
10	0.1417	0.14715	0.1526	0.16895	0.20928
11	0.1554	0.16695	0.1665	0.1887	0.2331
12	0.1776	0.18315	0.1887	0.20535	0.2553
13	0.1998	0.20535	0.219	0.222	0.2775
14	0.222	0.2331	0.2442	0.2553	BD
15	0.2442	0.2553	0.2664	0.2775	
16	BD	BD	BD	BD	

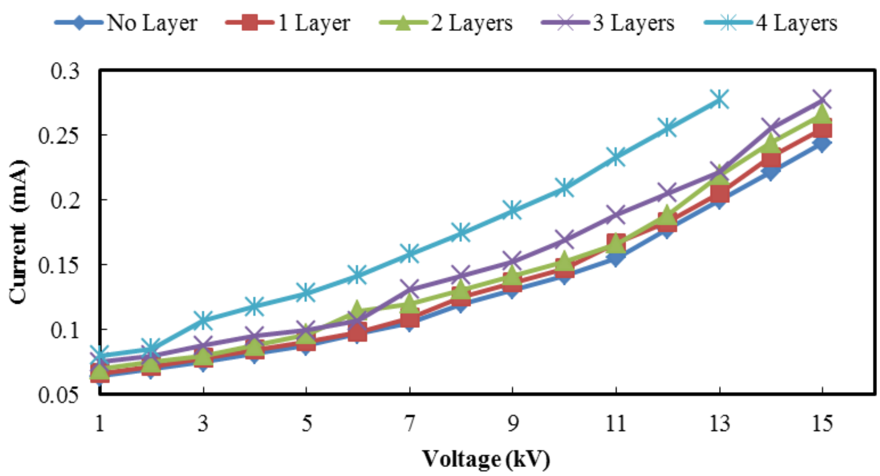

Fig. 9: Leakage current as a function of applied voltages when different layers of insulation paper are held between the electrodes in oil with 25 ppm DBPC concentration.

Table 6: Leakage current at different applied voltages for oil with DBPC (50 ppm) with different layers of papers placed between the electrodes

Voltage Applied (kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.0654	0.06758	0.07085	0.0763	0.08175
2	0.07085	0.07303	0.0763	0.08175	0.0872
3	0.0763	0.07957	0.08175	0.08938	0.109
4	0.08284	0.08611	0.08938	0.09701	0.1199
5	0.08938	0.09265	0.0981	0.09837	0.1308
6	0.09968	0.1008	0.1176	0.10976	0.1456
7	0.10864	0.112	0.1332	0.1356	0.1624
8	0.1232	0.1288	0.1344	0.1456	0.1792
9	0.1344	0.14	0.1456	0.1568	0.19712
10	0.1456	0.1512	0.1568	0.1736	0.215
11	0.161	0.16675	0.1725	0.1955	0.2415
12	0.184	0.18975	0.1955	0.21275	0.2645
13	0.207	0.2127	0.2185	0.23	0.2875
14	0.23	0.2415	0.253	0.2645	BD
15	0.253	0.2645	0.276	0.2875	
16	BD	BD	BD	BD	

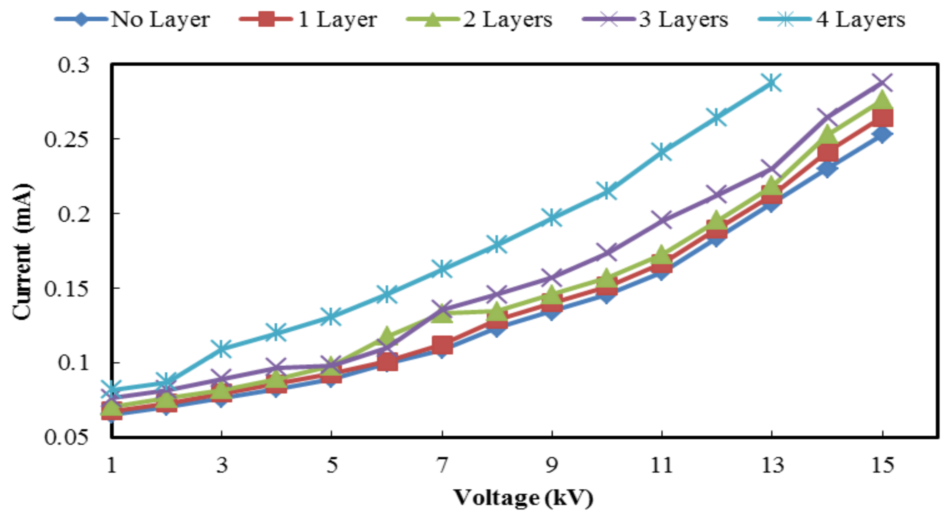

Fig. 10: Leakage current as a function of applied voltages when different layers of insulation paper are held between the electrodes in oil with 50ppm DBPC Concentration.

Table7: Leakage current at different applied voltages for oil with DBPC (100 ppm) with different layers of insulation papers placed between the electrodes.

Voltage Applied(kV)	Current (mA)				
	No Layer	1 Layer	2 Layers	3 Layers	4 Layers
1	0.066	0.0682	0.0715	0.077	0.0825
2	0.0715	0.0737	0.077	0.0825	0.088
3	0.077	0.0803	0.0825	0.0902	0.11
4	0.0836	0.0869	0.0902	0.0979	0.121
5	0.0902	0.0935	0.099	0.1023	0.132
6	0.10235	0.1035	0.12075	0.1127	0.1495
7	0.11155	0.115	0.1265	0.138	0.16675
8	0.1265	0.13225	0.138	0.1495	0.184
9	0.138	0.14375	0.1495	0.161	0.2024
10	0.1495	0.15525	0.161	0.17825	0.2208
11	0.1652	0.1711	0.177	0.2006	0.2478
12	0.188	0.1947	0.2006	0.2183	0.2714
13	0.2124	0.2183	0.2242	0.236	0.295
14	0.236	0.2478	0.2596	0.2714	BD
15	0.2596	0.2714	0.2832	0.295	
16	BD	BD	BD	BD	

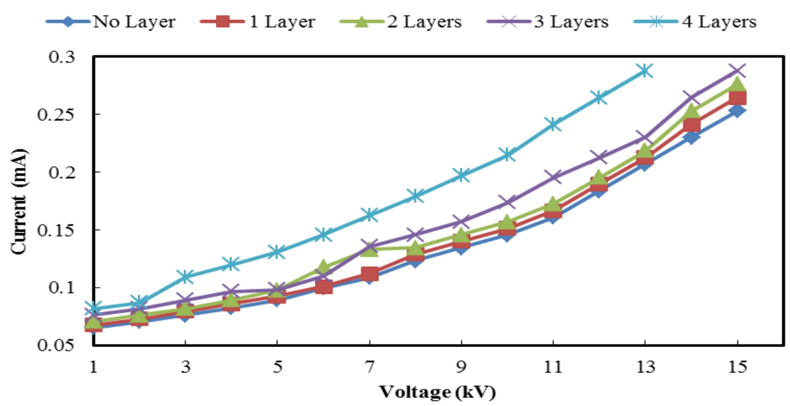

Fig. 11: Leakage current as a function of applied voltages when different layers of insulation paper are held between the electrodes in oil with 100ppm DBPC concentration.

For DBPC concentration of 25 ppm, Leakage current varies linearly when no paper layer is introduced, it increases exponentially as the number of paper layers between the electrodes increases as shown in Fig. 9.There was an average rise of 7% for an applied voltage of 1-5 kV, 9% for 6-10 kV and 11% till breakdown.

When the concentration of DBPC was increased to 50 ppm, the leakage current rises linearly when no paper is placed between the electrodes. The leakage current was found to be increasing exponentially as the layers of paper between the electrodes are increased as shown in Fig. 10. There was an average rise of 9% for an applied voltage of 1-5kV, 12% for 6-10kV and 15% till the breakdown.

In the next case for the concentration of 100 ppm DBPC, the leakage current rises linearly when no paper is placed between the electrodes. The leakage current was found to be increasing exponentially as the layers of paper between the electrodes are increased as shown in Fig. 11. For an applied voltage of 1-5 kV there was rise of about 10%, for 6-10kV it was about 15% and for voltage till breakdown it was about 18%.

Some results are found to vary from general trend and this may be due to variation in the supply voltage and this may also be due to variations in distribution of feed lines between the electrodes and this variation is not that significant.

IV. Conclusion

The presence of potentially corrosive sulfur species in insulating oil has caused a significant number of catastrophic failures. The primary effect of the presence of corrosive sulfur species in insulating oil is the formation of copper sulfide (Cu_2S) on the surface of copper conductors and its subsequent migration through the insulating paper layers, leading to electrical faults. The copper sulfide forms at the copper surface or with copper ions in the oil and paper. Some of the copper sulfide formed at the copper surface migrates to the paper insulation. Early Breakdown of Insulation occurs due to the penetration of copper sulfide from the transformer oil to the insulation paper. Paper insulation dielectric strength decreases due to the conductive copper sulfide.

The antioxidants when added in proper proportions enhance the life expectancy of the transformers. The following conclusions can be drawn from the experimental results obtained.
1) The average rise for leakage current for the DBDS concentrations of 25 ppm, 50 ppm and 100 ppm when compared to clean oil was found to be 9%, 13% and 16% respectively.
2) The average rise for leakage current for the DBPC concentrations of 25 ppm, 50 ppm and 100 ppm when compared to clean oil was found to be 11%, 15% and 18% respectively.

Acknowledgements

The authors would like to thank the authorities of Ghousia College of Engineering, Ramanagaram for all the co-operation and encouragement received in carrying out this work.

References

[1]. P. R. Krishnamoorthy, S.Vijayakumari, K.R. Krishnaswamy, P. Thomas, "Effect of Benzotriazole and 2, 6, Ditertiary butyl paracresol on the accelerated oxidation of new reclaimed transformer oils-A comparative study". Materials Technology Division Central Power Research Institute P.B. No. 9401, Bangalore, India.

[2]. Shuangzan Ren, Yang Xu, Xiaolong Cao, Lisheng Zhon, Qinxue Yu, Robert Jeanjean, "A Research Summary of Corrosive Sulfur in Mineral Oils" , Proceedings of the international conference on Properties and Applications of Dielectric Materials, July 19-23,2009, Harbin, China.

[3]. F. Scatiggio, V. Tumiatti, Asscociate Member, IEEE, R. Maina, M.zTumaiaati, M. Pompili, Senior Member, IEEE, and R. Bartnikas, Life Fellow, IEEE "Corrosive Sulfur Induced Failures In Oil-Filled Electrical Power Transformers And Shunt Reactors" IEEE Transaction on Power Delivery, Vol.24, No. 3, July 2009.

[4]. H. Kawarai, Y. Fujita, J. Tanimura, S. Toyama, N. Yamada, E. Nagaoand N. Hosokawa, T. Amimoto, "Role of Dissolved Copper and Oxygen on Copper Sulfide Generation in Insulating Oil", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 16, No. 5; October 2009..

[5]. F. Kato, T. Amimoto, E. Nagao, N. Hosokawa, S. Toyama and J. Tanimura, "Effect of DBDS Concentration and Heating Duration on Copper Sulfide Formation in Oil-immersed Transformer Insulation",IEEE Transactions on Dielectrics and Electrical Insulation Vol. 18, No. 6; December 2011.

About The Authors

Faheem Ahmed Khan was born in India in 1973. He received his Bachelor of Engineering in 1996, Master of Engineering in Power & Energy Systems in 2005 and currently is pursuing Ph.D. in Jawaharlal Nehru Technological University Hyderabad, India. He is an Associate Professor in Ghousia College of Engineering, Ramanagaram, India. He has 18years of teaching experience. His interests include dielectrics and insulation systems

**Asma Tamboli** was born in India in 1992. She received her Bachelor of Engineering in 2013 in Electrical and Electronics Engineering. Currently she is doing her post graduation in Power System Engineering from Ghousia College of Engineering, Ramanagaram affiliated to VTU, Belagavi, Karnataka.