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FURTHER CONTRIBUTION FOR EVALUATING THE AGING OF TRANSFORMER OIL OF POWER TRANSFORMER

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ABSTRACT

Transformers are essential parts in the power system for voltage level conversion and maintaining the power flow in the electrical power system, the stability of which is significant for the reliability of the whole supply. The oil used in all transformers is used for insulating and cooling purposes. Degradation of transformer oil occurs because of the ageing, high temperature and chemical reactions such as the oxidation. It is also affected by contaminants from the solid materials. Therefore, the oil condition must be checked regularly and reclaimed or replaced periodically, to avoid the sudden failure of the transformer. In this paper, breakdown voltages (BDV) as well as dielectric dissipation factor (Tan δ) at some different oil conditions are measured. The effect of temperature variation, particle existence in the oil and the water content are studied. The results explain that the aged oil at 80^{o}C (heated for two hours) provides a good dielectric strength than that fresh oil. The particles in the oil play an important part for decreasing the BDV as well as giving worst value of tan δ.

***Keywords*:** transformer, Mineral oil, Breakdown Voltage (BDV), Dielectric Dissipation Factor (tan δ), and water content.

1. Introduction

Transformers are one of the most expensive and strategically important components of any power system, so that their proper and continuous function is important to system reliability. In general, insulating materials will deteriorate under normal operating conditions. The aging rate of any material is influenced by several external aging stresses: thermal, electrical, mechanical, and ambient stresses [1]. Although there are test items required for transformer insulating oil such as the density, Color, kinematic viscosity, pour point, flash point, total acid value, oxidative stability, water content, breakdown voltage, dielectric loss tangent and volume resistivity. No different test items are used for different types of insulating oil. These tests give an early indication of the change in the dielectric properties and provide the useful information

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about the quality of the insulating oil. Several researches have been carried out to compare between the properties of mineral and ester oils [2, 3, 4, 5, and 6].

The breakdown voltage of mineral insulation oil under the influences of moisture, acidity, pressure and particles was systematically investigated in many researches [7, 8, and 9]. In [10], the influence of copper ion on the aging rate of both insulation paper and oil was investigated. The effect of the oil temperature and catalysts such as copper as well as water contents on the BDV and dielectric dissipation factor for different mineral oil samples (fresh and aged for two hours) are investigated.

2. Experiments setup

Experimental tests are carried out on transformers oil to determine experimentally their electrical, physical and chemical properties. The explained tests were carried out in the Extra High Voltage Research Centre and the Central chemical Laboratories, Egyptian Electricity Holding Company (EEHC). The tests are carried out with fresh oil, used oil and aged oil (heated for two hours) to measure the breakdown voltage, dielectric dissipation factor (tan δ) as well as the water contents. The effect of contaminants on the previous properties is also investigated. The particles used in the test are 200,400,600 and 800mg of red copper powder founded by the mesh of 0.6, 0.3 and 0.15mm. Some of oil samples are taken from real transformers to compare its properties with the properties of the other oils (fresh and aged oil) for Breakdown voltage test only.

Oil tester device with standard cell having two uniform copper electrodes 25 mm diameter with a gap spacing of 2.5 mm according to IEC standard 156 [11]. Determination of breakdown voltage of each transformer oil sample has been carried out according to the IEC 156 testing procedure [12]. The apparatus used to carry out the tests is FOSTER OTS75 with automatic voltage rising up to 2kv/s. A schematic diagram of the electric circuit of the system is given in Figure-1 gives the main configuration and dimensions of the test cell. In the IEC 156 test the breakdown events are repeated six times, and then the average of the breakdown voltage values is obtained and given as the breakdown voltage test result in kV. The dissipation factor measurements are made according to IEC 60247 and the test cell for atuomated insulation analyzer (type M4000), as shown in Figure 2, is used. Water content was measured by Karl-fisher moisture titrator (MKC-500) in Central chemical Laboratories. Air bubbles, water, and other foreign material is the usual cause of breakdown in the cell. If the sample is allowed to stand in the cell for a short time before the test is made, the entrapped air will have a chance to work out any foreign particles to settle to the bottom.

3. Results and discussions

3.1. Breakdown voltage (BDV)

The breakdown is the maximum voltage reached at the time the circuit is opened either automatically (established arc) or manually (visible or audible discharge detect) [12]. The volume of oil sample required for BDV cell lies between 300 ml and 500 ml. The voltage is started approximately 5 min after filling the oil container and checked that no air bubbles are visible in the electrode gap. Then apply voltage to the electrodes and increase voltage uniformly from zero with rate of 2kV/s until breakdown occurs.

At ambient temperature, the breakdown voltage of 3 transformer oil types (fresh, used and aged) without contaminants particle (copper) is investigated in Figure 3 and as shown, the breakdown voltage in case of aged oil (2 hour heated) is greater than the other cases. The aged oil is not influenced by many of stresses like sparks, the decomposition of the insulating paper and contaminants particle that produce in the oil.

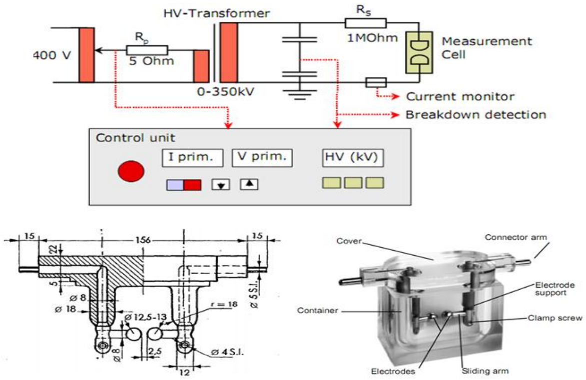

Fig. 1. A schematic diagram of the apparatus used for the determination of transformer oil breakdown voltage, the configuration and main dimensions of the test cell.

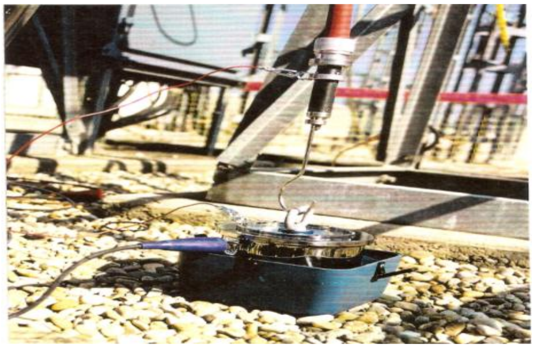

Fig. 2. Liquid inslution cell connected for testing.

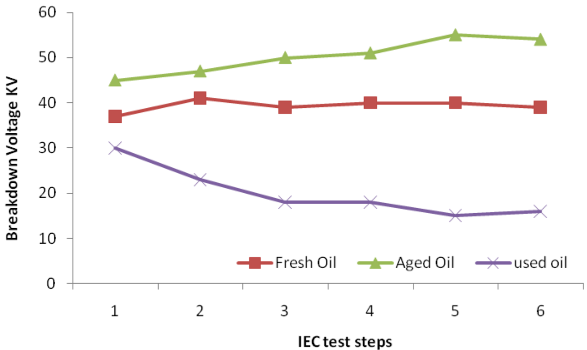

Fig. 3. The breakdown voltages for three oil type (fresh, aged and used oil).

The values of Breakdown Voltage for the 3 types of oil with red copper particles as contaminant at ambient temperature are lower than that without red copper particles. It refers that the harmful effect of the contaminants on the dielectric strength of the insulating oil. This fact is shown in Figure-4.

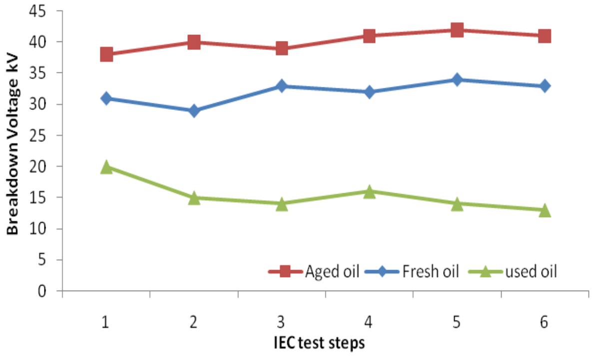

Fig. 4. The effect of oil type on the breakdown voltage with contaminants particle.

In Figure-5, the effect of the oil temperature on the breakdown voltage of the fresh oil is illustrated. An increase of the oil temperature results in an increase in the breakdown voltage. The normal oil temperature not exceeds 90^{o}c for the transformer under working and if temperature increased to 130^{o}c the oil may make transformer failure [10].

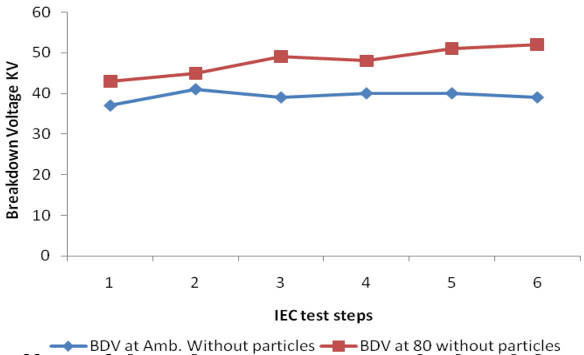

Fig. 5. Effect of the oil temperature on the breakdown voltage.

Particle contamination in insulating oil may lead to a decrease of the breakdown strength. A breakdown at relatively low voltage can happen if the oil is heavily contaminated with particles which can form a bridge between the electrodes along the highest field intensity. Moreover, in the case that particles exists in electrically stressed oil, it will cause a stream of water or vapor along with a breakdown channel, further decreasing the electric strength of the oil. In Figure-6, 7 and 8, the effect of 200mg, 0.6mm red copper particles on the breakdown voltages at different temperatures for the fresh oil is illustrated; the presence of the particles on the fresh oil will cause failure on the oil at low voltage. Then purification of the oil is very necessary to prevent the breakdown of it.

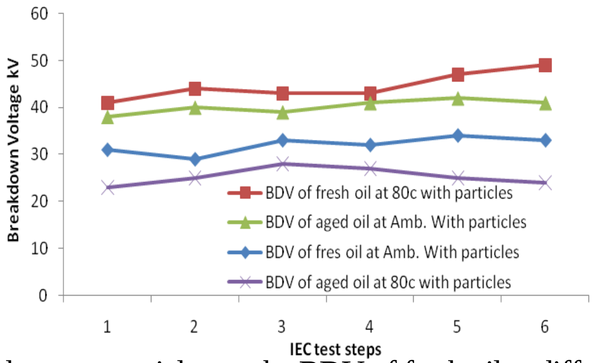

Fig. 6. Effect of red copper particles on the BDV of fresh oil at different temperatures.

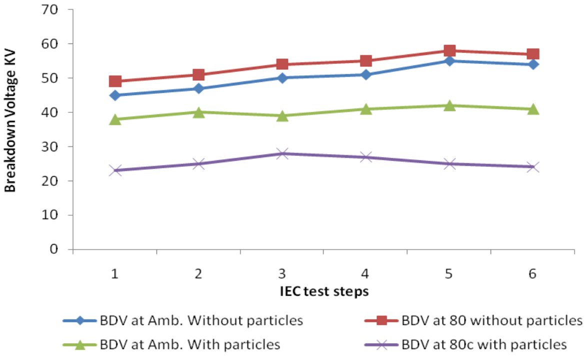

Fig. 7. Effect of the particles on the BDV for aged oil at different temperature.

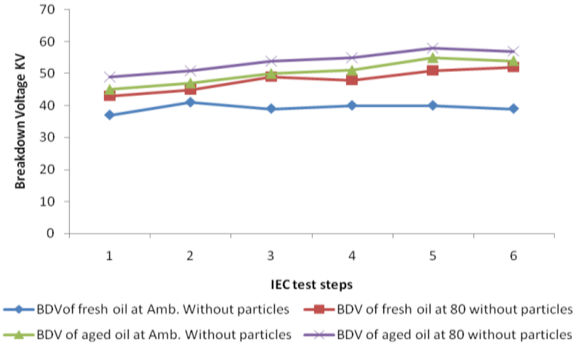

Fig. 8. Effect of the oil condition on the BDV.

In Figure-9, the effect of change of weight of red copper particles (200,400,600 and 800mg) founded by mesh of 0.6mm on the BDV. The BDV for the aged oil is decreased with the red copper particles weight increase.

In Figure-10, the effect of change of weight of red copper particles (200,400,600 and 800mg) founded by mesh of 0.3mm on the BDV. The BDV for the aged oil is further decreased with the red copper particles weight increase and may lead to transformer failure.

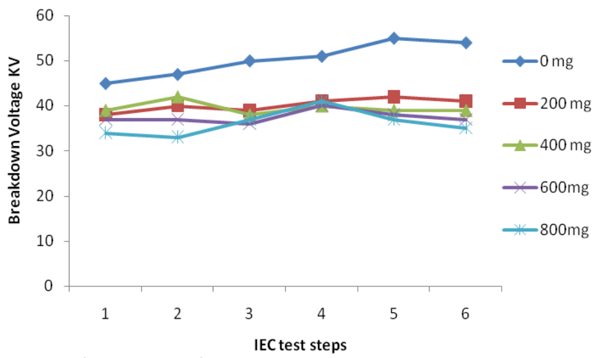

Fig. 9. Effect of change of weight of 0.6mm red copper particles on the BDV of aged oil.

But in Figure-11, the effect of change of weight of red copper particles (200,400,600 and 800mg) founded by mesh of 0.15mm on the BDV is illustrated. The BDV for the aged oil decreased more than the past two cases and that because of the very small size of these particles that makes it more homogenous with the oil and forming a bridge between the two electrodes of the BDV tester, also it increase the conductivity of oil and decreases the electric strength and causing the transformer failure.

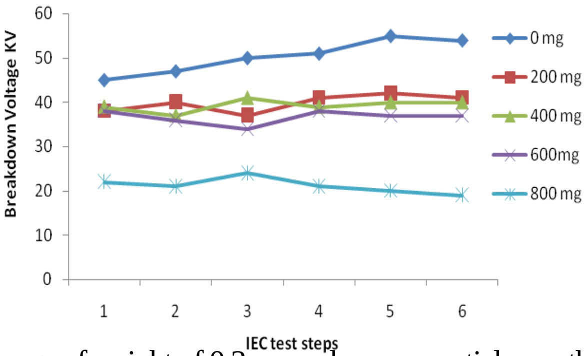

Fig. 10. Effect of change of weight of 0.3mm red copper particles on the BDV of aged oil.

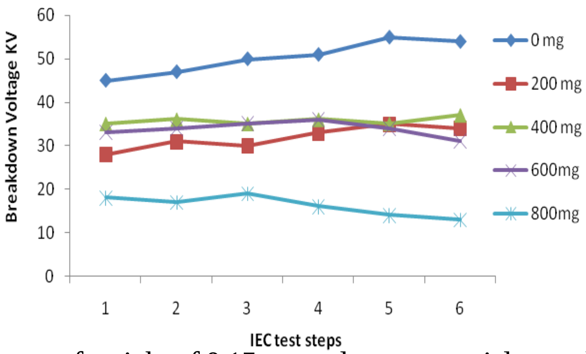

Fig. 11. Effect of change of weight of 0.15mm red copper particles on the BDV of aged oil.

In Figure-12 and Figure-13, the effect of change of weight of red copper particles (200,400,600 and 800mg) founded by mesh of 0.6 and 0.3mm on the BDV of fresh oil. The BDV for the fresh oil is further decreased (more than the same case with aged oil) with the red copper particles weight increase because this fresh oil still have a humidity amount that can increase the oil conductivity and decrease its dielectric strength.

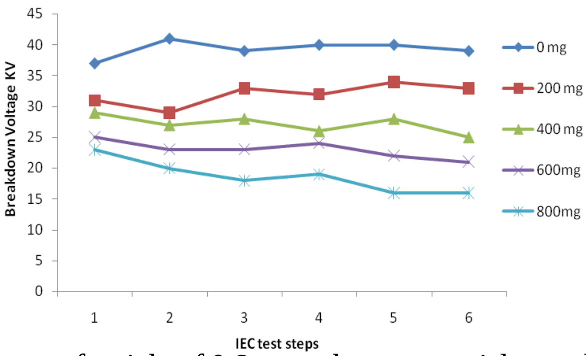

Fig. 12. Effect of change of weight of 0.6mm red copper particles on the BDV of fresh oil.

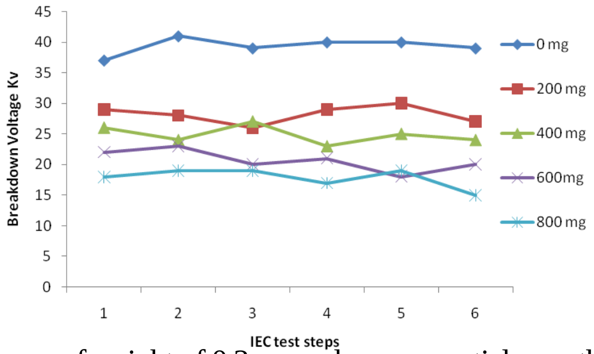

Fig. 13. Effect of change of weight of 0.3mm red copper particles on the BDV of fresh oil.

But in Figure-14, the effect of change of weight of red copper particles (200,400,600 and 800mg) founded by mesh of 0.15mm on the BDV is illustrated. The BDV for the fresh oil is failing down more than the other past cases and as shown, the behavior of this sample is the same the aged oil sample with the same particles size that because of the very small size of this particles makes it more homogenous with the oil and forming high conductivity between the two electrodes of the BDV tester, also increase the conductivity of oil and decrease the dielectric strength causing the transformer failure.

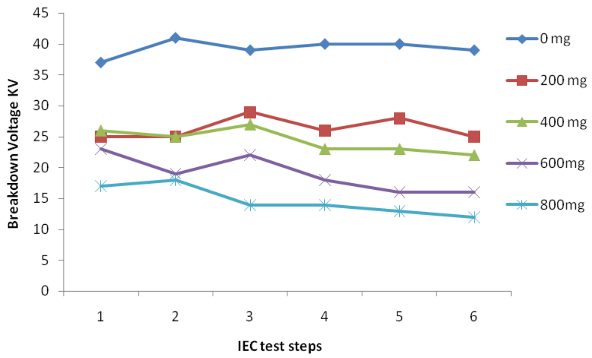

Fig. 14. Effect of change of weight of 0.15mm red copper particles on the BDV of fresh oil.

3.2. Dielectric dissipation factor (tan δ).

The tan δ is measured according to IEC 60247 [13] using test cell for automated insulation analyzer (type M4000). Air bubbles, water, and other foreign material are the usual cause of breakdown in the cell. If the sample is allowed to stand in the cell for a short time before the test is made, the entrapped air will have a chance to work out any foreign particles to settle to the bottom.

Figure-15 shows the effect of contamination particles (200mg, 0.6mm of red copper particles) on the tan δ value of the transformer oil. Existence of the contamination particles will lead to higher value of tan δ. Also higher temperature affects the value of tan δ as well as the greater of the applied voltage the higher of tan δ value.

Figure-16 illustrates the difference between four oil samples under different temperatures with red copper particles, the aged (heated for two hours) oil gives high values of tan δ than the fresh oil that because the solubility of aged oil is lower than that of the fresh oil.

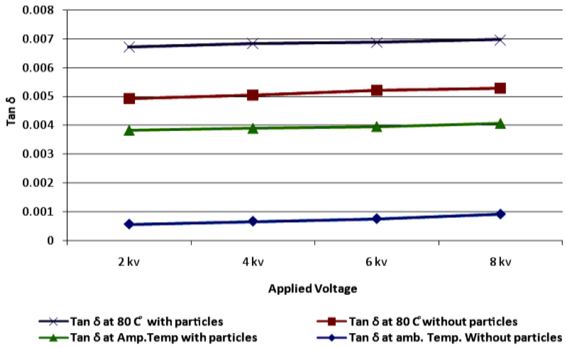

Fig. 15. Effect of particles at different temperatures on the measured tan δ of the aged (heated for two hours) oil.

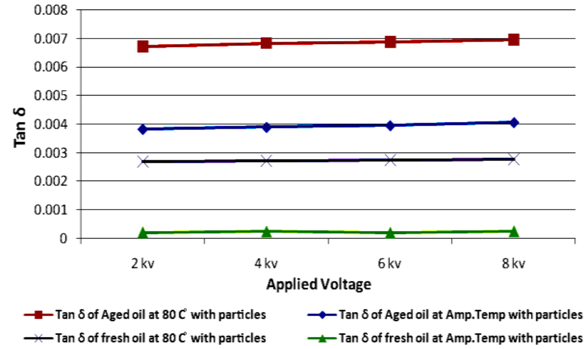

Fig. 16. Effect of the oil type on the value of tan δ at different oil temperature.

In Figure-17, the effect of temperature change (at 40,60 and 80 c°) on the transformer oil without using red copper particles is illustrated.as shown in the graph, a direct proportional relation between tan δ and oil temperature is explained and it means when increasing the temperature of fresh transformer oil, the tan δ value alsow increase.

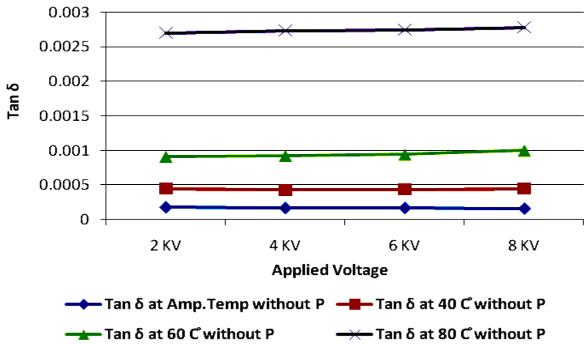

Fig. 17. The effect of the change (at 40, 60 and 80c°) of oil temperature on tan δ value of fresh transformer oil without using red copper particles.

In Figure-18, the effect of temperature change (at 40,60 and 80 c°) on the transformer oil in case of using 200 mg of red copper particles founded by the mesh of 0.6mm is illustrated.as shown in the graph, a direct proportional relation between tan δ and oil temperature plus copper particles is explained too.it's the same behaviour for the fresh transformer oil without adding red copper particles with respect to the higher values than the values of transformer oil without red copper pareticles.

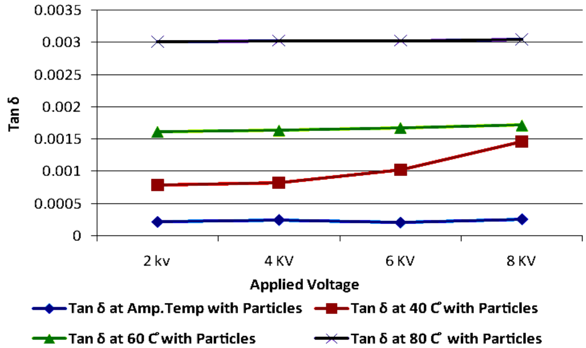

Fig. 18. The effect of the change (at 40, 60 and 80c˚) of oil temperature on tan δ measurement of fresh transformer oil using red copper particles.

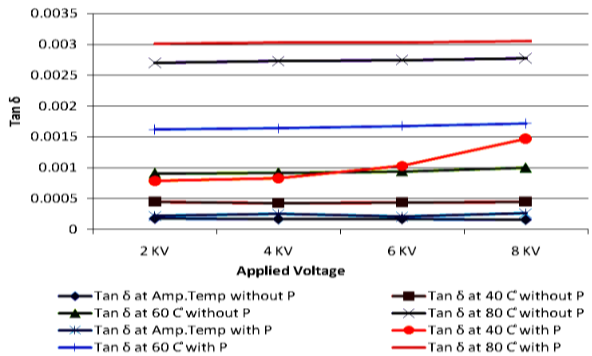

Fig. 19. Comparison between tan δ measurements of fresh transformer oil using and not using red copper particles.

Figure-19 shows the comparison between tan δ measurements for the fresh transformer oil in case of using and not using of red copper particles. There is a clear difference between the two cases in measurement values but at general it shows the same behavior at temperature increase for the two cases.

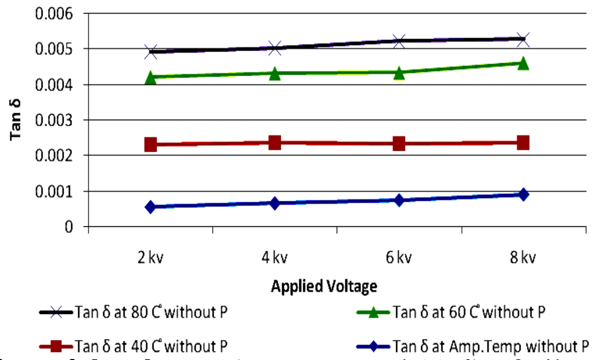

Fig. 20. The effect of the change (at 40, 60 and 80c˚) of oil temperature on tan δ value of fresh transformer oil without using red copper particles.

In Figure-20, the effect of temperature change (at 40,60 and 80 c˚) on aged transformer oil without using red copper particles is illustrated.as shown, a direct proportional relation between tan δ and oil temperature is explained of the aged transformer oil and it means when increasing the temperature of aged transformer oil, the tan δ value alsow increase.

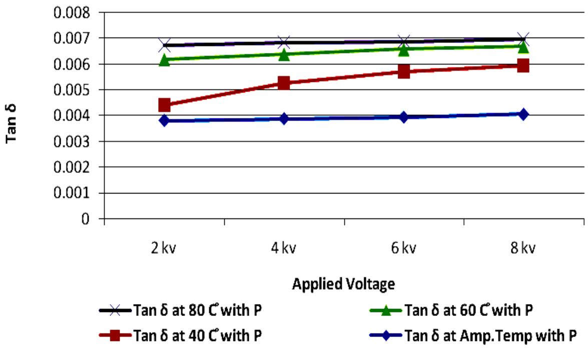

Fig. 21. The effect of the change (at 40, 60 and 80c˚) of oil temperature on tan δ measurement of aged transformer oil using red copper particles.

In Figure-21, the effect of temperature change (at 40,60 and 80 c˚) on the aged transformer oil in case of using 200 mg of red copper particles founded by the mesh of 0.6mm is illustrated and as shown, a direct proportional relation between tan δ and oil temperature plus copper particles is explained too.it's the same behaviour for the aged transformer oil without adding red copper particles with respect to the higher values than the values of aged transformer oil without red copper pareticles.

Figure-22 shows the comparison between tan δ measurements for the aged transformer oil in case of using and not using of red copper particles. The red copper particles affect with a clear difference between the two cases in measurement values but at general it shows the same behavior at temperature increase for the two cases.

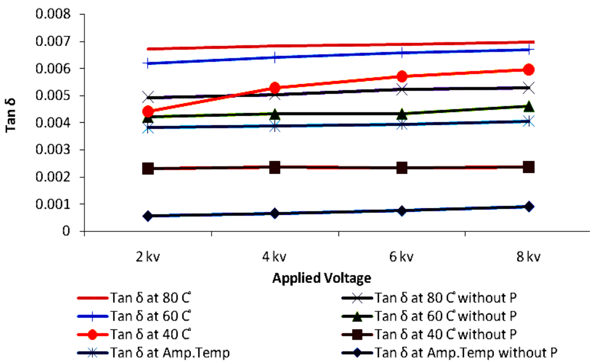

Fig. 22. Comparison between tan δ measurements of aged transformer oil using and not using red copper particles.

Figure-23 illustrate the temperature effect on eight oil samples (fresh and aged transformer oil) under different temperatures without using of red copper particles, the aged (heated for two hours) oil gives higher values of tan δ than the fresh oil that because the solubility of aged oil is lower than that of the fresh oil.

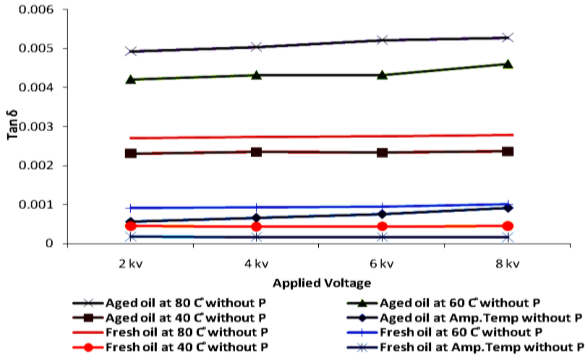

Fig. 23. The temperature effect on eight oil samples (fresh and aged transformer oil) under different temperatures without red copper particles.

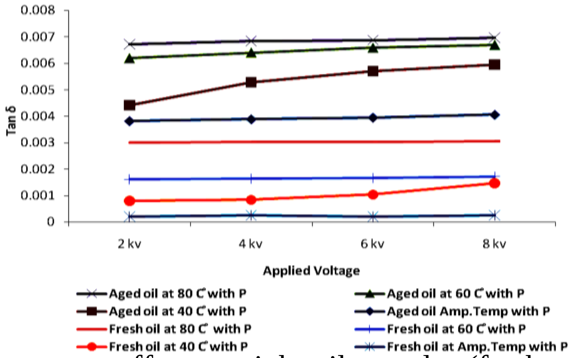

Fig. 24. The temperature effect on eight oil samples (fresh and aged transformer oil) under different temperatures with using of red copper particles.

In Figure-24, the temperature effect on eight oil samples (fresh and aged transformer oil) under different temperatures with using of red copper particles is explained. The aged (heated for two hours) oil gives higher values too of tan δ than the fresh oil, so the purification of oil is necessary to recover the oil solubility and dielectric properties

3.3. Effect of the Water Content

In Figures 25 and 26, we found some facts: 1- the relation between Tan δ and temperature is directly proportional, 2- the relation between Tan δ and water content (ppm) is inversely proportional, 3- the relation between water content (ppm) and Breakdown Voltage is inversely proportional and 4- the relation between Tan δ and Breakdown Voltage (kV) is directly proportional. Therefore, if the temperature of the fresh oil is increased (direct heat for 2 hours) therefore the water content is decreased (ppm value will be lower), the Breakdown Voltage is increased (the spark occurs at higher breakdown voltage) and Tan δ is increased also.

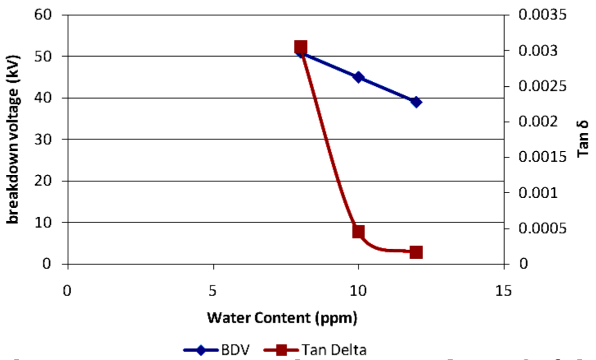

Fig. 25. Effect of the water contents on the BDV and tan δ of the transformer oil.

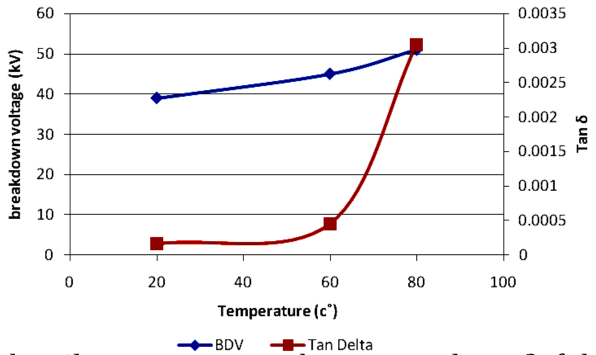

Fig. 26. Effect of the oil temperature on the BDV and tan δ of the transformer oil.

4. Conclusions

In this paper, three oil samples (Fresh, Aged and used) are used to know the transformer oil properties and to study the effect of accelerating thermal aging as well as red copper particles on the insulating oil behavior. The accelerated thermal aging process (heated for 2 hours) and the particles added (200,400,600and 800mg of red copper powder) to the oil samples give different effects on the Breakdown Voltage, Tan δ and Water content of oil samples. And It was found from the experiments that:

1- Red copper Particle contamination as an aging product decreases the dielectric strength and may lead to the transformer oil failure.
2- The aged oil is not influenced by many of stresses like sparks, the decomposition of the insulating paper and contaminants particle that produce in the oil.
3- The breakdown voltage of the aged oil is greater than that of the fresh oil because the heat process reduces the humidity and bubbles that increase the conductivity between the two electrodes of breakdown voltage tester.
4- An increasing of temperature increases the breakdown voltage too mention that the normal oil temperature not exceeds 90^{o}c for the transformer under working and if its temperature increased to 130^{o}c the oil may make transformer failure [10].
5- Size of red copper particles (0.6, 0.3 and 0.15 mm) played an important role on the electrical characteristics of transformer oil.
6- Also the weight of red copper particles (200, 400,600 and 800 mm) played an important factor in the breakdown voltage of transformer oil.
7- Tan δ of aged Oil experiences a significant increase along the aging process.
8- The Tan δ of the aged oil is greater than that for the fresh oil at both cases with and without red copper particles.

9- The relation between Tan δ and Breakdown Voltage (kV) is directly proportional.
10-Existence of the contamination particles will lead to higher value of tan δ.
11-Water content is an effective parameter in studying the electrical properties of transformer oil. It is inversely proportional to the dielectric strength (BDV) and dielectric dissipation factor (Tan δ).
12-When the humidity and bubbles decrease so the water content also decreases.

This research is consistent with what said about that most of the properties degraded with respect to service aging [9] and stressed that the particle size can lead to the collapse of the transformer oil properties of mineral oil, also in [2] and [5] talking about the characteristics of natural, synthetic esters and mineral oil under the aging process and their conclusions was very close to our results in this research. Extensive investigations still need to be performed on natural and synthetic esters oil to analyze the effect of particles and temperature on their properties and to determine whether natural, synthetic esters or mineral is the suitable transformer oil.

Acknowledgement

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REFERENCES

[1] R. Bartnikas, [1997]"Dielectrics and Insulators," in the Electrical Engineering Handbook, Second Edition, R. C. Dorf, Ed.: CRC Press,

[2] C. Perrier and A. Beroual, [2009]"Experimental Investigations on Insulating Liquids for Power Transformers: Mineral, Ester, and Silicone Oils," IEEE Electrical Insulation Magazine.

[3] T. V. Oommen, [2002]"Vegetable Oils for Liquid-Filled Transformers," IEEE-Electrical Insulation Magazine.

[4] L. Lewand, [2001]"Laboratory Evaluation of Several Synthetic and Agricultural-based Dielectric Liquids," Doble International Client Conference.

[5] H. Borsi, [1991]"Dielectric Behavior of Silicone and Ester Fluids for Use in Distribution Transformers," *IEEE Transaction on Electrical Insulation, vol. 26, pp. 755-762.*

[6] Jung J., Jung S. and Chang H., [2012] "Accelerated Aging Effects of Mineral and Vegetable Transformer Oils on Medium Voltage Power Transformers", *IEEE Transactions on Dielectrics and Electrical.*

[7] IEC Publication No. 156: [1963] "Method for the Determination of the Electrical Strength of Insulating Oils", *International Electro technical Commission, Geneva.*

[8] Masanori K., Genyo U., Shigemitsu O. [2010]" Transformer Insulating Oil Characteristic Changes Observed Using Accelerated Degradation in Consideration of Field Transformer Conditions", *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 17, No. 3.*

[9] Jashandeep S., Yog R. and Piush V. [2012]"The Influence of Service Aging on Transformer Insulating Oil Parameters", *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 19, No. 2.*

[10] Liao, Tang, Yang, Feng, and Sun [2009]"Influence of the copper ion on aging rate of oil–paper insulation in a power transformer", *IET Electr. Power Appl., Vol. 3, Issu. 5, pp. 407–412.*

[11] Maik Koch, Markus Fischer, Stefan Tenbohlen, [2007]"The Breakdown Voltage of Insulation Oil Under the Influences of Humidity, Acidity, Particles and Pressure", *International Conference APTADM, Wroclaw, Poland.*

[12] Reference number CEI/IEC 156 [1995] ''Insulating Liquids-Determination of Breakdown Voltage at Power Frequency-Test method''

[13] C57.12.00 [2000] ''IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers''.

Appendix: Numerical comparison between different measured results.

1- Breakdown Voltage Measurement Results.

Table 1.
Three oil samples (fresh, aged and used oil) measurement results.

	Oil without red copper particles.			Oil with 200 mg, 0.6mm red copper particles		
BDV test No.	Fresh Oil	Aged Oil	Used oil	Fresh oil	Aged oil	Used oil
1	37	45	30	31	38	20
2	41	47	23	29	40	15
3	39	50	18	33	39	14
4	40	51	18	32	41	16
5	40	55	15	34	42	14
6	39	54	16	33	41	13

Table 2.
Measurement results for the fresh oil without and with change of red copper particles weight and size at ambient temperature.

		Particle Size 0.15 mm				Particle Size 0.3 mm				Particle Size 0.6 mm			
BDV test No.	0 mg	200 mg	400 mg	600 mg	800 mg	200 mg	400 mg	600 mg	800 mg	200 mg	400 mg	600 mg	800 mg
1	37	25	26	23	17	29	26	22	18	31	29	25	23
2	41	25	25	19	18	28	24	23	19	29	27	23	20
3	39	29	27	22	14	26	27	20	19	33	28	23	18
4	40	26	23	18	14	29	23	21	17	32	26	24	19
5	40	28	23	16	13	30	25	18	19	34	28	22	16
6	39	25	22	16	12	27	24	20	15	33	25	21	16

Table. 3.
Measurement results for the aged oil without and with change of red copper particles weight and size heated for 2 hours at 80c˚.

		Particle size 0.15 mm				Particle size 0.3 mm				Particle size 0.6 mm			
BDV test No.	0 mg	200 mg	400 mg	600 mg	800 mg	200 mg	400 mg	600 mg	800 mg	200 mg	400 mg	600 mg	800 mg
1	45	28	35	33	18	38	39	38	22	38	39	37	34
2	47	31	36	34	17	40	37	36	21	40	42	37	33
3	50	30	35	35	19	37	41	34	24	39	38	36	37
4	51	33	36	36	16	41	39	38	21	41	40	40	41
5	55	35	35	34	14	42	40	37	20	42	39	38	37
6	54	34	37	31	13	41	40	37	19	41	39	37	35

Table. 4.
Measurement results for the fresh oil without and with adding 200mg, 6mm of red copper particles at ambient and 80c˚.

BDV test No.	BDV at amb.temp. Without particles	BDV at 80 c˚ without particles	BDV at amb.temp. With particles	BDV at 80 c˚ with particles
1	37	43	31	41
2	41	45	29	44
3	39	49	33	43
4	40	48	32	43
5	40	51	34	47
6	39	52	33	49

Table. 5.
Measurement results for the fresh oil without and with adding 200mg, 6mm of red copper particles at ambient and 80c˚.

BDV test No.	BDV at amb.temp Without particles	BDV at 80 without particles	BDV at amb.temp With particles	BDV at 80c with particles
1	45	49	38	23
2	47	51	40	25
3	50	54	39	28
4	51	55	41	27
5	55	58	42	25
6	54	57	41	24

2- Dielectric Dissipation Factor tan δ Measurement Results.

Table. 6.
Measurement results of dielectric dissipation factor (tan δ) of fresh oil under the change of oil temperature and 200mg, 0.6mm particles effect.

	Measurements without adding particles				Measurements with adding particles			
KV	at amp.Temp	at 40 C˚	at 60 C˚	at 80 C˚	at amp.temp	at 40 C˚	at 60 C˚	at 80 C˚
2 KV	0.00018	0.00045	0.00091	0.0027	0.00022	0.00079	0.00162	0.00301
4 KV	0.00017	0.00043	0.00092	0.00273	0.00025	0.00083	0.00164	0.00303
6 KV	0.00017	0.00044	0.00094	0.00275	0.00021	0.00103	0.00168	0.00303
8 KV	0.00016	0.00045	0.001	0.00278	0.00026	0.00147	0.00172	0.00305

Table. 7.
Measurement results of dielectric dissipation factor (tan δ) of fresh oil under the change of oil temperature and 200mg, 0.6mm particles effect.

	Measurements without adding particles				Measurements with adding particles			
KV	at amp.temp	at 40 C˚	at 60 C˚	at 80 C˚	at amp.temp	at 40 C˚	at 60 C˚	at 80 C˚
2 kv	0.00056	0.00231	0.00421	0.00493	0.00382	0.00441	0.00619	0.00672
4 kv	0.00066	0.00235	0.00432	0.00504	0.00389	0.00528	0.0064	0.00684
6 kv	0.00075	0.00233	0.00433	0.00522	0.00395	0.00571	0.00658	0.00688
8 kv	0.00091	0.00236	0.00461	0.00528	0.00406	0.00596	0.00669	0.00697

3- Water Content (moisture) Measurement Results.

Table. 8.
Measurement results of Water Content (moisture) of fresh oil under the change of oil temperature.

Temperature	Moisture content
20	12 ppm
60	10 ppm
80	8 ppm

مساهمه تعزيزية فى تقييم تقادم زيوت المحولات الكهربائية

الملخص العربى:

المحولات هي أجزاء أساسية في نظم الطاقة الكهربيه للتحكم فى الجهد والحفاظ على تدفق الطاقة في نظام الطاقة الكهربائية .يتم استخدام الزيت في جميع المحولات للعزل الكهربى و لتبريد المحولات الكهربيه .يحدث تدهور لزيوت المحولات بسبب التقادم، وارتفاع في درجة الحرارة والتفاعلات الكيميائية مثل الأكسدة .و يتأثر أيضا بالشوائب من المواد الصلبة .لذلك، يجب فحص حالة الزيت بانتظام لتجديده أو استبداله بشكل دوري لتجنب الانهيار المفاجئ للمحول .في هذا البحث تم قياس جهد الانهيار (BDV)، وكذلك معامل الفقد الكهربى عند تعرض الزيت لعوامل متعدده. ايضا تم دراسة تأثير تغيير درجة الحرارة، وكذلك تأثير الشوائب الصلبه (ذرات من النحاس الاحمر المعلوم وزنه وتم فلترته باستخدام جهاز فلتره الجسيمات الصغيره لمعرفة مقاسها). أظهرت نتائج البحث أن تقادم الزيت عند تسخينه على درجة حرارة $80^{\circ}C$ لمدة ساعتين يزيد من قوة عزل الزيت افضل من قوة عزل الزيت الجديد، وجود الشوائب الصلبه في زيت المحولات تلعب دورا هاما لخفض قيمة جهد الانهيار وكذلك إعطاء أسوأ قيمة لمعامل الفقد الكهربى.