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Measurement of Various Parameters for Reclaimed Transformer Oil

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Abstract
Charge carrier compounds are responsible for increased dissipation factor as acids are responsible for increased acidity for mineral insulating oil in service. The disadvantage of increased dissipation factor and increased acidity is their indication of oil degradation or excessive oxidation processes exist in oil during operation as a cause for aging and presence of fault. Oxidation of oil followed by increased dissipation factor and increased acidity is an alarm for solution required to eliminate oxidation products through convenient treatment process as reclaiming. Some inorganic fillers are activated bentonite AB, activated carbon AC and silica fume SF were used in this study for removal of oxidation products and enhancing dissipation factor and acidity. Results of these two properties were illustrated in terms of the effect of each filler on charge carriers and acid content for reclaimed oil.
Keywords: Transformer oil, Charge Carriers, Acidity, Dissipation Factor.

1. Introduction

The performance of insulating oil during operation depends mainly on its origin crude and its classification as naphthenic or paraffinic oil. Naphthenic oil is characteristic with low pour point and the ability to dissolve sludge which prevents sludge from sticking on insulating materials, aids in enhancing cooling performance. On the other hand, paraffinic oil contains paraffins which tend to crystallize at low temperature and has lower fluidity than naphthenic oil. Paraffinic oil has high pour point which can be lowered by dewaxing procedure **(Wang et al., 2018)**. Insulation and cooling are the main functions of mineral insulating oils **(Salvi et al., 2017)** also plays an important role in suppressing electrical charge and prevent inner component of transformer from corrosion **(Hussain et al., 2015)**. During service, insulating oil exposed to degradation due to aging or oxidation with presence of heat, metal (Cu, Fe) and dissolved oxygen. Oil degradation includes chemical and physical differences with implication of reactive intermediates known as free radicals which participates in several aging processes. Electrical stresses with heat, moisture and presence of oxygen cause oil oxidation and formation of free radicals, acids and sludge. Free radicals are very reactive and could affect chemical, physical and electrical properties of insulating oil **(Safiddine et al., 2019 ; Fofana et al., 2015)**. Aging of insulating oil is a change in chemical structure of oil with the production of free radicals as initiation of chain of oxidation processes. Redox reactions are initiated by presence of dissolved oxygen and secondary compounds produced are containing carbonyl group (C=O) or double bonds of carbon (C=C). Compounds produced during oxidation as secondary products are alcohols, aldehydes, ketones, carboxylic acids and esters of carboxylic acids, those products can lead to formation of free radicals and initiation of secondary reactions with hydro-peroxide causes decrease in insulating oil performance **(Safiddine et al., 2017)**.

1.1 Formation of Carboxylic Acids in Transformer Oil:

Hydrocarbon chains forming mineral oil consists of average number of carbon atoms equals to 18. During operation, oxidation reactions occurs due to reaction between hydrocarbon molecules of oil and oxygen molecules with generation of acids as one of oxidation products. Acids promotes corrosion, accelerates oil oxidation and tend to precipitate as colloids which decreases dielectric strength inside the transformer. Low molecular weight acids have the infinity to bond with carboxyl group of water and cellulose of insulation paper causing degradation of cellulosic paper **(Fofana et al., 2015 ; Kouassi et al., 2018)**. Acid number of transformer oil corresponds to acid content and defined as quantitative measure of acidic compounds for both weak and strong organic and inorganic acids. Oxidation of in-service transformer oil increases polar compounds especially organic acids corresponding to increased acid number. Aged oil with high acid content reflects oil oxidation or either contamination with materials such as varnish, paint or others. Aged oil containing high acid number need to be reclaimed for reducing acid content **(N'cho et al., 2016)**.

1.2 Factors Increasing Dissipation Factor:

Two factors are included in studying the effect of free radicals on oxidation processes during operation, first factor is increased population of free radicals via splitting of oil hydrocarbon chains into free radicals. Unpaired electrons of free radical tend to be coupled with a free electron and become a charge carrier which tend to increase dissipation factor. Second factor is two unpaired electrons of dissolved oxygen as unpaired electrons of free radicals can couple with one electron of the two unpaired electrons of oxygen molecule. Diradical character of oxygen molecule is responsible of successful attack of nearable hydrocarbons and formation of hydro-peroxide compounds which tend to change oil colour. Redox reactions are also promoted in exitance of cupper, produces charge carriers which increase dissipation factor of oil **(Fofana et al., 2009)**. Dissipation factor of transformer oil as an important parameter for insulation and cooling property is directly proportional to conductivity as shown by equation:

$$\mathrm{Tan}\ \delta = \sigma / 2\pi F \varepsilon s$$

Where: σ : Conductivity , F : Frequency ,
εs : Static Permittivity
and…

$$\sigma = e\,(\mu^{+} + \mu^{-})$$

as: e : Charge of electron , μ^{+} and μ^{-} : Ion Concentration

Cooling efficacy is measured in terms of conductivity which is related to presence of ions. Last equation shows the variation of conductivity expressed in terms of mobility of ions **(Rouabeh et al., 2019)**. Measured value of dissipation factor is related to presence of ions or charge carriers in transformer oil. Increased concentration of ions leads to increase in dissipation factor for transformer oil with in-service conditions.

1.3 Treatment of Aged Transformer oil:

Oil degradation reduces transformer's lifetime leading to transformer failure, there are three possibilities of oil treatment in maintenance, filtering, purification with drying process and regeneration (reclamation) with degassing. Filtering process take place at 40 °C for filtration from rude and fine particles from contaminated oil. Purification with drying is accomplished by heating oil to maximum 90 °C, when oil reaches 65 °C, special filters are used for removing acids and polar compounds. Regeneration with degassing is purification with additional oxidant additives **(Gavrilvos et al., 2011)**. Filtration of oil is proceeded using filtration machine which consists of inlet pump to pump aged oil from transformer to filtration machine, oil then passes through filters for elimination of particles and sludge. Next stage is heaters for heating oil to 60 – 70 °C, then passes through ionic column as an additional part for reducing acidity of oil. Final stage is degassing and dehydration chamber, purified oil is obtained after 3 to 5 cycles **(Salvi et al., 2017)**. Reclaiming is considered the optimal solution for elimination of oxidation products and improving acidity as chemical property and dissipation factor as electrical property. Reclaiming is an ideal procedure required for lowering oxidation products using proper materials for removal of free radicals, charge carriers and secondary products. Reclaiming process is defined as the process of elimination of soluble and insoluble polar contaminates from oil by chemical and physical techniques **(IEC 60422, 2010)**. The main aim of reclaiming process is removal of undesired compounds with subsequent enhancement in oil properties, some researches went for using low-cost fillers during reclaiming with eco-friendly impact.

Acidity and dissipation factor for series of samples were measured during this study and related criteria for both parameters were illustrated to establish action of reclaiming treatment against each filler, influence was discussed with Figures for more clarification.

2. Materials and Methods

2.1 Aged Oil Sample:

Aged Diala B oil was collected from upper Egypt electricity distribution company, Aswan, Egypt. Parameters of oil sample are collected in Table (1).

Table (1) Parameters of Aged Transformer Oil

Property	***Value***
Acidity, mg KOH/gm oil	*0.104*
Viscosity at 40 ℃, C.St	*9.3*
Flash Point PMCC, °C	*154*
Dissipation Factor (Tan δ) at 90°C	*0.01*
Breakdown Voltage, KV/2.5 mm	*35*
PCB content, ppm	*5.9*

2.2 Materials:

This study depends on reclaiming by three inorganic fillers which are activated bentonite (AB), activated carbon (AC) and silica fume (SF). Activated bentonite was collected from Kalabsha area, south Aswan, Aswan, Egypt. Bulk bentonite was crushed then activated by refluxing with 2N of H_2SO_4 at 80°C for 2 hours, filtered and washed thoroughly with distilled water. Activated carbon was purchased from Merck and silica fume was collected from the Egyptian Company for Chemical Industries (KIMA), Aswan, Egypt.

2.3 Methods:

Reclaiming treatment were proceeded according to the technique shown in Figure (1), technique is for preparing samples of mass/ volume percentages of 0.1, 0.3, 0.5, 0.7 and 0.9%.

Preparation of oil samples is carried out by heating up specific volume of aged oil sample to 70 °C, then weight of filler is added, and oil sample is stirred for 30 minutes. Oil samples are set for overnight then filtered using Whatman filter paper no. 42, reclaimed oil sample is heated to 90 °C for elimination of moisture before testing parameters of acidity and dissipation factor.

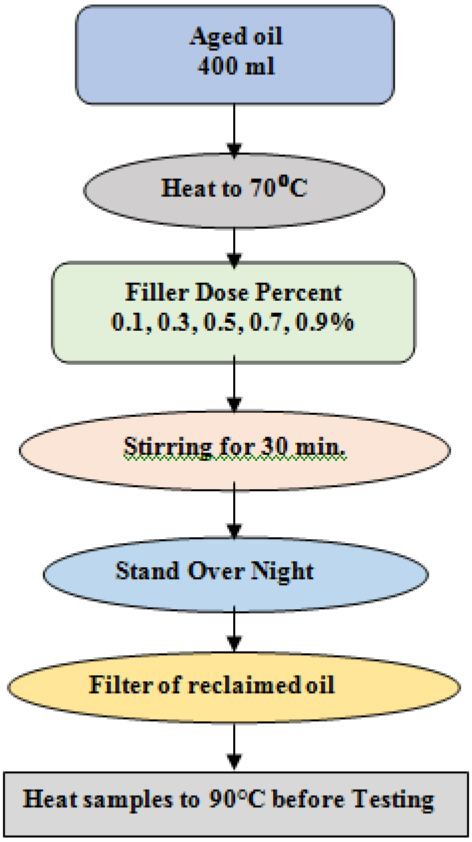

Figure 1: Steps for Preparation of Filler Dose percent Samples

3. Results and Discussion

3.1 Acidity:

Acidity or acid number is a measure of acid content in oil, importance of this test in its indication to the degree of oxidation for aged oil during service. Acidity was measured by chemical titration according to requirements of standard method of IEC 296 using highly pure chemicals for preparation of HCl 0.1 N solution, alcoholic KOH 0.1 N solution and Alkali Blue 6B indicator. Weight of 10 gm of oil is dissolved in 95% ethyl alcohol then the mixture is titrated against alcoholic solution of 0.1 N KOH in presence of Alkali Blue 6B indicator till colour changes from red to blue. Volume consumed of KOH is used in calculation of acid number of oil sample.

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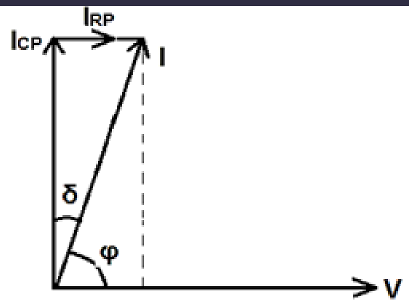

Figure 2: Theory of Measuring Dissipation Factor as tan δ

3.2 Dissipation Factor:

Measurement of dissipation factor or power factor is an important diagnostic parameter carried out according to standard method IEC 60247 **(IEC 60247, 2004)**. At a particular frequency for example 50-60 HZ the behavior of insulation can be represented with an equivalent circuit consisting of an ideal capacitor with a resistor in parallel, an ideal capacitor has no losses and the phase angle between voltage and current is 90 ^{0}, as a result of losses in real system represented by the resistor in the equivalent circuit, the phase angle differs from 90 ^{0} by the angle δ as shown in Figure (2). Dissipation factor is defined as the tangent of this angle δ hence its alternative name is tan δ, the dissipation factor is the ratio of the current flowing through the resistor and the current flowing through the ideal capacitor.

$$DF = \tan \delta = I_{RP}/I_{CP}$$

Temperature is a factor affecting tan δ , so this measurement is proceeded at 90 ^{0}C.

Measuring of dissipation factor as an electrical property depends on measuring tangent of angle δ, as lower as dissipation factor as good oil condition while high dissipation factor is a prove for high degree of oil oxidation.

3.3 Measurement of Acidity and Dissipation Factor for Reclaimed Oil:

Parameters of acidity and dissipation factor are measured for reclaimed oil samples prepared previously, relation is plotted for each filler to explore its performance against acids and charge carries. The relation between acidity and dissipation factor for oil samples is shown in Figures 3,4,5 for oil samples reclaimed with activated bentonite AB, activated carbon AC and silica fume SF respectively. Values of both acidity and dissipation factor are enhanced as a decrease is observed in Figure (3) for oil sample reclaimed using activated bentonite AB. Values decreased to optimum percentage of 0.7% then a slight increase is noticed. Enhancement can be attributed to the existence of Polar water molecules between 2:1 layers of bentonite which can be replaced by polar organic molecules **(ÖNAL, 2006)** such as acids and charge carriers.

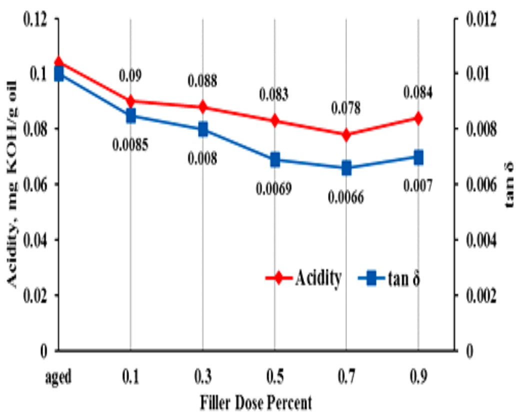

Figure 3: Relation between Acidity and Dissipation Factor for AB

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On the other hand, Figure (4) shows the effect of activated carbon on aged oil, it is observed that decrease in dissipation factor is more remarkable than acidity which is attributed to capability of removal of charge carriers than acids. Optimum percentage for acidity is 0.7% where for dissipation factor is 0.9%, it is strongly recommended the usage of activated carbon when decreasing dissipation factor is needed more. Removal of acids and charge carriers followed by enhancement in acidity and dissipation factor can strongly be related to capability of activated carbon surface to adsorb groups of carboxyl, phenol, carbonyl and quinone (**Figueiredo et al., 1999**) .

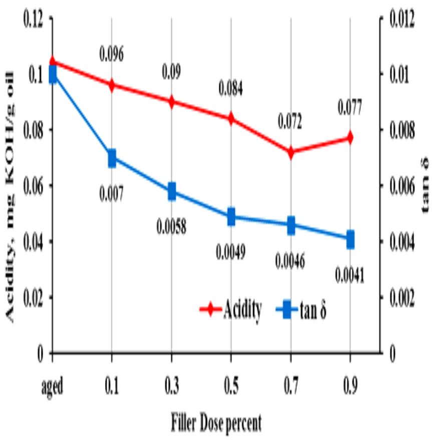

Figure 4: Relation of Acidity and Dissipation Factor for AC

Figure (5) shows the enhancement in acidity and dissipation factor for oil samples reclaimed via silica fume, decrease in both parameters is strongly observed to percentage of 0.7% then an increase of both at of 0.9% is noticed. From figure (5), it can be said that action of silica fume against acids and charge carriers is equal as it depends on the ability of unpaired electrons of oxygen to couple with unpaired electrons of charge carriers (**Fofana et al., 2009**).

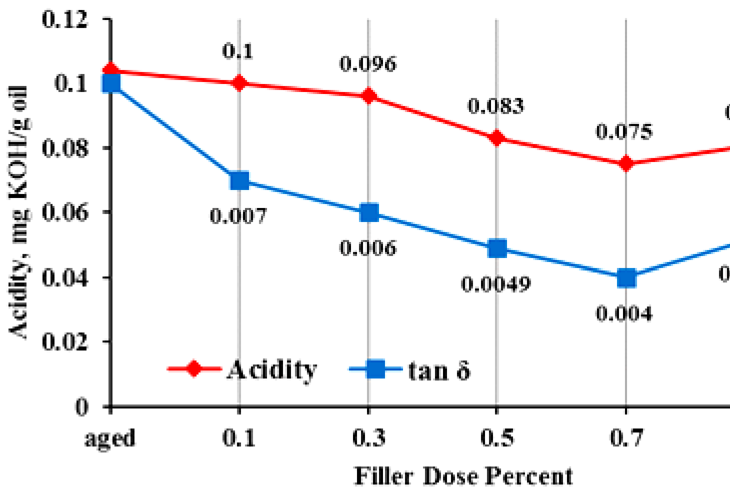

Figure 5: Relation between Acidity and Dissipation Factor

Behaviour of three fillers show similar optimum dose percentage at 0.7%, in most cases. Different enhancement degrees for oil samples reclaimed with three fillers can be attributed to the nature of each against acids or charge carriers. Enhancement in acidity depends on the ability of such a filler for adsorb or neutralize acids present in aged oil. Disposal of charge carriers is essential for enhancement of dissipation factor which depends either on powerful ability for sorption or presence of unpaired electron has the capability to couple with electron of charge carriers. AB has lowest action against charge carriers while SF with an electron pair can couple with charge carriers and further enhancement with best result in dissipation factor is achieved. AC has a great capability in removal of both charge carriers and acids hence, it managed to achieve best results in acidity and dissipation factor.

4. Conclusion

Three fillers, activated bentonite, activated carbon and silica fume, were used for the purpose of reclaiming aged transformer oil with the aim of studying the effect of each one on acidity as chemical property and dissipation factor as electrical property, this study reflects the effect of each filler on acids and charge carriers formed in aged transformer oil due to oxidation. Activated carbon at dose percentage of 0.7% showed best result in acidity with 0.072 mg KOH/g. Silica fume showed best result in dissipation factor with 0.004 at dose percentage of 0.7%. These promising results for acidity and dissipation factor using reclamation is attributed to removing of acids and charge carriers formed in aged transformer oil during operation due to oxidation or aging.

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