Analysis of Oil Quality Index and Dielectric Dissipation Factor

Evaluation of deterioration of mineral oil

Madan Lal Chowdary, Sunil Kumar Singh, and R.K.Jarial

Department of electrical engineering, NIT Hamirpur

Abstract

Mineral oil used in transformer not only acts as electrical insulation but also it acts as cooling medium. Oil is subjected to degradation because of the ageing, high temperature and chemical reactions such as oxidation .This in turn, allows more water to dissolve in the oil which reacts with cellulose paper which changes chemical makeup of oil. Oxidation products are usually acidic in nature and further reaction of these acids with oil can result in sludge as a by-product which affects cooling process. These problems can increase water content, decrease dielectric strength, increase acidity or neutralization number (NN), decrease interfacial tension (IFT), and decrease oil quality index (OQIN) i.e. color of the oil will change , . This paper mainly explains how acidity and interfacial tension affects the oil quality index and power or dissipation factor through experimental research when oil is aged.

Keywords: Transformer mineral oil, total acidity value (TAN), interfacial tension, oil quality index, power factor.

I. INTRODUCTION

Transformer is a versatile device used at various points in transmission and distribution substation. Mineral oil used in transformer possess specified characteristics and change in these characteristics is accomplished by ageing process. Using a combination of these diagnostic tests allows the oil to be monitored for changes over the time, whether the changes are due to thermal, dielectric or chemical effects. The benefit of knowing that how quickly the oil is aging, is that it allows the oil to be used as long as possible and then replacing or reclaiming it before it can cause damage to the insulating study or other materials inside the transformer.

The transformer mineral oil is one of the expensive extracts of the crude oil by distillation process. Hydrogenation refining is used and unwanted impurities are removed by neutralization, solvent extraction and clay treatment and finished oil is obtained. Because of the importance of the power transformers in electrical network, due to heating at high temperature continuous monitoring is a difficult task Oil in service is subjected to heat, oxygen and electrical, which may lead to its degradation. This severely limits the oil to carry out its functions of insulating and contaminated Products reduce electrical properties and cooling efficiency. Oxidation

products, such as acids and sludge, are also detrimental to the solid insulation. Therefore, monitoring and maintaining oil quality helps user in reliable operation of equipment and avoids failure rate.

STANDARD FOR TRANSFORMER OIL IS-335:1993

CHARACTERISTICS	REQUIRMENT	METHOD OF TEST
Appearance and color	The oil should be clear and free Suspended matter Or sediments	A representative sample of the oil shall be examined in a 100mm think layer at 27°C IS 335.
Interfacial tension at 27°C min	40 to 50 dynes/cm	**IS-6104**
Acidity (NN)	0.03mg KOH/g	**IS-1448(P-2)**
Dissipation factor at 90°c max	0.002	**IS-6262**

A. Interfacial tension:

The interfacial tension of transformer oil is related to its deterioration .Transformer oil is generally hydrocarbon and thus hydrophobic. However, when the sample undergoes oxidative degradation, oxygenated species such as carboxylic acids are formed, which are hydrophilic in nature. Interfacial tension is the surface tension of a sample of the oil carefully floated on top of a layer of water. The more the hydrophilic the oil becomes, the lower the value of the surface tension between the two liquids. Studies have shown that there is a definite relationship between acid number and interfacial tension .However, when there is loss in IFT without the corresponding increase in an acid number, it is generally because of contamination with another hydrophilic substance not derived from oxidation of the oil.

B. Acidity:

Total acidity also called total acid number (TAN) refers to the measurement of acidity that is gotten by the amount of potassium hydroxide (expressed in milligrams) which is required to neutralize the hydrogen ions in one gram of oil. The total acid number value shows to the crude oil refinery, the possibility of corrosion problems. To find the total acidity, different methods can be used to include POTENTIOMETRIC TITRATION, where TOLUENE and PROPANE are dissolved with a sample and a little water then titrated with alcoholic NaOH. A reference electrode and a glass electrode is immersed in the sample and connected to a potentiometer. The meter reading (in mill volts) is plotted against the volume of the titrant then the end point taken at the distinct inflection of the resulting titration curve corresponding to the basic buffer solution. Color indicating titration: A right pH color indicator for instance, phenolphthalein, is used. Titrant is added to the sample by means of a burette and the volume of titrant used to cause a permanent color change in the sample is recorded and used to calculate TAN value.

Transformer oil

acidity is never good for the performance of the transformer, if at any moment, oil gets acidified then the moisture content in the oil shall get high solubility levels. This shall later affect the paper insulation of the winding. Acidity increases the oxidation process in the Transformer oil. Acid presence also accelerates rusting of iron in combination with moisture. The KOH in mg is used to combat acidity of oil by neutralizing it in every gram of oil. This is referred to as neutralization number.

AS PER **ASTM –D974**

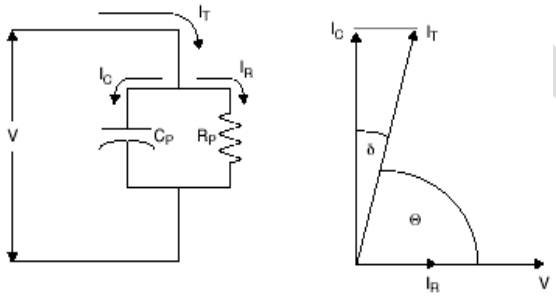
Acid content in oil(N)	Oil status
0.01-0.03	excellent
0.05-0.10	good
0.11-0.15	marginal
0.16-0.40	Bad
0.41-0.65	Very bad
0.66-1.50	Extremely bad
Over 1.50	High risk(transformer failure imminent)

C. Power or dissipation factor:

The power factor of transformer oil is the ratio of true power to apparent power and is a measure of the current leakage through the oil, which in turn is a measure of the contamination or deterioration of the oil. In a transformer, a high power factor is an indication of significant power loss in the transformer oil, usually as a result of Contaminants such as water, oxidized oil and cellulose paper degradation .It is as well referred to as loss factor. The dielectric dissipation factor of an insulating material is the tangent of the dielectric loss angle. This is an angle in which the phase difference between the applied voltage and consequential current diverges from $\pi/2$ rad, at the point where the capacitor's dielectric encompasses only of insulating material. The dielectric dissipation factor in relation to transformer oil is broken down as in this simple description: The loss angle is a vital property of dielectric oil. With an ideal dielectric material, voltage and current has a phase angle as 90 between them. But because of impurities, certain leakage current flows through the dielectric and actual phase angle is slightly less than 90. Arising dissipation factor is an indication of oil contamination or oil ageing. Polar components strongly influence the dissipation factor and are therefore a very sensitive parameter. The tan delta of transformer oil happens when an insulating material is placed between the live part and grounded part of an electrical circuit; resulting in leakage current flow. The insulation ideally leads the voltage by 90 because of the insulating material being dielectric naturally, thereby creating instantaneous voltage between live part and ground of the equipment. In a

practical world, no insulating materials are perfect dielectric in nature. This is simply called Dielectric Dissipation Factor or simply tan delta of transformer oil courtesy of tangent of an angle slightly short of 90 due to imperfections in insulating materials and their dielectric properties.

In a pure capacitor, the current is ahead of the voltage by 90 degrees. The insulation, in a pure condition, will behave similarly. However, if the insulation has deteriorated due to the entry of dirt and moisture, the current which flows through the insulation will also have a resistive component. This will cause the angle of the current to be less than 90 degrees. This difference in the angle is known as the loss angle. The tangent of the angle which is Ir/Ic (opposite/adjacent) gives us an indication of the condition of the insulation. A higher value for the loss angle indicates a high degree of contamination of the insulation.



V= Applied voltage IT = Total current
IR = Resistive current IC = Capacitive current
Dissipation factor = tangent = IR/IC Tan delta = cosine = IR/IT

If the power factor is greater than 0.5% and less than 1.0%, further investigation is required; the oil may require replacement or Fuller's earth filtering. **If the power factor is greater than 1.0% at 25 ◦C, the oil may cause failure of the transformer; replacement or reclaiming of the oil is required immediately.** Above 2%, oil should be removed from service and replaced because equipment failure is imminent. The oil cannot be reclaimed.

D. Quality index system(OQIN)

Good oil has a fixed 0QIN. It is measured by the ratio of Interfacial tension (IFT) to Neutralization number **(NN).** Generally for a good oil QQIN is 300 to 1500.

$$OQIN = \frac{IFT}{NN}$$

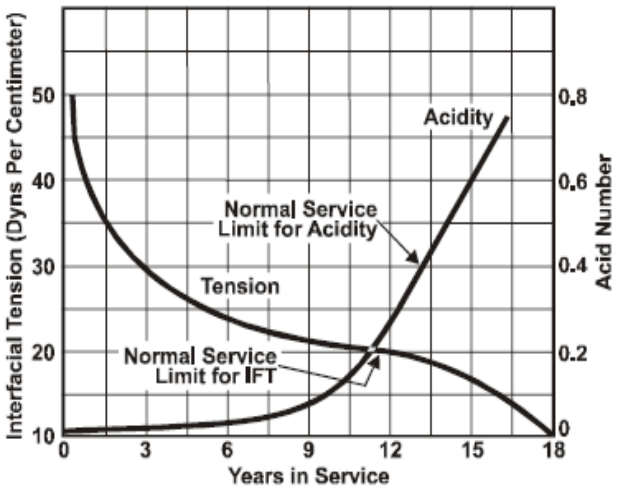
E. Color and Appearance:

Mineral oil used in electrical apparatus have definite color due to their distillation and acid treatment process .The contaminants present in oil increases the acidity and decrease in interfacial tension, in turn affects oil quality index (OQIN) and color. Good oils have–PALE YELLOW color, Bad oils have – AMBER color, very bad oils have- BROWN color and oil in disastrous condition – BLACK color. The quality index of the oil should be more as such the interfacial tension is more and neutralization number should be less.

II. RELATIONSHIP BETWEEN IFT and ACIDITY

As oil ages, it is contaminated by tiny particles (oxidation products) of the oil and paper insulation. Particles on top of the water extend across the water/oil interface line which weakens the surface tension between the two liquids. Particles in oil weaken interfacial tension and lower the IFT number. IFT and acid number (see below) together are an excellent indication of when oil needs to be reclaimed. It is recommended the oil be reclaimed when the IFT number falls to 25 dynes per centimeter. At this level, the oil is very contaminated and must be reclaimed to prevent sledging, which begins around 22 dynes per centimeter. If oil is not reclaimed, sludge will settle on windings, insulation, cooling surfaces, etc., and cause loading and cooling problems. This will greatly shorten transformer life.

There is a definite relationship between acid number and the IFT, and years-in-service. The accompanying curve shows the relationship and is found in many publications. Notice that the curve shows the normal service limits both for IFT and Acidity. The higher the acid number, the more acid is in the oil. New transformer oils contain practically no acid. Oxidation of insulation and oils form acids as the transformer ages. Oxidation products form sludge particles in suspension in the oil which rains (precipitates out) inside the transformer. The acids attack metals inside the tank and form soaps (more Sludge). Acid also attacks cellulose and accelerates insulation. Degradation. Sledging has been found to begin when the acid number reaches 0.40; it is obvious that the oil should be reclaimed long before it reaches 0.40. **It is recommended that the oil be reclaimed when the acid number reaches 0.20 mg KOH/gm.**



ACCEPTED VALUES	NOT ACCEPTED
NN = 0.00 TO 0.15	NN > 0.16
IFT = 25 TO 40 DYNES/CM	IFT < 23

OQIN AS PER GRAY CHEMICAL ANALYSIS

OIL CLASSIFICATIONS	OIL QULITY INDEX (OQIN)
GOOD OILS	OQIN =300-1500 [PALE YELLOW COLOUR]
PROPOSITION A OILS	OQIN=271-600[YELLOW]
MARGINAL OILS	OQIN =160-318 [BRIGHT YELLOW]
BAD OILS	OQIN =45-159 [AMBER]
VERY BAD OILS	OQIN =22-44 [BROWN]
OIL IN DISASTROUS CONDITION	OQIN = <5 [BLACK]

III. CASE STUDY

A 100kva transformer installed in year 2004 in hamirpur district ANU substation, Himachal Pradesh .oil sample was collected and examined in TIFAC-core laboratory in NIT Hamirpur.

C and tan_ measurement:

An ADTR-2K [Automatic Dielectric constant, tan and resistivity test] oil sample is collected and placed in oil cell heater, is used to heat the oil in the cell to required temperature. This uses a high frequency heater which raises the temperature to 90◦c in 15 minutes approximately. A knob and a dial are provided to set the temperature at required level. A temperature sensing probe is supplied and this senses the temperature and stops heating the oil once the set temperature is reached.

Acidity and interfacial measurement:

[a].For acidity measurement, LABINDIA TITRA-AUTOMATIC POTENTIOMETRIC TITRATOR is used. An automatic titrator is a combination of electrochemical potential measurement through electrode with microprocessor driven burette, thus increasing the accuracy of instrument. BURETTE assembly consists of a gas tight syringe with Teflon tipped plunger with luer fitting. Two Teflon tubings are fitted with finger tight fittings. The left side tubing is for titrant aspiration and the right side is for dispensing the titrant in reaction vessel sample titration 1 prepare titration solvent by mixing 495ml IPA (ISOPROPYL ALCOHOL) + 500ml TOLUENE +5ml WATER .

Labindia Titra –Automatic Potentiometric Titrator

1. Weight around 5gm of sample in breaker.
2. Add 60ml of titration solvent to it.
3. Set up titration parameters.
4. Run titration.

[b]. for interfacial tension measurement, EASY-DYNE TENSIOMETER is used. Easy Dyne is intended only for the measurements of the surface tension of liquids, the interfacial tension between two liquids and measurements of the density of liquid.

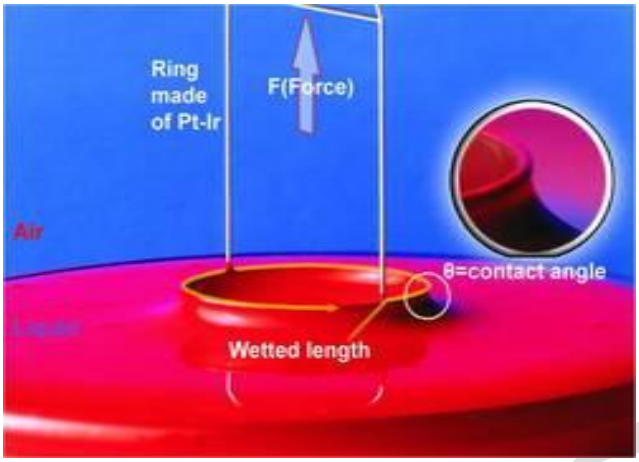
5.

The sample stage is moved downward and ring is suspended from the hook at the forced sensor. Light phase is filled and placed on sample stage then sample stage is moved upward until ring is immersed in to the light phase and press Tare to tare of the ring until weight 0.0000g is shown. Move the sample stage downward and fill sample vessel to one third with heavy phase and place it on the sample stage. At the end result is displayed.

IV. CONCLUSION

Oil quality is a good tool to indicate changes in physical, electrical and chemical properties of oil and based on the results obtained we go for preventive maintenance i.e. Reclamation process. From the above table it is observed that oil condition is bad due to low OQIN even though TAN value and IFT are marginal. It is recommended to reclaim the oil as soon as possible to avoid increment in sludge content and other by-products. So, reclamation of oil is done using dehydration or vacuum chamber as soon to avoid catastrophic failures.

Sample date	04/12/06	06/03/08	09/08/09	19/06/11	13/03/14
IFT	32	28	30	31	26
ACID	0.024	0.031	0.053	0.110	0.155
COLOR	Pale yellow	yellow	Bright yellow	amber	brown
DDF@90^{0}C%	0.22	0.25	0.52	0.75	1.2
OQIN	1333	875	566	281	167



asy dyne Tensiometer

V. ACKNOWLEDGEMENT

The author is thankful to TIFAC-CORE for providing testing facilities for conducting experiment and other infrastructural facilities.

REFERNCES

[1] A. N. Johromi, R. Piercy, S. Cress, J. R. R. Service, and W. Fan, "An Approach to power transformer asset management using health index," *IEEE Elect. Insul. Mag., vol. 100, no. 10, pp. 20-34, 2009.*

[2] N. Wang, F. C. Lu, and H. M. Li, "Analytical Processing of On-line Monitored Dissipation Factor Based on Morphological Filter", *IEEE TRANS. Dielec. Electr. Insul, vol. 11, pp. 840-846, march 2004.*

[3] IEEE standard C57.100-1999, "Test Procedure for Thermal Evaluation of Liquid-Immersed Distribution and Power Transformers".

[4] Myers, S.D. and J.J. Kelly "Testing Transformer Oil", plant engineering, March 16, 1978, Figure 3, p84.

[5] ASTM D-971-91, Standard Test Method for Interfacial Tension of Oil against Water by the Ring Method [6].

[6] A GUIDE TO TRANSFORMER OIL ANALYSIS BY I.A.R GRAY.

[7] Transformer Chemistry Services IEEE P C5 7. XX Draft 10, October 2001, *"IEEE Guide for Application of monitoring to Liquid Immersed Transformers and Components", Donald Chu, Chair*.

[8] IEC 354: 1991, "Loading Guide for Oil-Immerse Power Transformers".

[9] Tapan k.saha, 'Review of Modern Diagnostic Techniques for Assessing Insulation Condition in Aged Transformers", *IEEE Transitions on Dielectrics and Electrical Insulation Vol. 10, No.5; October 2003.*

[10] Dhingra Arvind, Singh Khushdeep, Kumar Deepak, "Condition Monitoring of Power Transformer: A Review", *IEEE Transitions on Dielectrics and Electrical Insulation Vol. 13, No.1; Feb 2006.*