CHAPTER (1)
LITERATURE REVIEW

1-1 Introduction

Almost all load bearing transformers in electric power delivery systems around the world are filled with liquid. The liquid functions both as an electrical insulation and as a heat transfer fluid. The liquid in almost all of these units is "transformer oil" petroleum-based insulating oil refined specifically to meet the requirements of this application.

Transformers in electric power distribution and transmission systems are expected to function reliably and efficiently to do this for many years. The quality of the oil in a transformer plays an important role in performing this function.

Transformer oil is made by refining a fraction of the hydrocarbons collected during the distillation of a petroleum crude stock. The boiling range of the collected fraction and the kind and degree of the refining process are selected so that the resulting oil has characteristics that fall within limits specified for use in transformers. Lower and higher boiling fractions are used to make other products. The crude oil stocks and the refining processes used in producing these oils are typical of those used in producing many common petroleum lubricating oils. Because of the wide availability and the cost benefit that results from this understanding, petroleum-based transformer oils are probably the most widely used electrical insulating liquids in the world today and have been for the past century.

Oils to be used in transformers are made by many regional and international refining companies, each using a particular crude oil(s) and refining technology. The chemical, electrical and physical characteristics of the transformer oil produced by each supplier then are, to some degree, unique to that oil. To assure that particular oil is acceptable for use in specific

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apparatus, the values measured for its relevant characteristics are compared with limits defined in specifications agreed to by manufacturers and users of electrical equipment and refiners of oils. A basis for these agreements often is a standard specification or guide developed by a group made up of experts in transformers and transformer materials. "ASTM Standard Specification D 3487-88(93) for Mineral Insulating Oil Used in Electrical Apparatus" is frequently used in the U.S. to define limits on the characteristics for new transformer oil received at the point of use. Individual users of transformer oil sometimes set more stringent limits or add additional requirements to meet special requirements.

1-2 Parameters Affecting the Characteristics of Transformer Oil

1-2-1 Ageing

Estimation of a power transformers remaining life is of concern to most owners, especially when burdened either continuously or intermittently over long periods. Therefore, to make economical decisions for transformer replacement, it is critical to be able to estimate with reasonable accuracy the transformer remaining life expectancy.

It is well known that the degraded transformer oil leads to the failure of transformer. The effect of aging on transformer oil physical, chemical and electrical properties was studied according to the international testing methods for the evaluation of transformer oil quality. An experimental studies and modeling of the effects of aging on the oil properties of twelve transformers in the field and for monitoring periods up to eight years has been studied by Abdel Wahab *et al* [1]. The main conclusion is that; the breakdown voltage, water content and total acidity are continuously deteriorating with extended service periods while the values of flash point, viscosity and ash content are approximately constant [1].

Kanno *et al* [2] carried out an investigation on the effects of the aging of

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insulating oils on the electrostatic charging tendency (ECT) and dielectric dissipation factor, tan(δ). The investigation covered the effects oxygen at elevated temperature on the aging. It was found that ECT and tan(δ) increased with aging time. In some oils aged with a small amount of oxygen, ECT and tan(δ) increased much more than in other oils aged with a large amount of oxygen. In yet other insulating oils, ECT and tan(δ) showed a peak and then declined. Moreover, it was found that aged insulating oil close to the peak in tan(δ) is very unstable, due to the quality of the insulating oil, especially aged oil.

Chon *et al* [3] discussed the characteristics of the porous ceramic sensor (PCS degradation sensor) checking transformer oil condition in live line. The degradation sensor composes with base ring, electrodes and porous ceramic passed through the transformer oil's conductive particles and checks the transformer oil condition with sensor's leakage current. So it is important to minimize the leakage current of base ring and connection parts. To investigate the leakage current of base ring and connection parts the characteristics of V-T-i at DC 2 kV was examined and other examinations were performed. It is verified that by increasing the oil temperature the leakage current of porous ceramic sensor increases.

It is certificated that the leakage current of other parts of porous ceramic is much smaller than that of the porous ceramic (about 2%) and it is confirmed that the leakage current in porous ceramic is changed sensitively according to the new oil and the deterioration.

Salah et al [4] described the sensitivity of microwaves to the variation of chemical and physical properties of a power transformer-oil. The evaluation of a power transformer-oil deterioration by measuring the complex permittivity (complex dielectric constant) in the frequency range of X-band (8.5-10.5 *GHz)* and Ku-band (17.63-18.07 *GHz)* is investigated. A completely filled short-circuited waveguide technique is used to perform these measurements. It is shown that the microwave measurement of both the dielectric constant and the loss tangent can be successfully implemented for transformer-oil evaluation. Moreover, the low cost of the measurements set-up together with its simplicity and safety encourage them to recommend it for transformer-oil evaluation rather than the traditional high-voltage measurement techniques.

Sabau [5] discussed the reclamation of aged transformer oils by Fuller's Earth which has long been practiced by the electrical power industry. Although the major analytical properties of processed oil such as the dissipation factor at 100°C, the interfacial tension (IFT) and the total acid number (TAN) improve to the level of new oils, the quality of reclaimed oil is considered to be doubtful. The quality of properly reclaimed aged oils can successfully compete with that of new oils. Thus, in addition to extending the life cycle of a nonrenewable resource, he proved that the online reclamation of liquid insulation might also prevent the premature ageing of paper insulation

Sjtahashi *et al* [6] discussed The Effect of the State of Bound Water in Aged Transformer Oil on Conductivity. They investigated that the water in the samples chosen as the aged transformer oils behaves as the cluster bonding to oxygen atom of carboxyl base, alkyl chain and the cluster which bounds the oxygen atom, and the large water cluster at free volume. The formation of water cluster depends on not the position of carboxyl base and the amount of water but the length of alkyl chain. The conductivity of the samples increases in accordance with only the water cluster which bounding the alkyl chain.

1-2-2 Brake Down Voltage and Discharging

Brake Down Voltage (BDV) is the voltage at which the insulting properties of the oil fails and the oil becomes conductor, i.e. it is the voltage at which an arc discharge occurs between two electrodes of a specified shape and a gap of a given distance . The dielectric breakdown testing of insulation liquids has a history of around 40 years.

Fodor et al [7] discussed the importance of measuring device design on the reduction of the influence of the test procedure on the dielectric BDV of silicon oils specimen. They highlight the need for dielectric testing under combined/composite AC/DC voltages. Electric strength of insulating materials either determined conventionally with either AC or DC voltages using a two terminal electrode system. The rapid rise method and the step voltage method are generally employed for determining the dielectric strength of materials. However, in the present day context, there is a need for measuring the dielectric strength under different unconventional voltages like combined or composite voltages which comprises of two voltage components instead of one.

Frayssines *et al* [8] showed that the ratio of impulse to AC breakdown voltage was surprisingly low (close to 1), whereas in the same conditions AC breakdown voltage in mineral oil is lower than impulse breakdown voltage. Further, practical consequences for the design of HV insulation in superconducting were also examined.

Waldron *et al* [9] investigated the behavior of insulating materials such as alumina and glass-bonded mica (Mycalex) used in accelerator systems for high voltage feed through, structural supports, and barriers between high voltage insulating oil and the vacuum beam pipe in induction accelerator cells. They proved that the electric fields in the triple points should be minimized to prevent voltage breakdown. Moreover, mechanical stress can compromise seals and result in oil contamination of the insulator surface.

Lorthongkam [10] carried out a laboratory investigation into the BDV of commercial transformer oil from a main transformer plant with controlled environment similar to site condition, particularly, ambient temperature, oil

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moisture and purification, and temperature rise up to 100 Celsius, with the test voltage up to 300 kV. The results showed that, such insulators have a linear characteristic in withstand the test voltages, whereas the temperature is increased, and field factors varied.

Pompili [11] carried out a study on the partial discharge pulse burst behavior in a mineral oil under AC conditions. The recurrence rate of pulse bursts was found to increase significantly with voltage above partial discharge inception. This was accompanied by an increase of both the number of discrete pulses and their amplitude within the pulse burst itself. These increases were reflected by a substantial rise in the apparent charge transfer per pulse burst as well as the overall charge transfer with increased applied voltage.

1-2-3 The Dissolved Gas Analysis

Insulating oils suffer from deterioration, which can become fatal for transformers. Also, discharge in oil can cause serious damage to the other insulating materials, making the monitoring of power transformers insulation an important task. When insulating oils and cellulose materials in reactive equipment are subjected to higher than normal electrical or thermal stresses, they decompose to produce certain combustible gases referred to as fault gases. For incipient fault conditions (i.e. slowly evolving fault), the gases generated will be dissolved into the oil long before any free gas is accumulated in the gas relay. Thus by analyzing oil sample for dissolved gas content it is possible to asses the condition of the equipment and detecting faults at an early stage. If a fault is indicated, the type of fault can be predicted using various analysis methods. Several dissolved gas analysis (DGA) tests should be taken over a period of time, in order to determine the rate of increase of the fault gases, and therefore the rate of advancement of the fault.

Presently there are several on-line monitoring methods. The most favorable tests for power transformer insulation assessment are on-line types, including

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partial discharge (PD) monitoring and dissolved gas-in-oil analysis. A more successful technique for on-line incipient fault diagnosis is DGA, which is based on routine oil sampling, and the modem technology of on-line gas monitors. Dissolved gas analysis (DGA) is widely accepted as the most reliable tool for the earliest detection of inception faults in transformers and other electrical equipments using insulating oil and Gas-in-oil analysis by gas chromatography has proven to be predictive and valuable some of the problems, which could progress to catastrophic failures in transformers that can be detected, are: arcing; corona; overheated oil, and cellulose degradation.

These problems result in gas production as they start to develop and gas production increases with increasing severity of the problem.

Ward [12] shows how dissolved gases in insulating oil can be used as a diagnostic tool for faults occurring on apparatus using insulating oil such as transformers. This is achieved by comparing the results of traditional testing techniques (quality tests) with those using DGA

He used dissolved gas analysis to study the history of different transformers in service, from which dissolved combustible gases (DCG) in oil are used as a diagnostic tool for evaluating the condition of the transformer. Oil quality and dissolved gasses tests are comparatively used for this purpose. The effect of transformer aging on dissolved combustible gasses is also examined. IE is noted that the oil quality tests for transformer oil are inconclusive and that the DGA test is then necessary for complete evaluation of transformer condition.

DGA of insulating oils has, over the last few decades, become a widely used technique for detecting and diagnosing incipient electrical failures inside the windings of power transformers. Since the decomposition of oil indicates a threat to the operational safety of these expensive machines, electrical engineers focus their attention on the amount and nature of the gases evolved. This is based upon the relationship that was established between the results of DGA and the potential cause of such deficiencies.

Sabau et al [13] described the unavoidable implications of secondary chemical reactions, caused by the gas evolvement of oil subjected to thermal and electrical stress. Appropriate preventive measures are taken to protect the transformer. However, the side effects of a hydrocarbon chain breakdown on the insulating properties of oil are generally not taken into consideration. When a hydrogen atom is knocked out from a hydrocarbon it means that the two electrons of a covalent bond were homiletically separated. While the hydrogen content of oil and other low molecular weight gases is carefully monitored, the decay products generated by the chemically reactive large fragments of decomposed molecules are ignored. Significant technological progress has been made in the laboratory analysis of oil, which offers the opportunity to reveal the link between gassing and the deterioration of liquid insulation quality under service conditions.

1-2-4 Testing and Improvement Devices

The state of insulating oils used in transformers is determined through the accomplishment of physical and chemical tests, which determine the state of oil, as well as the chromatography test, which determines possible faults in the equipment.

da Silva et al [14] concentrated on determining, from a new methodology, a relationship among the variation of the indices obtained from the physicochemical tests with those indices supplied by the chromatography tests. The determination of the relationship among the tests is accomplished through the application of neural networks. From the data obtained by physical-chemical tests, the network is capable of determining the relationship among the concentration of the main gases present in a certain sample, which were detected by the chromatography tests. More specifically, the proposed approach uses neural networks of perception type comprising multiple layers.

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After the process of network training, it is possible to determine the existing relationship between the physical chemical tests and the amount of gases present in the insulating oil.

In an attempt to enhance the electrical response of electro rheological (ER) fluids under DC electric field conditions, the influence of the electrode surface morphology has been studied by Hanaoka *et al* [15] using a rheometer in which the electrode surface was covered with a thin metallic net. The test fluids consisted of micro sphere particles suspended in two insulating oils, dimethylsilicone oil and fluoridated dimethylsilicone oil. The aggregation of particles and the ER responses in these fluids revealed the effect of local changes in the electric field on the metallic net surface. It is shown that a metallic net on the electrode surface is effective for further promoting the rheological response of the ER fluid suspended in fluoridated dimethylsilicone oil. The responses appear to depend on the material properties of the ER fluids and the mesh size of the metallic net.

Another investigation was carried out by Lick et al [16]. They dealt with the electrical strength properties of oil gaps. The investigations were carried out with uniform electrical fields and electrode distances up to 30 mm. Measurements were performed with alternating current (50 Hz), lightning impulses and switching impulses. Such investigations usually have a relative high dispersion of the measurement values. It will be shown that it is possible to minimize the coefficient of variation to values of about 5 to 6 percent.

Oinxue Yu *et al* [17] have studied the influence of various impurities produced due to thermal aging in transformer oil and ionic surfactant on static electrification. They introduced a model for producing the proposed static electrification and they conclude the following:

1) Thermal aging causes the quantitative and qualitative changes of static electrification in oil.
2) The paper can adsorb the positive ions under the special condition

resulting in the formation of negative charge in oil.

3) The experimental results showed that the tested impurities were not main cause of static electrification in aging oil. The aging oil may produce some very small trance polar impurities that are very similar to positive ionic surfactant and they are the source causing the negative charge in oil.

To improve .transformer oil characteristics Abdel Wahab *et al* [18] introduce a newly modified forced oil cooling system, which comprises bypass filter (BPF). The BPF has been introduced in such a way that its intake oil is the hot oil from the transformer top and to deliver it at the inlet of the oil-circulating pump. This system has been used for two transformers.

Periodical measurements of the physical, chemical, and electrical transformer oil characteristics by standard testing methods before BPF operation, in operation and after stopping its operation in the transformer have been carried out. Before BPF operation, the results revealed that these characteristics are continuously deteriorating with the increase in transformer oil service period. However, when BPF is in operation, this deterioration not only has been reduced but also some of the characteristics have been improved.

After the operation of BPF has been stopped, some of the characteristics resumed their deterioration. However, the rates by which these characteristics are deteriorating are noticeably smaller than their initial values. The deteriorated transformer oil characteristics (without installation of BPF) have been predicted by polynomial regression, multiple linear regression, and general linear multiple regression models. The efficiency and feasibility of the new cooling system in preserving in-service transformer oil characteristics have been proved and justified by quantitative evaluation of the measured and theoretically predicted deteriorated (without installation of BPF) characteristics.

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1-3 Transformer Oils

1-3-1 Properties of Transformer oils

Many properties of mineral transformer oils are of importance in their use as insulating liquids. They can be divided into physical, chemical and electrical properties.

1-3-1-1 Physical Properties

Physical properties of petroleum transformer oils can be divided into three groups:

First group:

The first group is composed of those properties, which are of importance in designing equipment. These determine the heat dissipation characteristics of the equipment and its performance under low temperature conditions. They are thermal conductivity, specific heat, density, viscosity, pour point and coefficient of volume expansion.

Thermal conductivity, specific heat and viscosity determine the rate at which heat is dissipated from the electric equipment and therefore, the oil volume and type of cooling remain in accordance with the equipment design.

Oil viscosity greatly reduces as temperature increases; accordingly heat can be easily dissipated. The rate of viscosity change is also important, under cold climatic condition or when equipment is started up [19].

Pour point measures the temperature at which oil ceases to flow, but the important requirement is that the oil should have sufficient fluidity to remove heat at the lowest temperature at which the equipment is expected to operate[20].

The coefficient of expansion is important in determining the free space required in transformer tanks, header tanks and conservators to cater for oil volume change over the whole temperature range encountered.

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Second group:

The second group is made up of these characteristics which are of interest in operating equipment. They are solvent power, vapour pressure, flammability, interfacial tension and particulate contaminants.

The solvent power or solvency of insulating oil is important in relation to its effect on the materials of construction of equipment. Materials which are wholly or partly dissolve in insulating oil can affect its electrical properties and very often its rate of degradation [21].

The vapor pressure of insulating oils is seldom mentioned in relation to their performance in electrical equipment.

Flammability of a liquid is given by a number of test methods amongst which are flash point, fire point and auto-ignition temperature. The flash and fire points are indication of the volatility of a liquid and are determined under pre-described conditions.

The presence of impurity particles in oil-insulated power equipment is unavoidable. Such contamination affects the insulating properties of the oil and hence the insulation integrity of the equipment itself.

Different concentrations of conducting and non-conducting particles of various sizes are known to exist in a practical insulating system. Particles that are most likely to be found in transformers are composed of iron, copper, aluminum and cellulose. These particles introduced into the tank by contact of the oil with coils, the core and solid insulating structures, both during manufacturing and in service conditions. Carbon particles are produced by electrical discharges in oil and their presence is unavoidable in the oil of circuit breakers and of transformers.

Trinh *et al* [22] have studied the influence of impurities inherent to oil-insulated power transformers, on AC breakdown strength of the oil. The failure rate was higher in 700 kV rating transformer than in lower voltage rating transformers.

Miners [23] showed that cellulose particles had a significant effect in reducing the oil breakdown strength if the oil contains a lot of moisture.

Particle concentration in insulating liquid is reduced by filtration; however, filtering the liquids can only reduce the number and can not completely remove the particles [24].

Third group:

The third groups are used to calculate the hydrocarbon constituents of oil by the n-d-m analysis. They are density, refractive index and molecular weight.

Density and refractive index are used to identify the source of the crude oils. Low values are associated with paraffinic hydrocarbons while high values with the naphthenic. Refractive indices values increase with the increase in density [25-27].

1-3-1-2 Chemical Properties

The following chemical properties are interest in using mineral oils as insulating liquids: oxidation stability, gassing characteristics and water content beside neutralization value, saponification value and nitrogen content.

Oxidation stability:

The primary factor causing deterioration of transformer oil is its oxidation. The oxidative products of the mineral insulating oils are acids, solids and water. Acid and water can cause metal corrosion and accordingly accelerate the degradation of solid insulants, whilst sludge is deposited on winding in cooler ducts and impedes heat convection which results in an increase in the temperature and in the rate of oxidation.

Mineral insulating oils contain varying amounts of aromatic and non-aromatic (naphthenic and paraffinic) compounds, with some non-hydrocarbons (Sulphur, oxygen, and nitrogen compounds) as impurities. The concentration of each of these components is usually a compromise between

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practical requirements such as the oxidation resistance, which is adversely affected by the presence of the aromatic constituents [28] and the ability to absorb gases which is enhanced by some of these aromatic components [29].

The important factors which affect the oxidation of insulating oils are oxygen, temperature and materials acting as oxidation catalysts. The metals predominantly present in electrical equipment which may act as oxidation catalysts are copper and iron.

It is well known that thermal oxidation induces significant variations in the oil electrical properties [30-36].

To simulate the thermal oxidation of transformer oil it is customary to oxidize the oil under accelerated conditions.

Natural anti-oxidants are present in the oil to some extent but they get depleted in a short time in service. In order to retard oil deterioration, artificial anti-oxidants are added. Such oil is termed as inhibited oil. The commonly used inhibitor is di-teriary butyl para cresol (DBPC).

Gassing tendency:

When the oil in a transformer is exposed to a very high voltage and partial discharges there will always be some gassing in the oil. This is due to that some molecules will be so excited that fragments will get loose from the molecules (cracking). These fragments will then react further and form, e.g.. H_2, CH_4 and C_2H_2. The content of different gases in the oil is regularly checked in power transformers.

If much gas is produced all can not be dissolved in the oil, and gas bubbles will be produced. Gas bubbles in the oil are dangerous, as this can lead to a complete breakdown of the transformer. The risk for breakdown because of gas bubbles in the oil depends on the design of the transformer.

The gassing behaviour differs between different oils. It has been found that low refined oil can absorb the gas produced. Some high aromatic oils can absorb more gas than are produced, i.e., they are gas absorbing. This phenomenon depends on that some of the aromatic molecules can react with the hydrogen produced. As it is a chemical hydrogenation process, aromatic ring in the molecule will be transformed into a naphthenic one, the word "gas absorption" is not a fully correct expression. High aromatic oils can also "absorb" nitrogen gas, but the mechanism for this is not fully understood. Not all aromatic molecules have the same gas absorbing effect. In mineral oil it is mainly the content of polyaromatics that affects the gassing tendency [37].

Water content:

The contamination of oil by water is common natural occurrence. The water content of insulating oil is importance due to its effect on the electrical properties oil and to its absorption into solid insulation [38, 39].

The content of water in oil is directly proportional to the relative humidity of the air and also depends on the hydrocarbon composition of the oil [40]. The insulating systems of transformers must be dried before impregnation with insulating oil.

1-3-1-3 Electrical Properties

The electrical properties of a liquid are important on its function as an insolent and their maintenance at an acceptable level ensures satisfactory equipment performance, reduce ohmic losses and limits discharge inception within the liquid. The level of test results is affected by the chemical constitution of the liquid, but with the exception of impulse strength and permittivity, is predominantly due to presence of conducting contaminants such as fibers, water, particulate matter (dirt), dipolar and ionic or dissociated compounds. The removal of such contaminants by drying filtration processes substantially improves results. The important electrical characteristics are:

Breakdown voltage (dielectric strength):

The breakdown voltage is the voltage at which an arc discharge occurs between two electrodes of a specified shape and a gap of a given distance,

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when voltage is increased at standard rate [41]. Nominal acceptable values range from 30 to 55 kV depending upon the type and voltage rating of the equipment.

A high electric strength gives no indication of the purity of oil in the sense of degree of refinement or the absence of most type of oil soluble contaminants. Because of the problem with water contamination from the air, the oil is normally vacuum filtered when it is filled into the transformer [42].

As dry oil is very hygroscopic it is difficult to maintain the high breakdown voltage of newly dried oil. The tanks, containers or drums have to be totally air-tight or have a silica gell drying filter.

Dielectric losses (Dissipation factors, tan δ):

Dissipation factor is a measure of electrical energy dissipated as a heat when the material is placed in an electrical field. Low dissipation is necessary so that less heat is developed in the oil [43]. Transformer oil must have low dielectric dissipation factor.

This characteristic is expressed as a dissipation factor tan (δ), where δ is the loss angle. The dissipation factor is quite sensitive to temperature changes and it is proportional conductivity. It has not always been included in transformer oil specification; it appears for cables and capacitors oils.

The demand for new oil is normally a dissipation factor of 0.005 at 90°C. The parameter is very set contamination of polar molecules, so every time pumped or filled in a tank or drum, tan (δ) will most impurities will affect tan(δ).

When oil start to oxidize, polar molecules will be formed, for example carboxylic acids, ketones and esters. Then the dielectric losses will increase rapidly.

As tan delta is always very low of a well refined oil, as for as it is not contaminated or oxidized, it is not depending on the refining technique or the origin of the oil, it measure on the cleanliness of the oil.

The dielectric breakdown impulse (impulse strength):

Oils in transformers and switch gear subjected to impulse stress produce a non-uniform field. These stresses may be negative or positive in polarity. Their mechanism is complex but gas bubble formation is considered as the principal reason of impulse stress.

If the composition of the oil has no influence on the breakdown voltage, it seems that an increase in carbons in the oil obtains a better response to the impulse stress.

There is still no international official test for determining the impulse strength because a lack of acceptance of its practical importance [44].

Ageing:

Ageing of transformer oils is best evaluated by measuring their interfacial tension and antioxidant content [45-47].

The interfacial tension (γ), antioxidant content, dielectric losses (tan δ) and electrical conductivity (σ) of new and aged transformer oils vary significantly with time exposure to light, especially UV light. Two weeks exposure is sufficient to increase the values of the electrical properties by a factor of two[48].

In fact that γ, tan (δ) and σ, vary exponentially over the same period of time prove they are related. The photo-oxidation generates a number of acidic and polar products [34] that reduce γ and seem to increase tan (δ) and σ. It is remarkable that in the first two months σ increases more rapidly with time than tan (δ). Obviously the two parameters do not obey the same mechanism. In fact, it is quite possible that tan δ is more sensitive to the dipolar products induced by photo degradation, whereas the conductivity is controlled by the density of ions hopping between the oxidation sites.

1-3-2 Egyptian Standard Specification

The Egyptian standard specification ES: 547-1985 specifies the requirements for unused insulating oils. The oils covered by this standard are uninhibited oils free from antioxidant additives. Table (1.1) represents the ES specification for transformer oil.

Table 1.1 Egyptian Standard Specifications for transformer oil.

Property	Test Method	Permissible values for measured characteristics
Density at 20°C, gm/cm^3	ES-80	0.895(max)
Flash point, °C	ES-177	140 (min)
Kinemaatic viscosity cst,	IP	
-15°C		800 (max)
20°C		40 (max)
Pour point, °C	ES-79	-30 (max)
Total acid N°, mgK OH/g	ES-825	0.03(max)
Water content, ppm	ASTM-D1533	50 (max)
Corrosive sulphur	ASTM-D1275	Non-corrosive
Total acid N°, mgK OH/g (after oxidation)		0.1 (max)
Breakdown voltage, kV	IP-5874	30 (min)
Dissipation factor, at 90°C	IP-5737	0.005 (max)
Appearance		Clear, free from sediment and suspended matter.