EXPERIMENTAL INVESTIGATION OF THE CHARACTERISTICS OF TRANSFORMER OIL AND SOME SELECTED VEGETABLE OILS

BY

TOLA, Omokhafe James

(M.ENG./SEET/2008/1911)

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING (M.ENG.) IN ELECTRICAL AND ELECTRONICS ENGINEERING (ELECTRICAL POWER AND MACHINES OPTION)

APRIL, 2012

DECLARATION

I hereby declare that this thesis titled: "Experimental investigation of the Characteristics of Transformer oil and some selected vegetable oils" is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

4/5/2011
Signature & Date

TOLA OMOKHAFE JAMES
(M.Eng/SEET/2008/1911)
FEDERAL UNIVERSITY OF TECHNOLOGY,
MINNA, NIGERIA

ACKNOWLEDGEMENTS

This thesis would never have been completed without the guidance from creator and sustainer of the universe. I thank God for guiding me through the dark and giving me a helping hand when I was down and directing me in the right direction when I was lost. I thank Him for all His blessings He has showered upon me to help me reach where I am.

I would like to express my sincere appreciation to my supervisor, Prof. O. Usifo, for his guidance, encouragement, and continued support throughout the course of this work. His extensive knowledge, advice and creative thinking have been an invaluable help to this research work. I learned a lot of knowledge, methods and ways of thinking from him.

I express deep appreciation to my wife for her unwavering love, care and support through the thick and thin. She has been my relentless source of motivation.

I wish to extend my appreciation to the Dean School of Engineering, Prof. M.S. Abolarin and the Deputy Dean School of Engineering Dr. S.A. Abdulkareem for the enabling environment given to me in the course of my studies.

My study and research was enjoyable and rewarding due to the excellent departmental staff. In particular, I would like to thank the head of department Electrical and Electronics Engineering, Engr. Dr. M.N. Nwohu and Engr. Dr. Jacob Tsado for their contributions to the success of my programme.

Also I would like to thank Mr. Isah Doko for his help with the experiments.

Recognition is extended to Dr. K. Omokhafe, Ogidefa Cyril and Akwu Jacob for their assistance and cooperation by providing parts and equipment.

I greatly appreciate the discussions with Dr. Olakunmi and Engr. Osinowo Emmanuel.

They gave me a lot of helpful suggestions on my research work.

I also thank my close friends Ambafi James, Abdulkadiri Isah, Ir. Imoru A.Y. Engr. M.Z. Adamu and Agbachi Okenna with whom I had an interesting discussion.

I thank all those, who kept asking me all these years: "Have you finished yet?" Silencing that question was a big motivation when life's many other attractions kept enticing me.

I thank all those, who may have helped me in any possible way.

I express my appreciation to my family for moral boosting, continued support and most importantly their belief in me, throughout my life.

ABSTRACT

The world's energy requirement has been dominated by petroleum oil for years and in many applications most especially in area of electricity. Mineral oil is an important insulating material in transformers; it has been used for many years. Mineral oil application in power system equipment can be potentially hazardous to the environment especially when there are incidents of transformer explosion which may cause a spill of oil to the soil or water stream. In the future, environmentally friendly insulating oil such as vegetable oil is expected to be utilized as a substitute for mineral oil for power transformers. Experimental results on breakdown voltage, flash point, pour point, viscosity, density and insulation resistance of conventional mineral oil and vegetable oils were analyzed. The experiments were done in an attempt to find new type of liquid insulating materials which are excellent in electrical characteristics and friendly to environment. Comparing the experimental results and values of several properties in international standard form such as America Standard Test of Material (ASTM). Rubber seed oil has the above good electrical properties and therefore recommended to be used as a biodegradable insulating liquid to replace the commonly used transformer oil, which is a mineral from petroleum product.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS AND SYMBOLS

ASTM	America society of test material
BDV	Break Down Voltage
DAR	Dielectric Absorption Ratio
IEC	International Electrotechnical Commission
PI	Polarization index
VDE	Verband Deutscher Electrotechniker
D	Length of sphere gaps
σ	conductivity
E	Electric field strength
ε	Relative Permittivity
$\Im$	Current density
Tan δ	Dielectric dissipation factor
V	Kinematic viscosity
V_b	Breakdown Voltage

CHAPTER ONE

1.0 INTRODUCTION

Transformer oil plays a critical role in keeping electrical generation systems reliable. Transformer oil is a small investment that protects the power industry's huge capital investment in the massive transformers that make up the backbone of a nation`s energy supply.

Power plant generators produce electricity that has to be stepped up to high voltage for more efficient transportation across wires to substations near business centre. factories and homes. The transformers that step up the electricity to high voltage do so efficiently with losses in the order of 0.5% of the electrical load being lost in the form of heat. Even though the loss percentage is small, the actual quantity of heat can be quite large. The heat that is produced must be carried away from the transformer and dissipated. If not, the transformer coils will overheat and be damaged or destroyed.

The windings of the transformer are immersed in an enhanced mineral oil that is circulated to cool the transformer. This oil also remains stable at high temperatures and has excellent insulating properties that protect against stray current path. The oil circulates through the transformer windings and the heat loss is transferred either to the ambient air around the transformer or to water. The oil-filled tank often has radiators through which the oil circulates by natural convection. Large transformers use forced oil circulation by electric pumps, aided by external fans or water-cooled heat exchangers.

Since long time ago, petroleum-based mineral oils have been used for liquid insulation in high voltage equipment. At present time the oil are still widely used as insulation for transmission and distribution power transformers, capacitors and other high voltage equipment. Petroleum-based insulating oil, in general has excellent dielectric properties such as high electric field strength, low dielectric losses and good long term performance. However, due to environmental consideration, recently many researches have been carried out in an attempt to search for the alternative of liquid insulating materials which are friendly to the environment. There are some reasons why it is important to search for the environmental-friendly insulating oil. Firstly, conventional transformer oil are usually non-biodegradable. It can contaminate soil and water when serious spill take place (Oommen, 2002). This may disturb the plantation and other lives. Secondly, the mineral oil was extracted from petroleum, which is going to run out in the future since petroleum is nonrenewable (Claiborne *et al*, 1999). An alternative for biodegradable high voltage insulating material is natural ester made from palm oil (Suwarno *et al*, 2003), (Hikosaka *et al*, 2007)

1.2 Statement of the Problem

Petroleum-based mineral oils have been used for liquid insulation in high voltage equipment's. At present, the existence of mineral oil in the world has been reduced as the time goes by and probably it will not occupy our need for the next millennium.

Vegetable oil has a capability as the alternative source for transformer insulation. The biggest advantage of vegetable oil is the non-toxic material characteristic which will not produce any toxic product during combustion. Carbon dioxide and water are the only products that are formed during the biodegradation process. They are also less flammable liquids with a minimum flash point above 300^0c. They resist oxidation and absorb more moisture than mineral oil. On the other hand, their high viscosity might cause a problem to the heat transfer system in the transformer (Fofana *et al*, 2001).

Several researches have been carried out in this field. The investigation conducted by (Oommen, 2002) and (Lewand, 2001) gave unsatisfactory results of application of ester oils because some natural ester oil tend to become a gel during aging process. But, investigation still continues to find out the optimal dielectric characteristics of vegetable oil.

However, it was reported that natural ester has superior characteristic of breakdown strength and water solubility but inferior in losses factor and viscosity (Wasserberg *et al*, 2005), (Suwarno and Aditama, 2005). Mineral oil has good thermal properties to evacuate heat from transformer, but inferior in ageing and biodegradability. In composite state with paper, natural ester also indicates much better compatibility than mineral oils. Mixture between different liquids may improve the dielectric as well as thermal properties of the insulating liquids (Perrie *et al*, 2006).

1.3 Objective of the Project

In this project, a comparative study will be conducted between mineral oil and vegetable oil (palm oil, ground nut oil, palm kernel oil, rubber seed oil and melon seed oil). The objective of this project is to analyze the properties of vegetable oil and mineral oil in order to determine the breakdown voltage, insulation resistance, viscosity, flash point and pour point. In comparison with mineral oil, tests were carried out on mineral and vegetable oil. The final result acknowledged the difference of their characteristics.

1.4 Project Methodology

The experimental researches were carried out in the high voltage laboratories (PHCN in shiroro dam, Kaduna Petrochemical refinery and also Thermal power Station in Ajaokuta Steel complex) and several measuring equipment were also used. The experiments used the following methods:

I. Material samples (mineral oil and vegetable oil).

II. Breakdown voltage measurement ;

III. Insulation Resistance test;

IV. Viscosity measurement;

V. Moisture content measurement;

VI. Flash Point test;

VII. Pour point test;

VIII. Specific gravity test;

IX. Collection and evaluation of the results and comparison of the properties between Mineral oil and each vegetable oil.

1.5 Project Outline

This project is divided into five chapters which include all aspects of investigating the two types of insulating oil. Chapter one introduces the important background of vegetable based insulating oil as an alternative for transformer oil, then, in Chapter two; Literature review, in Chapter three: material and methods. In Chapter four: the measured results and discussion of results. The properties of the mineral oil and each vegetable oil are compared. In Chapter five; conclusions are presented based on this work.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Transformer Insulating Oil

The fast growth of the use of electricity needs an improvement of the power system equipment with a high level of reliability and safety. The power system grid connects the power plants through transmission lines and distribution lines to the end users. The main goal is providing electrical power to the consumers in ready-to-use form.

Transformers are essential parts in the power system for voltage level conversion and maintaining the power flow. They are applied at four major regions (Endah, 2010).

a) At power plants, where power is generated and raised to transmission;

b) At sub-transmission stations, where the high transmission voltage is reduced to a medium high voltage;

c) At injection (medium high voltage) substations, where the incoming medium high voltage is reduced to distribution high voltage;

d) At service sub-station transformers, where the voltage is reduced to low voltage for utilization level for routing into consumers' homes and businesses.

Transformers may suffer from several conditions such as overload condition, which might lead to transformer failures. Among all of the transformer components, the insulation system plays a significant role in the transformer life, because most of transformer failures were caused by insulation failure according to the statistics of transformer failures in USA from 1997 to 2001 (Bartley, 2006) as we can see from the transformer failure classification in Figure 2.1.

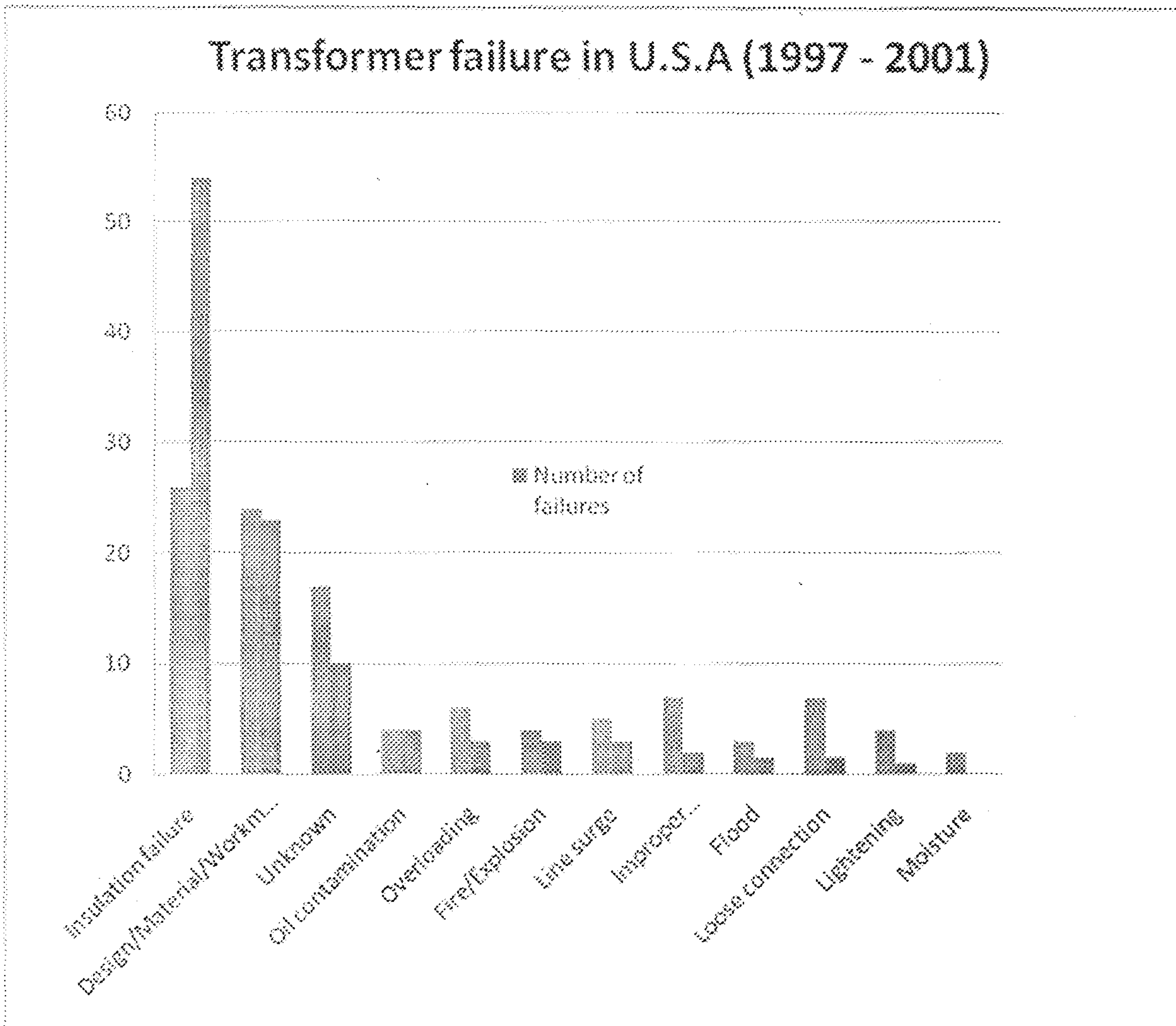

Figure 2.1: Number and cost of 25 kV transformer failures in USA (1997-2001)

There are two basic transformer insulation types, solid and liquid. Solid insulation can be made of paper, pressboard, epoxy, and wood. Among them, kraft paper is widely used as solid insulation in the transformer, which is made from unbleached softwood pulp and constructed through a sulphate process.

Oil as insulation provides two main purposes in the transformer operation, as the insulation material and the cooling medium. There are several requirements for transformer insulating oil:

a) To act as a coolant with the main task of absorbing the heat from the core and winding, then transmitting it to the outer surface of the transformer. At higher temperatures the viscosity of the oil decreases, thus facilitating the circulation of the oil. It is important to keep the pour point low so that the oil is effective at any observable flow;

b) To insulate different parts at different electrical potential. Oil makes a good contribution to transformer insulation by penetrating into and filling the spaces between wound insulation layers;

c) In order to minimize the evaporation losses, the oil volatility should remain low. Oil temperature in service should be maintained below its flash point;

There are three factors that influence the chemical stability of oil: temperature, oxygen availability, and catalyst presence. The oil degradation process is caused by decomposition of the hydrocarbon molecules in oil at high temperature. The oxygen contents in insulating oil might lead to a rise of the acidity number and to sludge formation (Willis *et al*, 2001). Catalysts such as copper and iron are dissolved in oil during aging and might accelerate the aging process.

Mineral oil was first introduced in 1892 by General Electric as a dielectric coolant (Manning, 2007). The main reason for using mineral oil was the high flash point characteristic and the widespread production around the world. As of today, mineral oil has been used as the main source of insulation material, for several equipment especially power transformers.

But due to the poor biodegradability characteristics of mineral oil there is still environmental concern in case of leakages during operation or due to an incident. In the beginning of 1930 until mid-1970, many transformers were insulated by Askarel, a mixture of PCB (polychlorinated biphenyl) and chlorobenzenes. This material was chosen because of its non-flammable characteristics (Fofana *et al*, 2001). Later, Askarel was no longer recommended as an insulation material any more due to the environmental issues of this hazardous material. In order to settle down the environmental and sustainable issues, people started to look for alternative sources for insulating oil. The latest insulating oil implementation is vegetable oil-based fluid which is known as the most potential source to replace the mineral oil because of its biodegradability characteristic. The first vegetable oil was used for capacitor insulation in 1962 and gave a good match with cellulose due to its higher dielectric constants (Oommen, 2002). One of the vegetable oil variants is known as ester oil since the extraction process of ester oil uses the vegetable source.

2.2 Vegetable Oil

Although most plants contain some oil, only the oil from certain major oil crops complemented by a few dozen minor oil crops is widely used and traded. Vegetable oils can be classified in several ways, for example:

- By source: most, but not all vegetable oils are extracted from the fruits or seeds of plants, and the oils may be classified by grouping oils from similar plants, such as "nut oils".
- By use: oils from plants are used in cooking, for fuel, for cosmetics, for medical purposes, and for other industrial purposes

2.2.1 Groundnuts

The groundnut is an annual plant. Varieties are grown as two types, either as a bushy bunch or as a runner. Hybrids of the two, 'semi-upright', are grown commercially. Groundnuts grow in tropical and subtropical regions, and in warm parts of temperate regions. They are cultivated as a rain fed crop, or under irrigation in the dry season.

When mature, plants are dug or pulled up and the pods removed by picking or flailing. Bunch-type groundnuts have small- to medium-sized pods containing one or two round kernels in a thin shell. Runner types have one to three oval kernels in medium-sized, thicker-shelled pods. The kernel consists of about 60-75% of the whole nut. Oil content of groundnut kernels is 45-55%, depending on variety.

Palm

l palm requires a rainy tropical climate. Natural distribution in West between 13°N and 12°S. It grows in the transition zone between the l savannah, in moister locations of the grasslands, and in forest l palms begin to fruit after 10 years and do not give a full crop for about 20 years. Cultivated palms come into bearing at about the fourth year, reach their peak after 12-15 years, and continue bearing fruit for 40 to 50 years.

The fruit is an oval-shaped drupe 2.5-5 cm in length and 2.5 cm in diameter. It consists of a thin, pliable exocarp, an orange/red pulpy mesocarp and a hard nut containing a single kernel (Weimer and Altes, 2011).

Fruits are borne tightly clustered in large bunches which may weigh from 5 kg in young poor palms, to as much as 40 kg in 15-year-old palms in good condition (Vaughan and Geissler, 2009).

Two types of oil are produced from the oil palm, red palm oil from the fruit, and white oil from the kernel. The oil content of the fruit is about 55% and that of the kernel is about 47%.

2.2.3 Melon

Melon seeds (Citrulus vulgaris) are small, flat and partly oval in shape ntaining cotyledons. The seed is covered with a thin shell having a thick ring the edges with a tip. The cotyledons contain 60% protein and 50% edible

2.2.4 Rubber seed oil

Many plant species produce natural rubber. Considerations of quality and economics, however, limit the source of natural rubber to one species, namely Hevea brasiliensis. The rubber plant which is widely used as a natural source of rubber has been reported to have oil rich seeds (Ikwuagwu *et al*, 2000).

Rubber seed is obtained in high yield as a by-product of Hevea brasiliensis cultivated primarily for its latex.

2.3 Functional based classification of oil properties

The insulating oil in a power transformer performs two major functions. Firstly, it serves as electrical insulation to withstand the high voltages present inside the transformer. Secondly, it functions as a heat transfer medium to dissipate heat generated within the transformer windings.

To meet the insulation function, the oil must have high dielectric strength and low dielectric dissipation factor to withstand the electric stresses imposed in service. Paraffinic oil is derived from crude oil containing substantial quantities of ...turally occurring n-paraffin's (wax).

...il has a relatively high pour point and may require the inclusion of ...duce the pour point.

Naphthenic oil is derived from crude oil containing a very low level or none of naturally occurring n-paraffin's (wax). Naphthenic oil has a low pour point and requires no additives to reduce the pour point. Naphthenic oil provides better viscosity characteristics and longer life expectancy, and sludge is soluble and thus does not deposit out on windings, blocking cooling ducts and reducing cooling efficiency.

To measure the quality of insulating oil, several tests are used. The following list describes some of the most common laboratory tests, and references the appropriate ASTM method.

(a) Dielectric Breakdown

Dielectric breakdown is the minimum voltage at which electrical flashover occurs in an oil. It's a measure of the ability of oil to withstand electrical stress at power frequencies without failure. A low value for the dielectric breakdown voltage generally indicates the presence of contaminants, such as water, dirt, or other conducting particles in the oil.

(b) Neutralization Number

The neutralization number of oil is a measure of the amount of acidic or alkaline materials present. As oil ages in service, the acidity and, therefore, the ...lization number increases. Used oil having a high neutralization number ... the oil is either oxidized or contaminated with materials such as ...t, or other foreign matter. A negative neutralization number results ...e contaminant in the oil.

(c) Specific Gravity

The specific gravity (relative density) of oil is the ratio of the weights of equal volumes of oil and water. A high specific gravity indicates the oil's ability to suspend water. In extremely cold climates, specific gravity can be used to determine whether ice, resulting from freezing of water in oil-filled apparatus, will float on the oil. Such a condition possibly may result in flashover of conductors extending above the oil level.

(d) Water Content

This test measures the concentration of water contained within the oil. Low water content is necessary to obtain and maintain acceptable electrical strength and low dielectric losses in insulation systems.

(e) Power Factor

Power factor indicates the dielectric loss of oil. A high power factor is an indication of the presence of contamination or deterioration products such as moisture, carbon, or other conducting matter, metal soaps, and products of oxidation.

(f) Flash Point

The flash point is the minimum temperature at which heated oil gives off sufficient vapor to form a flammable mixture with air. It is an indicator of the volatility of the oil.

(g) Pour Point

The pour point is the lowest temperature at which the oil will flow. A low pour point is important, particularly in cold climates, to ensure that the oil will circulate and serve its purpose as an insulating and cooling medium.

(h) Viscosity

Viscosity is the resistance of oil to flow under specified conditions and is the principal factor in the convection flow of oil in an electrical device. It influences heat transfer and, consequently, the temperature rise in apparatus. (Miller and George, 1999)

The property and the required level of insulating oil are described in Table 2.1 (Rao, 2007), (ASTM D117, 1998) and (ASTM D6871, 1998)

Table 2.1: Property and Required level of insulating oil

Property	Required Level	Function	Limiting value of New oil	
			Mineral oil	Vegetable oil
Breakdown voltage with 2.5mm standard gap	High	To provide dielectric strength to prevent breakdown of the oil under electrical stress	30kV	30kV
Dielectric dissipation factor	Low	To ensure that the dielectric losses are small and that the oil thus provides satisfactory insulating properties		
Viscosity at 40^0C (max.)	Low	To ensure that the oil flows well under all (particularly low) temperature conditions thus providing the necessary cooling and where appropriate, are quenching properties	12 cSt	50 cSt
Pour point	Low	To ensure that the oil flows satisfactorily under low temperature conditions	-40^0C	-10^0C
Flash point (closed cup)	High	To eliminate the risks of ignition of vapours above the oil during maintenance or in service	145^0C	145^0C
Density at 20^0C	Low	To ensure that ice cannot float on the oil surface at very low temperatures and cause internal flashover	0.91g/cm^3 (ASTM D1298)	0.91g/cm^3 (ASTM D1298)
Acidity	Low	To eliminate the risks of sludge formation and corrosion	0.030 mg KOH/g	0.060 mg KOH/g
Water content (oil received in drums) max.	Low	The electrical strength of the oil will be impaired and moisture will be absorbed into any paper insulation, reducing insulation life and increasing the risk of dielectric breakdown	200 mg/kg	35 mg/kg

The general side-to-side characteristic comparison between mineral oil and ester oil is described in Table 2.2 (Pahlavanpour and Eklund, 2011).

Table 2.2: Characteristic comparison between mineral oil and vegetable oil

Criteria	Mineral oil characteristic	Vegetable oil characteristic
Key properties	Produced from increasingly scarce and non-renewable.	Produced from domestically grown, renewable source, such as palm fruit, ground nut and melon
Environmental Properties	Contains compounds that do not readily biodegrade. May contain traces of a confirmed carcinogen.	Highly biodegradable; non-toxic; does not contain petroleum, silicone, or halogens
Leaks and Spills	Spill clean-ups are required by regulation and typically necessitate special equipment and material to help capture contaminated runoff	Relatively rapid biodegradation may eliminate the need for environmentally related clean-up operations
Fire Risk	Catches fire more easily, leading to higher probability of transformer fires	Higher fire point reduces the frequency and impart of transformer fires
Transformer Performance	Does not slow down the standard insulation aging rate; requires special and expensive processing to dry out the paper insulation	Proven to slow down the aging Rate of the insulation system, resulting in an increase in the expected life of a transformer by decades; also promote automatic dry-out of paper insulation
Utility Cost	Smaller investment leads to shortened life of transformer and diminished economic returns; increase liability	Upfront investment promotes transformer life and leads to longer-term economic

2.4 Breakdown Voltage in oil

The definition of the breakdown voltage according to IEC standard 60243 is:

a) For continuously rising voltage test

The breakdown voltage is the voltage at which the specimen suffers breakdown under the test condition of a given voltage.

b) For step-by-step test

The breakdown voltage is the highest voltage which a specimen withstands before breakdown for the duration of the time at the voltage level.

One of the characteristic of the insulator is breakdown voltage. Breakdown voltage defines as a maximum voltage applied to the insulation at the moment of breakdown. It also can be defined as maximum voltage difference that can be applied across the material before insulator collapse and conducts. Breakdown voltage also knows as striking voltage (Kuffel and Zaengal, 2005).

Meanwhile, some insulators will become electrically conductive when the dielectric strength of insulators is the minimum voltage. For a given configuration of dielectric material and electrodes, the minimum electric field that produces breakdown. The breakdown voltage can be defined as the maximum electric stress the dielectric material can withstand before breakdown as shown in equation 2.3

Important factor for high voltage system is electric field stress and dielectric strength of the insulating materials. Due to the space charge density caused by the application of high voltage stress across the insulating materials, electric field distribution was developing. An intrinsic property of the bulk material dependent on the configuration of the material or the electrodes with which the field is applied called as dielectric strength of the insulation material. Factor affecting the dielectric strength are temperature, humidity, frequency and thickness of the specimen. When the temperature, humidity and frequency increase, the value also will increase. It is also same to thickness of the specimen. The values of the dielectric strength increase if the thickness of the specimen was increase

In gases, two mechanism of breakdown voltage are avalanche and streamer mechanism. Avalanche mechanism also called Townsend Breakdown Process. This mechanism based on the generation of successive secondary avalanche to produce breakdown. Where an electric field exist in gas, free electron suppose exist. Free electron likely to ionize a gas molecule by simple collision resulting in two electrons and a positive ion during the field strength is sufficiently high. This process will continue and cumulative cause the number of free electron will increase. The producers of electron and free electron in this way called electron avalanche.

Streamer breakdown because of add effect of the space charge field of an avalanche and photo-electric ionization in the gas volume. The development of a spark discharge directly from a single avalanche predict in the streamer theory causes sufficient distortion of the electric field that those free electron move towards the avalanche head, and in so doing generate further avalanches in a process that rapidly becomes cumulative. This process leads to very rapid development of breakdown.

In liquid condition, breakdown control by phenomena similarly with gas. The electric strength for the liquid condition also high (estimates 100 KV/mm).

Unfortunately, liquids are easily contaminated, and may contain solids, other liquids in suspension and dissolved gasses.

The effect of these impurities is relatively small for short duration pulses (10μs). Due to the liquid globules and the presence of solid particles causes breakdown. Breakdown voltage for liquids can be determined by experimental investigations only and it is not a simple phenomenon. Breakdown also depends on applied voltage mode, time application and voltage nature. Breakdown of liquid can be determined using equation 2.1 (Naidu and Kamaraju, 2003)

$$V_b = Ad^n \qquad (2.1)$$

where V_b is a breakdown voltage, d is a sphere gap length of test cell, A is a constant and n also is a constant that always less than 1.

2.4.1 Breakdown phenomena

Thermal breakdown in oil may take place under a.c field condition at localized hot spots (Bartnikas, 1997). If the temperature at such hot spots continues to increase when the heat generation rate exceeds the dissipation ability of the surrounding medium, the oil may be vaporized. This condition can ignite a channel development between the opposite electrodes to generate a breakdown. Thermally induced breakdown depends on the time of ac voltage application and may apply to breakdown under long-term operating conditions.

However, a thermal breakdown may occur over a very short time condition if the oil is subjected to very short repetitive pulses.

Breakdown voltage, are based mainly on ASTM standards, but for the purpose of comparison, IEC equivalents were also considered for this study (ASTM D-1816-84a, 1998) (IEC 156, 1995).

Table 2.3 presents some of the parameters of the standard testing procedures where significant differences related to the electrode gap and the rate of rise of the AC voltage can be seen.

Table 2.3: Comparison of standard test parameters

	ASTM D1816	IEC60156
Electrode shape	VDE	Spherical or VDE
Electrode gap	2.0mm	2.5mm
Number of breakdown	5	6
Voltage rate of rise	500 v/s	2000 v/s

2.4.2 The influence of bubbles

Gas bubbles can be produced during heating process in insulating oil as the product of gas and water contamination. In this case, the bubbles may be a source of discharges in oil with uniform electric field E. The electric field in a gas-filled cavity in oil with a relative permittivity

$$\varepsilon_R = \frac{3\varepsilon E}{2\varepsilon + 1} \qquad (2.2)$$

The maximum field in the cavity is 1.5E assuming $\varepsilon_R \to \infty$.

For mineral oil with $\varepsilon_R = 2.2$, the maximum value is 1.22E.

For silicone oil with $\varepsilon_R = 2.8$, the maximum value is 1.27E.

And for ester oil with $\varepsilon_R = 3.3$, the maximum value is 1.30E.

Spherical bubbles often occur in low density areas in oils. The discharge process may initiates from the bubbles due to the higher electric field and lower electric strength of the enclosed gases in the bubbles. Effective spherical bubbles can be developed within a space where a sphere is highly conducting compared to the surrounding liquid. The gap g between point cathode and plane anode will be reduced to g-d after the discharge region has formed a conducting sphere with diameter d. The gap reduction can accelerate the speed of travel of the streamer away from point cathode and develop a breakdown. The illustration of spherical discharge region is shown in Figure 2.2.

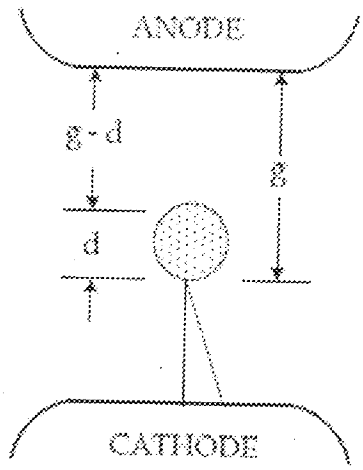

Figure 2.2: Spherical discharge region

There are several causes of breakdown in oil (Usifo, 2003) such as impurities (water and gas), distance between electrodes, rise in temperature of the oil, electric wave form, pressure in oil and surface electrode contamination.

Figure 2.3 depicts the variation of voltage against the distance of electrode in a liquid dielectric such as transformer oil.

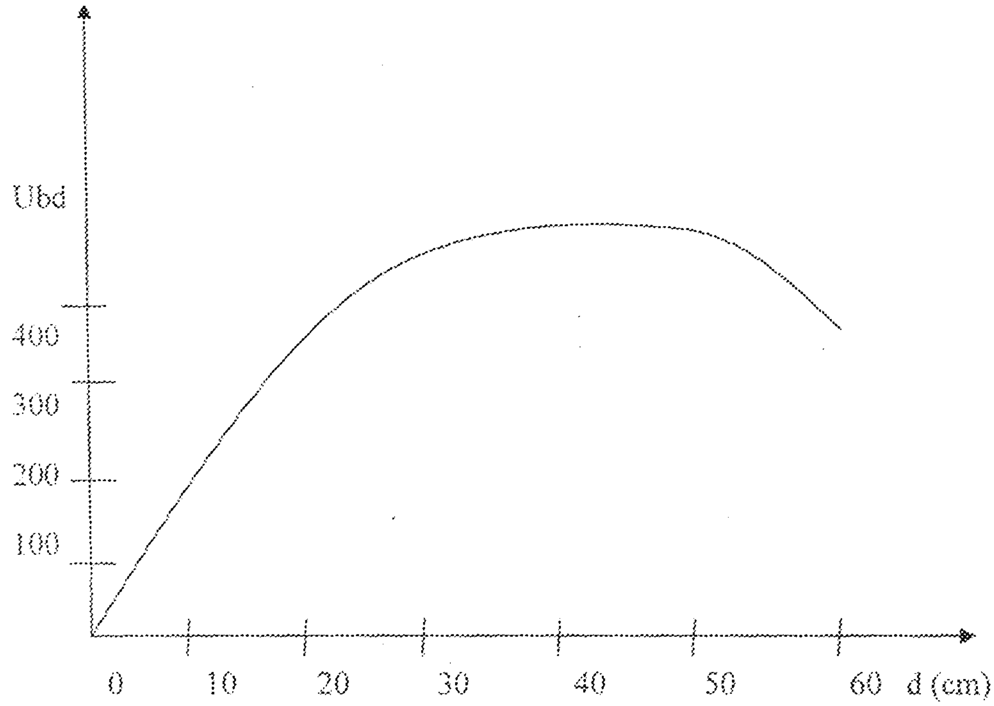

Figure 2.3: Variation of Break down voltage with increase in distance between electrodes in transformer oil

$$E = \frac{U_{bd}}{d} \quad (2.3)$$

E= Dielectric strength or potential gradient (kV)

U_{bd} = break down voltage (volts)

d= distance between electrodes (cm)

Also the Figure 2.4 below shows the variation of applied voltage against the pressure in a liquid dielectric (transformer oil)

1 under normal atmospheric pressure

2 in a vacuum

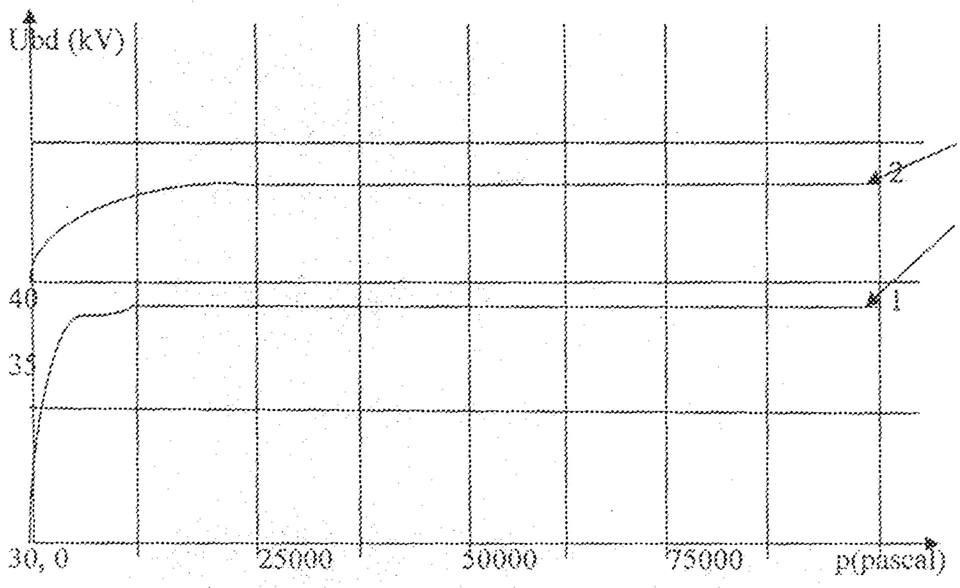

Figure 2.4: Variation of applied voltage against the pressure

Moisture in the oil delivers charge carriers and decreases the withstand strength. Acids as the aging byproduct also deliver charge carriers through dissociation processes. They are surface active and decreasing the surface tension. This will also lead to the development of bubbles and weaken the dielectric strength (Koch *et al*, 2007).

2.4.3 The effect of contaminations

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 fibres which can form a bridge of fibres between the electrodes along the highest field intensity. Moreover, in the case that a wet fibre 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.

Liquid movement may also lead to a breakdown. For example, if oil is pumped through an electrode gap or the electrodes are rotated, then it will initiate the breaking of fibre chains or movement of gas accumulation (Naidu and Kamaraju, 2003). This will result in a lowering of the alternating and direct breakdown voltage, but it will not affect the lightning impulse breakdown strength.

2.5 Dielectric Dissipation Factor (tan δ) and Relative Permittivity (ε)

There are two fundamental parameters characterizing a dielectric material, the conductivity σ and the real part of the permittivity or dielectric constant ε^{*} (or ε_R).

The conductivity σ of a dielectric material is defined as the ratio of the leakage Current density $\Im$ (A cm-2) to the applied electric field density E (in V cm-1),

$$\sigma = \frac{\Im}{E} \qquad (2.4)$$

It is also determined in terms of the measured insulation resistance R (in Ω) as

$$\sigma = \frac{\tau}{RA} \qquad (2.5)$$

where τ is the insulation thickness (in cm) and A is the surface area (in cm^2).

The dielectric constant ε^{*} is defined as the amount of electrostatic energy which can be stored per unit volume per unit potential gradient. But it is also known as the real part of permittivity which is determined as the ratio of

$$\varepsilon^{**} = \frac{C}{C_o} \qquad (2.6)$$

where $A = \pi r^2$re C is the measured capacitance (in F) and C_0 is the equivalent capacitance in vacuum. C_0 can be obtained from the same specimen geometry of

$$C_0 = \varepsilon_o = \frac{A}{r} \tag{2.7}$$

while ε_o represents the permittivity in vacuum with the value of 8.854 x 10^{-12} F cm-1. The value of ε_o in free space is essentially equal to that in a gas ($\varepsilon_{\Re}{}^{*}$ of air = 1.000536).The relative permittivity definition from IEC 60247 is the ratio of capacitance C_X of a capacitor in which the space between and around the electrodes is entirely and exclusively filled with the insulating material, to the capacitance C_0 of the same configuration of electrodes in vacuum,

$$\varepsilon_{\Re}{}^{*} = \frac{C_X}{C_o} \tag{2.8}$$

Dielectric losses may initially be caused by the movement of free charge carriers (electrons and ions), space charge polarization or dipole orientation (Endah, 2010). Most causes are influenced by the temperature, electric field strength, and are frequency dependent. A complex permittivity ε is defined as

$$\varepsilon = \varepsilon^{*} - j\varepsilon^{**} \tag{2.9}$$

where ε^{**} is the imaginary value of permittivity and means the dielectric loss contributed by the leakage current and the polarizations, ε is the complex permittivity and equal to the ratio of dielectric displacement vector ∂ to the electric field vector E. The losses determine the phase angle A between vector ∂ and E. Based on the position in the vector, ∂ and E should have the complex notation ∂_0 exp [j(wt-δ)] and E_0 exp[jwt] and with ∂_0 and E_0 as the vector magnitudes, respectively. Thus, the following relations result

$$\varepsilon^{*} = \frac{\partial_0}{E_0}\cos\delta \tag{2.10}$$

$$\varepsilon^{**} = \frac{\partial_0}{E_0}\sin\delta \tag{2.11}$$

The dielectric dissipation factor (tan δ) can be expressed as:

$$\tan\delta = \frac{\varepsilon^{**} + \frac{\sigma}{\omega}}{\varepsilon^{*}} \tag{2.12}$$

The behavior of the losses of a dielectric can be determined from an equivalent electrical circuit. The parallel circuit is commonly used for analysis as seen in Figure 2.5

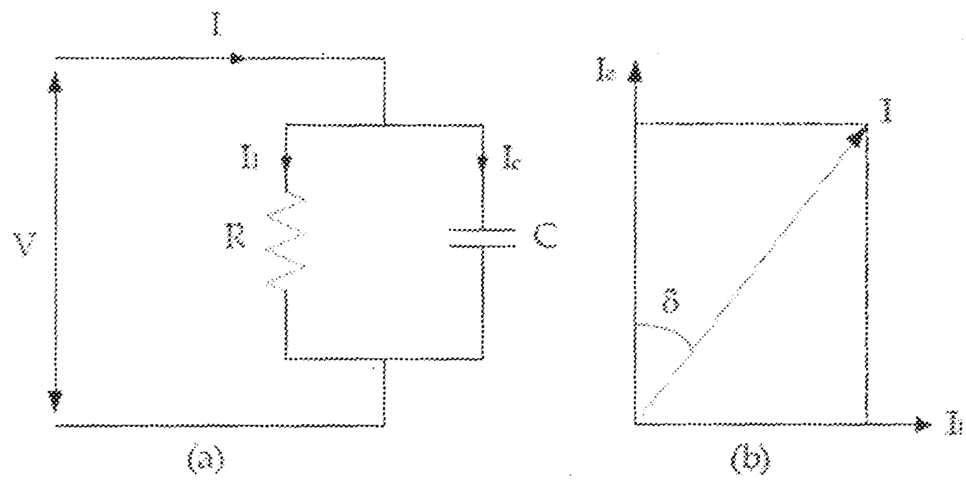

Figure 2.5: (a) Parallel circuit and (b) Phasor diagram

The behavior of equation (2.7) is commonly described in parallel circuit representation, with dielectric components such a capacitance C parallel with resistance $\Re$. When an applied voltage V passes through a dielectric material, it generates a leakage current $I_L = \frac{V}{R}$ and displacement current I_c = jw CV. From the phasor diagram in Figure 2.5 (b), it represents the value of $\tan\delta = \frac{I_L}{I_C}$. Then by applying the substitution on I_L and I_c, it will give a final expression of

$$\tan\delta = \frac{1}{\omega RC} \tag{2.13}$$

The definition of dielectric dissipation factor (tan δ) according to IEC 60247 is the tangent of the loss angle and the loss angle here is described as the angle difference between applied voltage and the resulting current deviating from π/2 rad.

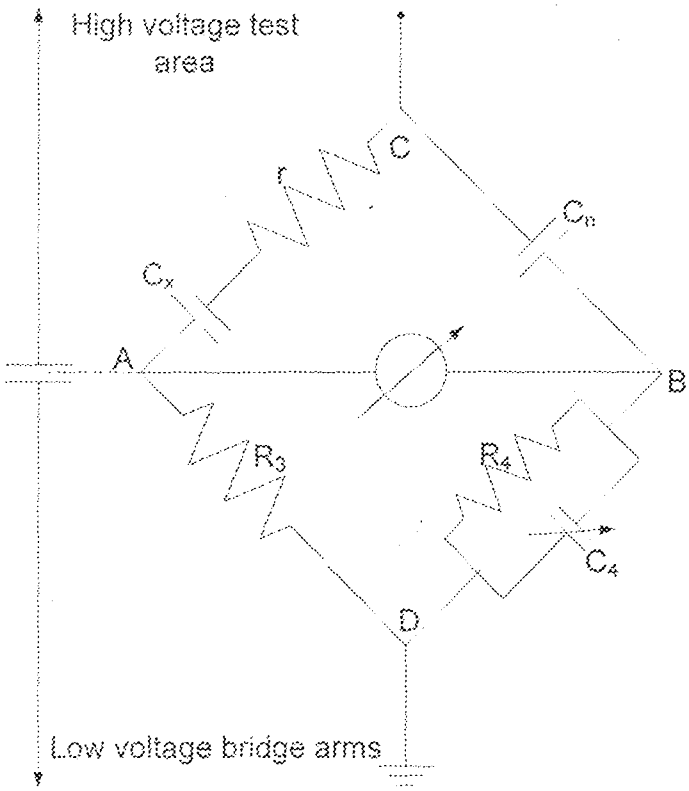

Figure 2.6: Principle of Schering Bridge

The Schering Bridge is equipment for measuring tan A and capacitances (shown Figure 2.6). This equipment is divided into two test areas, i.e. the high-voltage area and the low-voltage area. The standard lossless capacitor C_n has an accurately known capacitance (typically 92.926 pF) and connects the earth side at low-voltage Bridge arms (node A and B) together with test object capacitance C_x. In the high-voltage area, the applied voltage is energized here and passes through C_n and C_x. Standard resistor R3, calibrated impedances R4 and C4 are placed in low voltage test area for adjusting the balance of the bridge. At the balance condition, the value of C_x is obtained from

$$C_x = \frac{R_4}{R_3} C_n \tag{2.14}$$

and tan A will be determined by

$$\tan \delta = w R_4 C_4 \tag{2.15}$$

The loss mechanism in insulating oil might have several causes:

i. Conductive losses

The low value of insulation resistance R may increase the leakage current (I_l) and tend to add losses in dielectric insulation. According to equation (2.12), tanδ value will decrease as the frequency rises.

ii. Dipole orientation losses

It is only applied for material with permanent molecular or side-link dipoles when a considerable overlap occurs between the permanent dipole and ionic relaxation regions.

iii. Ionic relaxation losses

These losses occur due to a short range jump of ions between two or more equilibrium position.

2.6 Viscosity of the oil

Viscosity describes the internal resistance of a fluid to flow.

The more viscous a fluid is, the greater the resistance to its movement and hence the slower flow speed inside the capillaries will be. Consequently the oil with low viscosity is preferred. For oils with high viscosity, since the viscosity is temperature dependent, a lower viscosity of the oil can be obtained by heating it up to a higher temperature.

The principle of operation of capillary viscometers is described by the Poiseuille equation where the rate of liquid flow (*V/t*) through the viscometer can be determined by the following.

$$V/t = (\rho' gl + \Delta\rho)\Pi R^4 / 8\eta l \qquad (2.16)$$

Where p^1 is the density of the fluid, g is the force due to gravity, l is the length of the capillary tube, and Δp is the pressure difference between the entrance and exit of the capillary tube. The equation can be rearranged and further simplified to account for all the constants that characterize the viscometer. This also assumes that the difference in height of the two liquid columns is relatively constant during the time required for flow. Thus, the only pressure difference across the liquid is due to the weight of the liquid. With these conditions:

$$\eta = A\rho t \qquad (2.17)$$

where A is a constant that incorporates all the parameters that characterize a viscometer.

2.7 Insulation Resistance Concepts

Insulation resistance can be considered by applying Ohm's Law.

The measured resistance is determined from the applied voltage divided by the resultant current.

$$R = \frac{V}{I} \qquad (2.18)$$

There are two further important factors to be considered.

These are (i) the nature of the current through and/or over the insulation, and (ii) the length of time for which the test voltage is applied. These two factors are linked. The total current that flows is made up of three separate currents:-

1. Capacitance charging current. This current is initially high and drops as the insulation becomes charged up to the applied voltage.

2. Absorption current. This current is also initially high but drops at a much slower rate than the charging current.

3. Conduction or Leakage current. This is a small steady current that can be sub-divided into two:-

(a) A current flowing along conduction paths through the insulation material.

(b) A current flowing along conduction paths over the surface of the insulation material.

As the total current depends upon the time for which the voltage is applied, Ohm's Law theoretically applies at infinite time. Insulation resistance measurement values can be accomplished by four common test methods:

- Short-time readings
- Time-resistance readings (dielectric absorption ratio [DAR] test)

• Polarization index (PI) test

• Step-voltage readings

2.7.1 Short-Time Readings

This test simply measures the insulation resistance value for a short duration of time, such as 30 or 60 s, through a spot reading that lies on the curve of increasing insulation resistance values. The reading only allows a rough check of the insulation condition. However, comparison of this value with previous values is of importance. A continued downward trend is indicative of insulation deterioration ahead. For interpreting the results, the values used for comparison should all be normalized to 20°C with humidity effects considered.

2.7.2 Time-Resistance Readings

A good insulation system shows a continued increase in its resistance value over the period of time in which voltage is applied. On the other hand, an insulation system that is contaminated with moisture, dirt, and the like will show a low resistance value. In good insulation, the effects of absorption current decreases as time increases. In bad insulation, the absorption effect is perpetuated by high leakage current. The time-resistance method is independent of temperature and equipment size. It can provide conclusive results as to the condition of the insulation. The ratio of time-resistance readings can be used to indicate the condition of the insulation system (Rao, 2007).

The ratio of a 60 s reading to a 15 s reading is called the DAR:

$$DAR = \frac{R_{60S}}{R_{15S}} \qquad (2.19)$$

2.7.3 Polarization Index (PI) Test

The PI test is a specialized application of the dielectric absorption test. The PI is the ratio of the insulation resistance at 10 min to the insulation resistance at 1 min. A PI of less than 1 indicates equipment deterioration and the need for immediate maintenance. This test is used for dry insulation systems such as dry type transformers, cables, rotating machines, etc

2.7.4 Step-Voltage Readings (DC Voltage Tip-Up Test)

In this method, voltage is applied in steps to the insulation under test by a way of a controlled voltage method. As voltage is increased, the weak insulation will show lower resistance that was not obvious at lower voltage levels. Moisture, dirt, and other contaminants can be detected at lower voltage levels, that is, below operating voltages, whereas aging and physical damage in clean, dry insulation systems can only be revealed at higher voltages. The step-voltage test is very valuable when conducted on a regular periodic basis

2.8 Acidity measurement

Good liquid insulation is chemically neutral. Acid may arise in liquid insulating materials during fabrication or operation. During operating condition this acid appearance indicates degradation of insulation quality. Excessive content of acid is not tolerable. The acidity of the samples will to be determined by titration according to ASTM D 974. The acidity number indicates the number of mg potassium hydroxide (KOH) to neutralize per gram sample oil. The end point of titration was determined using phenolptaline indicator.

$$\text{Acid Value} = \frac{mLkoh * N * 56.1}{\text{Wt of Sample in gms}}$$

CHAPTER THREE

3.0 MATERIALS AND METHODS

This chapter discussed the experimental procedures used in this project, including the measurement procedure of breakdown voltage, insulation resistance, flash point, pour point, Relative density, and moisture content. Fixed oils (groundnut oil, palm oil, palm kernel oil melon seed oil and rubber seed oil) were subjected to the various tests in order to compare the characteristic of insulating liquid with standard Transformer oil as control experiment.

However, out of the mentioned insulating characteristic in chapter two, the research work principally focused on the breakdown voltage, insulation resistance, flash point, pour point, Relative density, viscosity and moisture content. The tests or experiments conducted on each sample of the oil were guided by IEC and ASTM standard.

3.1 Breakdown voltage measurement in oil

Determination of the AC breakdown voltage of insulating oil is included in international and national standards on liquid dielectrics. Among the most well-known are IEC60156 and ASTM D-1816. For manufacturers and users of liquid-insulated power equipment, these standards are used for checking the oil quality when filling new equipment and diagnosing in-service insulation contamination or aging.

This test reveals the conductive contaminants & moisture present in the transformer oil. The dielectric strength is that minimum voltage at which arc discharge occurs between two electrodes set 2.5 mm apart. High BDV is desirable. Oil with low electric strength indicates presence of contaminants. The breakdown test set up for oils is illustrated in *Plate I* and the description of the set up is explained below:

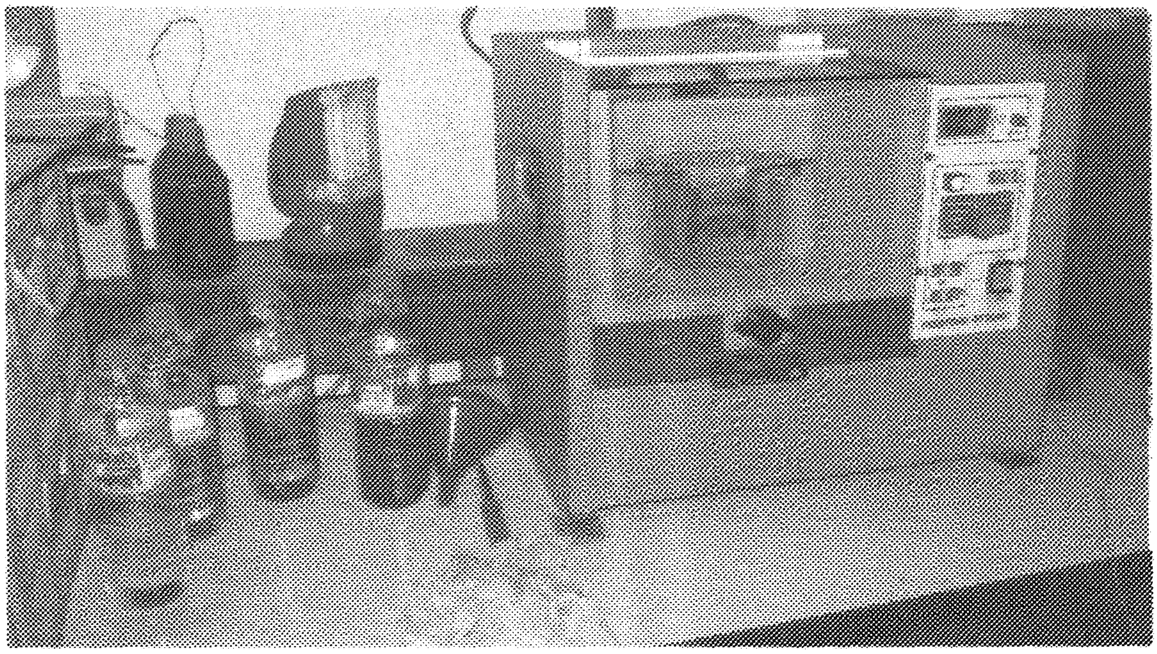

Plate I: the breakdown test set up

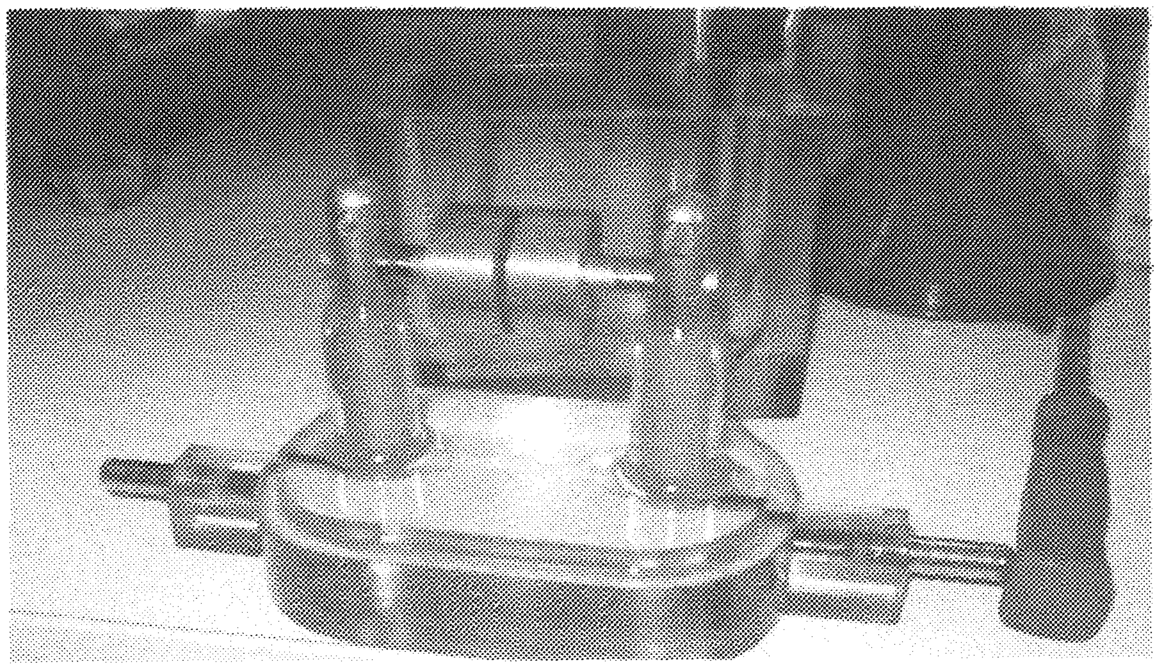

Plate II: the VDE electrodes

• The electrodes shall be polished and either spherical (12.5 mm – 13 mm diameter) or partially spherical. The axis of the electrode system shall be horizontal and at least 40 mm below the surface of the test liquid in the cell. No part of the electrode should be closer than 12 mm to the cell wall. According to IEC standard 60156, the gap between the electrodes is originally set to 2.5 mm ± 0.05 mm.

• When filling oil sample in, containers should be almost filled with sample, leaving about 3% of the container volume as free air space. At the time of test, temperature of the oil sample should be equal to ambient temperature. The test cell should be drained and rinsed the walls, electrodes and other component parts, with the oil sample.

3.1.1 Measurement procedures

• First voltage application is started approximately 5 min after completion of the filling and there should be no air bubbles which are visible in the electrode gap.

• The applied voltages uniformly increase from zero at the rate of 2 kV/s ± 0.2 kV/s until breakdown occurs.

• The measurements are carried out until 6 breakdowns on the same cell filling have occurred, allowing a pause of at least 2 min after each breakdown before reapplication of voltage or until there is no gas bubbles present within the electrode gap.

• The final result is calculated from the mean value of the 6 breakdowns in kV.

The procedures were used on the sphere gap (1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0mm), respectively

3.2 Insulation resistance Test

It is based on the absorption effect using time-resistance method. It is measured by simply take successive readings at specific time and notes the difference in readings. Tests by this method are sometimes referred to as Dielectric absorption ratio test.

$$DAR = \frac{R_{60s}}{R_{15s}}$$

A dc voltage of 1,000 volts is applied to the insulation and readings are taken to the insulation resistance versus time. Data were recorded at the 15 second and 60 second intervals.

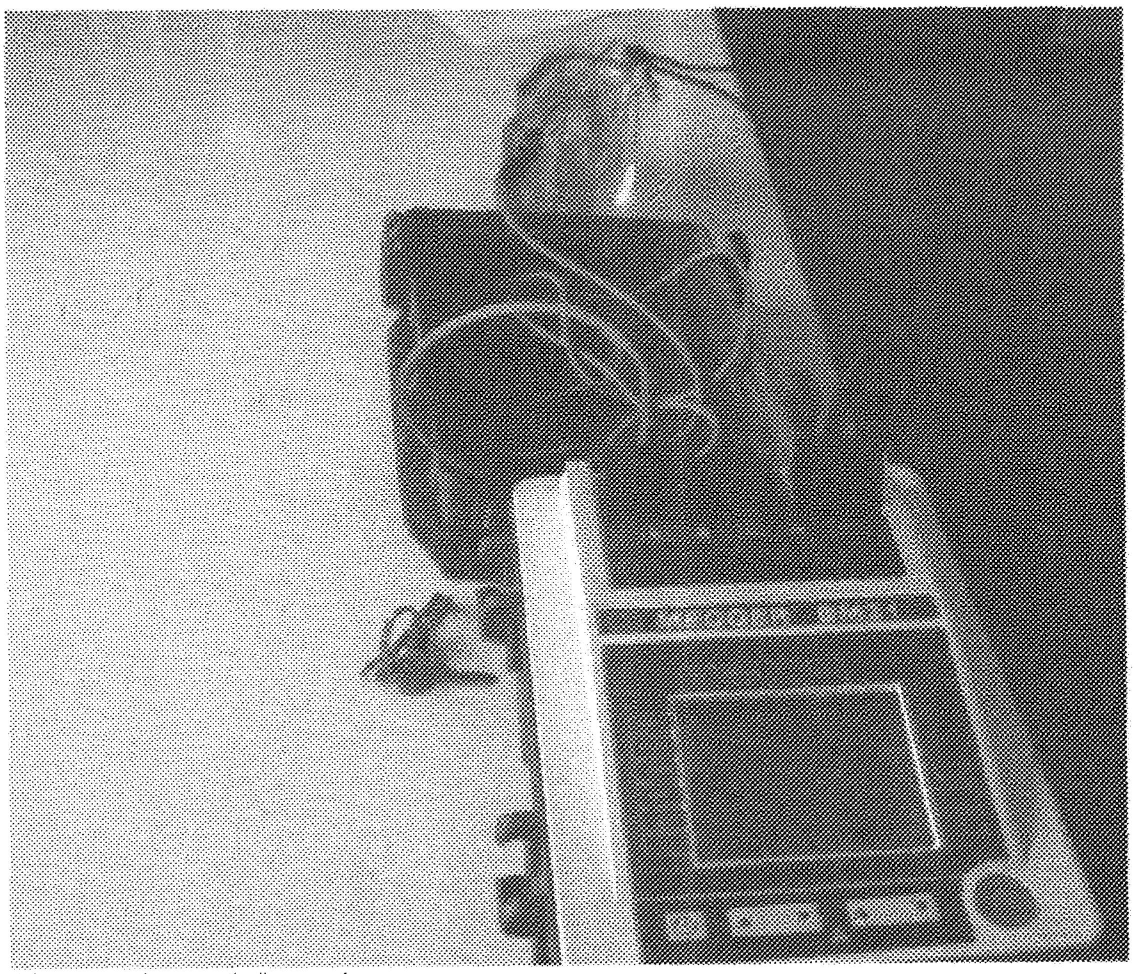

Plate III: the Insulation resistance test set up

CALCULATIONS

Dielectric Absorption Ratio (DAR) = $\frac{R_{60s}}{R_{15s}}$

Transformer oil:

$$DAR = \frac{R_{60s}}{R_{15S}} = \frac{86.0G\Omega}{51.2G\Omega} = 1.68$$

Palm oil:

$$DAR = \frac{R_{60s}}{R_{15S}} = \frac{7.24G\Omega}{6.92G\Omega} = 1.05$$

Groundnut oil :

$$DAR = \frac{R_{60s}}{R_{15S}} = \frac{11.1G\Omega}{10.5G\Omega} = 1.06$$

Palm Kernel oil:

$$DAR = \frac{R_{60s}}{R_{15S}} = \frac{7.4G\Omega}{4.2G\Omega} = 1.76$$

Melon seed oil:

$$DAR = \frac{R_{60s}}{R_{15S}} = \frac{14.3G\Omega}{10.2G\Omega} = 1.40$$

Rubber seed oil:

$$DAR = \frac{R_{60s}}{R_{15S}} = \frac{560M\Omega}{520M\Omega} = 1.08$$

3.3 Determination of acid value

25 ml of diethyl ether and 25 ml of ethanol was mixed in a 250 ml beaker. The resulting mixture was added to 20 g of oil in a 25 ml conical flask and a few drops of phenolphthalein were added to the mixture. The mixture was titrated

with 0.1 m KOH to the end point with consistent shaking for which a dark pink colour was observed and the volume of 0.1 m KOH (Vo) was noted.

The calculations were carryout in accordance with equation (2.20)

Calculations:

$$\text{Acid Value} = \frac{\text{mL KOH*N*56.1}}{\text{wt of Sample in gms}}$$

where mL KOH is the standardization of 0.1mKOH against 0.1mHCL = 0.1064 KOH

Average Volume of acid obtained during titration= N

Weight of the sample = 0.2 kg

Standard transformer oil

$N = 0.02\ cm^3$

$$\text{Acid Value} = \frac{(56.1*0.1064*0.02)}{0.2} = 0.597$$

Palm oil

$N = 1.95\ cm^3$

$$\text{Acid Value} = \frac{(56.1*0.1064*1.95)}{0.2} = 58.198$$

Groundnut oil

$N = 0.15\ cm^3$

$$\text{Acid Value} = \frac{(56.1*0.1064*0.15)}{0.2} = 4.477$$

Palm kernel oil

$N = 2.25\ cm^3$

$$\text{Acid Value} = \frac{(56.1*0.1064*2.25)}{0.2} = 67.152$$

Melon seed oil

$N = 0.2\ cm^3$

$$\text{Acid Value} = \frac{(56.1*0.1064*0.2)}{0.2} = 5.969$$

Rubber seed oil

$N = 0.016\ cm^3$

$$\text{Acid Value} = \frac{(56.1*0.1064*0.016)}{0.2} = 0.478$$

3.4 Determination of Viscosity of the oil

Experimental procedures

The experimental procedures were performed with Cannon-Fenske, constant-temperature bath was used in the procedures for viscosity determinations. This assembly maintains temperature uniformity. Cannon-Fenske viscometers were used for the measurements of the kinematic viscosities

Materials

Cleaning solvent appropriate for sample

Pure liquid or solution sample

Temperature-controlled 40^{0}C water bath consisting of:

4.5-gallon glass tank

Temperature-controlled immersion water circulator

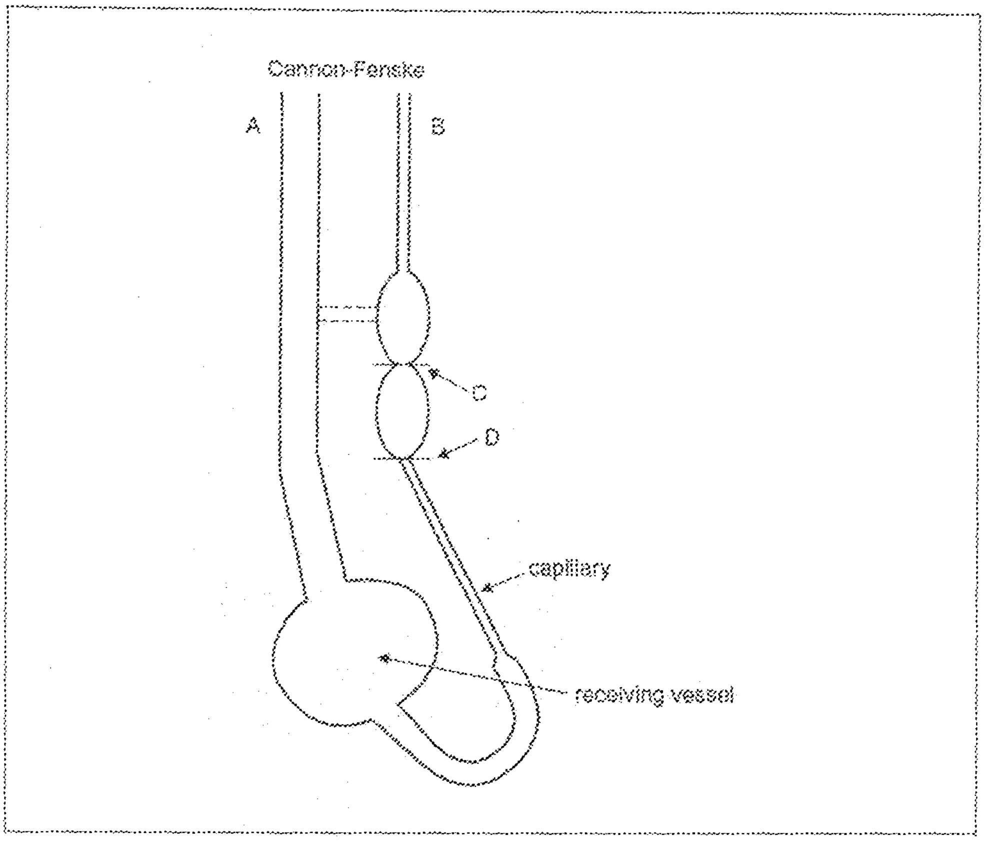

Figure 3.1: Schematic of a glass capillary (U-tube) viscometer.

Load and equilibrate viscometer

1. Turn on the temperature-controlled water bath and set the temperature to 40^{0}C. Allow the water bath to heat and equilibrate for 30 min before measuring the viscosity of any fluids. Verify the water bath temperature with a thermometer before proceeding.

2. Clean the Cannon-Fenske viscometer by placing the appropriate solvent into a solvent wash bottle. Continuously flush and aspirate the solvent through the viscometer until it is clean.

3. Pass dry filtered air through the viscometer to remove final traces of solvent. Mount viscometer in water bath.

4. To remove lint, dust, or other solid material from the sample, filter sample using a 10-ml syringe fitted with a syringe filter holder and a nylon filter.

5. To charge the sample into the viscometer discharges the sample from the syringe with filter directly into tube A of the viscometer. Discharge enough sample to fill the receiving vessel (see Figure 3.1) to about 3/4 full. The same sample volume should be used for all subsequent measurements.

6. Make sure that the viscometer is in a vertical position in the bath.

7. Equilibrate the sample in the water bath for 10 min.

Make the measurement

8. With the suction bulb connected to one end of the tubing, connect the other end of tubing to tube B and apply suction to draw the sample through the capillary and to a level above the etched line noted as C.

9. Remove the tubing and measure the efflux time using a stopwatch by allowing the sample to flow freely down past mark C, then measure the time it takes for the meniscus to pass from mark C to mark D in seconds.

CALCULATIONS

Kinematic viscosity (v) expressed in centistokes, were calculated from the measured flow time, t, and instrument constant, c, by means of the following equation

Kinematic viscosity (cSt), $v = ct$

The values for c are provided by the viscometer manufacturer. In this research the value of the constant used:

$c = 1.111 (mm^2/s)s$

3.5 Determination of moisture content using dean and stack method

Water in oil appears as an unwanted substance, it is generally accepted that water in microscopic amounts - not gallons- is the cause of more electrical breakdowns than any other impurity. Moisture constitutes a hazard not only to the insulating qualities of the oil but also to the insulations that are immersed in the oil.

The Dean and Stack method: A known weight of oil sample is placed in a flask with organic solvent (methylated spirit) as reagent. The organic solvent must be insoluble with water; have a higher boiling point (110^0C -120^0C) than water; be less dense than water; and be safe to use. The flask containing the oil sample and the organic solvent is attached to a condenser by a side arm and the mixture is heated. The water in the sample evaporates and moves up into the condenser where it is cooled and converted back into liquid water, which then trickles into the graduated tube. When no more water is collected in the graduated tube, distillation is stopped and the volume of water is read from the tube.

3.6 Determination of Pour Point

The pour point of oil is the temperature below which the oil ceases to flow when it is cooled. As per ASTM D97 method, pour point of mineral oils is defined as the lowest temperature at which movement of the test specimen is observed under the prescribed conditions of the test.

The apparatus used were, beakers, cellophane of nylon material, refrigerator, container, retort stand, and thermometer. For this experiment, six beakers were filled completely with a sample of the vegetable oils. The beakers were sealed with cellophane material to protect the oil from being contaminated by moisture. The oils were then placed inside a refrigerator and allowed to freeze. After it has frozen, one beaker after the other was brought out and mounted on retort stand and tilted at angle 45^0 to the horizontal in order for the oil to pour when it started melting. The thermometer was placed on the surface of the solid oil where it can pour when the temperature was reached. The nylon was removed from the surface before the beaker was placed on the retort stand. The temperature at which each of the oils started to pour was noted and recorded. The vegetable oils tested as described above were groundnut oil, melon seed oil, palm kernel oil, palm oil, and rubber seed oil.

3.7 Determination of Flash point by Pensky-Martens closed cup method

The flash point of a liquid is the lowest temperature at which it can form an ignitable mixture in air. At this temperature the vapor may cease to burn when the source of ignition is removed. A slightly higher temperature, the fire point, is defined as the temperature at which the vapor continues to burn after being ignited. Neither of these parameters is related to the temperatures of the ignition source or of the burning liquid, which are much higher. The flash point is often used as one descriptive characteristic of liquid fuel, but it is also used to describe liquids that are not used intentionally as fuels.

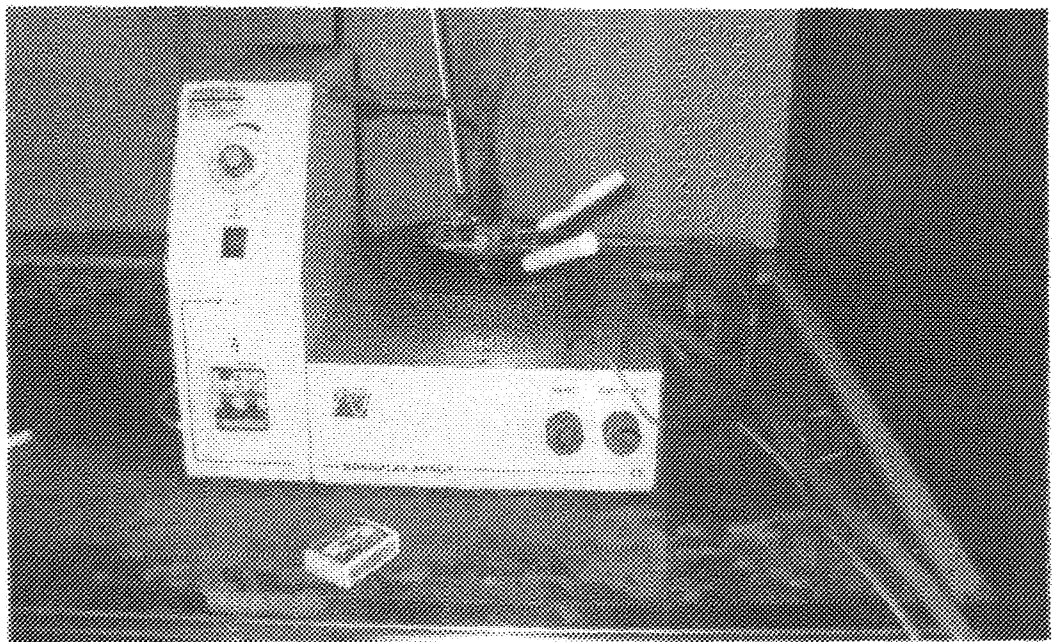

Plate V: Pensky-Martens closed cup apparatus

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1. Breakdown voltage (BDV)

The results of breakdown voltage (BDV), pour point, flash point, water content, density, resistance and viscosity measurements for standard transformer oil and vegetable oil are listed in Table 4.1. BDV measurement was performed in such a way that six breakdown tests were conducted on each sample.

Table 4.1: Results of the comparison between vegetable oil and control transformer oil

Property	Standard Transformer Oil	Palm oil	Ground-nut oil	Palm kernel oil	Melon seed oil	Rubber seed oil	International Standard value
Break down Voltage(kV)	56.8	39	42	40	44.6	48.3	≥30
Pour Point (°C)	-40	25	8	20	23	-11	≤-10
Flash Point (°C)	146	263	268	244	282	175	≥145
water Content (mg/kg)	nil	0.02	0.01	Nil	Nil	Nil	≤35
Viscosity (cSt) at 40°C	7.9	49.58	37.9	28.1	33.15	45.9	≤50
Viscosity (cSt) at 100^0C	2.3	8.2	8.41	6.57	8	6.4	
Density (kg/dm^3) at 20°C	0.81	0,924	0.907	0.912	0.912	0.915	≤0.91
Acid Number (mg KOH/g)	0.597	58.2	4.477	67.152	5.969	0.478	
Insulation resistance at 60s (MΩ)	86000	7240	1110	7400	1430	560	≥200
Insulation resistance at 15s(MΩ)	51200	6920	1050	4200	1020	520	≥200
DAR	1.68	1.05	1.06	1.76	1.4	1.08	>1

The breakdown voltage of transformer oil and the vegetable oil with different electrode gap (mm) are shown in Table 4.2

Table 4.2: Variation of breakdown voltage (kV) with electrode gap (mm)

Oil	1.0mm	1.5mm	2.0mm	2.5mm	3.0mm	3.5mm	4.0mm
Transformer oil	20	32.3	45	56.8	72	84	94
Palm oil	12.6	20.2	30	39	48	58.6	68
Groundnut oil	15	23.8	34	42	54	65	78
Palm kernel oil	13.8	20.4	32	40	51	62.3	75
Melon seed oil	16	24.7	35	44.6	55	68	80
Rubber seed oil	18.4	30	40.6	48.3	63	76	88

4.2 Comparison between standard transformer oil and vegetable oil properties

A graphic presentation of the breakdown voltage comparison between standard transformer oil and vegetable oil against the electrode gap is shown in Table 4.1.

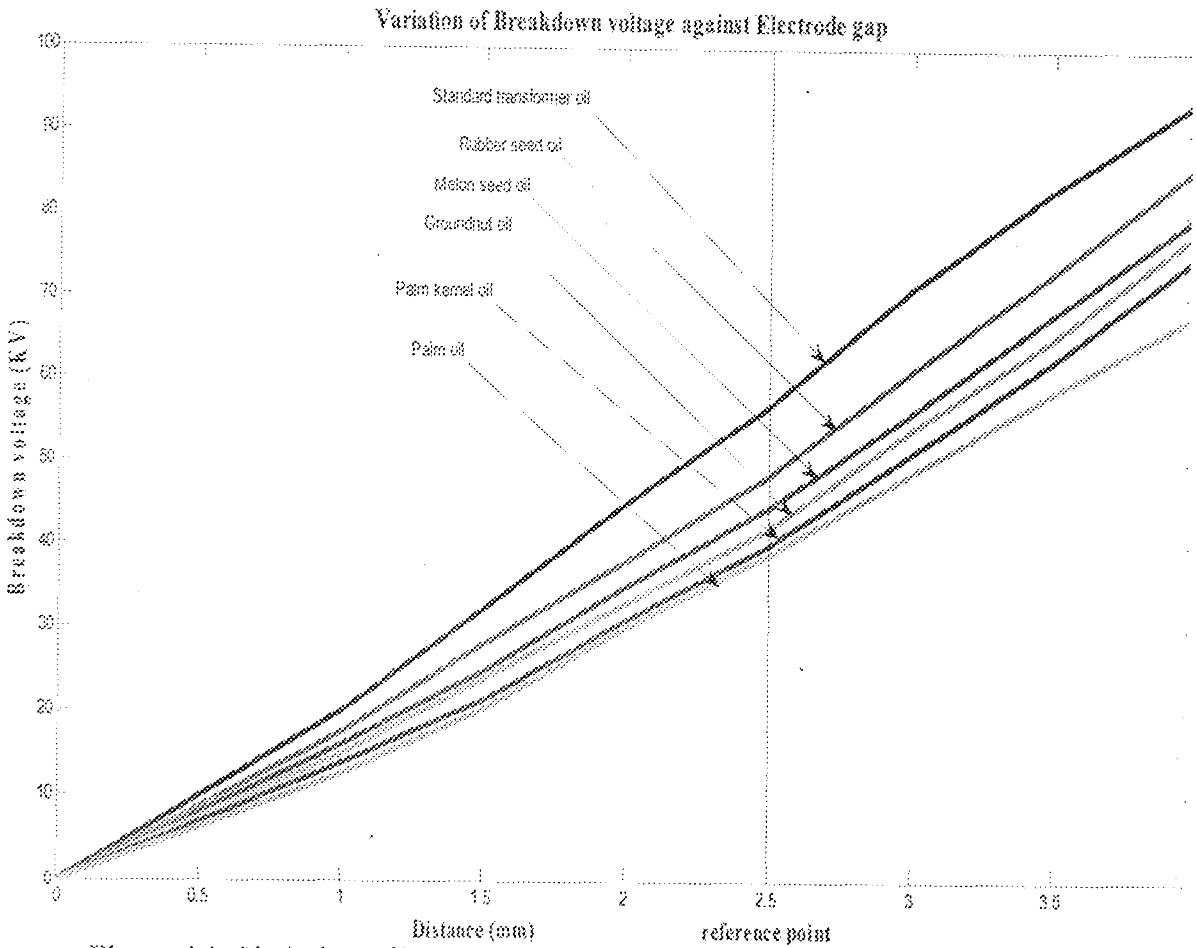

Figure 4.1: Variation of breakdown voltages against electrode gap

The values of viscosities of standard transformer oil and vegetable oil measured at 40^0C and 100^0C were shown in Figure 4.2

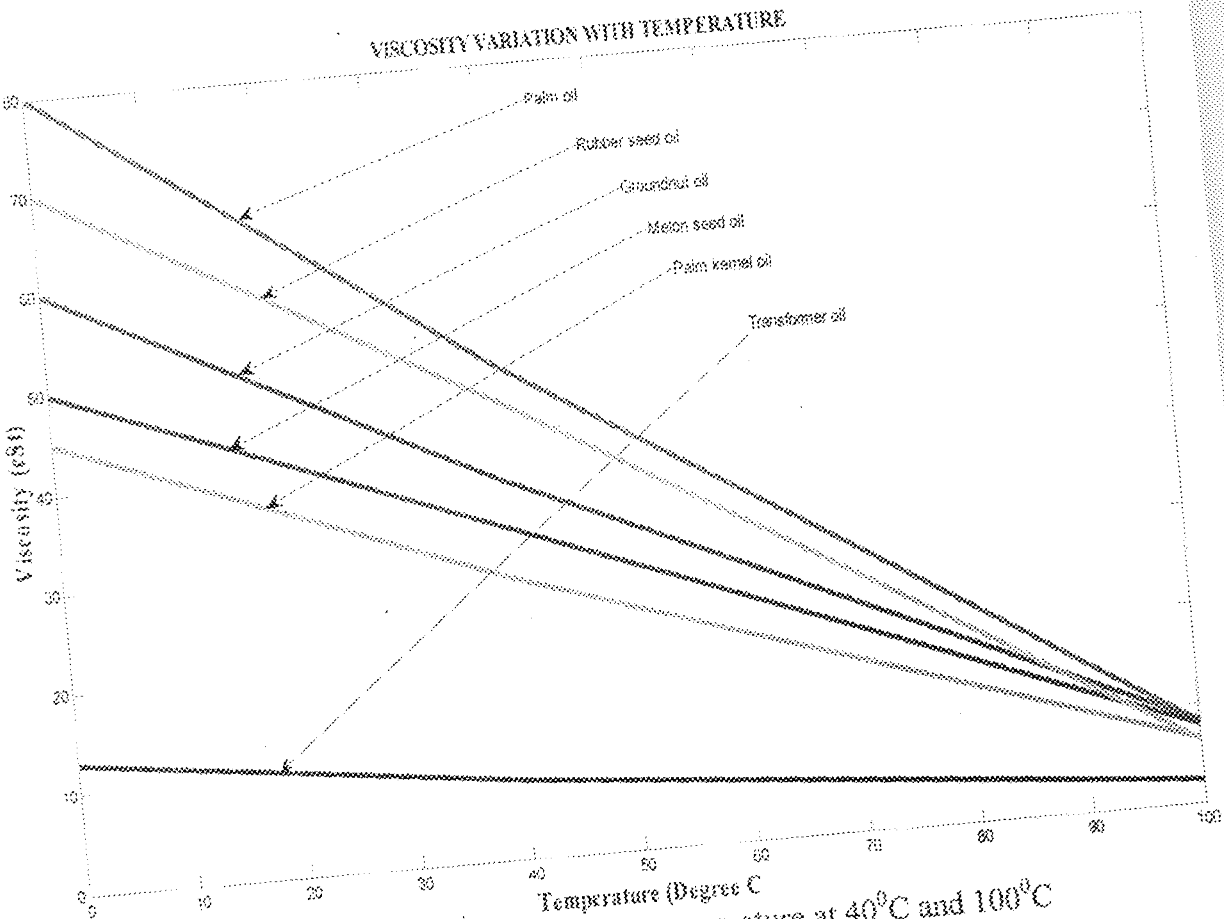

Figure 4.2: viscosity variation versus temperature at 40^0C and 100^0C

The water content measurement of transformer oil and vegetable oil are shown in Figure 4.3

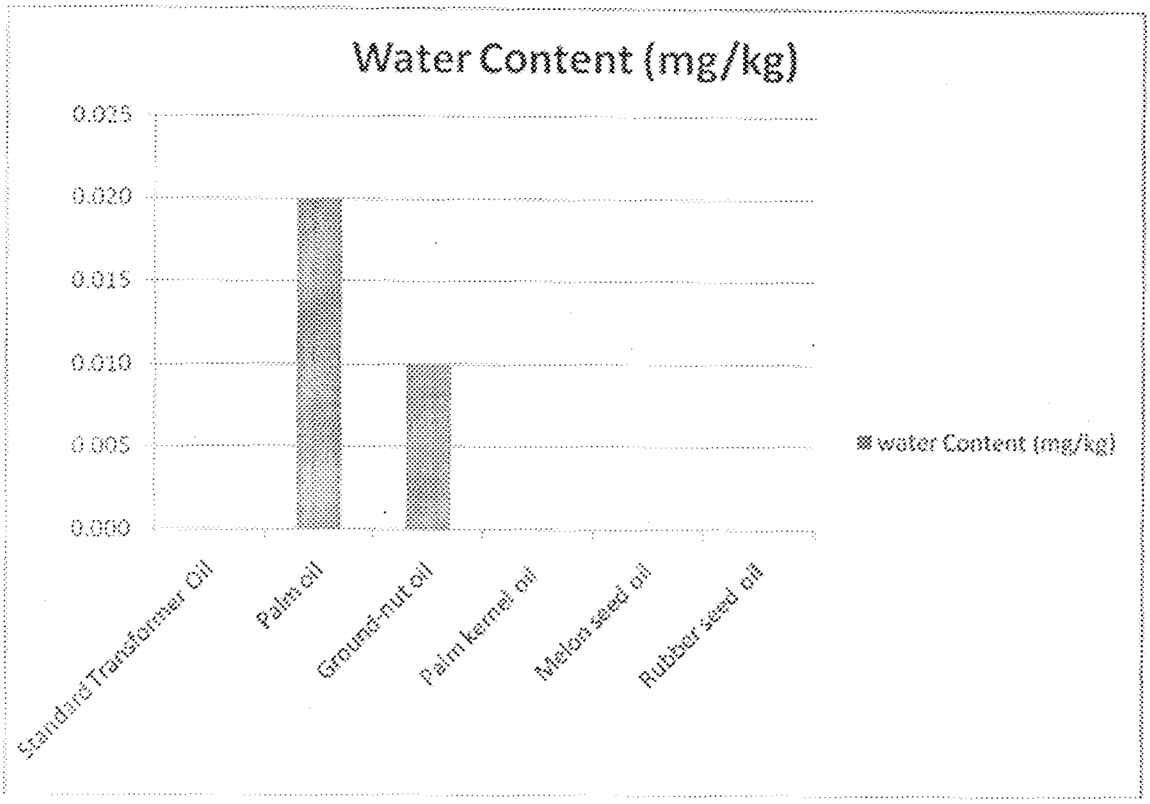

Figure 4.3: Comparison between transformer oil and vegetable oil water content

The result of flash point determined in degree Celsius for the selected oil samples as tabulated in Table 4.1 were represented in Figure 4.4

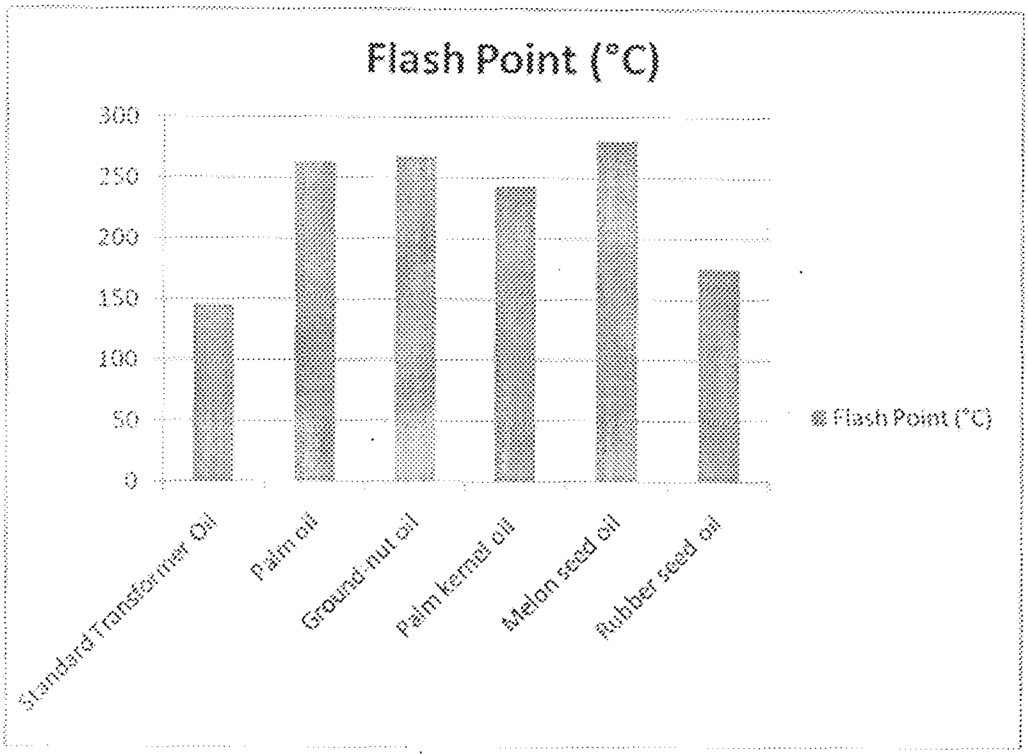

Figure 4.4: Comparison between transformer oil and vegetable oil flash point

The comparison between standard transformer oil and vegetable oil densities are shown in Figure 4.5

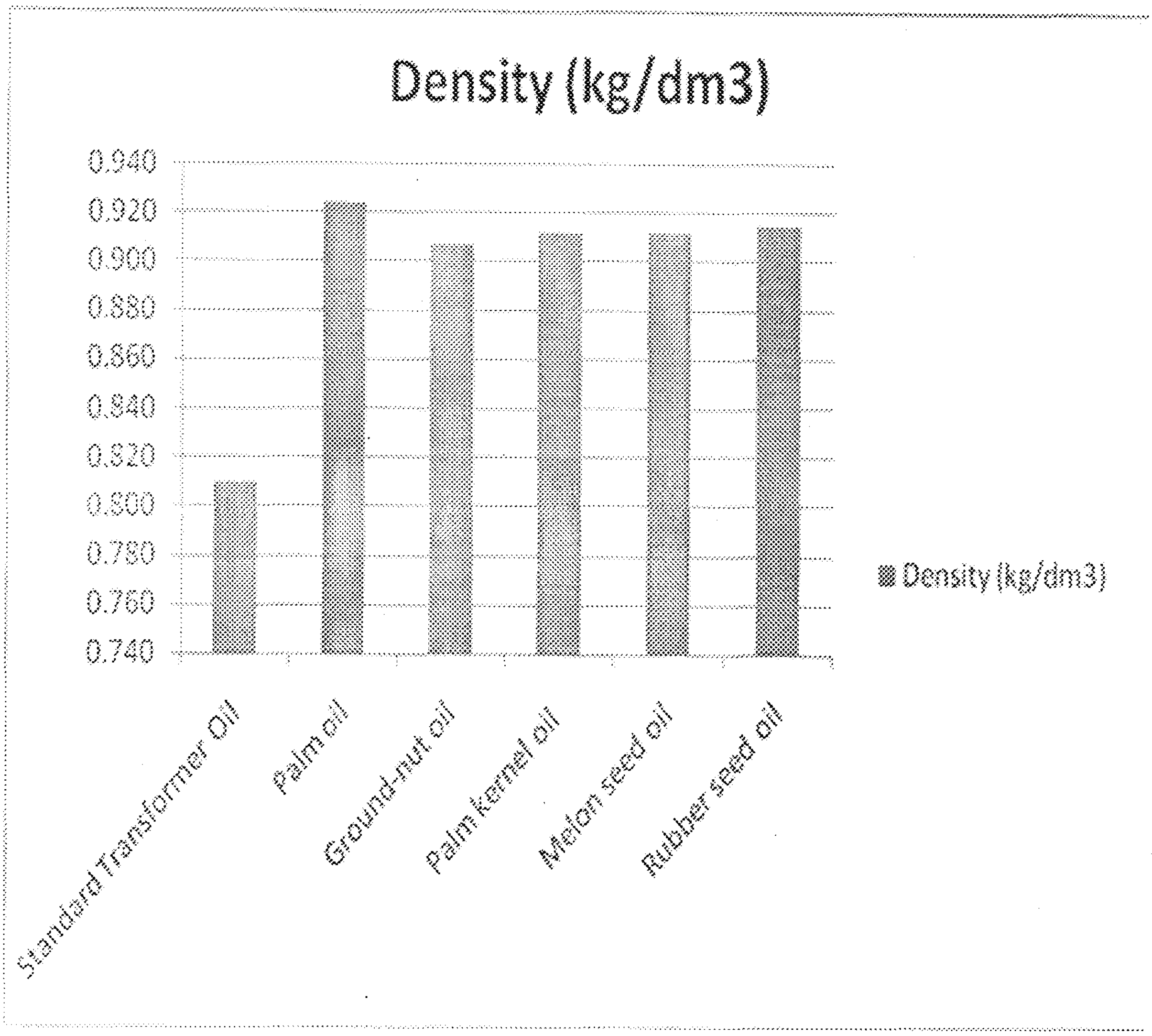

Figure 4.5: Comparison between transformer oil and vegetable oil density

The acid value or acidity of the oil samples measured in mg of potassium hydroxide per gram are shown in Figure 4.6

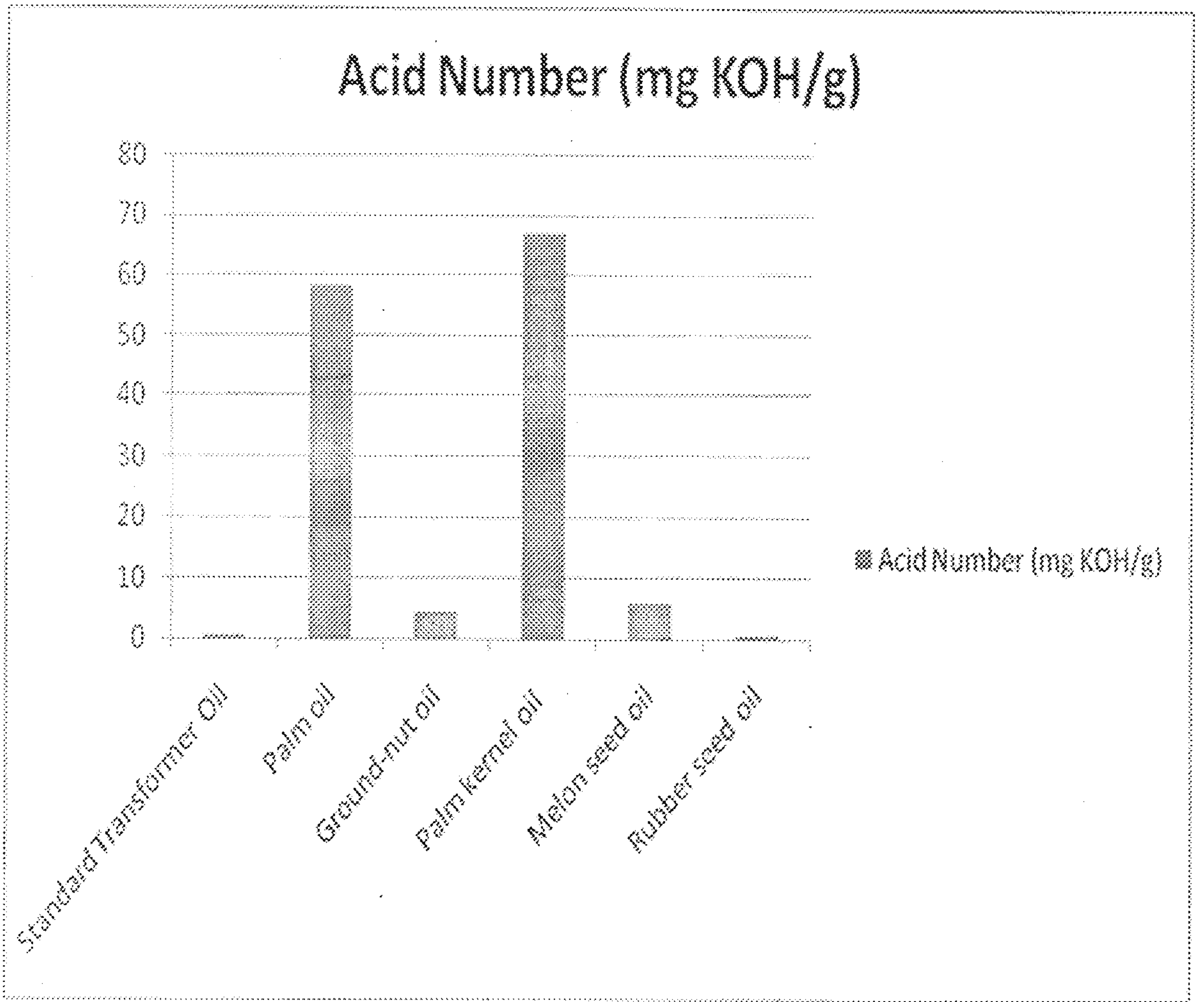

Figure 4.6: Comparison between standard transformer oil and vegetable oil acid number

The variation of insulation resistance at 15 second and insulation resistance at 60 second are shown in Figure 4.7

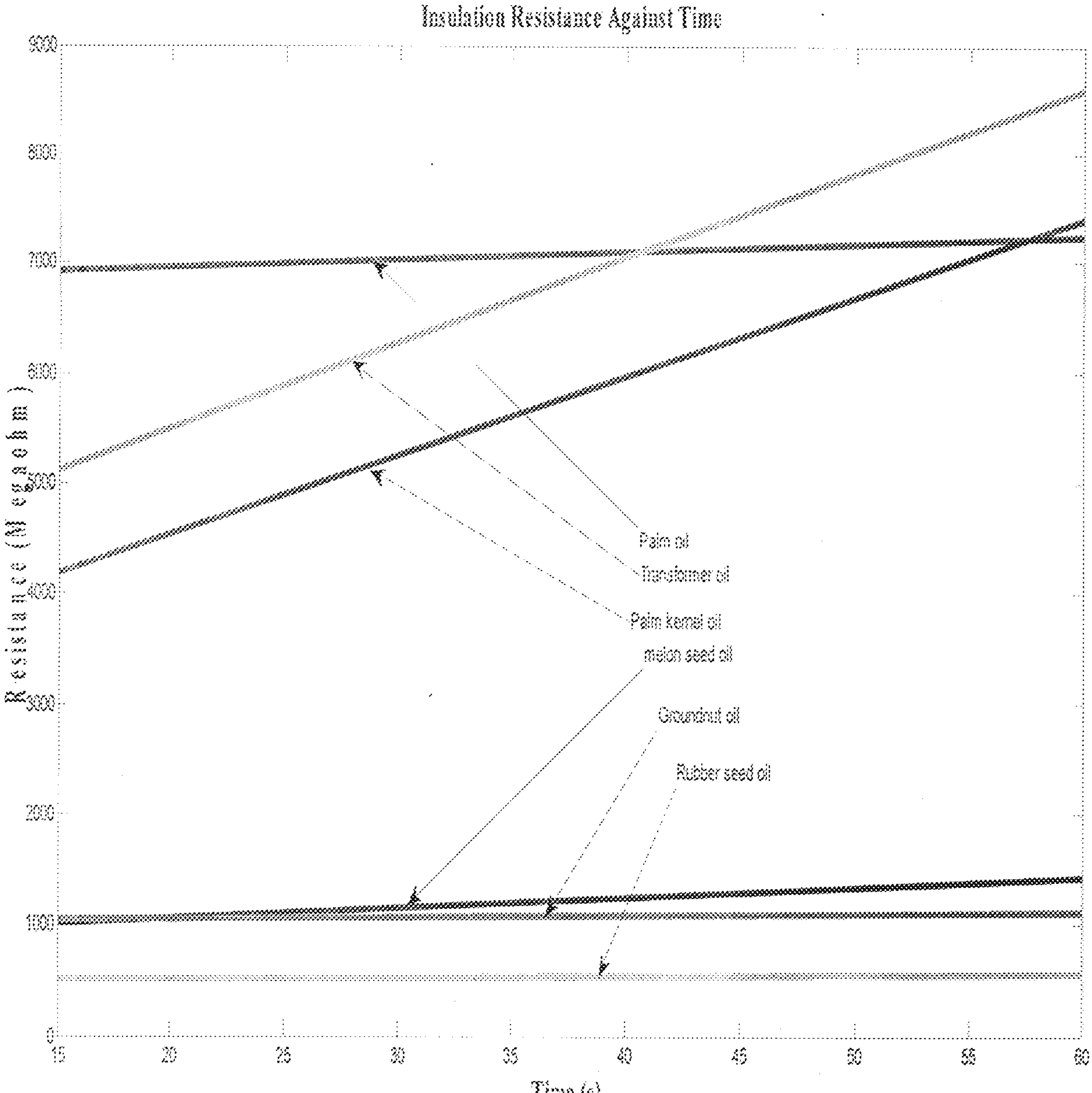

Figure 4.7: Comparison between transformer oil and vegetable oil insulation resistance against time(s)

The pour point measured in degree Celsius of standard transformer oil and vegetable oil are shown in Figure 4.8

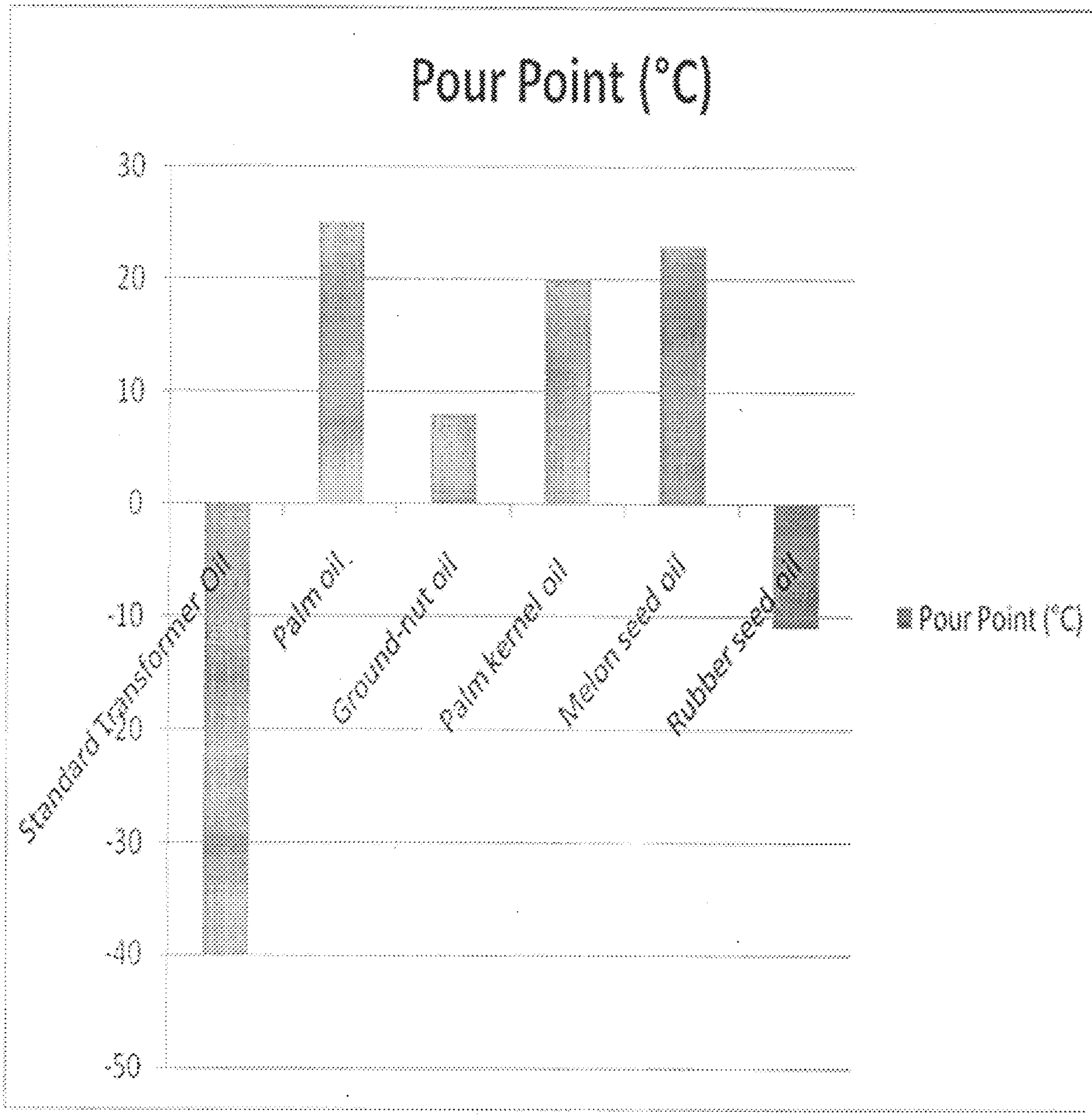

Figure 4.8: Comparison between transformer oil and vegetable oil pour point

4.3 Discussion of Results

The discussion that follows below refers to the results in Table 4.1 and figures above.

The breakdown voltage (BDV) value of all the oils considered place them at a comfortable level to be utilized as insulating oil for transformer with Rubber seed the highest (48.3kV); but this parameter is not the sole determinant. It was observed that the breakdown voltage increases with an increase in the electrode gap.

Fluid viscosity is used to optimize the transformer cooling design. From Figure 4.2, the viscosity at 40^0C shows that all the vegetable oil are slightly higher and falls within the limiting value.

It is also note worthy from Figure 4.4 that the flash point of all the samples are in a comfortable level to be utilized as insulating liquid, since a high flash point is required to eliminate the risk of ignition.

Lower the density, better the flow of oil and it facilitates convection. Apart from transformer oil and groundnut oil which are low, all other samples are slightly higher than the standard value.

As shown in (Figure 4.6) the acid value of rubber seed oil and transformer oil are slightly low as compared to other sample with high acid value. This placed the other sample on the platform of harmful to the transformer.

Figure 4.7 shows the comparison of insulation resistance by using dielectric absorption ratio of transformer oil and vegetable oil. Since the insulation resistance value measured are all above 200MΩ it shows that the insulation resistance of all samples is good and all DAR test are above unity.

The pour points of the oil are shown in Figure 4.8. Apart from Rubber seed oil which has low pour point value of -11^0C which is below the limit of -10^0C, all other samples have high pour point which cannot be used even in the temperate regions.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this project an experimental research is described on the investigation of different insulating oils for transformer. In order to rate the properties of alternative insulating oil, (vegetable oils) and widely used transformer oil (Honeywell) were investigated. The conclusions from Chapter one to five are summarized below.

1. The lack of mineral oil resources become a world issue and encourage people to find the alternative energy source. On the other side, the application of mineral oil in transformer also brings a problem when there is a leakage during operation and the oil become a pollutant to the environment due to its less biodegradable characteristic.

2. Vegetable oil has been acknowledged as good alternative material for transformer oil due to its good biodegradability characteristic, low pour point, high flash point, and high solubility.

3. The results of the investigations have confirmed that Rubber seed oil is the most suitable because of its high BDV, low pour point and low acid value as observed in other liquids.

5.2 Recommendations

It is being recommended that these oil samples be improved upon through more standard industrial refining processes, that is, the material shall be obtained from good quality undamaged, mature seeds from the plant by a process of solvent extraction.

REFERENCES

ASTM D-1816-84a, (1998). Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin using VDE Electrodes, Annual Book of ASTM Standards, Section10, Volume 10, pp. 3

Bartley, W. H. (2003). Analysis of Transformer Failures, International Association of Engineering Insurers, 36th Annual Conference–Stockholm, pp.87

Bartnikas, R. (2000). Dielectrics and Insulators, in The Electrical Engineering Handbook 2nd Edition, CRC Press, pp. 4 - 20

Claiborne, C.C, Walsh, E.J, and Oommen, T.V (1999). *Agricultural Based Biodegradable Dielectric Fluid*, IEEE, pp.876 – 881

Crine, J.P. (2011). Newly Developed Analytical Techniques for Characterization of Insulating Oils, in Electrical Insulating Oils, Retrieved from: www.astm.org/DIGITAL_LIBRARY/STP/.../STP998

Endah, Y. (2010). Analysis of Dielectric Properties Comparison between Mineral oil and Synthetic Ester oil Unpublished Master Thesis, Delft University of Technology, pp. 2-30.

Fofana ,I., Wasserberg, V., Borsi, H., and Gockenbach, E. (2001). *Retro filling Conditions of High-Voltage Transformers*, IEEE, pp.1040 – 1047.

Hikosaka, T., Yamazaki, A., Hatta, Y., and Hidenobu, K. (2007). Basic Characteristic of Environment-conscious Transformers Impregnated with Oil Palm Fatty Acid Ester (PFAE), XVth International Symposium on High Voltage Engineering, Slovenia, pp.17 - 22

IEC 156 (1995). Method of Determination of the Breakdown Voltage of Insulating Liquids, IEC Publication, Section 7, pp.7.0 – 7.12.

Ikwuagwu, O.E., Ononogbu, I.C., and Njoku, O.U. (2000). *Production of Biodiesel Using Rubber Oil*, International Journal of Industrial crops and products, Elsevier, pp.1–2

Koch, M., Fischer, M., and Tenbohlen, S. (2007). *The Breakdown Voltage of Insulation Oil Under The Influences of Humidity, Acidity, Particles, and Pressure*, International Conference APTADM, Poland, pp.29 – 33

Kuffel, E., and Zaengal, W.S., and Kuffel, J. (2005). High Voltage Engineering Fundamentals 2nd Edition, Elsevier, 2005.pp.387-394

Lewand, L. (2001). *Laboratory Evaluation of Several Synthetic and Agricultural-based Dielectric Liquids*, Doble International Client Conference, pp.44 - 48

Manning, M.L. (2007). Fundamental of insulating Transformer, IEEE Electrical Insulating magazine, vol.3 No.6. pp.19 – 23

Miller, and George (2011). Analyzing transformer insulating fluid. Retrieved from **http://ecmweb.com/mag/electric_analyzing_transformer_insulating/**

Naidu, M. S., and Kamaraju, V. (2003). High Voltage Engineering (3rd Edition). New York: McGraw-Hill, pp.26 - 64

Oommen, T.V. (2002). Vegetable Oils for Liquid-Filled Transformers, IEEE Electrical Insulation Magazine, Vol. 18, pp. 6 - 7.

Pahlavanpour, B. and Eklund, M. (2011). Development in maintenance of Insulation Liquid Retrieved from http://electricenergyonline.com

Perrie. C., Beoual, A. and Bessede, J.L (2006). Improvement of power transformers by using mixtures of mineral oil with synthetic ester. IEEE Tras. DEI vol. 13, No. 3, pp. 556 – 564

Rao, S. (2007). Testing Commissioning Operation & Maintenance of Electrical Equipments. Khanna publishers Six Edition, pp.214 – 219

Suwarno, F. S., and Aditama, P. (2005). Dielectric properties of palm oils as liquid insulating materials: Effect of Fat content, Proc. Int. symposium on Electrical Insulation, pp.6 -13

Suwarno, F. S., Suhariadi, I., and Imsak, L. (2003). *Study on the Characteristics of Palm Oil and its Derivatives as Liquid Insulating Materials*, Proc. Int. Conference, pp. 15.

Usifo, O. (2003). Electrical High Voltage Engineering 1st Edition ECAS, pp. 24–27

Vaughan, J.G., and Geissler, C.A. (2009). The New Oxford Book of Food Plants, Oxford University press, pp.24 - 28

Wasserberg, V., Dolata, B., Borsi, H., Gockenbach, E., and Baehr H. (2005). Ecological Friendly Alternative to mineral Base Transformer insulating oils with superior properties Pro. Int. symposium on High voltage Eng. Beijing, pp.1 – 37

Weimer, R., and Altes, C. (2011). Oil palm processing operation. Retrieved from http://www.greenstone.org/greenstone3/nzdl;jsessionid

Willis, H. L., Welch, G. V., and Schrieber, R. R. (2001). Aging Power Delivery Infrastructures vol.12. New York: Marcel Dekker, Inc, pp.28 -43