ELECTRICAL AND CHEMICAL PROPERTIES OF THERMALLY AGED VEGETABLE-BASED OILS AS HIGH VOLTAGE INSULATING MATERIAL

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Dedicated to my beloved family for their encouragement and support

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ABSTRACT

Researches on the viability of using vegetable-based or plant-based oils in power transformers are gaining much attention due to their excellent biodegradability and good dielectric properties. Several vegetable-based oils have been studied and found to have potentials to be used as transformer insulating oil. However, studies on their long-term ageing properties and improvement on their dielectric properties are still lacking. This thesis reports laboratory studies carried out on eight different vegetable oils and their blends to investigate their dielectric properties when subjected to accelerate thermal ageing. The vegetable oils are canola oil, coconut oil, olive oil, palm olein oil, sesame oil, CO25 oil (75% canola 25% olive), CO50 oil (50% canola 50% olive) and CO75 oil (25% canola 75% olive). The samples were thermally aged at 150°C for 520 hours and their dielectric properties were investigated. The dielectric properties were fire point, pour point, dielectric dissipation factor (tan δ), breakdown voltage, refractive index, kinematic viscosity and Fourier Transform Infrared Spectroscopy (FTIR). Mineral oil was also investigated in the same fashion for comparison purposes. Results from this study show that in overall, mineral oil was the least aged and most stable oil sample after undergoing accelerated thermal ageing. Vegetable oil samples experienced higher degree of ageing and oxidation. However, the vegetable oil samples showed higher breakdown voltage. Among these vegetable oil samples, coconut and sesame oil samples were the most aged and have the lowest breakdown voltage, while olive was the least aged and the most stable. In terms of oxidation stability, sesame and canola experienced the highest oxidation while olive and coconut experienced the least. Furthermore, in this study the blending of the canola and olive oils improves their dielectric properties and oxidation by as much as 37%. The finding in this study thus suggests that vegetable-based oils can have good long-term dielectric properties as insulating oils for high voltage applications. In addition, blending of vegetable oils can also improve their insulating properties and oxidation stability.

ABSTRAK

Kini penyelidikan dan pembelajaran ke atas kemajuan menggunakan produk berasaskan tumbuhan atau minyak tumbuhan dalam pengubah kuasa semakin banyak diberi perhatian kerana sifat biodegredasi yang baik dan sifat dielektrik yang baik pada minyak tumbuhan. Sesetengah minyak tumbuhan menunjukkan potensi yang baik. Walau bagaimanapun, kajian ke atas proses penuaan jangka panjang dan peningkatan pada sifat dielektrik masih berkurangan. Projek ini membuat kajian ke atas lapan jenis minyak tumbuhan yang berbeza dan juga melibatkan campuran minyak tumbuhan. Minyak tumbuhan tersebut adalah minyak kanola, minyak kelapa, minyak zaitun, minyak kelapa sawit, minyak bijan, minyak CO25 (75% kanola 25% zaitun), minyak CO50 (50% kanola 50% zaitun) dan minyak CO75 (25% kanola 75% zaitun). Sampel tersebut telah melalui proses penuaan pada 150^{o}C selama 520 jam dan sifat dielektrik minyak tersebut telah dikaji. Sifat-sifat dielektrik yang dikaji adalah takat api, takat tuang, faktor kehilangan dielektrik (tan δ), voltan pecah tebat, indeks biasan, kelikatan kinematik dan inframerah (FTIR). Minyak mineral juga dikaji dengan cara yang sama bagi tujuan perbandingan dengan minyak tumbuhan. Hasil kajian menunjukkan proses penuaan minyak mineral sangat rendah dan lebih stabil selepas melalui proses penuaan. Minyak tumbuhan menunjukkan proses penuaan yang tinggi dan lebih teroksida. Namun begitu, minyak tumbuhan menunjukkan bacaan voltan pecah tebat yang tinggi. Di antara minyak tumbuhan yang diuji, minyak kelapa dan minyak bijan mengalami proses penuaan paling tinggi dan mempunyai voltan pecah tebat yang paling rendah. Minyak zaitun mengalami proses penuaan yang rendah dan lebih stabil. Merujuk kepada kestabilan pengoksidaan, minyak bijan dan minyak kanola lebih stabil manakala minyak zaitun dan minyak kelapa kurang stabil. Minyak campuran kanola dan zaitun dapat memperbaiki tahap kestabilan pengoksidaan sesebuah minyak sebanyak 37%. Kajian ini menunjukkan minyak tumbuhan mempunyai sifat dielektrik yang bagus jika diaplikasikan dalam penggunakan voltan tinggi. Secara keseluruhannya, campuran minyak tumbuhan dapat memperbaiki sifat dielektrik dan kestabilan pengoksidaan.

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LIST OF SYMBOLS

$\tan \delta$	-	Dielectric Dissipation Factor (DDF)
ε_r	-	Permittivity
n	-	Refractive Index
c	-	Speed of Light
v	-	Velocity of Light in The Material
I_R	-	Resistive Current
I_C	-	Capacitive Current

LIST OF ABBREVIATIONS

AC	-	Alternating Current
CO	-	Canola-Olive Blends
IEC	-	International Electrotechnical Commission
ASTM	-	American Society for Testing and Materials
IR	-	Infra-Red
ESD	-	Electrostatic Discharge
IEEE	-	Institute of Electrical and Electronics Engineers
ANSI	-	American National Standards Institute
ECT	-	Electrostatic Charging Tendency
GB	-	Guo-Biao (Chinese Standard)
HMWH	-	High Molecular Weight Hydrocarbons
RBD	-	Refined, Bleached and Deodorized
ISO	-	International Organization for Standardization
FDS	-	Frequency Dielectric Spectroscopy
RC	-	Resistor–Capacitor Circuit
DDF	-	Dielectric Dissipation Factor
RI	-	Refractive Index
DSM	-	Dispersion Staining Method
FBG	-	Fiber Bragg Grating
DGA	-	Dissolved Gas Analysis
CPO	-	Coconut Palm Oil
NaCl	-	Sodium chloride
FTIR	-	Fourier Transform Infra-Red
PFAE	-	Palm Fatty Acid Ester

BDV	-	Breakdown Voltages
IFT	-	Inter Facial Tension
TAN	-	Total Acid Number
DDP	-	Dissolved Decay Products
HONE	-	High Oleic Natural Ester
DC	-	Direct Current
DDB	-	Dodecylbenzene
COC	-	Cleveland Open Cup
BATH	-	Auto Pour and Cloud Point Frigistat
HV	-	High Voltage
LV	-	Low Voltage
KBr	-	Potassium Bromide

CHAPTER 1

INTRODUCTION

1.1 Background

Transformers are essential elements in any power system. They allow the relatively low voltage from generators to be raised to a very high level for efficient power transmission. At the user end of the system, transformers reduce the voltage to a value most suitable for utilization. In modern utility system, the energy may undergo four to five transformations between generator and ultimate user. As a result, a given system is likely to have about five times more kVA of installed capacity of transformers than of generators.

Two or more coils of wire wrapped around a common ferromagnetic core will create a transformer. Usually the coils are not directly connected. The magnetic flux present within the core is the only connection between the coils. One of the transformer windings is connected to a source of AC electric power and called primary winding or input winding. Meanwhile, the secondary winding or output winding will supply electric power to the loads. If there is a third winding on the transformer, it is called the tertiary winding.

Insulation is a major component, which play an important role in the life expectancy of the transformer [1]. Using the right oil assures transformer longevity. Currently, the most widely used oil for insulation in transformer is mineral oil. Mineral oil derived from crude petroleum is widely used as insulating and cooling liquid in electrical equipment. However, mineral oil can cause pollution if leaked or discarded in the wrong place. This is because mineral oil is non-biodegradable oil. It can contaminate soil and water when serious spill takes place [2] and consequently causing serious problems to plantations, living organisms as well as human being.

Mineral oil is made of petroleum. Petroleum products (fossil fuels) are eventually going to run out, and there can be serious shortages even by the mid-twenty-first century. Almost 85% of the energy used in the world comes from fossil fuel [3, 4] which is known as the main resource of mineral oil. Figure 1.1 shows the world sources of energy [5]. From the figure, it can be seen that most of the world's energy resources are fossil fuel. If this trend continues, this will lead to deteriorating resources. Conserving the petroleum reserves and recycling are vital for petroleum-based products-plastics, pharmaceuticals, organic chemicals, and so on. Until economically viable alternate energy sources are developed, there is no easy replacement for gasoline, jet fuel, and heating oil.

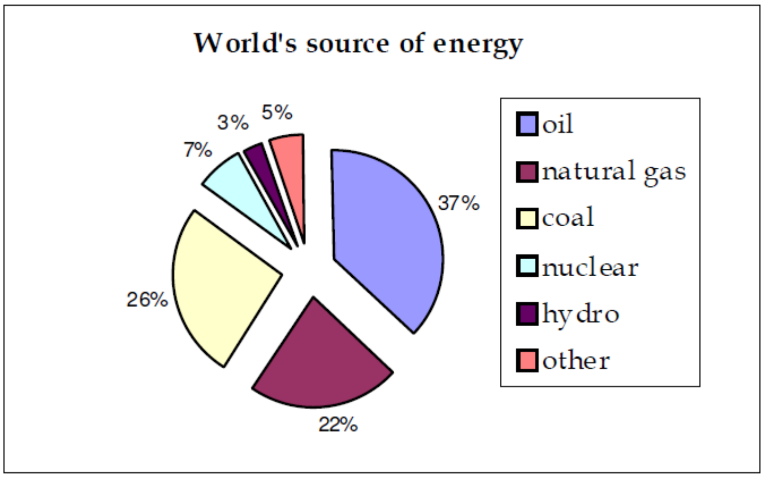

Figure 1.1 World's Sources of Energy [5]

Vegetable oils are natural products available in abundance. They are used mostly for edible purposes, and special oils for drying and cutting oils [6]. The only significant electrical use of vegetable oils suggested until the late 1990s were for power capacitors. Even then, the use is more experimental than commercial [7]. However currently, vegetable oils have been receiving great attention in power transformers as candidates for insulating oils and results from such studies have shown these oils possess some dielectric properties suitable for use as insulating oils [8 – 11].

In conclusion, by introducing vegetable oil as one of the oil in the transformers replacing mineral oil, it can ensure more preserved natural surroundings. At the same time, it enable industry involving biodegradable oil to grow and more studies will be done in the future.

1.2 Problem Statement

In the effort to protect the environment and prevent pollution, biodegradable products should be used. Utilization of oils from biodegradable sources can prevent the environment from further contamination. Biodegradation, which provides an indication of the persistence of a particular substance in the environment, is the yardstick for assessing the ecological friendliness of substances. Mineral oil is non-biodegradable and takes years to unravel because it is made from petroleum. Mineral oil can cause pollution when there is a spill or leak in the transformer. Other environmental aspects in question are toxicity, water pollution and waste treatment. Besides the issue of pollution, the clean-up costs of the leakage or spills as well as replacement costs are very expensive.

In view of the above reasons, an alternative source has to be used to replace mineral oil. Vegetable oil has been suggested as a viable candidate. Vegetable oils have been reported to have high flash point and fire point as well as high breakdown voltage and good dissipation factor (tan δ). In addition they possess better moisture absorption capability from transformer kraft paper. However, compared to mineral oil, vegetable oils possess higher viscosity, pour point and poor oxidative stability.

Numerous studies in the past have been conducted in the past have shown various types of vegetable oil as candidates for transformer oil. However, studies investigating the long term electrical and chemical performance vis-à-vis ageing and oxidative stability are lacking. Furthermore, recently some researches have reported that blending between vegetable oils improved their oxidative stability. However, investigation on their electrical characteristics has not been conducted.

In view of the foregoing, there is a need to conduct electrical and chemical studies on long term ageing characteristics of vegetable oils.

1.3 Objectives of Study

The objectives of this study are:

1. To investigate the dielectric properties of vegetable-based oils as insulating oils for high voltage equipment.
2. To investigate the dielectric properties of blended vegetable-based oils.
3. To assess the long-term performance and stability of vegetable-based oils as insulating oils during accelerated ageing processes.
4. To compare the dielectric properties of vegetable-based oils with transformer mineral oil.

1.4 Scope of Study

The scopes of this study are (in lab):

1. Five vegetable oil samples and three blended vegetable oil samples were investigated along with mineral oil for comparison purpose.
2. Dielectric properties of Canola Oil, Coconut Oil, Olive Oil, Palm Olein Oil, Sesame Oil, CO25 Oil (75% Canola 25% Olive), CO50 Oil (50% Canola 50% Olive) and CO75 Oil (25% Canola 75% Olive) were investigated.
3. Vegetable oil samples were aged thermally and their dielectric properties and chemical properties were investigated during the ageing period.
4. Dielectric and chemical tests were conducted according to IEC 60247, IEC 60243, IEC 60156, ASTM D92, ASTM D5853, ASTM D97 and ASTM D6871.

1.5 Significance of the Research

The significances of this study are:

1. Investigating the dielectric properties of Canola Oil, Coconut Oil, Olive Oil, Palm Olein Oil, Sesame Oil, CO25 Oil (75% Canola 25% Olive), CO50 Oil (50% Canola 50% Olive) and CO75 Oil (25% Canola 75% Olive) for potential use in high voltage equipment oils as insulating oils.
2. Electrical and chemical performance of blended vegetable oils for possible application/use as insulating oils in high voltage equipment.
3. Long term performance and ageing characteristics of vegetable oils for application as insulating oils.

1.6 Organization of the Thesis

Chapter 1 presents an introduction of the project, the research background study, the problem statements, the research objectives, scope of study and the significance of the research.

Chapter 2 reviews the mineral oil, vegetable oil, ageing of the oil, and dielectric properties of the oil such as fire point, pour point, dielectric dissipation factor (tan δ), breakdown voltage, refractive index, kinematic viscosity and Infrared (IR) Spectroscopy. A review on previous studies of vegetable-based oils for application as insulating oils is also presented.

Chapter 3 elaborates the research methodology to achieve the objectives of this study. This chapter details the experimental procedure, methods and equipment used.

Chapter 4 presents the result of the electrical and chemical tests conducted on the vegetable oil samples during the ageing period. Discussion of the results and implications are also presented in this chapter.

Chapter 5 summarized the main findings of this work together with suggestions for future work in the area.

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