AGEING AND DISSOLVED GAS ASSESSMENTS OF RICE BRAN OIL AND PALM OIL FOR POWER TRANSFORMER APPLICATION

MASLINA BINTI MOHD ARIFFIN

DOCTOR OF PHILOSOPHY (ELECTRICAL AND ELECTRONIC ENGINEERING)

NATIONAL DEFENCE UNIVERSITY OF MALAYSIA

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ABSTRACT

Natural ester insulating oils (NEO) have high fire points and excellent biodegradable characteristics. As a result, there is an increasing demand for NEO as transformer insulating oils. Among the promising NEOs are Palm Oil (PO) and Rice Bran Oil (RBO). Since the failure of in-service transformers could be costly, it is essential to understand the oil characteristics; this can be carried out through accelerated thermal ageing study. The ageing characteristics of Mineral oil (MO) knowledge is well established as it has been researched extensively. On the other hand, the ageing studies on NEOs are currently ongoing. According to the findings of these studies, the ageing characteristics and compositions of the NEO were slightly different compared to conventional MO. Thus, there are differences in the variety and proportion of gas production during ageing and fault conditions especially PO and RBO. In this thesis, the ageing behaviour of presence and absence of Kraft paper insulation in MO, PO, and RBO and as well as DGA were investigated. All physicochemical, mechanical, dielectric, and electrical properties were measured at different ageing times of 2, 30, 90, and 180 days and temperatures of 90°C, 110°C, and 130°C. For DGA study, the simulated thermal fault and electrical fault were studied, and the sample of gasses produced due to the faults were taken and analysed. Based on the results, the moisture content in RBO impregnated paper is lower than in MO, which slower the paper ageing in RBO. Moisture content in oil, vegetable-based oils have higher values because they can absorb more moisture from the paper by the effect of hydrolysis. The acid value of PO and RBO are bigger than mineral oil because the triglyceride molecule in the vegetable oil is easy to hydrolyse to produce a large amount of high molecular acid. Relative permittivity and dielectric dissipation factor (DDF) for PO and RBO were higher (1.59 and 2.02) compared to the MO. The higher DDF value of PO and RBO is due to the molecular structure which has a slightly more polar character compared to MO. The RBO has the highest resistivity compared to PO and MO and this is reflected well with the result of the AC breakdown voltages. For DGA study, it could be identified that the main fault gases of thermal fault for PO and RBO are CH_4, C_2H_4, C_2H_6, H_2 and C_2H_6. The DGA analysis for both faults for NEO might be inaccurate due to different interpretation. Therefore, for PO and RBO, the DGA analysis needs further improvement before it can be used as transformer oil.

ABSTRAK

Cecair penebat minyak sayuran mempunyai titik kebakaran yang tinggi dan ciri terbiodegradasi yang sangat baik. Oleh itu, terdapat peningkatan permintaan untuk NEO sebagai minyak penebat pengubah. Antara NEO yang berpotensi adalah minyak sawit (PO) dan minyak dedak padi (RBO). Memandangkan kos kerosakan pengubah adalah sangat mahal, adalah penting untuk memahami ciri-ciri minyak penebat baru melalui kajian penuaan haba. Ciri-ciri penuaan untuk minyak mineral (MO) sudah banyak dikaji secara meluas. Sebaliknya, kajian penuaan untuk NEO kini sedang dijalankan. Menurut penemuan kajian ini, ciri penuaan dan komposisi NEO adalah sedikit berbeza berbanding MO. Selain itu, terdapat perbezaan kepelbagaian dalam pengeluaran gas semasa penuaan dan keadaan kerosakan terutama PO dan RBO. Dalam tesis ini, tingkah laku penuaan dan ketiadaan penebat kertas Kraft dalam MO, PO, RBO dan DGA telah dikaji. Semua sifat fiziokimia, mekanikal, dielektrik dan elektrik diukur pada masa penuaan yang berbeza iaitu 2, 30, 90 dan 180 hari serta suhu 90°C. 110°C dan 130°C. Untuk kajian DGA, simulasi kerosakan haba dan kerosakan elektrik telah dibuat, dan sampel gas yang dihasilkan akibat kerosakan telah diambil dan dianalisis. Berdasarkan keputusan, kandungan lembapan dalam RBO dengan kertas Kraft adalah rendah dari MO, menyebabkan kertas menua dengan lebih lambat. Mengenai kandungan lembapan dalam minyak yang berasakan sayuran, ia mempunyai nilai lembapan yang lebih tinggi kerana kesan hidrolisis. Nilai asid PO dan RBO lebih tinggi daripada MO kerana molekul trigliserida dalam minyak sayuran mudah dihidrolisis untuk menghasilkan sejumlah besar asid molekul tinggi. Kepelbagaian relatif dan faktor pelesapan dielektrik (DDF) untuk PO dan RBO adalah tinggi (1.59 and 2.02) berbanding MO. DDF yang tinggi dalam PO dan RBO disebabkan oleh struktur molekul yang mempunyai watak polar yang sedikit berbanding MO. RBO mempunyai kerintangan tertinggi berbanding PO dan MO dan ini ditunjukkan dengan baik dengan hasil voltan kerosakan AC. Bagi kajian DGA, dapat dikenalpasti bahawa kandungan gas kerosakan bagi PO dan RBO ialah CH_4, C_2H_4, C_2H_2, H_2 dan C_2H_6. Analisis DGA untuk kedua-dua kesalahan untuk NEO mungkin tidak tepat kerana tafsiran yang berbeza. Oleh itu, untuk PO dan RBO, analisis DGA memerlukan penambahbaikan lagi sebelum boleh digunakan sebagai minyak pengubah.

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The Examination Committee has met on the **17th November 2022** to conduct the final examination of **MASLINA BINTI MOHD ARIFFIN** on her PhD thesis entitled '**Ageing and Dissolved Gas Assessments of Rice Bran Oil and Palm oil for Power Transformer Application'**.

The committee recommends that the student be awarded the Doctor of Philosophy (Electrical and Electronic Engineering).

Members of the Examination Committee were as follows.

Assoc. Prof. Dr. Mohd Taufik Bin Jusoh@ Tajudin
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Chairman)

Dr. Asnor Mazuan Bin Dato' Haji Ishak
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
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Prof. Ir. Ts. Dr. Muzamir Bin Isa
Faculty of Electrical Engineering Technology
Universiti Malaysia Perlis
(External Examiner)

Assoc. Prof. Ir. Dr. Rahisham Bin Abdul Rahman
Faculty of Electrical & Electronic Engineering
Universiti Tun Hussien Onn Malaysia
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Doctor of Philosophy (Electrical and Electronic Engineering).** The members of the Supervisory Committee were as follows.

Prof. Dr. Mohd Taufiq bin Ishak
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Prof. Ir. Dr. Mohd Zainal Abidin bin Ab Kadir
Faculty of Engineering
Universiti Putra Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name	: MASLINA BINTI MOHD ARIFFIN
Date of birth	: 29TH NOVEMBER 1986
Title	: AGEING AND DISSOLVED GAS ASSESSMENTS OF RICE BRAN OIL AND PALM OIL FOR POWER TRANSFORMER APPLICATION
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TABLE OF CONTENTS

TITLE	PAGE
ABSTRACT	**ii**
ABSTRAK	**iii**
ACKNOWLEDGEMENTS	**iv**
APPROVAL	**v**
APPROVAL	**vi**
DECLARATION OF THESIS	**vii**
TABLE OF CONTENTS	**viii**
LIST OF TABLES	**xi**
LIST OF FIGURES	**xiii**
LIST OF ABBREVIATIONS	**xvi**
LIST OF SYMBOLS	**xvii**
LIST OF APPENDICES	**xviii**

CHAPTER

1	**INTRODUCTION**	**1**
	1.1 Background	1
	1.2 Problem Statements	6
	1.3 Research Objective and Scope	8
	1.4 Major Contribution	10
	1.5 Thesis Summary	10
2	**LITERATURE REVIEW**	**13**
	2.1 Introduction	13
	2.2 Transformer Working Principle and Application	14
	2.3 Insulation in Transformer	16
	2.3.1 Transformer Oil	16
	2.3.1.1 Mineral Insulating oil	18
	2.3.1.2 Natural Ester oil	19
	2.3.1.2.1 Palm oil	20
	2.3.1.2.2 Rice Bran oil	21
	2.3.2 Cellulose Insulation	23
	2.3.2.1 Electrical Grade-Kraft paper	24
	2.3.2.2 Paper Ageing Mechanism	25
	2.4 Ageing Effects on Physicochemical Properties	28
	2.4.1 Moisture of Oil and Paper	28
	2.4.2 Acidity	29
	2.4.3 Dynamic Viscosity	30
	2.5 Ageing Effects on Mechanical Properties	31
	2.5.1 Tensile Strength	31
	2.6 Ageing Effect on Dielectric properties	32
	2.6.1 Relative permittivity	32
	2.6.2 Dielectric Dissipation Factor	33
	2.6.3 Resistivity	34
	2.7 Ageing Effects on Electrical Properties	35

2.7.1 AC breakdown voltage Performance 35
2.8 Dissolved Gas Analysis 36
2.8.1 Gases in Conventional Transformer Oil 36
2.8.2 Thermal Faults 37
2.8.3 Electrical Faults 37
2.8.4 Interpretation of Dissolved gas analysis 38
2.8.5 Duval Triangle and Pentagon method 38
2.8.6 Doernenburg Ratio method 40
2.8.7 Rogers Ratio and IEC method 41
2.9 Summary 43

3 METHODOLOGY 44
3.1 Introductions 44
3.2 Sample description 46
3.2.1 Pre-processing of the oil 48
3.2.2 Pre-processing of Kraft paper 49
3.2.3 Kraft paper impregnation with oil 50
3.2.4 Ageing of oil and paper 51
3.3 Parameter of oil testing 52
3.3.1 Physicochemical properties 52
3.3.2.1 Moisture in oil and Kraft paper 53
3.3.2.2 Acidity 56
3.3.2.3 Dynamic Viscosity 58
3.3.2 Mechanical properties 60
3.3.2.1 Tensile strength 60
3.3.3 Dielectric properties 62
3.3.4 Electrical properties –AC breakdown voltage test 66
3.3.5 Dissolved Gas Analysis (DGA) 69
3.3.5.1 Pre-processing of oil for Electrical Fault and Thermal Fault 69
3.3.5.1.1 Electrical Fault Experiment 70
3.3.5.1.2 Thermal Fault Experiment 71
3.3.5.2 Testing with Gas Extraction method 72
3.3.5.2.1 Extraction result data processing 74
3.4 Summary 75

4 RESULT AND ANALYSIS 76
4.1 Introduction 76
4.2 Physicochemical Properties 77
4.2.1 Moisture in Oil 77
4.2.1.1 Moisture in Oil with the Presence of Kraft Paper 79
4.2.1.2 Moisture in Oil without the Presence of Kraft paper 82
4.2.2 Moisture in Kraft paper 85
4.2.3 Acidity 87
4.2.3.1 TAN with the presence of Kraft paper 89
4.2.3.2 TAN without the presence of Kraft paper 90
4.2.4 Dynamic Viscosity 90
4.2.4.1 Dynamic Viscosity with the presence of 92

Kraft paper
4.2.4.2 Dynamic Viscosity without the presence of Kraft Paper 92
4.3 Mechanical Properties 93
4.3.1 Tensile Strength 93
4.4 Dielectric Properties 96
4.4.1 Relative Permittivity 96
4.4.1.1 Relative permittivity with the presence of Kraft Paper 98
4.4.1.2 Relative Permittivity without the presence of Kraft Paper 100
4.4.2 Dielectric Dissipation Factor 102
4.4.2.1 Dielectric Dissipation Factor with the presence of Kraft paper 103
4.4.2.2 Dielectric Dissipation Factor without the presence of Kraft Paper 105
4.4.3 Resistivity 106
4.4.3.1 Resistivity with the Presence of Kraft Paper 108
4.4.3.2 Resistivity without the Presence of Kraft Paper 110
4.5 Electrical Properties 111
4.5.1 AC Breakdown Voltage Effect of Oil with the Presence of Kraft Paper 113
4.5.2 AC Breakdown Voltage Effect of oil without the Presence of Kraft Paper 115
4.6 Dissolved Gas Analysis 117
4.6.1 Thermal Fault Gas Generation 117
4.6.1.1 Duval Triangle and Pentagon Method Analysis 118
4.6.1.2 Doernenburg Ratio Method Analysis 122
4.6.1.3 Rogers Ratio Method Analysis 123
4.6.1.4 IEC Ratio Method Analysis 124
4.6.2 Breakdown Voltage Fault Gas Generation 125
4.6.2.1 Duval Triangle and Pentagon Method Analysis 126
4.6.2.2 Doernenburg Ratio Method Analysis 128
4.6.2.3 Rogers Ratio Method Analysis 129
4.6.2.4 IEC Ratio Method Analysis 130
4.6.3 Diagnostic Results of DGA 130
4.7 Summary 134

5 CONCLUSION AND RECOMMEDATION 137
5.1 Conclusions 137
5.2 Future Research 140

REFERENCES 141
APPENDICES 152
BIODATA OF STUDENT 176
LIST OF PUBLICATIONS 177

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Previous ageing experiments for paper ageing mechanism	27
2.2	Types of faults that can be used as reference s when using the Duval Triangle and Duval Pentagon 1 and 2 methods	39
2.3	Gas concentration ratio limit to determine faults according to Deornenburg Ratio method	41
2.4	Gas concentration ratio limit to determine faults according to Rogers Ratio method	42
2.5	Gas concentration ratio limit to determine faults according to IEC Ratio method	42
3.1	Detail components in sample of oil	46
3.2	Fatty acid components	47
3.3	Final moisture content	49
3.4	Basic properties of paper	50
3.5	Summarize of important parameter for testing all samples	52
3.6	Detail information on BAUR equipment	67
4.1	Moisture in oil with presence of Kraft paper for MO, PO and BO	80
4.2	Moisture in oil without presence of Kraft paper for MO, PO and RBO	83
4.3	Tensile strength retention (%) for all of the oil samples	94
4.4	Relative permittivity, ε_r with the presence of Kraft paper at 90°C, 110°C and 130°C	99
4.5	Relative permittivity ε_r without the presence of Kraft paper at 90°C, 110°C and 130°C	101

4.6	Dissipation Factor, Tan δ with presence of Kraft paper at all temperature	104
4.7	Dissipation Factor, Tan δ without presence of Kraft paper at all temperature	105
4.8	Resistivity, TΩ with presence of Kraft paper at all temperature	109
4.9	Resistivity, TΩ without presence of Kraft paper at all temperature	110
4.10	Average AC breakdown voltage, kV effect of oil with presence of Kraft paper	114
4.11	Average AC breakdown voltage, kV effect of oil without presence of Kraft paper	116
4.12	Concentration of gases in oil	118
4.13	References acronym for the Duval Triangle and Duval Pentagon 1and 2 methods	119
4.14	Gas concentration ratio of mineral oil, palm oil and rice bran oil based on Doernenburg Ratio method	123
4.15	Gas concentration ratio of mineral oil, palm oil and rice bran oil based on Rogers Ratio method	124
4.16	Gas concentration ratio of mineral oil, palm oil and rice bran oil based on IEC Ratio method	124
4.17	Concentration of gases in oil	125
4.18	Gas concentration ratio of mineral oil, palm oil and rice bran oil based on Doernenburg Ratio method	129
4.19	Gas concentration ratio of mineral oil, palm oil and rice bran oil based on Rogers Ratio method	129
4.20	Gas concentration ratio of mineral oil, palm oil and rice bran oil based on IEC Ratio Method	130
4.21	Summarise the diagnostic tools found in IEEE guide	131
4.22	Results of dissolved gas analysis by using different methods	133

LIST OF FIGURES

FIGURES	TITLE	PAGE
2.1	Molecular structures of three main groups of hydrocarbon molecules in mineral insulating oil (a) Paraffinic, (b) Naphthenic, (c) Aromatic	19
2.2	Cross section of palm nut	20
2.3	Rice kernel structure	22
2.4	Factors that could influence oil and paper ageing in the transformer	26
2.5	Trend of acidity with age	30
2.6	Effect of different ageing mechanisms on the ageing rate of paper (arrow indicates the increase in the reaction rate due to the increase in water content)	32
2.7	Comparison of DDF of natural ester oils	34
2.8	Conventinal Duval Triangle, where DT represents combination of thermal and electrical discharge faults	40
2.9	Representation of faults areas in Duval Pentagon 1 and Duval Pentagon 2	40
3.1	The general flowchart comprising the samples and experimental set up procedures involved in this study	45
3.2	Flow of pre-processing of oil	48
3.3	Flow of pre-processing of Kraft paper	49
3.4	Flow of Kraft paper impregnation with oil	50
3.5	Sample of (a) Ageing of oil with presence of Kraft paper (b) Ageing of oil without presence of Kraft paper	51
3.6	Coulometric Karl Fisher Titration	54
3.7	Flows of moisture in oil test	56
3.8	Digital Burette	57
3.9	Flows of acidity test	58

3.10	Flows of dynamic viscosity testing	59
3.11	Brookfield R/S Plus Rheometer	60
3.12	Universal Testing Machine (UTM) Instron 5569A	61
3.13	Flows of tensile strength testing	62
3.14	Automatic ADTR-2K Plus	63
3.15	The test cell for measurements on liquids proposed by IEC 60247	64
3.16	Sample of result from Automatic ADTR-2K Plus	64
3.17	Flows of dielectric properties test	65
3.18	BAUR Fully Automatic Insulating Tester DTA100C	66
3.19	Copper spherical electrodes with a diameter of 12.5 mm	67
3.20	Flows of the AC breakdown voltage test	68
3.21	Pre-processing of oil for electrical and thermal fault	69
3.22	Electrical faults experiment	71
3.23	Thermal faults experiment	71
3.24	Extraction of gas from insulating oil	73
3.25	Gas extraction data processing from insulating oils	74
4.1	Flowchart of specific qualities measured in the research	77
4.2	Moisture in oil for (a) 90°C (b) 110°C 130°C at all time durations with and without presence of Kraft paper	79
4.3	Moisture in paper for (a) 90°C (b) 110°C (c) 130°C at all time durations	86
4.4	TAN for all sample of oils for (a) 90°C (b) 110°C (c) 130°C at all time durations	88
4.5	Dynamic viscosity for all samples at (a) 90°C (b) 110°C (c) 130°C at all time durations	91
4.6	Tensile strength retention (%) at (a) 90°C (b) 110°C (c) 130°C for all samples of oils	95

4.7	Relative Permittivity at (a) 90°C (b) 110°C (c) 130°C at all time durations	98
4.8	Dissipation Factor, Tan δ at (a) 90°C (b) 110°C (c) 130°C at all time durations	103
4.9	Resistivity, TΩ cm at (a) 90°C (b) 110°C (c) 130°C at all time durations	108
4.10	AC Breakdown Voltage, kV at (a) 90°C (b) 110°C (c) 130°C at all time durations	113
4.11	Duval Triangle formed by the three axes that corresponds to the relative proportion of CH_4, C_2H_2 and C_2H_4 gases for thermal fault detection: (a) mineral oil, (b) palm oil and (c) rice bran oil	120
4.12	The irregular polygon formed by five relative proportion of H_2, C_2H_6, CH_4, C_2H_4, C_2H_2 and gases for thermal fault detection: (a) Mineral oil, (b) Palm oil (c) Rice Bran oil	121
4.13	Duval Triangle formed by the three axes that corresponds to the relative proportion of CH_4, C_2H_2 and C_2H_4 gases for breakdown voltage fault detection: (a) mineral oil, (b) palm oil and (c) rice bran oil	127
4.14	The irregular polygon formed by five relative proportion of H_2, C_2H_6, CH_4, C_2H_4, C_2H_2 and gases for breakdown voltage fault gas detection: (a) Mineral oil, (b) Palm oil (c) Rice Bran oil	128

LIST OF ABBREVIATIONS

AC	-	Alternating current
ASTM	-	American Society for Testing and Materials
BDV	-	Breakdown voltage
CH_4	-	methane
CO_2	-	carbon dioxide
CO	-	carbon monoxide
C_2H_4	-	ethylene
C_2H_6	-	ethane
C_2H_2	-	acetylene
DDF	-	Dielectric dissipation factor
DGA	-	Dissolved gas analysis
DP	-	Degree of depolymerisation
DPg1	-	Duval pentagon 1
DPg2	-	Duval pentagon 2
H_2	-	hydrogen
IEC	-	International Electrotechnical Commission
IEEE	-	Institute of Electrical and Electronic Engineers
IFT	-	Interfacial Tension
NEO	-	Natural Ester oil
mc	-	Moisture content
MPa	-	Megapascal pressure unit
MO	-	Mineral oil
PO	-	Palm oil
RBO	-	Rice Bran oil
RP	-	Relative permittivity
Std	-	standard
TS	-	Tensile Strength

LIST OF SYMBOLS

°C	-	Celsius
δ	-	Delta
Ω	-	ohm
v/m	-	volt/meter
A/m^2	-	ampere/square meter
g	-	gram
mg	-	milligram
cSt	-	Centistokes
mm	-	millimetre
kN/m	-	kilonewton/meter
kN	-	kilonewton
dc	-	direct current
kV/m	-	kilovolt/meter
Hz	-	hertz
ppm	-	parts per million

LIST OF APPENDICES

APPENDIX		TITLE	PAGE
APPENDIX A			
	A.1	Data Collection on AC breakdown voltage with presence of Kraft paper at 90°C	153
	A.2	Data Collection on AC breakdown voltage with presence of Kraft paper at 110°C	156
	A.3	Data Collection on AC breakdown voltage with presence of Kraft paper at 130°C	159
APPENDIX B			
	B.1	Data Collection on AC breakdown voltage without presence of Kraft paper at 90°C	162
	B.2	Data Collection on AC breakdown voltage without presence of Kraft paper at 110°C	165
	B.3	Data Collection on AC breakdown voltage without presence of Kraft paper at 130°C	168
APPENDIX C			
	C.1	Thermal Fault Gas Generation Calculation	171
	C.2	Breakdown Voltage Fault Gas Generation Calculation	174

CHAPTER 1

INTRODUCTION

1.1 Background

Transformers, and particularly power transformers, are one of the most important assets in the system that convert power from one voltage level to another in electrical power system[1], [2]. During operation, power transformers are subjected to a variety of stresses, including thermal, electrical, mechanical, and chemical, all of which contribute to the deterioration of the insulation system [3]. The efficiency of a power transformer is mainly determined by the performance of its insulation materials, which is the most important component contained within the transformer [4]. Therefore, continuous study on how to maintain the performance of the insulation system is required.

Any kind of failure related to the insulation system, including the ageing related process is crucial and needs to be focused on because it involves a long-term operation process. Insulating oil also known as transformer oil and Kraft paper are the two primary components that comprise a transformer's insulation system [4]. Due to the fact that transformer oil has a higher dielectric strength than air, their primary purpose is to provide an electrical insulation. The secondary purpose of transformer oil is to function as a coolant or dissipate heat within the transformer. It is because, when flux leakage/eddy current and winding (I^2R) losses occur in transformers, there will be a loss of energy in the form of windings and cores. This will experience an increase in temperature as a direct consequence of this. The heat will be absorbed by the insulation oil, and it will be transferred to the cooled exterior surfaces. The provision of diagnostic information regarding the operational health of the transformer and the lifetime of the transformer is the third purpose of transformer oil [4]–[6].

The main insulation oil in industrial power system since the 1990s is mineral oil (MO) [7]. MO continues to serve as a major type of insulating fluid in electrical equipment until now. Insulating oils derived from minerals have excellent dielectric and cooling properties, which is the primary reason for their market dominance in terms of consumption on a global scale [4], [8], [9]. However, MO is non-biodegradable and causes serious spills occurs during incidents such as transformer explosion [10], [11]. In addition, MO have disadvantages which is a flammable liquid that has a flash point and fire point of 170°C (high temperature) and transformer fires are an unavoidably risk. However, due to the environmental aspects in the future, the concern of fire safety performance of MO starts to be limited [4], [8], [9].

In recent years, NEO such as rapeseed, sunflower, olive, castor, palm and coconut have been considered as one of the alternatives to replace the MO [12]–[14]. Furthermore, NEO have excellent thermophysical and improved dielectric properties both of which contribute to increasing the motivations for using NEO as alternative transformer oil. In order for these vegetable oils to be considered a viable replacement for MO, they will first need to meet the requirements of being risk-free, cost-effective, and able to maintain a high level of electrical properties over the course of the transformer's lifetime.

Recently, extensive works were carried out to investigate the suitability of vegetable oils as the alternative to MO [12], [13], [15]–[23]. The studies evaluated dielectric properties, physical and chemical performances under different conditions and ageing properties. Although some poor features of esters limit their usage, e.g low oxidation stability for vegetable oils, they have been used worldwide for many years in either small or medium distribution transformer up to 66kV [24], [25].

In 2006 it was reported by Martins [26] that two Brazilian Utilities, CELESC and ELETRONORTE, were experimenting with power transformers filled with vegetable-based oil, Environtemp FR3. Environtemp FR3 is a biodegradable natural ester and it is derived from seed oil with additives to improve performance. CELESC was using FR3 in a 138kV 30MVA transformer and two 138kV 40MVA substation transformers. ELETRONORTE has revised its specification to use FR3 in all transformers and reactors rated up to 138kV and have recently ordered a 242kV shunt reactor from ALSTOM Grid (previously AREVA T & D).

One of the most considered VO to be applied as transformer oil is Palm-based oil(PO). Recently, a number of studies have been conducted, on PO, comprising various electrical, physical and chemical properties [12], [15], [30], [36], [45], [55], [66], [70]. The findings indicated that PO has a the potential to serve as an alternative transformer oil due to the fact that its AC breakdown strength and lightning impulse strength were comparable to MO [4], [6], [9], [19], [22], [27]–[31]

Rice bran oil (RBO) is yet another variety of VO that has demonstrated strong performance. In 2016, S. Senthil Kumar reported RBO for the capability to be utilised as an alternative transformer oil. Studies on RBO especially on physical, chemical, and electrical properties are very limited number. The study showed that the AC breakdown voltage and lightning impulse breakdown voltage of RBO has a comparable performance to another natural esters [32]–[34]. According to the findings, RBO possesses better insulating properties in comparison to other VO.

The performance of insulation oil is gradually deteriorating in the long-term operation and may lead to failures of the transformer. This deterioration is influenced by the internal electrical, thermal, mechanical vibration, moisture, oxygen, and other factors of the transformer. Among those factors, thermal ageing caused more than half of the total failures in transformer which makes it the main cause of oil paper insulation degradation. The influences of thermal ageing on oil's electrical and paper's mechanical properties become the concerns of ageing diagnosis and residual lifetime predictions for transformers. Thus, it is important to determine the ageing status of transformers by monitoring the condition of the oil and paper.

Dissolved gas analysis (DGA) is the study of dissolved gases in transformer oil. Whenever a transformer undergoes abnormal thermal and electrical stresses, certain gases are produced due to the decomposition of the transformer oil. When the fault is major, the production of decomposed gases is significant. However, when abnormal thermal and electrical stresses are not significantly high the gasses due to decomposition of transformer insulating oil will get enough time to dissolve in the oil.

PO and RBO have different compositions from the conventional mineral insulating oil. PO and RBO consists of hundreds of triglycerides, while mineral oils are mixtures of alkane, cyclones, and aromatic hydrocarbons containing carbon and hydrogen linked together by single and double bonds. In addition, different types of vegetable insulating oils are also composed of different kinds and proportions of triglyceride molecules. Thus, there are differences in the variety and proportion of gas production among different types of insulating oils especially PO and RBO. The percentage of different gas produced by both oils can be measure using a dissolved gas analysis (DGA).

Since the physicochemical properties of PO and RBO are distinct from those of MO, both the design and production processes of power transformers may be impacted as a consequence. Thus, a complete understanding of the ageing performances of vegetable oils and their impact on transformer design and operation is required.

Therefore, in this thesis, a detailed study of ageing properties of PO and RBO was carried out through the study of physicochemical, mechanical, and electrical properties in order to comply the industrial standard. Besides that, an assessment of dissolved gas analysis especially for thermal faults and electrical breakdown is also observed. Before these VO can be utilized in power transformers, it is necessary to ascertain whether the limitation that has been specified for MO is also applicable to PO and RBO.

1.2 Problem Statement

Since the failure of in-service transformers could be costly, it is essential to understand the oil characteristics; this can be carried out through accelerated thermal ageing study. The ageing characteristics of MO knowledge is well established as it has been research extensively [35]–[37]. On the other hand, the ageing studies on NEO are currently ongoing [19]. According to the finding of these studies, the ageing characteristics of the NEO were different compared to traditional MO. It was discovered that insulation paper could benefit from the protection provided by NEO during the ageing process [19]. Furthermore, it was also implied hydrolytic protection and water-scavenging mechanisms that are present in NEO might delayed the ageing process of insulation paper [19].

Other research showed that most of NEO electrical properties are not significantly impacted by the process of ageing [19]. In the presence of copper, iron, and insulation paper, there was a clear reduction in the resistivity of NEO can be observed, according to certain studies. Besides, the dielectric dissipation factor of NEO may increase with time due to the presence of moisture in insulation paper [38]. Physicochemical properties of NEO may also be affected by aging process [1], [8],