Indonesian Journal of Electrical Engineering and Computer Science
Vol. 29, No. 2, February 2023, pp. 609~617
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v29.i2.pp609-617

Investigation of electrical properties of developed indigenous natural ester liquid used as alternate to transformer insulation

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Article Info

Article history:

Received Nov 21, 2021
Revised Sep 21, 2022
Accepted Oct 17, 2022

Keywords:

Antioxidants
Breakdown voltage
Flash point
Indigenous oil
Load test
Transformer oil
Viscosity

ABSTRACT

The performance of every electrical system depends on the different electrical devices especially transformers. Petroleum-based mineral oil is widely used for insulation and cooling purpose. The disadvantage of mineral oil is its low biodegradability and is a major threat to the ecosystem due to its poor oxidative stability. To remedy the drawbacks, focus on alternative fluids that can replace traditional mineral oil. Alternative liquids such as natural esters are used which do not panic the ecosystem. With the support of additives in natural esters liquids, the productivity of the oil can be increased, paving the path for the green conversion of liquids in high voltage applications. The purpose of this article is to analyze the electrical properties of the newly developed indigenous oil. The inhibited oil was insulating oil to which antioxidants were added such as 2,6-ditertiary-butylparacresol, butylated hydroxyl anisole and tertiary butyl hydro qunine to slow down the oxidation rate and to check the electrical properties. This article discusses the electrical properties of mineral oil, developed indigenous oil with and without antioxidants as per IEC62770 standards. A 1.1 kVA transformer was then designed in a laboratory for load tests and Indigenous oil performance under load was evaluated.

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1. INTRODUCTION

Insulating oil in transformers is usually called mineral oil. Crude oil is refined and processed into mineral oil. The transformer oil acts as an insulator to turn the choke on the transformer and also acts as a coolant. The behaviour of transformer oil under working conditions is impossible to predict. Traditional mineral oil is very harmful to the environment in the event of a transformer explosion. Therefore, the liquid dielectric must be non-toxic, easy to use, safe and thermally stable. Different ester oil is blended with antioxidants and nano powder to measure various properties. Synthetic antioxidants such as beta-carotene and tert-butyl hydro quinine (TBHQ) and selenium are preferred as natural antioxidants to reduce oxidation stability [1]. Physio-chemical tests were conducted for five litres of crude coconut oil. Breakdown voltages were measured for the ball electrode and sponge electrode. The results are compared with the IEC standard 60422 [2]. Trans-esterification process is adopted for pongamia oil to improve performance properties. Additional oil was conditioned to evaluate the oxidation stability for 48 h and 96 h. Properties are improved by processing the oil to meet the requirements of IEC62770 [3]. Analysis of dielectric properties and partial discharges has been done and results are compared for the mineral oil, with ELECTROL A, and FR3 [4]. An electrical and chemical property of coconut oil has been found out by experimentation and the chemical properties are comparatively good with respect to Transformer oil [5]. Coconut oil, Pongamia pinnata oil and palm oil which are available in the market are used for the investigation. Palm oil may be an alternative for mineral oil as BDV of palm oil is more than the coconut oil and pongamia pinnata oil [6]. The vegetable oils were considered for analysis of dielectric properties and Activation energy was computed [7].

The properties of extra virgin olive oil and castor oil under different aging conditions were examined. Exposure to vegetable oil degradation is more than mineral oil under aging conditions [8]. Analysis of various properties was carried out for thermal aging (with and without catalyst) of pongamia pinnata oil (PPO) and mineral oil (MO), which were sampled for 180 days at 110 °C. Based on the research results, pongamia pinnata oil can be a better substitute for liquid dielectrics in distribution transformers [9]. Development of vegetable-based insulation oils is necessary to replace the mineral oil as it is difficult to decompose and non-biodegradable [10]-[12]. Vegetable oil is good choice in transformers as they exhibit high flash point and environmentally friendly with respect to conventional mineral oil [13]-[15]. In this document, Thermally Modernized Kraft Paper (TUK) with Nomex in soybean-based natural oil esters was tested at 120 °C, 150 °C and 100 °C according to modified ASTM D1934[16]. Cooking oil which is already used (WCO) as an alternative to mineral oils. This encourages use of plant resources towards waste management [17]. The comparison has been made among five different types of natural ester liquids to assess their properties [18]. Investigation of the dielectric, physical, and chemical properties of different vegetable oils were carried out under thermal aging [19]. The aging properties of mineral oils and the behavior of TEs to evaluate the life expectancy of liquid dielectrics [20]. The quality of the treated rapeseed and palm oil is checked on the basis of moisture content, acidity and AC load, and the effect of temperature is examined when determining the optimal time required for processing the oil. [21]. Vegetable oil dielectric data, ie. Corn and cottonseed oils were compared with transformer oil in the frequency range from 330 Hz to 3 MHz and in the temperature range from 250 ˚C to 700 ˚C [22]. The properties of vegetable oils with antioxidants for a better insulation environment in transformer applications were investigated. Ester-based natural vegetable oils with BHT, BHA and gallic acid were selected as antioxidants [23]. The performance of single-phase step-down transformer using a 220 V power supply and a frequency of 50 Hz tested for dry condition and with crude coconut oil [24]. A 1 kVA transformer is used to test the insulating fluids [25].

Many researcher works on different vegetable oils which are fresh in nature. But Vegetable oils go rancid due to oxidation. The oxidation products are producing organic acids, sludges and other odour producing products. It contains butyric acids, polymerised sludges and carboxylic acids such as lactic acid, linoleic acids. Due to the availability of these products' vegetable oils will be unfit for human consumption. Often, vegetable oils produce unpleasant odours through oxidation and are also unsuitable. This oil can be used as dielectrics by removing unwanted products. The research work will be useful in the following aspects:

- Provide data on cheaper and highly efficient insulating oils for our electrical equipment.
- The survey will encourage the government to make agriculture more attractive to our farmers due to the increasing demand for these agricultural products.
- This will be very beneficial for our local farmers as it increases the value for money and the demand for this oil extract.
- This will help create jobs for our young school graduates.
- This will increase the standard of living of farmers.

In this research, an experiment was conducted to investigate the electrical properties of developed indigenous oil which is rancid in nature. These oils are chemically treated to maintain the edible state and then tested. In this article, introduction and the work involved has been explained in part I. Part II defines the experimental methodology and procedures. The results and discussion are listed in Part III and Part IV will be the conclusion.

2. METHOD

The presence of oxygen causes the oil to decompose. This will produce unwanted products in the oil. Hence the oil becomes rancid. Utilizing antioxidants components causes oxidation processes to be postponed or slowed down. By lowering the amount of free radicals in the oil, antioxidants prevent oxidation and the production of peroxide. They are working as free radical scavengers and are more effective at enhancing the oil's resistance to oxidation. The dielectric properties for smooth operation of the transformer are checked.

2.1. Experimental procedure

The procedure of removal of unwanted products in the present work is carried out as per Figure 1. The removal of unwanted products like gums, wax, free acid, bad odour, polar pigments and oxygen has been carriedout as per the procedure mentioned below:

- Removal gums and wax: Vegetable oil is placed in a steel container and added with boiled water (70˚C) and stirred for almost 10 minutes, and kept for 30 minutes. The supernatant oil was separated and stirred with boiled water at 60-70 °C for 30 minutes. This helps to remove gums, wax, and other water-soluble products from the oil.
- Removal of free acid: The oil is mixed with an equal volume of 5% sodium hydroxide solution and stirred for 20 minutes. The fatty acids react with the caustic soda and the lead of this acid to form sodium soap, which can agglomerate on heating and allow the soap to settle.
- Eliminate bad odour: vegetable oil is treated with steam for 1 hour to remove non-volatile oxidized elements. The supernatant oil layer is removed, leaving thick water.
- Removal of polar pigments and contaminants: The oil is then filled in adsorbent column of scaled impurities where pigments and other polar contaminants are absorbed, leaving the oil ready for use as a dielectric fluid.
- Dissolved oxygen removal and moisture traces & other polar components removal: controlled oil is bubbled with hot nitrogen gas.

Thus, the vegetable oil used in this experiment has been reconditioned in the above manner and used as dielectric in the electric equipment. The following step by step procedure has been adopted in the sample preparation to carryout experimentation.

Mineral oil (Electrol-IS335), developed indigenous oil without antioxidants and 1,108 ml of developed indigenous oil were mixed separately with 9 grams of DBPC (2,6-di-tert-butyl-p-cresol), BHA (butyl hydroxyl anisole) and TBHQ (butyl hydro quinine) and stirred with a magnetic stirrer to ensure complete dissolution were samples which were checked for different properties. Developed indigenous oil without antioxidants is called DM, developed indigenous oil with DBPC is called DM-1, developed indigenous oil with BHA is called DM-2, and developed indigenous oil with TBHQ is called DM-3.

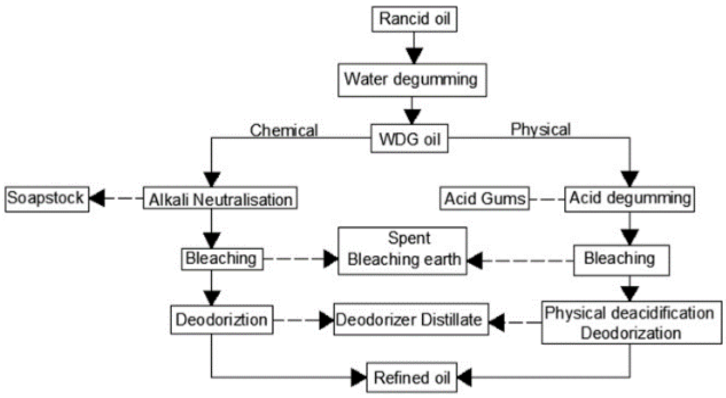

Figure 1. Process for removal of contamination

3. RESULTS AND DISCUSSION

Mineral oil and developed indigenous oil with different antioxidants is investigated to know the breakdown strength, dielectric dissipation factor, volume resistivity, relative permittivity and water content by conducting experiments. The range of various liquid dielectric properties according to the IEC62770 standard is listed in Table 1. After the experiment, the results of MO, DM, DM-1, DM-2 and DM-3is analyzed with the IEC standard and observed that their values were below the IEC62770 acceptance range.

Table 1. Liquid dielectrics standard ranges as per IEC62770

Characteristics	Acceptable limits	Mineral oil (MO)	DM	DM-1	DM-2	DM-3
Breakdown voltage, kV (BDV)	30 (min)	32	29	37	43	44
Dielectric dissipation factor (DDF)	0.05 (max)	0.00064	0.038	0.034	0.0511	0.0449
Resistivity at 90ºC	Under Consideration	35GΩ-cm	1.95GΩ-cm	2.81 GΩ-cm	1.068 GΩ-cm	2.384 GΩ-cm
Relative permittivity at 90ºC	2.1-2.4	2.4	3.12	2.01	3.079	3.045
Water content, ppm	200 (max)	11 ppm	501 ppm	454 ppm	340 ppm	484 ppm

From Figure 2, the BDV of DM-3 is more than MO, DM, DM-1, and DM-2. This shows that the breakdown voltage of DM-3 is greater than other oils. The impurities present in the oil had a significant effect for dielectric strength reduction of the insulating oil. Figure 3 shows the dielectric scattering coefficient of all types of oil, and the observed value is within 0.05 of the standard limits. The desired low oil loss coefficient is achieved except DM-2. Dielectric dissipation factor is a crucial indicator of how much energy is lost in a substance. From Figure 4 volume resistivity value has been observed. MO is having higher resistivity compared to Indigenous oil without and with antioxidants. DM-1 is having better value compared to DM, DM-2, and DM-3. Higher the value of resistivity, the insulating property is better.

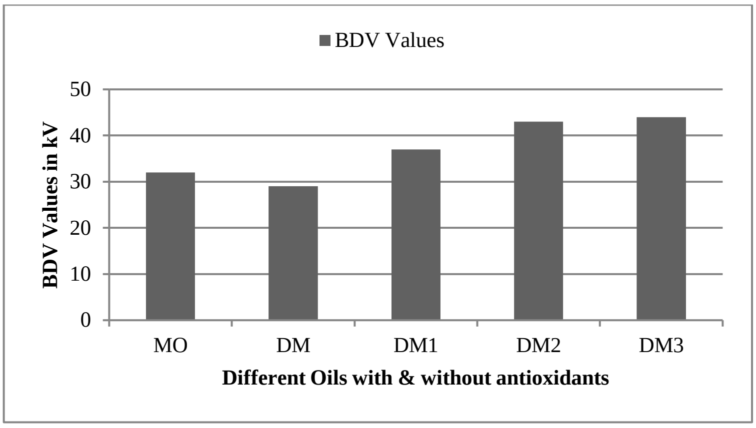

Figure 2. BDV Values of oils

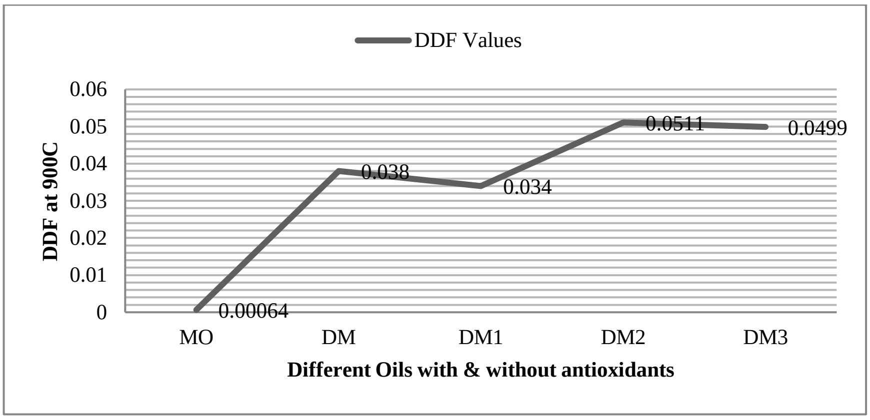

Figure 3. DDF of all types of oil

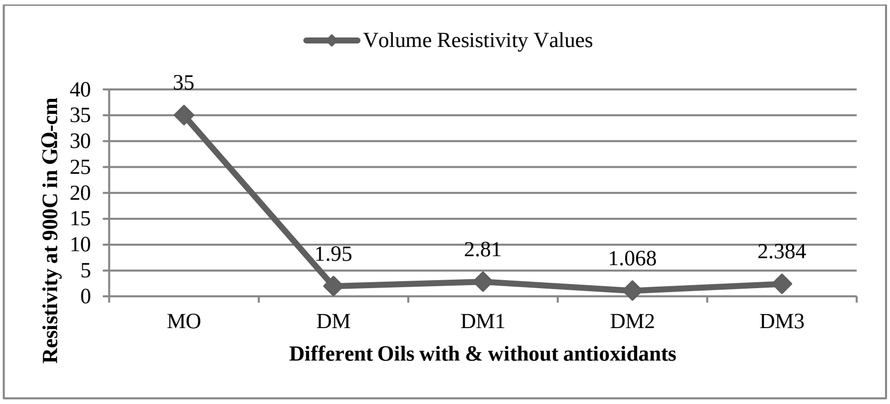

Figure 4. Volume resistivity of all types of oils

From Figure 5, Relative permittivity has been observed and the value of DM-1 is better compared to all other oils with antioxidants. A higher relative permittivity indicates that the substance can be polarized. As a result, the durable insulation can resist the strains associated with transformer operation.

From Figure 6, the water content in DM was higher and relatively high in DM-1, DM-2, and DM-3 compared to MO. Higher water content indicates higher contamination in oil. Water has an impact on the insulation's dielectric properties and the rate at which it degrades. Lowering the moisture value, there is a scope for improving electrical properties.

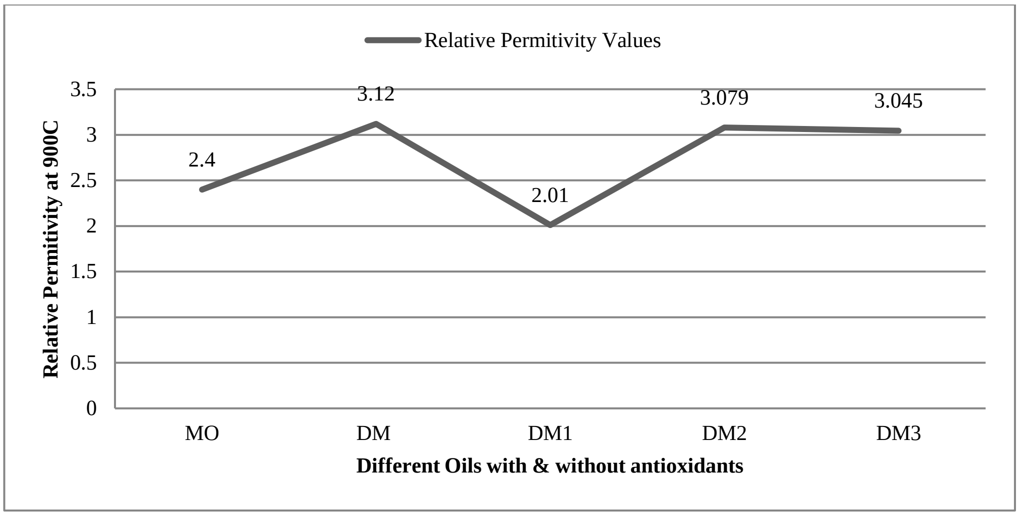

Figure 5. Relative permittivity of all oils

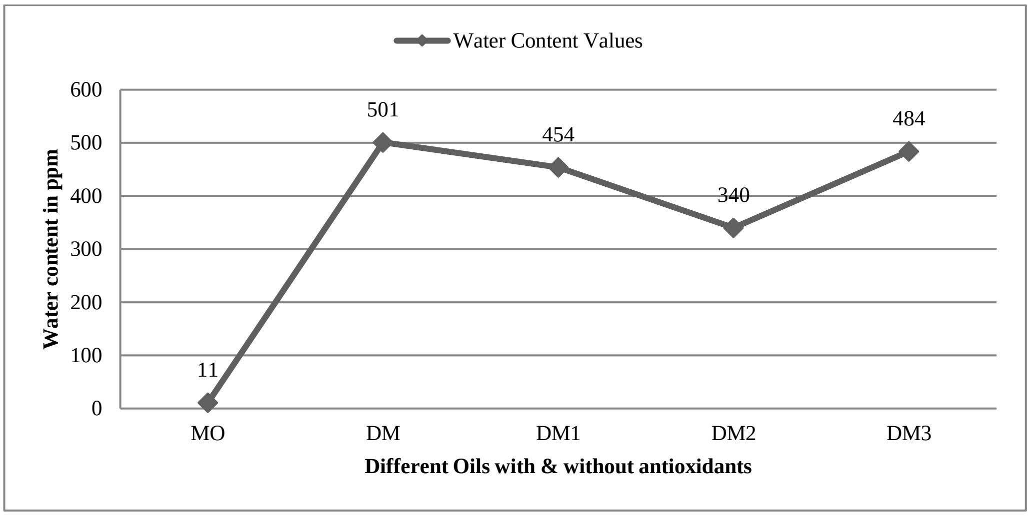

Figure 6. Water content of oils

Load test on transformer is dielectric fluids in power equipment perform dual functions: i) insulate conductors and ii) dissipate heat away from the conductors. Insulation characteristic is measurable in terms of volume resistivity and also dielectric dissipation factor (which is a measure of energy that is getting lost in the fluid due to its polar impurities). Heat is produced in the power equipment due to its I^2R factors.

Depending up on the amperage and dimensions of the conductor heat is generated. This heat will be increasing the temperature of the conductor and in turn will increase the resistance of the conductor. This continues until the power equipment is managing to take away the heat and keep the temperature of the system below a threshold value or else the equipment will fail. A prototype transformer design and purchased with a rating of 220/110 V, 10 A, Single phase, 50 Hz, Distribution Transformer as shown in Figure 7.

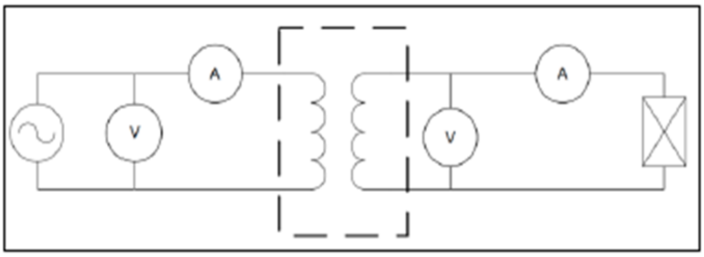

Figure 7. Drawing of single-phase step-down transformer with load

A distribution transformer with an output of 1.1 kVA, 220/110 V, 50 Hz, 10 A was purchased, which is shown in Figure 8. Primary side of the transformer is connected to supply. Secondary side of the transformer connected with ohmic load. Transformer load test is carried out with mineral oil, available natural ester oil (pure coconut oil) and developed indigenous oil also under dry condition. Initially transformer is operated under dry condition for about 120 minutes. The primary and secondary voltage and current has been noted for each interval of 10 minutes and also the variation in temperature has been noted. This procedure has been repeated for mineral oil, available natural ester oil (refined coconut oil) and also for developed indigenous oil. In the experiment conducted for load test on transformer as the amount of heat lost in the developed indigenous oil will be lesser as compared to the mineral oil and available natural ester oil (refined coconut oil) as per table 2 and efficiency has been improved in the developed indigenous oil as compare to mineral oil and available natural ester oil (refined coconut oil) as per table 3.

From Figure 9 and Figure 10, it is observed that the temperature increase in the developed indigenous oil will be lower, as heat is efficiently conducted away from conductors and the efficiency also higher compared to the mineral oil and available natural ester oil (refined coconut oil). The multiple effect of energy loss due to I^2R and increasing temperature in developed indigenous oil will be much lower as compared to the mineral oil.

Figure 8. 1.1 kVA, 220/110 V, 10A, 50 Hz, distribution transformer

Table 2. Variation of temperature in degree celsius with time intervals

Time interval in minutes	Dry condition	Mineral oil	Developed Indigenous oil	Available natural ester oil (refined coconut oil)
0	29	30	27	30.4
10	30	31	27.4	30.8
20	31	31.5	27.8	31
30	32	32	27.9	31.6
40	33	32.7	28	32
50	34	33	28.5	32.6
60	35	33.4	29	33
70	36	34	29.5	33.6
80	37	34.1	30	34
90	38	34.7	30.4	34.2
100	39	35	30.8	34.6
120	40	35.8	31	34.8

Table 3. Variation of efficiency with time intervals

Time in minutes	Mineral oil	Developed indigenous oil	Available natural ester oil refined coconut oil
0	94.56	98.94	98.01
20	94.2	98.28	98.09
40	93.26	98.16	98.08
60	93.69	96.87	96.31
80	93.39	97	96.88
100	94.17	98.68	98.25
120	94.2	98.82	98.42

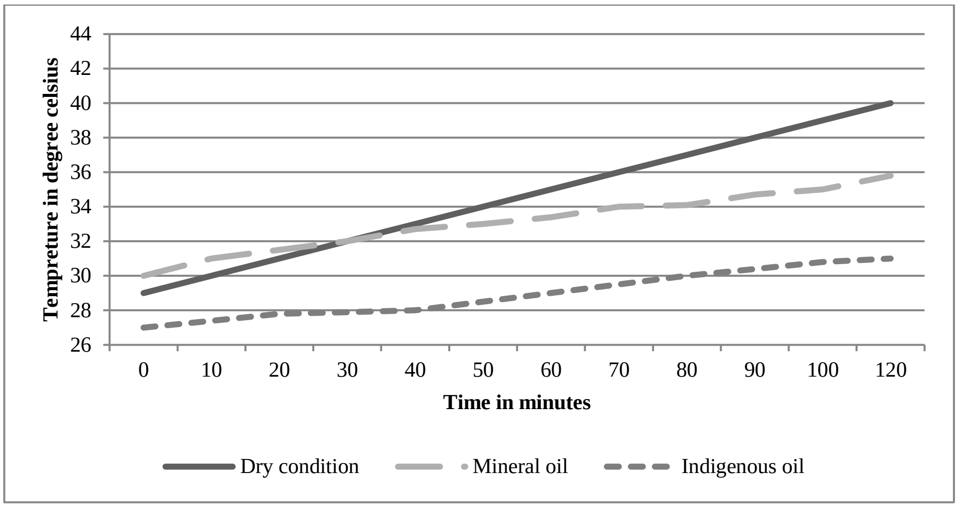

Figure 9. Temperature v/s time interval

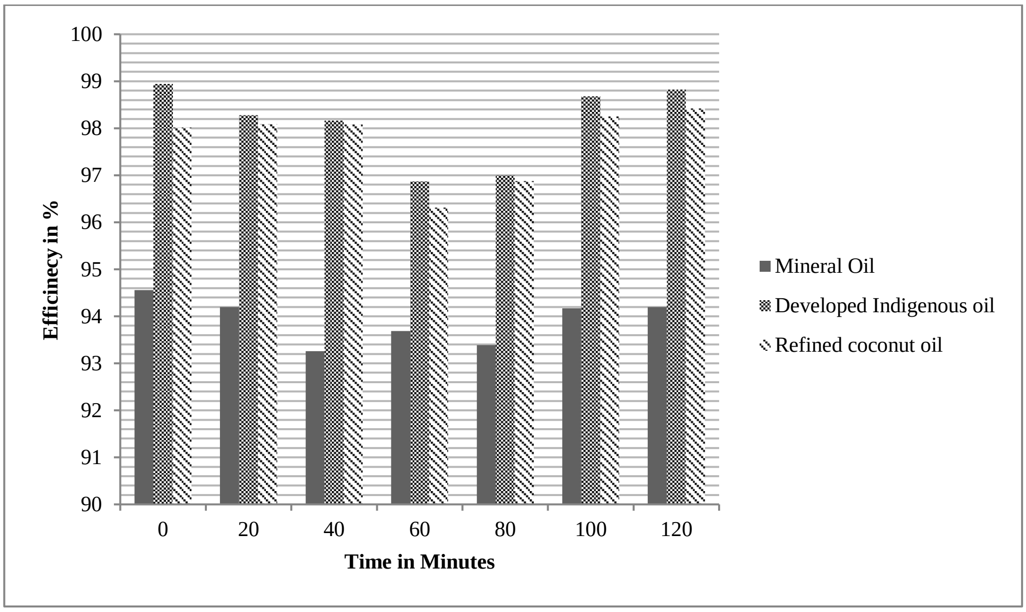

Figure 10. Efficiency curve

4. CONCLUSION

Insulating properties will act as the most important active part of high-voltage equipment. The experimental results indicated that BDV of developed indigenous oil with antioxidants is enhanced by 151% compared with developed indigenous oil without antioxidants. After adding antioxidants, the electrical properties like dielectric dissipation factor are found to be well within the limits. The volume resistivity of oils is found to be with in the standard limit. In the similar manner, relative permittivity of DM, DM-1, DM-2 and

DM-3 has been observed and determined that the value will be within the standard values of IEC62770. The test results above confirm that developed indigenous oil mixed with antioxidants will become substitute and is also environmentally friendly through biodegradation. Research has shown that the investigated natural ester-based vegetable oil is a promising alternative liquid insulation for high-voltage devices such as transformers. It is observed that the temperature increase in the developed indigenous oil will be lower, as heat is efficiently conducted away from conductors and the efficiency also higher compared to the mineral oil and available natural ester oil (refined coconut oil). The multiple effect of energy loss due to I^2R and increasing temperature in developed indigenous oil will be much lower as compared to the mineral oil. Therefore, the developed indigenous natural ester liquid dielectric serves as substitute to mineral oil in terms of oxidation stability, dielectric properties and acts as a better cooling medium and is environmentally friendly.

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