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NEW NATURAL POLYESTER TO BE USED IN POWER AND DISTRIBUTION TRANSFORMERS

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Abstract

There is a great effort and continuous work to get benefit of renewable resources as much as possible. According to this concept of energy conservation, there are many trials to get an insulating liquid instead of mineral oil to be used in power equipment as an insulating liquid. This is because mineral oil has shortages in the environmental aspects such as being nonrenewable, poor biodegradable and harmful for soil if splits whereas natural ester vegetable based oil is readily biodegradable, comes from renewable source and has very good insulating properties. There are several kinds of natural esters approved as insulating liquids and are in use practically. In this paper, a polyester of used frying oil has been prepared, treated with DBPC (2,6-di-tert-butyl-p-cresol) 2% w/w. Then, a simple module of electric transformer was constructed and filled with the prepared natural polyester to be tested as insulating liquid according to the(American Society for Testing and Materials ASTM) methods and the **(**International Electro-technical Commission IEC) regulations. The module has been put under normal operation conditions for a specified period of time, then the insulating liquid was tested after aging conditions. The results were compared with the IEC standards. The results are satisfying and reliable.

1. Introduction

Mineral oils are widely used as insulating and cooling liquids in electrical equipments. However, there are many alternatives of the mineral oils right now for many purposes, mainly economical and basically environmental. Vegetable oils are promising ones in this respect.

Vegetable oils which have high concentrations of saturated fatty acids are more stable to oxidation but they have high melting points whereas vegetable oils which have unsaturated fatty acids are highly unstable to oxidation and have low melting points. The most suitable vegetable based oil, being natural ester, is that having low melting point, pour point and viscosity has high breakdown voltage and high oxidation stability**. [1]**

Therefore, eight of the vegetable oils have been selected for investigation as promising insulating oils, having the advantage of low cost and environmentally appreciated. These oils are castor oil, jatropha oil, linseed oil, mustard oil, jojoba oil, rapeseed oil, radish oil and used frying oil. These oils have been treated with methyl alcohol to transform into methyl ester. The test results showed that; only four esters of them namely; linseed ester, rapeseed ester, radish ester and used frying ester have promising chemical, physical and electrical properties**[2].** Thus, treatments with pentaerythritol have been carried out on these four esters producing polyesters which are promising as insulating oils for use in electrical equipments. Only two polyesters showed reasonable characteristics with IEC standards. which are linseed polyester and used frying polyester. The latter has been selected for further investigation in the present paper as it is less costly.

2.Properties of vegetable based oils

Pentaerythritol polyesters are called synthetic esters and they have suitable dielectric properties. They are more biodegradable than mineral oils or High Molecular Weight Hydrocarbons (HMWHs). Their high cost compared to other less-flammable fluids generally limits their use for electric equipments and electric transformers. However, other specialty

applications such as relatively low viscosity, high lubricity, and very low pour point properties justify their higher cost. **[3]**
Further, oxidation stability is one of the major characteristics to be considered on dealing with vegetable based insulating oils. Oxidation causes increase of polarity due to acidity increase that accelerates cellulose ageing. However there are some of the vegetable based oils that have good characteristics. Meanwhile Envirotemp FR3 which is a natural ester is also vegetable based insulating oil, and is widely used several years ago. It has a higher dielectric breakdown voltage than mineral oil. It has a higher susceptibility to absorb moisture from the kraft paper, which is a better advantage than the mineral oil. This characteristic of ester oil is uniquely important as it reduces the rate of kraft paper degradation and so elongates the life cycle of the oil-filled electric transformer. It also has a high flash point, which invariably reduces the risk of transformer fires due to insulation oil burning after arcing faults inside the transformer. In fact it generates ethane and hydrogen under non fault conditions. Ethane formation can be an advantage as it is an indicator of transformer sealing failure. [**4],[5]**

Furthermore, Biotemp is an example of biodegradable electrical insulating fluids created from high oleic vegetable oil. It has excellent dielectric characteristics with high temperature stability and superior flash and fire point. It also has excellent compatibility with solid insulating materials and is biodegradable in a short time period. Due to its great affinity of to absorb water, the life of insulation paper can be increased in comparison with mineral oils. It was proven that Biotemp/Kraft paper has double the life of mineral oil/Kraft paper with tensile strength and degree of polymerization measurements validating this conclusion and this allows a higher hot spot temperature in the winding. **[6]**

3. Experimental arrangement and investigation procedure

To evaluate the full scale accelerated ageing of natural ester, it is exposed , as insulating system, to elevated levels of thermal, mechanical and electrical stresses.

3.1. Materials And Chemicals

Used frying oil - Methyl alcohol- Sodium hydroxide- Pentaerythritol- Xylene- p-toluenesulphonic acid- DBPC(2,6-di-tert-butyl-p-cresol)

3.2. Investigation Procedure

1- Used frying oil is converted to methyl ester by transesterification process, then methyl ester is reacted with pentaerythritol and converted into erythrityl polyester

DBPC(2,6-di-tert-butyl-p-cresol) 2%w/w antioxidant is added to the used frying erythrityl yield

2- A small current transformer 150/1 Ampere is put in a transparent container fitted with 2 copper electrodes and a well-sealed cover fitted with a gas valve. The container was filled with used frying oil erythrityl and then connected to the power supply to simulate operation conditions of a transformer. Fig. (1) Then, the apparatus was kept under operation for one month.

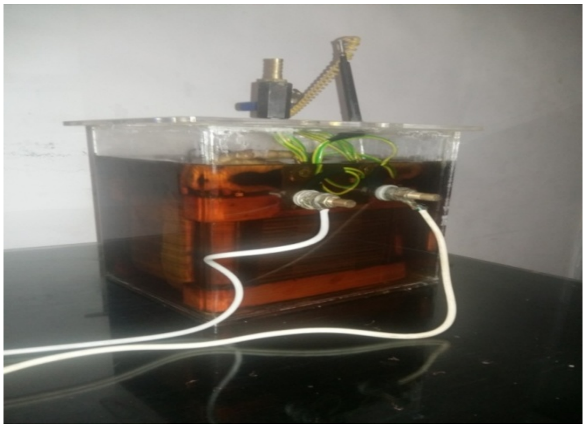
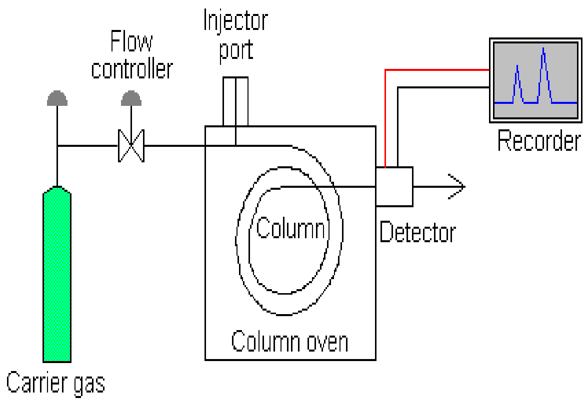


Figure (1)

3- Thereafter, the acidity of the oil, its breakdown voltage and dissolved gases are measured and compared with the corresponding IEC Standards.

Dissolved gas analysis is carried out by using Gas Chromatograph analyzer as shown in Fig. (2) in a simplified form. **[7]**where,
i) The Gas sample injected into the column.
ii) Gases are absorbed onto carrier walls at different rates, thus separating out different gases
iii) Gas quantities are determined as gases exit the column into detector unit.



Figure(2) Gas Chromatography

4. Results and Discussion

Table (1) presents a comparison between oil properties data before and after operation for one month.

Table(1)Characteristic tests before and after operation

Tests	Before performance	After performance for a month	IEC standard values
Breakdown voltage	45	27	≥35 KV
Flash point	177	170	≥250∘C
Viscosity at 40°C	28	30	≤50mm²s⁻¹
Viscosity at 100°C	8	12	≤15mm²s⁻¹
Acidity	0.06	0.094	≤0.06mg KOH
Water content	47	112	≤200 mg kg⁻¹

One can see from the results that the breakdown voltage decreased during operation while the acidity increased . This resembles what happens under the same conditions in the case of mineral oil operation.

Further, it is found that the viscosity is slightly increased, while the water content increased but within limits of IEC standards.

Furthermore, the flash point almost remained the same, still being under the limits for natural ester standards according to the IEC standards, but it exceeds that accepted for mineral oils.**[8]**

The dissolved gases analysis, resulting after putting the insulating liquid under operation conditions for one month, are also shown in Table(2).The gas analysis process has been carried out according to the code for examining analysis of dissolved gases described in IEC 60599**[9].**

Table (2) Dissolved gas analysis

Gas	Conc.(ppm)	IEC
Hydrogen (H_2)	5	100 ppm
Methane (CH_4)	27	50 ppm
Carbon Monoxide(CO)	181	200 ppm
Carbon Dioxide (CO_2)	1920	5000 ppm
Ethylene (C_2H_4)	12	50 ppm
Ethane (C_2H_6)	28	50 ppm
Acetylene (C_2H_2)	0	5 ppm

Examination of Table (2), one gets the following ratio;CO_2/CO=10.6. According to the IEC 60599, this ratio is an indication of the quality of the insulation properties. The ratio CO_2/CO should be according to IEC in the range 3.0 to11.0 in order to avoid any degradation effect of the insulating oil on the insulating paper of the transformer.

Further, the total dissolved combustible gases (TDCG) is defined as the sum of the combustible gas concentrations as follows:

$$TDCG = H_2+CH_4+C_2H_2+C_2H_4+C_2H_6+ CO$$

It is an indication of the conditions of the insulating oil after being under operation. For example this number for the presently investigated oil after being put under operation for one month, as given in Table (2) is: TDCG = 5+27+0+12+28+181=253

which is within the acceptable range for normal transformer oil operation, as given by IEC standards.

Furthermore, the dissolved gases analysis can be an indication of the expected transformer faults. These dissolved gases are produced under faults due to mainly thermal, arcing and partial discharges. Then, the ratios of the specific dissolved gas concentrations can be processed using predefined criteria. This gas analysis can indicate one or more possible fault states of a transformer and thus allows taking necessary action to prevent fault.**[9],[10]**

According to IEC Standards 60599 four level criteria classify risks of transformers as follows in Table(3)

Condition (1): TDCG below this level indicates that, the transformer is operating satisfactorily

Condition (2): TDCG within this range, indicates greater combustion than normal level. Action should be taken to avoid protect the transformer.

Condition (3): TDCG within this range indicates a high level of decomposition. Immediate action should be taken to save the transformer.

Condition (4): TDCG within this range indicates excessive decomposition. Continued operation could result in failure of the transformer.**[10]**

Table (3) Dissolved gas concentrations (ppm)

Status	H_2	CH_4	C_2H_2	C_2H_4
Cond.(1)	<100	<120	<35	<50
Cond.(2)	101-700	121-400	36-50	51-100
Cond.(3)	701-1800	401-1000	51-80	101-200
Cond.(4)	>1800	>1000	>80	>200

Status	C_2H_6	CO	CO_2	TDCG
Cond.(1)	<65	<350	<2500	<750
Cond.(2)	66-100	351-570	2501-4000	1921-4630
Cond.(3)	101-150	571-1400	4001-10000	1921-4630
Cond.(4)	>150	>1400	>10000	>4630

When TDCG or one of them exceeds the IEC limits, diagnosis of faults is accomplished via a simple coding scheme based on ranges of ratios (CH_4 /H_2 , C_2H_2 /C_2H_4 , C_2H_4 /C_2H_6) called IEC basic ratios, in which these gasses ratios have a code illustrated in the first part of (Appendix A) according to IEC 60599 (1978-1999) and the rest of the Table indicates the diagnosis of the fault and the explanation of how it occurred to take a suitable action.

Comparing the results of the dissolved gases analysis with the standard IEC 60599, one finds that; all combustible gases are within the acceptable limits which allows the insulating liquid to be used safely in the power equipments.

However, the obtained results are promising for future wide use of vegetable-based oil as insulating and cooling materials for electrical equipment, a comparison with the mineral oil can be useful in the present discussions on this investigation.

In this respect, it was found that the dissipation factor and the absolute moisture of natural ester is higher than those in mineral oil. In fact, natural esters have much higher tolerance for moisture and have saturation level greater than 1000 ppm of water compared to 40-60 ppm for mineral oil.**[8]**

Further, ageing stability of the mineral oil and the natural ester are compared by the heat accelerated test with regarding to oxidation stability. The result is that the natural ester is much more susceptible to oxidation than the mineral oil. This may be a scribed to that it absorbs water 15 times higher than the mineral oil. The oxidation process also increases the viscosity and polymerization of the natural ester. For that, hermetical sealing is required to avoid such problems of natural ester**.[11]**

Furthermore, natural ester has higher absolute moisture content than mineral oil in the ageing process while mineral oils have much higher relative moisture content than natural esters. **[12]**

In this work, the authors considered these polyesters as a natural esters because they have vegetable oil origin and compared their results with natural esters IEC standards which is more restricted than that of mineral oil and the rest of insulating liquids.

5. Conclusion

Proper treatment of some of the vegetable based oils as alternatives of the mineral oils for use as insulating and cooling materials in electrical equipment are found promising. The results of the present work shows that, the used frying oil properties, after being treated in the manner detailed in the paper, have been considerably improved to agree with the required values of the IEC 60599 standards. Thus it can be used as an alternative of the mineral oil with the advantages of low cost and harmony with the environmental conditions.

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