International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Preparation and Characterization of Chemically Modified Vegetable Oils as Liquid Insulation in Transformers

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Abstract: Due to demand for development of sustainable alternative liquid insulation for transformers, vegetable oils have attracted many researchers as potential substitute to traditionally used mineral oil. Even though vegetable oils have better dielectric characteristics, they have some demerits related to its flow nature due to presence of fatty acid content in it. In this work, it is proposed to study the characteristics and analyze the suitability of crude and refined form of ground nut oil and gingelly oil as liquid insulation after processing for removal the fatty acid components. For removing the fatty acid content from investigating oil samples, transesterification process is adopted in this work. Suitability of oil samples are investigated with measurement of the properties related to flow characteristics (viscosity and pour point), electrical characteristic (breakdown voltage) and thermal flammability characteristic (flash point). The investigation reveals that the investigated vegetable oil samples have necessary characteristics to be an alternative to traditional transformer oil in future.

Keywords: Breakdown Voltage, Flash Point, Liquid Insulation, Pour Point, Transformer, Transesterification, Vegetable Oil, Viscosity

I. INTRODUCTION

In power system network, transformers are one of the unavoidable and important equipment particularly for transmission and distribution of electrical power from generating stations to last consumer.

Manuscript received on February 10, 2020.
Revised Manuscript received on February 20, 2020.
Manuscript published on March 30, 2020.

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The reliability and expected life time of transformers are majorly depending on the conditions of liquid and solid insulation used in it. When the stress level on insulation increases, there are possibility of deterioration of condition of insulations and thus transformers. Hence insulation should provide the proper stress withstanding capacity.

Among the insulation used in transformers, liquid insulation is predominant in the aspect of acting as insulation, providing path for removing heat as coolant and also as ageing marker by predicting the condition of transformer with the content available in liquid insulation. One of the petroleum's derivatives, namely mineral oil (also termed as transformer oil) is mostly used liquid insulation for several decades due to its merits and its recognition as per required characteristics of liquid insulation. However as year passes, the mineral oil suffered some setbacks due to its poor biodegradability which will affect the ecosystems and contaminate the soil and water resources, poor thermal characteristics which will restrict the usage in ecologically sensitive areas, possibility of serious shortages of resources for mineral oil in future, etc.

With the above said aspects, many researchers are focusing towards alternative liquid insulation which will overcome the drawbacks of mineral oil and also environmental friendly. In the process, vegetable oils are gaining attention in the late 90s as a viable substitute to mineral oil, since they were derivatives of natural products, environmental friendly, plenty of availability of resources, its benefits on safety and health aspects, etc. Recent finding are also showing encouraging results as suitability of vegetable oil based natural esters as liquid insulation.

Vegetable oil based liquid insulation has the potential to be a competitor to mineral oil based on its properties, resource, cost, etc. Some commercial products on vegetable oil based natural esters for medium voltage and distribution transformers. However, some technical aspects have to be addressed which are preventing the deployment of vegetable oil as liquid insulation. Some of them are their higher value viscosity, pour point and permittivity, lower oxidation stability, etc. Vegetable oil based natural esters are the compositions of glycerol with three fatty acid molecule which are determining the behavior of oil and impacting the overall properties of oil. The properties such as viscosity and pour point have the decisive role in designing by posting the challenges and issues with flow characteristics and further impacting the cooling operation of transformers. In general, the values of viscosity and pour point of vegetable oil are much higher the expected values as per the standard specifications.

Those properties are majorly influenced by the presence of fatty acid content.

With the above concerns, in this work an attempt is made to remove the fatty acid components present in the investigating vegetable oil samples with chemical treatment process of transesterification.

Further the critical properties related with flow nature, electrical characteristics and thermal behavior of investigating oil samples are proposed to measure as per the standards for ensuring the capability of process and impact incorporated in properties before and after the chemical treatment process.

II. EXPERIMENTAL DESCRIPTIONS

In this section, sample selections, chemical treatment process and experimentation on measurement of properties are discussed.

A. Oil Sample Selection

For this investigation, it is proposed to study the vegetable oil with higher unsaturated fatty acid content in its composition. Based on proposed methodology, groundnut oil and gingelly oil are considered for the investigations as two oil samples with two categories of crude form and refined form. The oil samples are pre-processed with removal of suspended particles present in oil as per the guidance of CIGRE Work Group's Study Committee Report 12.17. Further the excess moisture present in the oil samples is removed with the drying treatment process. The processed oil samples are used for the investigation purpose. The oil sample descriptions are listed in Table 1.

Table 1 Oil Sample Descriptions

Sample No	Acronym	Oil Sample Details
Sample 1	CGNO	Crude Ground Nut Oil
Sample 2	RGNO	Refined Ground Nut Oil
Sample 3	CGO	Crude Gingelly Oil
Sample 4	RGO	Refined Gingelly Oil
Sample 5	TCGNO	Transesterified Crude Ground Nut Oil
Sample 6	TRGNO	Transesterified Refined Ground Nut Oil
Sample 7	TCGO	Transesterified Crude Gingelly Oil
Sample 8	TRGO	Transesterified Refined Gingelly Oil

B. Transesterification Process

Transesterification process is a chemical treatment process which exchanges the organic group of an ester with organic group of alcohol. Organic groups are the constitutes of fatty acid. The process is catalyzed with inclusion of acid or base catalyst. The transesterification process is carried out as per the following steps.

- Preparation of accelerate solution with mixing of 100ml methanol (CH_3OH) and 4.5g of Potassium Hydroxide (KOH) with the help of magnetic stirrer at uniform speed of 700rpm and temperature of 65˚C.
- The accelerate solution is added with 500ml of vegetable oil sample and mixed with magnetic stirrer for 3 hours at uniform speed of 700rpm and temperature of 65˚C.
- The chemical solution is then placed in separating funnel and shaken gently until the formation two layers (Lower layer – Glycerol and Upper Layer – Methyl Ester) from cloudy mixture of chemical solution.

The separated methyl esters are fatty acid removed oil samples which are further used for investigation. The experimental steps involved in transesterification process which carried out in this work are illustrated with picture in Figs. 1-4.

Fig. 1. Mixing of methanol and potassium hydroxide

Fig. 2. Mixing of accelerate solution with vegetable oil

Fig. 3. Oil sample after transesterification

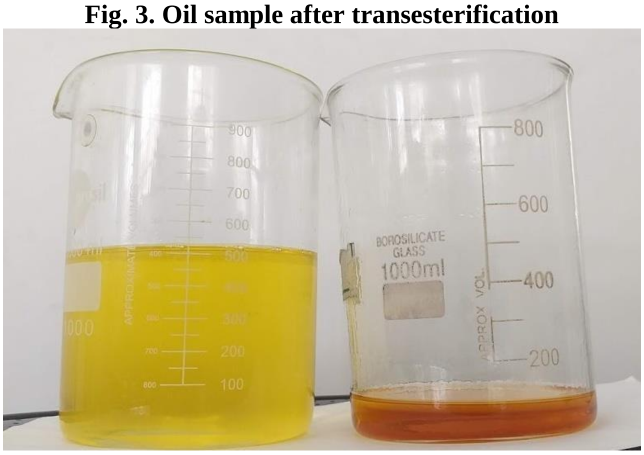

Fig. 4. Oil Sample after separation of ester and glycerol

III. EXPERIMENTATION PROCESS

For ensuring the reliability of oil samples, the properties of oil samples are measured as per the international standards. In this proposed work, the properties associated with flow nature, electrical characteristics and thermal behavior are measured as explained in this section.

A. Viscosity

Viscosity of liquid insulation is an indication of flow rate under specified condition. Higher viscosity means very slow flow of oil in the given medium which will surely influence in the heat transfer capability of medium. Viscosity is measured as per ASTM D445 in redwood viscometer. The viscometer is shown in Fig. 5. Viscosity is calculated from the time taken for the flow of 50ml of oil sample through orifice opening in redwood viscometer.

Fig. 5. Redwood viscometer – Setup

B. Pour point

For usage of liquid insulation in cold climate operating area, the low temperature flow performance is one of the important criteria which are identified with measurement of pour point value. With the reference to the standard ASTM D97-17b, pour point is measured at which temperature, oil samples stopped its pouring inside test cell as temperature reduces. The pour point measuring apparatus is shown in Fig. 6.

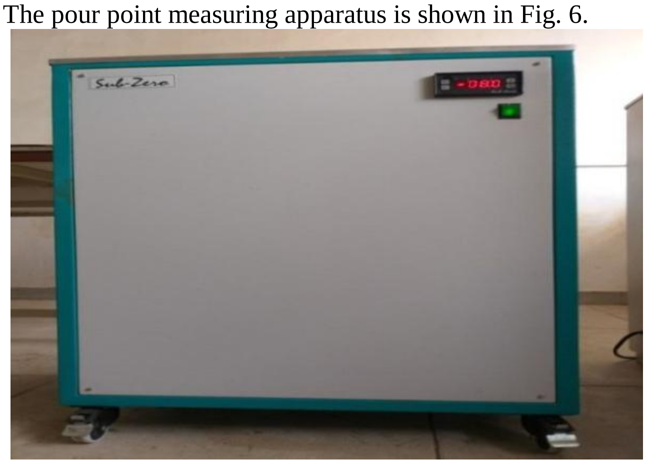

Fig. 6. Pour point apparatus - Setup

C. Breakdown voltage

Electrical characteristics of any insulation are evaluated with its breakdown voltage or breakdown strength. Breakdown voltage of liquid insulation is the lowest withstand voltage required to create spark inside the medium. Standard IEC60156 explain the procedure for determining the breakdown voltage of liquid insulation. With oil immersed 2.5mm gap spaced spherical electrode in test cell, breakdown voltage is found by taking mean value of 3 to 6 readings in breakdown voltage measurement process. The breakdown voltage kit is shown in Fig. 7.

Fig. 7. Breakdown voltage kit - Setup

D. Flash point

Flash point is one of the properties which determine the safest operating temperature of liquid insulation. Flash point is the lowest temperature at which a layer of flammable vapor formed on the surface of oil when any cause of fire is introduced. Flash point is measured with Pensky-Martin Closed cup apparatus as per the standard of ASTM D93. Pensky-Martin closed cup setup is shown in Fig. 8.

Fig. 8. Pensky-Martin closed cup flash point apparatus - Setup

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The properties of oil samples are measured as per the standard procedure before and after transesterification process.

A. Properties of Oil Samples before Transesterification

The properties of vegetable oil samples before transesterification are listed in Table 2.

Table 2 Properties of Oil Sample before Transesterification

Properties	Samples			
	CGNO	RGNO	CGO	RGO
Viscosity (cSt)	103	93	92	86
Pour point (^{O}C)	-5	-8	-4	-9
Breakdown voltage (kV)	33	35	30	34
Flash point (^{O}C)	340	320	340	330

From the results, it is inferred the following observations with the measurement of properties of oil samples before transesterification.

- Values of viscosity and pour point of all the samples are higher than the standard specified value of 50cSt and -10^{O}C respectively. These two properties will influence in the flow characteristics of oil samples in transformer.
- All the samples have higher breakdown voltage which will meet out the standard value of minimum of 28kV. Similarly, flash point temperature is also much higher than the standard value of minimum of 275 ^{O}C.
- Among the two categories of crude form and refined form, oil samples in refined form have lesser viscosity and pour point, higher breakdown voltage and lower flash point than that of crude form.
- From the above point, it is found that investigated vegetable oil samples have good electrical and thermal flammability characteristics and poor flow characteristics. These natures are majorly shown due to presence of glycerol content in the oil samples.

For improving the flow characteristics, viscosity and pour point have to be reduced with some techniques. In this work, transesterification is proposed as the viscosity and pour point reduction technique with removal of fatty acid components.

B. Properties of Oil Samples after Transesterification

The properties of Transesterified vegetable oil samples are given in Table 3.

Table 3 Properties of Oil Samples after Transesterification

Properties	Samples			
	TCGNO	TRGNO	TCGO	TRGO
Viscosity (cSt)	62	48	52	44
Pour point (^{O}C)	-7	-11	-6	-13
Breakdown voltage (kV)	31	33	28	32
Flash point (^{O}C)	320	305	315	310

From the results after transesterification of vegetable oil samples, it is inferred the following observations with the measurement of properties.

- Viscosities of oil samples have shown reduction from its original values. But only vegetable oil in refined form is satisfied the standard value after transesterification. Crude form of groundnut oil has higher value of viscosity, even though reduced from the original.
- Pour points of vegetable oil samples after transesterification have reduced to meet out the standard specification under only with refined form of oil samples. Crude form of oil samples has reduced its pour point values, but for fulfilling the standards, the value is not sufficient.
- Both breakdown voltage and flash point values are reduced after performing transesterification. Those values are within the standard range.

The percentage deviations in properties of vegetable oil samples from the original value after transesterification process are tabulated in Table 4.

Table 4 Deviations in Properties of Oil Samples after Transesterification

Properties	% Deviation in properties			
	TCGNO	TRGNO	TCGO	TRGO
Viscosity (cSt)	-39.81	-48.39	-43.48	-48.84
Pour point (^{O}C)	-40.00	-37.50	-50.00	-44.44
Breakdown voltage (kV)	-6.06	-5.71	-6.67	-5.88
Flash point (^{O}C)	-5.88	-4.69	-7.35	-6.06

The reduction in the properties of investigated oil samples may be due to the removal of fatty acid components present inside the vegetable oil after performing transesterification. Viscosity and pour point of vegetable oil in crude form have to be reduced further with transesterification process to meet out the standard specifications of all properties.

V. CONCLUSION

In this work, crude from and refined form of vegetable oil samples of groundnut oil and gingelly oil are investigated for the suitability as liquid insulation after the removal of fatty acids components. Removal of fatty acid glycerol from vegetable oil samples, the oil samples have been attributed in the development of improved flow characteristics for the application as high voltage liquid insul
ating medium. Based on analysis of properties of vegetable oils before and after performing transesterification process and also from the literatures, it is found that all the properties have changed from its original values due to the removal of fatty acid components. Values of properties of transesterified vegetable oil samples are more or less within the specified value as per IEEE recommendations for liquid insulation, even though properties get altered after the chemical treatment. From overall investigations, it is evident that a fruitful impact is created with the transesterification process in the process of developing the chemically modified vegetable oil samples as liquid insulation for the applications in transformers. Further for ensuring the reliability of these vegetable oil samples as a suitable candidate to replace mineral oil in future, an broad investigation may be carried out with impact on ageing behavior, response for application of impulse voltages, real field implementation in different transformers, etc.

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