Experimental studies on the influence of benzyl benzoate on viscosity of vegetable oil based insulating liquids for power transformer

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For insulating liquids in power transformers, the development of low viscous vegetable oil based liquids has been proposed in this work. The viscosity reduction of vegetable oil based liquids has been achieved by processing of the natural esters with different levels of concentration of aromatic solvent of benzyl benzoate. Two categories of vegetable oil based liquids, namely edible such as sunflower oil, palm oil and sesame oil, and non edible such as honge oil, neem oil and punna oil are considered for this investigation. The analysis is also extended to investigate the influence of benzyl benzoate on other critical properties of vegetable oil based liquids such as breakdown voltage, flash point, moisture content, acidity, and density. From the experimental results, it is revealed that inclusion of benzyl benzoate has shown considerable reduction in viscosity of vegetable oil based liquids. Also based on properties of processed natural esters, results have given away the positive encouragement towards the development of low viscous insulating liquids with combined benzyl benzoate and natural esters for application in high voltage power transformers.

1 INTRODUCTION

In power system network, demand for a higher rating of electrical apparatus has been increased over the years due to development in industrial sectors and commercial applications [1, 2]. This huge development increases the necessity for highly reliable and functional insulating materials, which will determine the dynamic performance of the electrical apparatus under the various degree of operating conditions [3, 4]. Among the insulation used in electrical apparatus, insulating liquids have been a very important one in electrical apparatus majorly in the transformers. It satisfies the requirement as insulation along with cooling within the same electrical apparatus [5].

Generally, insulating liquids is majorly used in oil-filled transformers for providing insulation between live conducting parts inside it and also removing the heat produced due to operating conditions. Apart from that, insulating liquids have been utilized in circuit breakers, capacitors, cables, etc.

Over the past many decades, petroleum-based mineral oil has been employed as insulating liquids on the electrical system due to its better dielectric and cooling characteristics under different operating conditions, the resource of availability and low cost [6].

Over the years, various kind of insulating liquids such as high-temperature hydrocarbon, silicon oil, and synthetic esters are also developed for employing in different applications based on requirements. But still in high voltage transformers, mineral oil based transformer oil is used as insulating liquids. Presently, many researchers are focused towards development of alternate insulating liquids to mineral oil due to mineral oil’s downside aspects such as non-biodegradable nature, the possibility of production of toxic gases, reduction in available petroleum resources for further applications in future, etc. [7].

By considering the above aspects and for overcoming those problems, vegetable oil based liquids have gained attention among various researchers for developing insulating liquids for future applications in high voltage apparatus. Because, vegetable oil based liquids have better biodegradable nature, non-toxic nature, huge availability of resources all over the globe and similar characteristics as like mineral oil insulation [1, 8].

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Vegetable oils based insulating liquids have contained triglycerides constitution which will be the influential component in determining the nature of vegetable based natural esters. Triglycerides in vegetable oil are present as saturated fatty acids and unsaturated fatty acids (mono-, di-, tri- and poly-) esters. A higher percentage of unsaturated fatty acids in vegetable oil indicate higher susceptibility to oxidation and lower viscosity. Higher content of saturated fatty acids in vegetable oil is a sign of the higher value of viscosity and less prone to oxidation process [8]. The higher viscosity of insulating liquids leads to poor heat transfer characteristics inside the application field, such as high voltage apparatus. Further, it may lead to unwanted consequences such as a reduction in the lifetime of insulating liquids and concern apparatus. Various research works are carried out to reduce the viscosity of vegetable oil based natural esters using various methodologies such as thermal breaking, transesterification, blending with low viscous oil samples and inclusion of viscosity reducing agents [9].

In the thermal breaking method, the temperature of oil samples is increased for reducing the viscosity. Long term influence on viscosity is low for this method since once application of temperature is kept off, viscosity slowly regains its original value [10]. In blending method of reducing viscosity, characteristics of vegetable oil based natural esters are almost overlooked by the low viscous medium used in the process. Transesterification is another way of reducing viscosity of vegetable oil based liquids by producing low viscous methyl compound with chemical processes [10]. For reducing the viscosity of vegetable oil based natural esters ultrasonic wave treatment is employed with different operating temperature and operating time. Every method has its pros and cons in many aspects such as percentage of reduction, influence on other properties of investigated oil samples, etc. [10].

Further, in petroleum-based industry, the viscosity of crude oil is reduced by adding some aromatic solvents for the transportation purpose. Chemical solvents such as tertamyl methyl ether (TAME), methyl tert butyl ether (MTBE), toluene (TE), xylenes (XYE), etc. are used in many studies of viscosity reduction in petroleum field [11, 12]. Also, benzyl acid derived benzyl benzoate is used as solvents in some applications related to paramedical and perfume industries [13, 14]. All of the above solvent compounds are used in various fields of applications rather than usage in insulation. All solvents have low viscous nature. But by comparing properties of above solvents, benzyl benzoate is the only component that has better flash point value than that of solvents used in other fields [15].

Based on the above literature, a novel initiative is proposed in this work to reduce the viscosity of natural esters by treating edible and non-edible natural esters are treated with a different volume percentage of aromatic benzyl benzoate. Effectiveness of the treatment process is estimated with the measurement of viscosity. Also, the influence of benzyl benzoate on other critical properties of treated oil samples such as breakdown voltage, flash point, moisture content, acidity, and density are studied to investigate the usefulness of treated oil samples as insulating liquids medium for high voltage power apparatus.

In this paper, section 2 explains about the materials used and methodology of the work. Section 3 describes possible causes of changes in properties based on methodology. Section 4 provides the results of measured characteristics of oil samples, and section 5 concludes the outcomes from the investigations.

### MATERIALS AND METHODOLOGY

In this work, two categories of vegetable oil based natural esters are considered for the investigation, namely edible and non-edible natural esters. Based on fatty acid content, cost, and local availability, the samples are selected. Selected vegetable oil based liquids and their fatty acid content are given in Table 1.

Since oil samples are collected from the regional manufacturer, selected samples are pre-processed to filter out suspended impurity particles presented inside oil samples to meet the standard for pure oil samples as per the report by CIGRE Work Group's Study Committee Report 12.17 [16]. The processed natural esters are utilized in this investigational work.

Vegetable oil based natural esters are generally having a much higher viscosity than traditional mineral oil. Viscosity values of natural esters should be decreased to an acceptable range for using those oils as insulating liquids and to be a better coolant as per standards [17].

Based on the literature on the properties of different materials used in the viscosity reduction process, aromatic benzyl benzoate is selected for this investigation. Benzyl benzoate is a colorless liquid with a faint, aromatic odor. It is both naturally and chemically occurring chemical used as an ingredient for fragrance, artificial flavor, preservative, and solvent in different fields of application [13]. The molecular formula for benzyl benzoate is \( C_{14}H_{12}O_2 \). Chemical structure of benzyl benzoate is given in Figure 1.

For preparing oil samples, benzyl benzoate is mixed with different category of natural esters at a different volume concentration of 10, 20, 30, 40, and 50%. 500 ml of base oil sample of natural esters are taken for investigation. Volume concentrations of benzyl benzoate are considered concerning the volume of base oil. Samples are prepared by mixing benzyl benzoate and vegetable oil based liquids. For complete dispersion of

| Category   | Oil Samples       | Saturated Fatty Acids (%) | Unsaturated Fatty Acids (%) |
|------------|-------------------|---------------------------|-----------------------------|
|            |                   | Mono | Poly | Mono | Poly |
| Edible     | Sunflower Oil (E1) | 11   | 30   | 59   |      |
|            | Palm Oil (E2)     | 48   | 37   | 9    |      |
|            | Sesame Oil (E3)   | 14   | 39   | 42   |      |
| Non Edible | Honge Oil (NE1)   | 23   | 19   | 58   |      |
|            | Neem Oil (NE2)    | 34   | 14   | 53   |      |
|            | Punna Oil (NE3)   | 14   | 57   | 29   |      |

TABLE 1 Investigating vegetable oil based liquids and fatty acid content
TABLE 2 Investigating property

| Property                  | Standard              | Measurement Equipment | Limit Value |
|---------------------------|-----------------------|-----------------------|-------------|
| Viscosity at 40°C (cSt)   | ASTM D445 [17]        | Redwood Viscometer    | 50 Max.     |
| Breakdown Voltage (kV)    | IEC 60156 [18]        | BDV Measurement Kit   | 35 Min.     |
| Moisture Content (ppm)    | IEC 60814 [19]        | Karl Fischer Titration| 200 Max.    |
| Flash point (°C)          | ASTM D93 [20]         | Pensky-Martin apparatus| 275 Min.   |
| Acidity (mgKOH/g)         | ASTM D974 [21]        | Titration             | 0.06 Max.   |
| Density (g/cm³)           | ASTM D4052 [22]       | Densometer            | 0.96 Max.   |

benzyl benzoate into natural esters, samples are stirred for 1 hour with a magnetic stirrer at a uniform speed.

For analyzing the effectiveness of reduction in viscosity of natural esters after inclusion of benzyl benzoate, the viscosity of oil samples are measured as per the standard of ASTM D 445 [17]. For that viscosity measurement, Redwood viscometer is used to find out the time taken for the flow of 50 ml of oil sample through the orifice. Also, for studying the effect of benzyl benzoate on other properties of oil samples, those properties are measured as per standards. Measurement standards and tools of investigating properties are listed in Table 2.

3 | POSSIBLE CHEMICAL REACTION BETWEEN VEGETABLE OIL BASED LIQUIDS AND BENZYL BENZOATE

Vegetable oil composition is constituted with glycerol which liquid compound consists of three fatty acids forming the triglycerides with varying composition and length of chains. These fatty acid chains can be saturated or unsaturated, and the chemical composition of each chain is different. Each chain consists of carbon and hydrogen atoms with varying single or double-bonded chains, depending on the degree of saturation or unsaturation.

In general, vegetable oil based liquids are extracted from vegetable seeds and plants which can attract more water than mineral oils due to the molecules with hydrogen bonds in the chemical structure. Moisture content in vegetable oil based natural esters is completely dispersed and dissolved in it. Dissolved moisture content cannot be visualized with the naked eye and can be found out with the physical or chemical test. Moisture saturation rate of natural esters is significantly higher than that of mineral oil [23].

During the inclusion of benzyl benzoate natural esters and subsequent stirring processes, there are some possibilities of induced chemical reactions. One of the possible chemical reactions of hydrolysis may take place primarily between benzyl benzoate and moisture in natural esters, which is naturally available along with vegetable oil based natural esters. Benzyl benzoate (C₁₄H₁₂O₂) may produce benzoic acid (C₇H₆O₂) and benzyl alcohol (C₇H₈O₂) due to hydrolysis reaction, which is illustrated in Figure 2.

During hydrolysis reaction, benzyl benzoate will take away moisture content present in vegetable oil based natural esters. Further one of the products of the hydrolysis reaction, benzyl alcohol is a low viscous solvent by its nature [24]. This low viscous benzyl alcohol may secondarily react with natural esters as a solvent and may lead to dilution processes. Those possible dilutions may be lead to a reduction in viscosity of natural esters [25].

4 | EXPERIMENTAL RESULTS AND DISCUSSION

Experimental results of proposed investigations before and after the inclusion of benzyl benzoate are presented in this section.

4.1 | Properties of based benzyl benzoate and vegetable oil based liquids

Properties of benzyl benzoate and edible and non-edible natural esters are measured according to procedures specified in corresponding standards. Values of properties of benzyl benzoate and vegetable oil based liquids are listed in Tables 3 and 4 respectively.

From the properties of benzyl benzoate, the comparisons are made with IEEE standard [26]. Benzyl benzoate is a very low viscous liquid medium with the higher fire ignition temperature, i.e., flash point temperature. Also from the results, it is revealed that moisture content of the initial sample of benzyl benzoate is low. Benzyl benzoate has the ability of dielectric liquids with sufficient breakdown voltage, density and acidity.
From properties of base vegetable oil based natural esters, it is evident that selected vegetable oil based liquids have higher value of viscosity greater than the specified value of 50 cSt at 40°C by IEEE Guide for Acceptance and Maintenance of Natural Ester Fluids in Transformers [26]. From the values of other properties of vegetable oil based natural esters, it is found that selected oil samples have the potential to meet out the requirement for replacing traditional insulating liquids in the future. Higher value viscosity is one of the restrictions for the above claim. Hence viscosity reduction with natural esters must be done to derive a solution for problems associated with traditional mineral oil.

4.2 Analysis on viscosity of benzyl benzoate modified vegetable oil based liquids

Aromatic benzyl benzoate is added with selected natural esters as per our proposed methodology to develop oil samples with low viscous nature. For ensuring the objective of work, viscous nature of prepared samples is studied as per standard procedure, and variations in obtained results from original viscosity of base vegetable oil based liquids are pictorially given in Figures 3a and 3b respectively for edible and non edible natural esters.

Reduction in viscosity of natural esters is achieved by the inclusion of benzyl benzoate. Values of viscosity are reduced up to 46.12, 64.34, 58.3, 54.21, 50.23 and 64.1 cSt respectively for E1, E2, E3, NE1, NE2 and NE3 with 50% volume concentration of benzyl benzoate. It is evident from figures of viscosity variations that as volume concentration of benzyl benzoate increases, the value of viscosity reduces from its previous value.

Possible derivation of benzyl alcohol during the inclusion of benzyl benzoate with natural esters is a low viscous solvent by its property. Low viscous benzyl alcohol will mix with high viscous natural esters and yield low viscous oil medium. Reduction in viscosity may be due to the dilution process takes place between natural esters and low viscous benzyl alcohol, which is a solvent [23, 24]. As volume concentration of benzyl benzoate increases, there is a possibility of increasing ratio of benzyl alcohol, which results in a further reduction in viscosity of vegetable oil based natural esters.

Viscosities of proposed natural esters are reduced to lower values from its original values. Reduced viscosities are more or less nearer to the standard values. Further viscosity may be reduced with some other treatment processes as per various literatures on viscosity reduction processes.
4.3 Analysis on other properties of benzyl benzoate modified vegetable oil based liquids

Inclusion of benzyl benzoate in natural esters also causes variations in other properties due to possible chemical modification. For analyzing the influence of benzyl benzoate on properties such as breakdown voltage, flash point, moisture content, acidity and density of natural esters, those properties are measured as per mentioned standards before and after inclusion of benzyl benzoate. Changes in the properties of natural esters are discussed in the following sections.

Breakdown voltages of edible and non-edible vegetable oil based liquids are illustrated respectively in Figures 4a and 4b as a pictorial representation for analyzing the influence of benzyl benzoate on breakdown voltages. From pictorial representation, it is evident that the inclusion of benzyl benzoate has an impact on breakdown voltages of vegetable oil based liquids. As concentrations of benzyl benzoate increases, breakdown voltages of edible and non-edible vegetable oil based liquids have also shown increment pattern. Breakdown voltages of edible vegetable oil based liquids have changed from original values of 35.4, 41.2, 38.66 kV to 48.24, 52.4 and 50.48 kV respectively for E1, E2, and E3. Similarly, for non-edible natural esters, breakdown voltages have modified from 43.2, 44.6, and 42.1 kV to 54.8, 59.6 and 56.32 kV respectively for NE1, NE2, and NE3.

Above results on breakdown voltages are justified with the investigation of moisture content of edible and non edible vegetable oil based natural esters which are shown in Figures 5a and 5b. Moisture content in insulating liquids is also influenced in breakdown strength of insulating liquids. Lower moisture content is one of the indications for higher breakdown voltages. In this research study, it is observed that the moisture content of vegetable oil based natural esters is reduced from its original value. Maximum percentages of reduction achieved with 50% volume concentration of benzyl benzoate are 27.19, 20, 16.67, 23.26, 17.07 and 23.6% respectively in E1, E2, E3, NE1, NE2, and NE3.

The possible chemical reaction during the experimentation process is mainly initiated with hydrolysis process, which will take up moisture content from the vegetable oil based natural esters. This is a major reason for the reduction in moisture content in natural esters after inclusion of benzyl benzoate. Reduction percentage in moisture content has shown increasing pattern as an increase in volume concentration of benzyl benzoate. This probable reduction in moisture content will increase the breakdown voltage of natural esters. By relating decrement in moisture content and increment in breakdown voltage, it is revealed that changes in breakdown voltage may also be due to the decrease in the moisture content of oil samples. This claim is visualized with the correlation between values of breakdown voltage and moisture content.

Inclusion of benzyl benzoate in natural esters also influences in flashpoint temperatures of natural esters. Flashpoint
temperatures of vegetable oil based liquids reduced from the original values as percentage volume concentration of benzyl benzoate increases. Reduction in flash point temperature may be due to the mixing of one of the yields from hydrolysis reaction. Benzyl alcohol has a property of less ignition temperature, which may be one of the causes for the reduction in flash point temperature. Percentage decrements in flashpoint temperatures attained with 50% volume concentration of benzyl benzoate are 15.79, 16.36, 13.79, 11.67, 15.52 and 11.67% respectively for E1, E2, E3, NE1, NE2, and NE3. Variations in flashpoint temperatures of natural esters are publicized in Figures 6a and 6b for edible and non edible natural esters respectively.

Acidities and densities of vegetable oil based natural esters are also modified after the inclusion of benzyl benzoate. Those modifications are exemplified in Figures 7 and 8. Variations in acidity before and after modification are also increased with increment in volume concentration of benzyl benzoate. Densities of edible vegetable oil based liquids E1, E2, and E3 are changed to 0.05, 0.043 and 0.051 mgKOH/g of oil correspondingly from initial values of 0.012, 0.011 and 0.017 mgKOH/g of oil for a maximum of 50% volume concentration of benzyl benzoate. In the same way, variations in non-edible natural esters NE1, NE2 and NE3 are observed such that densities are modified to 0.056, 0.056 and 0.059 mgKOH/g of oil from 0.023, 0.023 and 0.031 mgKOH/g of oil.
The chemical reaction between benzyl benzoate and moisture content will produce benzoic acid along with benzyl alcohol due to hydrolysis reaction. Likely reason for the increase in acidity nature of natural esters may be due to the mixing of benzoic acid with natural esters. As the increase in benzyl benzoate content, percentage of production of benzoic acid increases and further that will increase the acidity of natural esters [27]. With possible reduction in moisture, benzyl alcohol and benzoic acid may be produced from the benzyl benzoate. The reduction in moisture will increase the breakdown strength of liquids. At same instant, reduction in moisture will lead to production of alcohol and acids inside the medium, which will increase the acidity of oil sample. With combinational inference, increase in reduction of moisture in the mixed sample will be resulted in the increment in breakdown voltage and decrement in acidity.

From the experimental observations with density of oil samples after inclusion of benzyl benzoate, the density values have increased with proportional to volume concentration of benzyl benzoate included. With edible natural esters, the variation is steadily increasing after the sudden initial increment. But variations in densities of non-edible vegetable oil based liquids are steadily increasing from the original value of density. Maximum increment density variations for inclusion of maximum of 50% volume concentration of benzyl benzoate in natural esters are observed with changes in the initial densities of 0.92, 0.82, 0.86, 0.92, 0.92 and 0.94 g/cm³ to 0.957, 0.95, 0.97, 0.97, 0.98 and 0.98 g/cm³ for E1, E2, E3, NE1, NE2 and NE3 respectively. Above variations in density of natural esters are mainly because of the inclusion of external material and subsequent production of chemical components into vegetable oil based liquids. Inclusion of benzyl benzoate increases density values relatively proportional to the volume concentration of benzyl benzoate.

Thus benzyl benzoate produces alteration in properties of natural esters after its inclusion at different volume concentration. Impact of changes in properties after benzyl benzoate addition is proportional to the volume concentration of benzyl benzoate. The major cause for alteration in properties is byproducts developed due to the hydrolysis reaction between benzyl benzoate and moisture content. Values of properties of natural esters after inclusion of benzyl vegetable oil based liquids as insulating liquids as per IEEE recommendations. From overall investigations of properties, it is evident that benzyl benzoate added natural esters could be potential low viscous insulating liquids used in high voltage apparatus.

5 | CONCLUSION

In this work, experimental analysis is carried out with vegetable oils for developing low viscous vegetable oil based insulating liquids. Two categories of vegetable oil based liquids are mixed with different concentration of aromatic benzyl benzoate solvent and the following observations / conclusions are made:

1. With the inclusion of benzyl benzoate with vegetable oil based natural esters, reduction in viscosity of edible and non-edible category of vegetable oil based liquids has been observed. Reduction in viscosity is directly relative with the volume concentrations of benzyl benzoate. This observation of reduction in viscosity of studied samples from experimental results has given the scope for development of low viscous insulating liquids with vegetable oil based natural esters.

2. Based on analysis of other properties of natural esters before and after inclusion of benzyl benzoate, values of properties such as breakdown voltage, moisture content, flash point, acidity, and density have changed from its original values due to the impact of benzyl benzoate along with the reduction in viscosity.

3. From the literature and results obtained, possible primary hydrolysis reaction between benzyl benzoate and moisture content in natural esters may be one of the reasons for changes in the properties.

4. Values of properties of benzyl benzoate added vegetable oil based liquids are more or less within the specified value vegetable oil based natural esters as insulating liquids as per IEEE recommendations, even though properties get altered after inclusion of benzyl benzoate.

From overall investigations, it is evident that a fruitful impact is created with the addition of benzyl benzoate in the process of developing low viscous insulating liquids for the application in high voltage power apparatus.

As extension to this work, computational chemistry may provide the possible modification in the molecular state with necessary theoretical study to know the internal structure of liquids with quantitative and qualitative analysis about fatty acid content before and after inclusion of benzyl benzoate. Further for ensuring the reliability of these oil samples as a perfect representative for the potential candidate to replace traditional mineral oil, an extensive investigation may be carried out with impact on ageing behavior, gassing tendency, response for application of impulse voltages, real field implementation in different transformers, etc.

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REFERENCES

1. Fofana, L: 50 Years in the Development of Insulating Liquids. IEEE Electr. Insul. Mag. 29(5), 13–25 (2013)
2. Abd-Elhady, A.M., et al: Effect of temperature on AC breakdown voltage of nanofilled transformer oil. IET Sci. Meas. Technol. 12(1), 138–144 (2018)
3. Razzaq, A., et al.: Transformer oil diagnostic using an optical fibre system: A review. IET Sci. Meas. Technol. 13(5), 615–621 (2019)
4. IEEE Standard, C57.91: IEEE Guide for Loading Mineral oil immersed Transformer and Step Voltage Regulators. (2011)
5. Inyang, H.I., Kaanagbra, L.: Estimation of electric transformer service life from oil degradation kinetics. J. Electr. Eng. 133(19), 19–25 (2007)
6. Ommen, T.V: Vegetable oils for liquid filled transformers. IEEE Electr. Insul. Mag. 18(1), 6-11 (2002)
7. Peppas, G.D., et al.: Statistical investigation of AC breakdown voltage of nanofluids compared with mineral and natural ester oil. IET Sci. Meas. Technol. 10(6), 644–652 (2016)
8. Rafiq, M., et al.: Use of vegetable oils as transformer oils – A review. Renewable Sustainable Energy Rev. 52, 308–324 (2015)
9. Mohan Rao, U., Sood, Y.R., Jarial, R.K.: Ester dielectrics: current perspectives and future challenges. IETE Tech. Rev. 1–12 (2016)
10. Bakrutheen, M., Willjuice Iruthayarajan, M., Narayani, A.: Influence of ultrasonic waves on viscosity of edible natural esters based liquid insulation. IEEE Trans. Dielectr. Electr. Insul. 25(8), 1628–1635 (2018)
11. Hart, A.: A review of technologies for transportation of heavy crude oil and bitumen via pipelines. J. Petro. Explor., Prod. and Tech. 4, 327-336 (2014)
12. Hussein, H.Q., Mohammad, S.A.w.: Viscosity reduction of Shaniq Baghdad heavy crude oil using different polar hydrocarbons, oxygenated solvents. Iraq J. Chem.and Petro. Eng. 15(2), 39-48 (2014)
13. Riddick, J.A., Burger, WB., Sakano, T.K.: Organic solvents: Physical properties and methods of purification, 4, vol. 2, p. 430, John Wiley and Sons NY (1985)
14. Wohlarth, C.: Viscosity of benzy i benzoate. In: Lechner M.D., (eds) Viscosity of Pure Organic Liquids and Binary Liquid Mixtures. Berlin, Heidelberg: Physical Chemistry, Springer, p. 29 (2019)
15. Haynes, W.M.: CRC Handbook of Chemistry and Physics. Boca Raton: CRC Press LLC, 94, pp. 6–234 (2014)
16. Nair, B.: Final report on the safety assessment of Benzyl Alcohol, Benzoic Acid, and Sodium Benzoate. Int. J.Toxicol. 20(3), 23–50 (2001)
17. IEC Standard. C57.147: IEEE Guide for Acceptance and Maintenance of Natural Ester Insulating Liquid in Transformers. IEEE Power and Energy Society, New York, USA (2018)
18. Haynes, W.E.: CRC Handbook of Chemistry and Physics. Boca Raton: CRC Press LLC, 94, pp. 6–234 (2014)
19. IEC 60814: Determination of Water by Coulometric Karl Fischer Titration. IEC standard, (1994)
20. ASTM D93: Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester. ASTM Standard, (2012)
21. ASTM D974: Standard Test Method for Acid and Base Number by color Indicator Titration. ASTM Standard, (2014)
22. ASTM D4052: Standard test method for Density, Relative Density and API Gravity of Liquids by Digital Density Meter. ASTM Standard, (2015)
23. Rodriguez, R.D.V.: Moisture dynamics in transformers insulated with natural esters. PhD dissertation. Electr. Eng. Dept., University Carlos III of Madrid, (2015) https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwit_MM4ri7MvivJmWgKHZUUIU8QFjAQegQIwAQ&url=https%3A%2F%2Fwww.uc3m.es%2Fbitstream%2Fhandle%2F10016%2F21660%2Ftesis_rafael_villarroel_rodriguez_2015.pdf%3Fsequence%3D1&usg=AOvVaw07Mw36imS4yqDDGZjZ68PG
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