International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-2, December 2018

# A Chemically Customized Ester Fluid- A More Effective Liquid for Insulation

**Vishavdeep Jindal, Jashandeep Singh**

***Abstract*: Mineral transformer liquids are used as dielectric liquids from a long time and preferred by power utilities worldwide because of its good physical, mechanical & dielectric properties, ease of accessibility and low cost. But due to environmental constraints, non-biodegradability nature and less fire resistive nature of it proves to be destructive for surroundings as well as to the manpower dealing with it. Number of alternatives were suggested by researchers have been implemented in distribution and power transformers. In current research work, biodegradable modified synthetic ester fluid is proposed as an alternative to mineral transformer oil because of its electrochemical properties such as; dielectric strength, resistivity, flash and fire point, acidity and water content which have been practically analyzed in laboratory. Analysis reveals that ester oil has astounded fire resistive properties and moisture tolerant liquid over mineral oil.***

***Index Terms*: Oil Insulation, Synthetic Ester (SE), Mineral Oil (MO), Fire Point, Pour Point, Breakdown Voltage (BDV), Water Content.***

## I. INTRODUCTION

Due to the higher electrical power dependency of the society, the demand for reliable power supply is increasing [1]. In respect of fulfillment of electricity requirement of present and future generations, the transformer's protection and healthier condition is an important concern for the power industry [2]. The life of transformer eventually depends upon its insulation which, if fails will cause the failure of operation of transformer resulting in the interruption of supply [3]. Thus the insulation of transformer should be in accordance as required for its vigorous existence. The oil used in transformer tank and paper wrapped on its windings both act as the main key elements for providing insulation to the transformer [4]. Further paper condition depends upon its compatibility with the liquid in which it is immersed. The aging of insulating liquid by thermal and accelerating stress, greatly affect the solid insulation i.e kraft paper and cause degradation in its cellulose structure. Thus, it is important to consider the type and characteristics of dielectric liquid used for cellulose impregnation.

The mineral transformer oil is the first dielectric fluid which was adopted in medium and high voltage transformers since last centuries [5-6]. This is a refined by-product of petroleum based by–products obtained from crude oil through fractional distillation process [7]. It is preferred as a dielectric fluid commercially for high voltage devices because of its ease of accessibility, insulating characteristics and lesser cost. Mineral oil is a hydrocarbon product composed by linear and branched alkanes, paraffins and aromatic linkages [7-8]. Though this oil is widely accepted and has a number of advantages but still it lacks due to its poor fire resistance ability, low dielectric breakdown voltage and non- biodegradable nature. In addition to this the naphthenic crude oil reserves from which mineral oil is obtained are limited [9-10]. Paraffinic and Naphthenic are two main compositions of mineral oil which can be used as dielectric liquids but these oils have poor stability in terms of oxidation which is enhanced by doping it with additional inhibitors of compounds of poly-alkylacetol to make it usable for transformer [11]. These disadvantages led the industry to search for more possible alternatives [12-14] and a plenty of work has been done by researchers on the concerned area for the replacement of mineral oil with another insulating fluid.

An effort is made in current research work to provide a better substitute for mineral oil with a more biodegradable liquid having enhanced electrical and chemical dielectric properties such as: good dielectric and thermal properties, low viscosity, chemical and thermal stability, low flammability, compatibility with other transformer materials, miscibility with other liquids, environmental acceptability and low cost [15]. To make the change happen, the replacement of mineral oil with an ester fluid is the most remarkable way out in case of transformers.

The growing need of commercialization towards the eco-friendly and safe product have led to alternatives which are proposed and practically implemented as alternative sources for mineral oils. Esters have been adapted as an insulating fluid from the times when liquid immersed transformers were came into existence from 19$^{th}$ century but due to uncertain conditions and incompatibility, they were replaced by mineral oil [16]. From last few decades there has been a surge of usage of esters including liquids because of green credentials. Natural ester over mineral oil has advantages of environment concerns, biodegradability, non-toxicity, and is a sustainable source with carbon neutral characteristics [17]. Recent research shows that ester based fluids are in demand as a green product because it is safe to use and also environment friendly but its use is limited to distribution, traction, mobile transformers and other specialized applications.

**Manuscript published on 30 December 2018.**
***** Correspondence Author (s)
**Vishavdeep Jindal**, Research Scholar, Department of Electrical Engineering, IKG Punjab technical University, Jalandhar, Punjab, India.
**Jashandeep Singh,** Department of Electrical Engineering, BGGI, Sangrur, Punjab, India.

This paper analyses synthetic ester based fluid and is tested in laboratory to explore its insulating properties for desired outcomes.

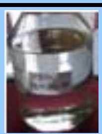
## II. EXPERIMENTAL SETUP AND TESTS

In order to find out the perfect alternative fluid, the fundamental aspects of physical and chemical properties of a synthetic ester liquid are examined by experimental procedures as designed by Indian Standards mentioned in Table 1. Each test was carried out individually with fresh quantity of sample. The final results are concluded after comparison of observed mean parametric values for this new ester fluid sample over standard mineral oil properties.

### A. Material Collection

The mixed esters of Pentaerythritol are prepared by using long chain of fatty acids having C5-10, C14 alpha olefin. The polyester prepared by this stuff consists of a muddle of polypentanoate, polyhexanoate, polyheptanoate and polyoctanoates of pentaerythritol in a molar ratio 1:1.32:0.45:0.15. This ester is a type of synthetic ester and it satisfies characteristics required for liquid insulation as of mineral oil for power transformer. The mineral oil analyzed in this study was collected from electrical power substation. Table 1 describes the comparison of basic physical properties and appearance of mineral oil & synthetic ester liquids used in this study.

**Table 1: Basic Properties of Insulating Liquids used in this Research Work (Mineral Oil and Synthetic Ester)**

| Property | Standard | MO | SE | Ref. |
|---|---|---|---|---|
| Material used | - | Petroleum crude oil | Synthesized from organic acids and alcohols | 11 |
| Principal components | - | Complex mixture of hydro-carbons | Plant based synthetic ester | 11 |
| Visual examination | ASTM D 1524 | Clear and bright | Clear and bright | 11, 18, 19 |
| Color | ASTM D 1500 | Pale Yellow | Light green | 20, 21, 22 |
| Physical appearance | - |  |  | 19, 22 |
| Density@ 20ºc (kg/cm$^3$) | IEC12185 ISO 3675 | 0.844 | 0.97 | 22 |
| Viscosity @ 40ºc (cSt) | ISO 3104 | 13.3 | 33.5 | 22, 23 |

To evaluate and relate the new synthetic ester oil with existing mineral oil in terms of environmental concern, breakdown strength, fire safety, physical properties and dielectric performance experimental procedures have been followed according to Indian Standards to have apparent and noticeable conclusions in this paper as described in further sections.

### B. Breakdown Voltage

Breakdown voltage (BDV) of an insulating fluid is one of the main parameters for the design of power transformer. It depends upon the physicochemical properties of the oil and impurities that can be present as well as the arrangement of electrodes. It determines the insulating strength of a dielectric fluid. It also indicates the existence of additional contaminants like water and other particles. Low value of breakdown voltage means oil has more amounts of impurities present [24]. The oil insulation test kit (Model No. OTS100M), manufactured by Siyanada Electronics is used for the measurement of BDV for mineral oil and synthetic ester in current research work as is shown in figure 1.


**Figure 1: Set up used for Measurement of Breakdown Voltage at Room Temperature**

The same procedure is adopted for measurement of BDV as mentioned in Indian Standard IS: 6792:1992 [24]. BDV is tested on 500 ml. sample of mineral oil and synthetic ester in an oil insulation test kit having electrode gap of 2.5 mm and subjected an ac electric field with continually increasing voltage at 36ºC with a uniform rate of 3 KV/s starting from zero to the moment till the oil sample breaks down. The comparison chart of the observed value of breakdown voltage for both of the samples is plotted in figure 2. The figure clearly predicts that the breakdown voltage for the synthetic ester is very high as compared to mineral oil. The breakdown voltage obtained for the synthetic ester is 50.2 kv/mm whereas for mineral oil is 30.0 kv/mm. It means that synthetic ester is more sustainable on high electric stress as compared to mineral oil.

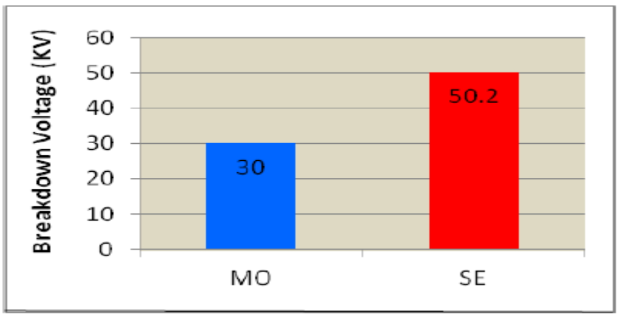



**Figure 2: Comparison of Breakdown Voltage obtained for mineral oil (MO) and synthetic Ester (SE) with electrode gap of 2.5 mm**


Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

### C. Specific Resistance

The standard IS: 6103:1971 [25] is used for the determination of specific resistance (resistivity) of insulating oils. The resistivity of a liquid is a measure of electrical insulating properties. High value of resistivity reflects low contents of free ions and low concentration of conductive contaminants [25]. Both the samples are preheated, filtered and cooled before measurement of specific resistance.

The test for measurement of specific resistance is carried out using Million Megohm meter (model no. LS-3D as shown in figure 3) at temperature 90ºC with supply voltage not more than 500 V. The test cell is cleaned with carbon-tetra-chloride before executing of the experiment. A total of 10 ml sample is used for the measurement of specific resistance.

**Figure 3: Pictorial View of Test Cell used for Measurement of Specific Resistance**

### D. Flash & Fire Point

The fire and flash points measures the liquid resistivity to catch fire. The flash point of a flammable liquid is the lowest temperature at which the vapor pressure is sufficient to form an ignitable mixture with air near the surface of the liquid. The fire point is the lowest temperature at which a liquid in an open container will attain a vapor pressure sufficient to continue to burn when once ignited [26].

The procedure mentioned in Indian Standard IS: 1448 (P:21), 1992 [27] is adopted to determine the flash point and fire point of residual fuel oils, unused lubricant oils, liquids which do not form a surface film. The test sample of quantity 200 ml was placed in a Pensky-Martens closed cup tester and heated to give a constant temperature increase by continuous stirring. An ignition source is directed through an opening in the test cup lid at regular temperature intervals with simultaneous interruption of stirring. The lowest temperature at which the application of the ignition source causes the vapour of the test portion to ignite and propagate over the surface of the liquid is recorded as the flash point at the ambient barometric pressure. The test was continued until the application of the test flame causes the vapour above the oil sample used to ignite and burn for at least 5 s. The fire point obtained is noted down. The test was performed three times and comparisons of recorded values with mineral oil are presented in figure 4 and figure 5 respectively. The figure clearly indicates that mineral oil has lower flash and fire point in comparison with synthetic ester. Synthetic ester proves to be fire safe having high fire point.

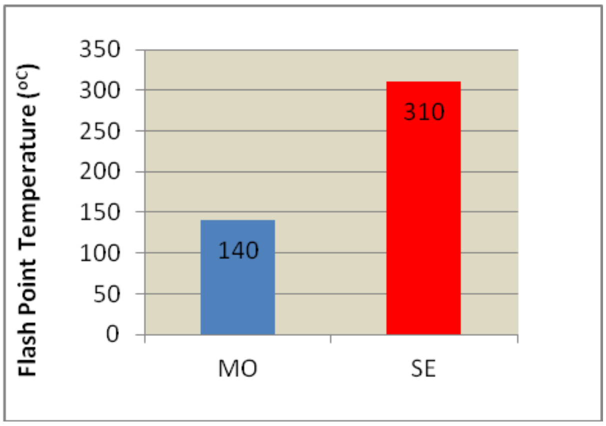



**Figure 4: Flash point obtained values for mineral oil (MO) and synthetic ester (SE)**

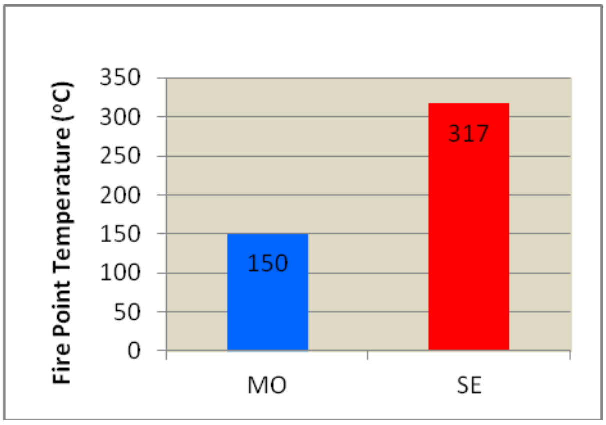



**Figure 5: Fire point obtained values for mineral oil (MO) and synthetic ester (SE)**

### E. Pour Point

Pour point is defined as 3ºC above the temperature of fluid in a tube titled at 90ºC where the fluid does not flow within five seconds of time [27-28]. Pour point of an insulating liquid is a vital property mostly where ambient temperature can be below freezing point. If the oil temperature drops below pour point of the insulating liquid, flow may stop.

The test methodology as per Indian Standard IS: 1448 (P: 10), 1970, reaffirmed 1991 is adopted for the determination of pour point based on the principle that the sample is first heated and then cooled at a specified rate [29]. It is examined at intervals of 3°C for flow characteristics. The lowest temperature at which the oil is observed to flow is noted and recorded as the pour point of the material. The oil sample of 50 ml is heated initially up to 100°C by using a heating chamber then kept at room temperature for 24 hours so that it can be poured into the test tube. After that the oil sample is poured into the burette up-to 55 mm marking. Then test tube is closed using cork inserted with a thermometer such that the mercury level may remain below 3 mm. Thus oil sample is now heated at 48°C without stirring and then allowed to cool in refrigerator at 7°C. When the oil is cooled enough that all the wax crystals are deposited, test jar is removed out and checked whether there is any movement or not in oil by tilting it at some angle. The first reading of movement is measured and then again oil is allowed to cool at lower temperature to -17°C.


*Published By:*
*Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)*

Third reading is measured by cooling the sample at -35°C where the flow of oil sample is ceased as there was no movement of oil when holding the test jar horizontally for minimum of 5 seconds. The pour point measurements for mineral oil and synthetic ester are shown in figure 6.

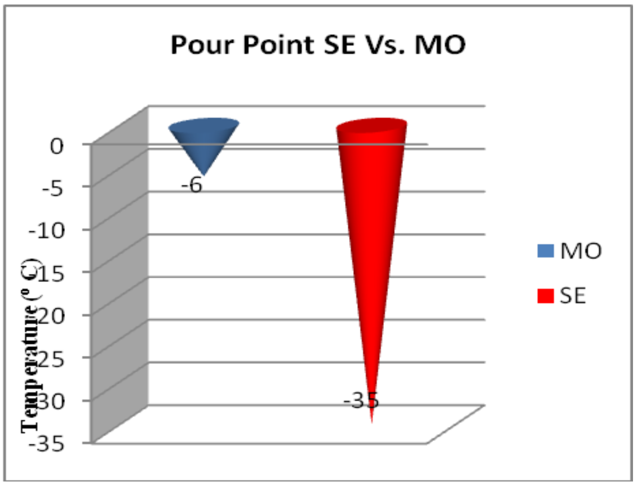



**Figure 6: Comparison of Pour point of mineral oil (Mo) and synthetic ester (SE)**

### F. Neutralization Value (Acidity)

The acid number is a measure of the amount of acidic substances in the oil under the conditions of the test [30]. Acidity of oil is expressed in mg of KOH required to neutralize the acid present in a gram of oil. This is also known as neutralization number. Acids in the oil originate from oil decomposition/oxidation products. Acids can also come from external sources such as atmospheric contamination. If oil becomes acidic, water content in the oil becomes more soluble to the oil. These organic acids are detrimental to the insulation system and can induce corrosion inside the transformer when water is present. An increase in the acidity is an indication of the rate of deterioration of the oil with sludge.

Neutralization value (Acidity) for both of the samples i.e mineral and synthetic ester is measured with the procedure of Indian Standard IS 1448 (P: 2) 1967, reaffirmed 1991 [30] with the 20g quantity of oil samples and 130 milliliter of titration solvent. Stirring process is preferred for proper mixing of the fluids by placing the beaker on stand in a way such that electrodes are half immersed. Burette is filled with 0.1 mol/ml KOH solution and placed in the test assembly i.e in the middle of electrodes such that it is immersed in liquid of beaker. A potentiometer was already inserted in the arrangement which measured the change in cell potential. When KCl was added, the cell potential changes by 32 mV. The whole experiment of titration is performed till the change in cell potential drops to 5 mV which indicates that the liquid sample is more basic than buffer KOH.

### G. Water Content

Water presence in transformer insulation is dangerous to insulation system and to overall life of transformers. It may be present in insulating liquids in several forms. Presence of water in the form of distinct droplets or as a cloud detached throughout liquid can be noticed by visual examination. This type of water presence results into decreased dielectric strength of the liquid insulation. It is important to note that water saturation limit for mineral oil is not directly applicable to ester liquids as it is hygroscopic in nature and can handle more water and still can maintain the dielectric strength to permissible value. [26]

The presence of moisture content in the liquid samples of mineral oil and synthetic ester is measured by Karl Fischer reagent process as mentioned in IS 13567:1992 by [31]. To perform the test 5 ml syringes were used. Samples were dried at temperature 120ºC for 10 hours by placing it in clean and dry oven. After then 5 ml quantity of oil sample is poured into them in such a manner that pin point of needle may remain below the surface of liquid. Needle is allowed to standstill vertically and let the air bubbles vanish. After that discharge the contents of sample from the syringe and refill it again. Then align the piston fitted in assembly to 5 ml marking syringe scale and start electrolysis process. The water titrated in process is shown by the current integrator in µg which is noted and measured by the weight of the sample to determine the discharged value of oil. Repeat the process mentioned above four times and evaluate the result by taking the ratio of their mean values. The measured values of water content in new synthetic ester fluid is compared with mineral oil and plotted in figure 7. The figure shows that water saturation limits of synthetic ester being are very high and it can hold more water. Also, due to hygroscopic nature of synthetic ester, water remains in liquid instead of migrating to solid insulation which extends the life of solid insulation material such as kraft paper.

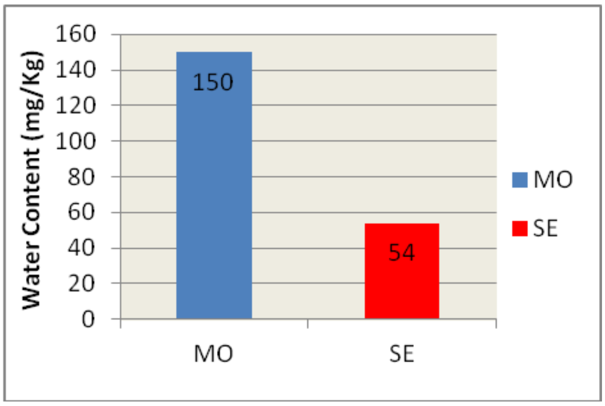



**Figure 7. Stastical Illustration of Presence of Water Content In Mineral Oil (MO) and Synthetic Ester (SE) Indicating Less Moisture Content in Synthetic Ester**

## III. RESULTS & DISCUSSIONS

The results obtained from all the parameters which define insulation characteristics of a synthetic ester oil sample described in previous section are noticeably observed and calculated by specified methodology. But to identify whether the oil sample is adaptable for industrial power transformer applications as an insulating liquid for which it is essential to weigh against it with the standards adapted by power industries for the insulating oils and with properties of previously used mineral transformer oil [32]. The comparison of physical and dielectric properties is examined using mineral oil and synthetic ester fluid are highlighted in Table 2 and demonstrates that the insulating properties of newly modified ester fluid are comparatively superior than the limits described.

**Table 2: Comparison of Examined Properties of Mineral oil and Synthetic Ester**

| Property | Units | Standard | MO | SE |
|---|---|---|---|---|
| Appearance | -- | -- | Pale yellow | Clear, light green |
| Breakdown Voltage | kV | ISO 6792 | 30 | 50.2 |
| Specific Resistance @ 90$^0$C | Ω-cm | ISO 6103 | 3.5x10$^{12}$ | 15.05 x 10$^{12}$ |
| Flash Point | $^0$C | ISO 1448 | 140 | 310 |
| Fire Point | $^0$C | ISO 1448 | 150 | 317 |
| Pour Point | $^0$C | ISO 1448 | -6 | -35 |
| Water Content | mg/K | ISO13567 | 150 | 54 |
| Neutralization Number | Mg KOH/g | ISO 1448 | 0.02 | 0.04 |

Fire safety is a big issue for operators and workers which deal with insulating fluids especially in power industries, underground systems and in busy areas. Fire Safety measures and awareness are provided to companies in pact with government and private sector agencies. Fire produced from a igniting transformer liquid causes not only harm to human life but also to surrounding areas which also affects economically. Figure-4, drawn in previous section represents that mineral transformer oils have less fire point so it can easily catch fire, starts ignition and continuously remain in burning state. So new synthetic ester analyzed in this work is a better solution to ease the risk of fire. Because synthetic esters have higher fire points at 317°C which is far more than fire point 150°C of mineral oil. No ignition appears even up to temperature 300°C after span of 70 minutes. So this new investigated fluid is recognized as less flammable fluid for dielectric purposes. This means it requires lesser fire safety measures than mineral oil. Its fire safety properties allow it to be used in transformers, inside buildings and other critical areas where mineral oil would not be acceptable.

As the temperature of the mineral oil increases quickly, it ignites after every 4 minutes and continues to burn even after the ignition source is removed, emitting thick black smoke [11]. The comparison as in Figure 8 shows that the smoke produced by new SE is having thin white smoke, and it is one third of the smoke produced by mineral oil. Thus SE fluid is less ash producing material and its low heating rate is due to its high specific heat and thermal conductivity, which combines to give high fire point making synthetic ester excellently resistive to fire.

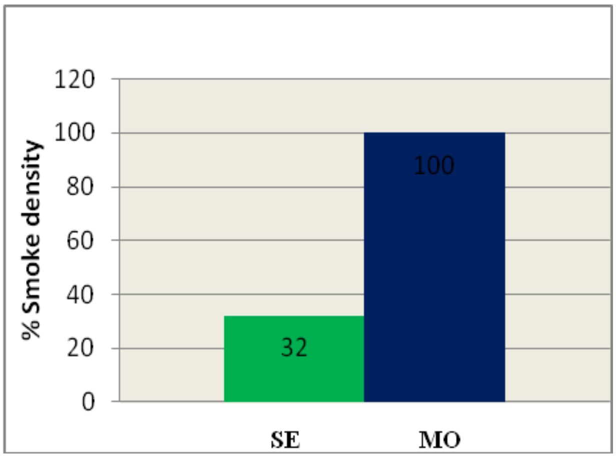



**Figure 8: Comparison of % Smoke density in SE and MO**

A variety of tests can measure breakdown voltage by applying electric field on a small quantity of sample. Breakdown voltage is a measure of insulation capability of the oil as well as it gives an idea about the presence of water particles in the oil. The values obtained from mineral oil and synthetic ester after comparison are shown graphically using figure 9. The plot shown in figure 2, describes that lower limit of breakdown voltage of synthetic ester is observed at room temperature is more than the minimum value of breakdown voltage required for mineral oil. More the value of breakdown voltage more is the solubility of water in oil. As SE has higher value of insulating strength so it will have greater solubility of water which will further reduce the paper degradation at higher rate. In case of mineral oil, even a small amount of water causes rapid deterioration in breakdown voltage whereas synthetic ester can maintain high breakdown voltage greater than 75 KV even when the moisture exceeds 300 mg/Kg as shown in Figure 9. It has greater ability to trap more moisture than mineral oil, which can reduce the amount of water in the paper and hence will reduce the aging rate.

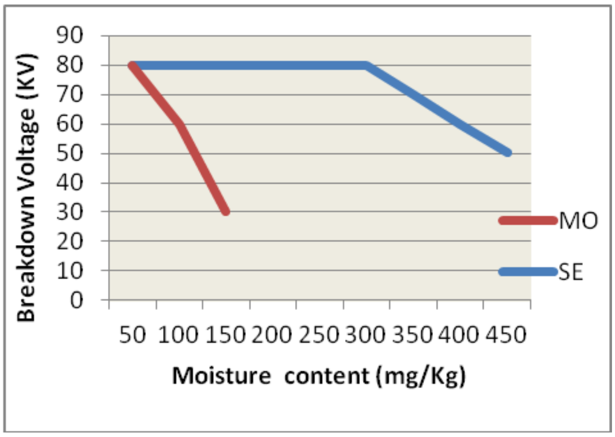



**Figure 9: Variation of Moisture Content with Breakdown Voltage at 36°C**

Pour point is another important consideration for any dielectric fluid because if a device is filled with it for a long duration and remains in service, it has to go through seasonal changes consisting of low and high temperatures. So the lowest temperature up to which a fluid can remain in its liquid state and does not cease its movement or freeze down. The figure 6 represents that the pour point for the new modified ester based insulating is much lower up to -35°C where as mineral oil has -6°C due to which mineral oils easily changes their state and starts freezing at lower temperatures. Because of this reason the mineral oil is not suitable as an insulating fluid used for transformers or any servicing device in colder climate regions. But synthetic ester has much better pour point and it can tolerate much lower temperatures approximately -35°C which makes it highly effective solution suitable for colder climate regions.

For any material to work as an insulator, it is essential for it to have higher resistance towards oxidation [33]. The oxidation stability of synthetic ester is more than that of mineral oil. Because mineral oil easily oxidizes at temperature nearly 100°C due to which solid insulation degradation occurs accompanied


Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

by acid formation and sludge appearance in the liquid which decreases its insulation capability whereas synthetic ester is used for being highly resistive to oxygen as per specifications provided by the manufacturer unit. Because it react very slowly with oxygen even at the temperature of 130$^{o}$C and upon oxidizing there is no formation of sludge but results only into organic acid formation.

To estimate the heat transfer capability and cooling capacity, viscosity is the main factor to realize the actuality of the product. Viscosity determines the cooling nature of a liquid and provides confrontation against movement. Higher the viscosity means high resistance to flow which restricts the fluid to transfer heat by ceasing movement resulting in rise of temperature. As the synthetic ester fluid has high viscosity at lower temperature but this difference in viscosities in comparison to mineral transformer oil disappears with rise in temperature. Still higher value of viscosity is required for paper impregnation at moderate temperatures which is in favour of synthetic ester to be use as a dielectric fluid.

Ecological protection is another main concern for any user and manufacturer. Environment friendly nature of any product depends mainly upon two factors that are less toxicity and biodegradability. As per the information provided by the manufacturer unit, pentaerythritol ester oil is not only biodegradable but also non-toxic. This biodegradable nature is already checked by Umwelt Bundes Amt (UBA), Germany's Central Environment Authority. Thus its use as transformer insulating oil will protect the environment from damage and help to reduce containment measures.

## IV. CONCLUSION

The objective of the present work was to gear up replacement of mineral insulating oils with ester based insulating oils. In this work physical and dielectric properties of mineral oil and synthetic ester oils are examined.

The analysis show that the pentaerythritol based synthetic ester fluid has superior combustibility as compared to mineral transformer oils because of high ignition temperature, which diminishes the peril of conflagration and requirement of protection devices for maintenance boosting fire safety.

The synthetic ester fluid has tremendously low pour point due to which these oils can be adapted as dielectric liquids for transformers in typical weather regions having lower temperatures throughout the year where mineral oils cannot be used due to unfavourable pour points.

The dielectric strength of this ester material is nearly double than that of mineral oil due to which they have more insulating capability as well as high moisture acceptance with larger dielectric strength. This material entraps high amount of water which decreases the rate of paper degradation without affecting the insulating characteristics of the fluid.

This customized fluid has effectively high specific resistance than mineral oil liquid which shows negligible presence of conductive contaminants and other impurities which affect the properties of the insulating oils. Also, the liquid has improved aging stability having higher resistance to oxidation making it environment friendly consequently avoids damage to ecology due to less toxic generation and higher rate of biodegradability. So from the above analysis of results, this paper concludes that synthetic ester can be acknowledged as an alternative dielectric transformer fluid because of its impactful properties of being non toxic, biodegradable, fire resistant, higher breakdown voltage and for maintaining better ecological balance than other dielectric insulating fluids.

## ACKNOWLEDGMENT

The authors are thankful to Thapar University Patiala, Punjab, India for providing technical support through SAI Labs in completion of laboratory procedures. The authors also obliged IKG Punjab Technical University, Kapurthala, Punjab, India for providing a productive environment for planning of this work.

## REFERENCES

1. Fofana, I, Wasserberg, V., Borsi, H., and Gockenbach, E., “Challenge of mixed insulating liquids for use in high-voltage transformers. Part 2: Investigations of mixed liquids impregnated paper insulation”, IEEE Electr. Insul. Mag.18 (04) 2002, pp. 5-16.
2. Fernandez, I., Ortiz, A., Delgado, F., Renedo, C. and Perez, S., “Comparative evaluation of alternative fluids for power transformers”, Elect. Power Syst. Res., vol. 98, 2013, pp.58-69.
3. Aggarwal, T., Jindal, V. and Singh, J., “A review of conditioning monitoring assessment of power transformers insulation”, Int. J. Adv. Res, 4 (10), 2016, pp.1664-1674.
4. Kraweic, S., “Review of recent changes to mineral insulating oil specifications” Proc. IEEE Electr. Insul. Conf., 2009, pp. 363-367.
5. Fofana, I., Wasserberg, V., Borsi, H. and Gockenbach, E., “Challenge of mixed insulating liquids for use in high voltage transformers. Part 1: Investigation of mixed liquids”, IEEE Electr. Insul. Mag., 18 (3), 2002, pp. 18–31.
6. Liu, R., Törnkvist, C., Chandramouli, V., Girlanda, O., and Pettersson, L.A.A., “Ester fluids as alternative for mineral oil: the difference in streamer velocity and LI breakdown voltage”, Proc. IEEE Electr. Insul. and Dielectr. Pheno. Conf., 2009, pp. 543–548.
7. Eberhardt, R., Muhr, H.M., Lick, W., Wieser, B., Schwarz, R. and Pukel, G., “Partial discharge behaviour of an alternative insulating liquid compared to mineral oil”, Proc. IEEE Int. Electr. Insul. Symp., 2010, pp. 1–4.
8. Pukel, G.J., Eberhardt, R., Muhr, H.M., Baumann, F. and Lick, W., “Large power transformers for alternative insulating fluids”, Proc. 16$^{th}$ Int. High Voltage Engineering Symp, 2009, pp.1–4.
9. Oommen, T.V., Claiborne, C.C. and Walsh E.J., “Introduction of a new fully biodegradable dielectric fluid”, Proc. IEEE Tech. Annu. Textile, Fiber and Film Industry Conf., 1998, pp.3/1–3/4.
10. Oommen T.V., “Vegetable oils for liquid-filled transformers”, IEEE Electr. Insul. Mag., 18 (1), 2002, pp. 6–11.
11. Martin, R., Athanassatou, V, et al., “New experiences in service with new insulating liquids”, CIGRE publication. CIGRE WG A2-35. Brochure No. 436.
12. Abeysundara, D.C., Weerakoon, C., Lucas, J.R., Gunatunga, K.A.I. and Obadage, K.C., “Coconut oil as an alternative to transformer oil”, Engg. Res. Unit. Symp., 2001, pp. 1–8.
13. Borsi, H., “Dielectric behaviour of silicone and ester fluids for use in distribution transformer”, IEEE Trans. Dielectr. Electr. Insul., 26 (4), 1991, pp.755–762.
14. Kuwahara, H., Tsuruha, K., Munemura, H. and Ishii, T., “Partial discharge characteristics of silicone liquids, IEEE Trans. Dielectr. Electr. Insul., vol. 11, 1975, pp. 86–91.
15. McShane, C.P, Gauger, G. and Luksich, J., “Fire resistant natural ester dielectric fluid and novel insulation system for its use”, In IEEE/PES Transmission & Distribution Conference, 1999, pp. 1–5.
16. IS: 6792: 1992 Reaffirmed 2003, “Indian standard, Method of determination of Electric Strength of insulating fluids”, First revision, second reprint February 1998, UDC 621.315.615.2:621.17.333.6, BIS 1992.
17. Mehta, D.M., Kundu, P., Chowdhury, A., Lakhiani, V.K. and Jhala, A.S., “A review on critical evaluation of natural ester vis-à-vis mineral oil insulating liquid for use in transformers: Part-1”, IEEE Trans. Dielectr. Electr. Insul., 23 (2), 2016, pp. 873–880.


*Published By:*
*Blue Eyes Intelligence Engineering*
*and Sciences Publication (BEIESP)*

18. Martin, R., "Esters–Their Structure and Their Properties", CPRI National Conf. on environmental friendly insulating Liquids (EFIL), 2013, pp. 1-16.
19. Rao, U. M., Sood, Y. R. and Jarial, R. K., "Performance analysis of alternate liquid dielectrics for power transformers", IEEE Trans. Dielectr. Electr. Insul., 23 (4), 2016, pp.2475–2483.
20. IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment, IEEE STD. C57.106 – 2006.
21. Cooper Power Systems, Bulletin 00092 – Product Information – Envirotemp TM FR3TM Fluid – Description, 2001.
22. Rao, U. M., Sood, Y. R. and Jarial, R. K., "Oxidation stability enhancement of a blend of mineral oil and synthetic ester", IEEE Electr. Insul. Mag., 32 (2), 2016, pp. 43-47.
23. Fluids for Electro-technical Applications - Unused Mineral Insulating Oils for Transformers and Switchgear, IEC 60296 - Edition 4.0 - 2012-02.
24. IS: 6792: 1992 Reaffirmed 2003, "Indian standard, Method of determination of Electric Strength of insulating fluids", First revision, second reprint February 1998, UDC 621.315.615.2:621.17.333.6, BIS 1992.
25. IS: 6103: 1971 Reaffirmed 2001, "Indian standard, Method of test for specific resistance (resistivity) of electrical insulating liquids", Fifth reprint august 1996, UDC 621.315.615:621.317.332.3, BIS 1972.
26. Mehta, D.M., Kundu, P., Chowdhury, A., Lakhiani, V.K. and Jhala, A.S., "A review on critical evaluation of natural ester vis-à-vis mineral oil insulating liquid for use in transformers: Part 1", IEEE Trans. Dielectr. Electr. Insul. 23 (2), 2016, pp. 873–880.
27. IS: 1448 [P:21]: 2012 ISO 2719:2002, "Indian standard, Methods of test for petroleum and its products, Determination of flash point-Pensky- Martens closed cup method", Third revision, ICS 75.080, BIS 2012.
28. Moore, S. P., Wangard, W., Rapp, K. J., Woods, D. L. and Vecchio, R. M. D., "Cold Start of a 240-MVA Generator Step-Up Transformer filled with Natural Ester Fluid", IEEE Trans. Power Del., 2014, pp. 256- 263.
29. IS: 1448 [P:10]- 1970 Reaffirmed 2003, "Indian standard, Method of test for petroleum and its products, Cloud point and Pour point", First revision, sixth reprint December 1998, UDC 665.6/.7:536.421.2, BIS 1971.
30. IS: 1448 [P:2] 2007 ISO 6619:1988, "Indian standard, Methods of test for petroleum and its products, Petroleum products and lubricants-neutralization number- Potentiometric Titration Method", Second revision, ICS 75.160.30, BIS 2007.
31. IS 13567:1992 Reaffirmed 2003, "Indian standard, Determination of water in insulating liquids and in oil- impregnated paperand pressboard by automatic coulometric Karl Fischer titration- method of test", UDC 621.315.615/ 621.315.64/65: 543.812, BIS 1992.
32. IS: 335: 1993 Reaffirmed 2005, "Indian standard, New Insulating Oils-specification", Fourth revision, third reprint September 1998, UDC 621.315.615.2, BIS 1993.
33. Darwin, A., Perrier, C. and Folliot, P., "The use of natural ester fluids in transformers", MatPost, III Europian Conf. on HV & MV substation equipment.

## AUTHOR PROFILE

**Vishavdeep Jindal (S'15)** was born in Punjab India in 1987. He is a student member of IEEE and Dielectric & Electrical insulation society (DEIS). He is also a reviewer member in International Journal of Engineering Research & Technology (IJERT). He received the B.Tech. in Electrical Engineering from the university of Kurukshetra, India 2009 and the Master degree in Electrical Engineering from I. K. G. Punjab Technical University, Kapurthala, Punjab, India in 2012. He is currently pursuing his Ph. D. degree from I.K.G Punjab Technical University, Kapurthala, Punjab, India. His main research interests are Power quality, conditioning monitoring of transformers, aging effects on kraft paper, dielectric insulating liquids.

**Dr. Jashandeep Singh (M'16)** was born in Ludhiana (Punjab), India. He obtained his Diploma in Electrical Engineering in 1999, B. Tech in Electrical Engineering, M. Tech & Ph.D from NIT Hamirpur in 2002, 2004, 2011 respectively. He is presently working at BGGI, Sangrur, Punjab. His research interests are energy management, transformer diagnosis and electrical machines.