Natural Ester Oil a Sustainable Alternative Insulation Oil to Mineral Oil for Power Transformer Industries and Electric Power System

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ABSTRACT
Natural ester oil is an important concern for power transformer industries, commercial and electric power system to explore sustainable technology. It is most suitable alternative to mineral oil for insulation and coolant medium for electric power transformer to operate efficient. Mineral oil is paraffin and naphtha based insulating oil derived from petroleum crude oil by fractional distillation method and have been banned due to polychlorinated biphenyls (PCBs). The disadvantage was its toxic nature and the lack of biodegradability while the natural ester oil is renewable energy source, easily available and eco-friendly in nature, derived from plant, animal fats, crops, fruits and their seeds, such as soybean oil, olive oil, mustard oil, sunflower oil, palm oil, coconut oil, cottonseed oil and canola oil etc. PCBs are harmful for human tissue, many species of birds and fishes, persistent biodegradability in soil and water. This paper explores the physical, chemical and electric properties to find better natural ester oil source instead of mineral oil. The purpose of utilization natural ester oil is to save the environment from toxic, dioxin, hazards and fire. Natural ester oil is deliberated to be one of the feasible substitute for mineral oil and silicone oil due to non-toxic, not produce any dioxin and toxic hazards in environment, low explosion risk, high flash, less flammable, low sludge in transformer tank, less time take to biodegradable processing, high value of pour point, good dielectric strength breakdown voltage, long paper aging life indicates better insulation oil medium for transformer.

Keywords: *Natural ester oil, mineral oil, polychlorinated biphenyls (PCBs), transformer insulation oil*

1. INTRODUCTION

Power transformer plays an important role in electric power system to exchange the voltage and current one level to another level without changing the frequency in distribution and transmission power. Mineral Oil (MO) which is petroleum based insulation oil is mostly usage for transformer insulation, it is concern point to environmental and safety which fortified the improvement of biodegradable substitutes [1]. Consequently, it is necessary to intensification the trustworthiness and operating life without damage and burn of transformers otherwise its affect the life expectation of transformer, deteriorate due to oxidation and moisture contagion [2]. The Polychlorinated Biphenyls (PCBs) are combinations of up and around to 209 different chlorinated base compounds also termed as congeners. PCB was first made in 1930 which overcame the flammability of naphthenic oils. In year 1970, it was determined that PCB was no longer environmentally acceptable and hence new uses and production of PCBs have been banned [3]. With the closure of the PCBs, the power industries move on to other alternative to liquid insulation like synthetic esters, vegetable oil, and silicone fluid [4]. MO having poor and very slow biodegradable, solemn mineral oil leaks can pollute the soil and waterways, a toxic effect on the environment, human tissues, bird species and rain water, toxic rain water affects the water living species like fishes, turtle and also impact on environment. Fire exposures are a real threat risk when using mineral oils, due to fire forest and animal can be destroys especially in densely populated areas. Due to this depletion of the mineral oil source and environmental impacts, transformer manufacturing industries has shifted from petroleum-based crude

mineral oil to natural oil (NEO) and synthetic esters [5]. NEO renewable energy source and clean for environment and have excellent physical chemical and electric properties which completely satisfies the standard parameters [6]. MO oxidizes freely sludge precipitates and needs for periodic cleaning and conservation, but in case of NEO, resistant to oxidize degradation. With mineral oil, fire safety is a concern because temperature of the oil rises with transformer loading [7].

2. TRANSFORMER INSULATION OIL

The first transformer oil was established oil in year 1890 which is paraffinic based mineral oil substituted by its naphthenic based oil in 1925 [3]. Transformer insulation oil provides transformer's core and windings- as a coolant and insulation to maintain the operating temperature, fully dipped inside the oil tank. The purpose of transformer oil is to be responsible for insulation, performance as coolants and helpful for diagnostic tool to analyses the types of fault occur inside the transformer [8]. The insulating oil has property to prevent oxidation process of cellulose paper insulation. It performs as an obstruction among atmospherically oxygen and cellulose, avoid the direct contact and hence minimizing oxidation [9]. Power system components can operate with some amount of energy loss which leads to rise in temperature of the corresponding equipment. Hence there is a necessity to dissipate the heat generated by the energy loss. If it fails, premature aging causes failure of the equipment [10]. Heat dissipation can be attained by circulating various liquids, which also ensures the electrical insulation. The transformer oil acts as a barrier between the atmospheric oxygen and the cellulose- avoiding direct contact and hence minimizing oxidation. The major functions of insulating liquids are: heat dissipation, electrical insulation, protecting solid insulation and arc quenching medium, core winding protection to burn, dissolve gas analysis to evaluate the fault condition of the electrical transformer [11]. These insulating liquids are classified into different types:

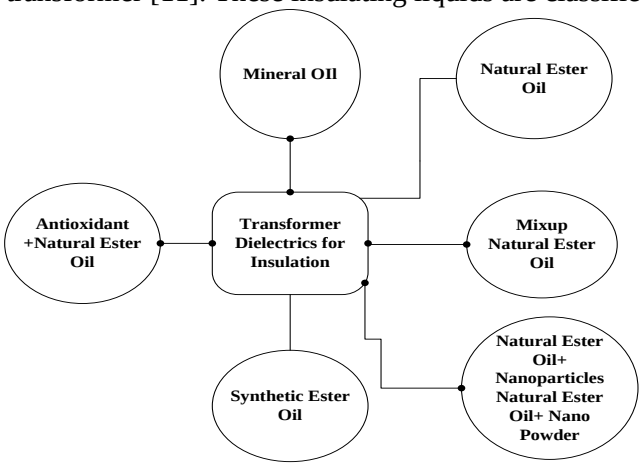

Figure 1. Dielectric oil for transformer insulation

From all the above liquids, easily availability and good dielectric properties, mineral oil are used widely over a century. In the recent years, due to the environmental issues, mineral oils are replaced by natural ester oils.

3. COMMERCIAL NATURAL ESTER OIL

A. ENVIROTEMP FR3

Envirotemp FR3 insulation is bio-based, renewable natural ester oil derived from seed oils with performance-enhancing additives, used in transformers as insulating liquid and coolant [12]. It does not contain silicones, petroleum, corrosive sulfur or halogens. This type of alternative oil gives better fire safety; increase reliability and overload operating capacity and insulation life of transformer. It is non-toxic and completely biodegradable, less flammable dielectric, extremely high fire point of 360 °C, flash point of 330 °C and high ignition resistance [7].

Virginia Transformer has developed Envirotemp™ FR3™ ester-filled transformers, tinted green in color and can withstand an extent amount of water than MO. The physical property as viscosity of liquid is four times of mineral oil for operative temperature of 80 °C [13].
Fire safety: FR3 insulation oil is two times greater than flash and fire point of mineral oil.
Transformer life and load ability: FR3 oil advantages to drawn-out retained moisture and absorb water driven off by aging paper [8].
Environmental benefits: FR3 Oil decreases carbon, 56-60 times less carbon emissions than mineral oil [7-9].

B. **MIDELeN 1215/MIDEL eN 1204**
MIDELeN 1215/MIDEL eN 1204 are exceptional alternative NEO to silicon liquid, mineral oil, derived from renewable sources hence highly environment-friendly and readily biodegradable. It is soya-based NEO and MIDEL eN 1204 is a rapeseed-based NEO. These type esters have high fire point and less flammable comparison mineral oil, provides the ideal solution in terms of fire risk easing and decreases the extra fire fortification devices, reducing additional cost. It has the property to sustain high moisture tolerance and increase the life of solid cellulose-based insulation and extended life expectancy of a transformer. MIDEL eN 1215 is perfect for temperate environment installations for non-breathing transformers whereas MIDEL eN 1204 is best for quite cooler climates and a nominal solution for nonfree-breathing transformers [11].

C. **BIOTEMP**
BIOTEMP is a NE fluid is vegetable-based oils made from safflower and sunflower, containing monounsaturated fatty acid, easily biodegradable and environment-friendly, is not treated as toxic or hazardous waste [8]. It compromises higher fire safety, major operational advantages over mineral oil and can be used in outdoor and indoor transformers. It reduces air pollution by producing only water and carbon dioxide at the time of combustion [14]. It has dielectric characteristic within high flash, fire resistance and stability of temperature than mineral. It has capability of absorbing more water, moistures than MO, generated by ageing insulation paper, extent life of solid based cellulose insulating paper immersed inside the transformer tank.

D. **BIOTRAN-35**
BIOTRAN-35 is eco-friendly, non-toxic, and biodegradable insulating oil, Oil leak does not harm the environment, reduced carbon emissions. DONGNAM Petroleum Ind. Co. Ltd. is one of the major insulating oil producers in South Korea established in 1973, have developed and patent registered own environmentally friendly NE (vegetable oil) “BIOTRAN-35” which is less flammable property excellent heat-resistant and offers a longer lifespan, due to its moisture tolerance characteristics, able to absorb a high level of moisture while maintaining breakdown voltage, excellent dielectric breakdown voltage, thermal stability and low deterioration specific over time [15-17].

3. COMPARISON BETWEEN NATURAL ESTER OIL AND MINERAL OIL

Load capacity- up to 20% more load capacity than MO.
Insulation life- up to 8X longer insulation life than MO.
Flash and ire point- 2X Mineral oil's flash and fire points.
CO_2 emission- 56X less CO2 emissions than MO.
Saturation point- NEO has much higher saturation point than MO.
Loading capability- increased loading capability by up to 20%.
Operating capability- ester can operate up to 20°C warmer than MO.
Fire safety- NEO better than MO.
Permittivity- NEO higher than MO.
Oil leakage harm for environment- Oil leak does not harm the environment in case of NEO.
Flammable- Less flammable dielectric fluid (K-class)

Moisture tolerance- NEO has capable to absorb high level of moisture, to maintaining breakdown voltage which improves the life performance of cellulose paper insulation.
Hazardous-NEO is Non-toxic and non-hazardous.
Reliability- Long term for NEO.
Biodegradability- NEO completely 99% biodegradable and take less time to biodegrade while MO 20-30% biodegradable and take more time to biodegradation.

A. BOIDEGRADIBILITY

Biodegradable terns refers the ability to decomposed through micro-organisms such as bacteria or fungi biological with or without presence oxygen. Compostable or liquids that to be biodegrade in water, lessens impact on environment, less toxicity to human health , birds and living organisms.

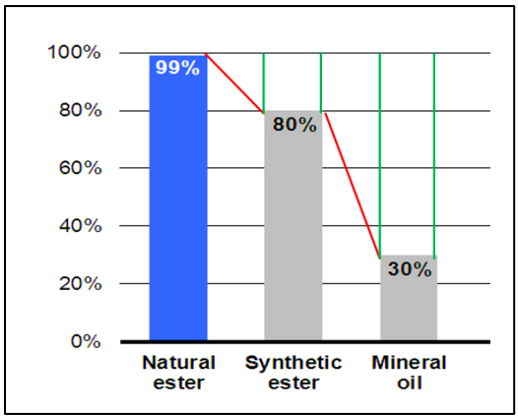

Figure 2. Biodegradation of NEO, MO and synthetic Ester oil

In figure 2, NE has 99 % biodegrdable than MO. NE also take less time to omplete biodegradation than others.

B. PAPER AGING LIFE OF TRANSFORMER INSULATION OIL

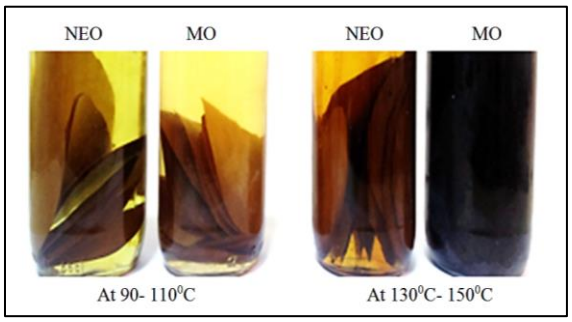

Figure 4. Paper aging of NEO and MO with respect to temperature

C. NATURAL ESTER OIL AND MINERAL OIL COLOR CHANGES IN TRANSFORMER INSULATION OIL

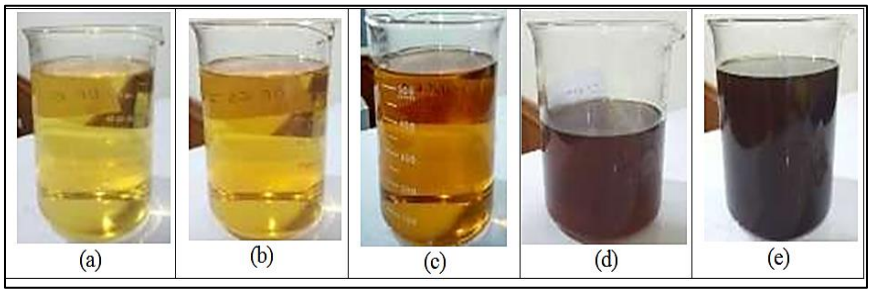

Figure 5. Color of the oil becomes darker with aging time and the aging temperature

(a) Visual appearances of oil before aging
(b) After aging of 330 hours at 120^0C
(c) After aging of 670 hours at 120^0C
(d) After aging of 330 hours at 150^0C
(e) After aging of 670 hours at 150^0C

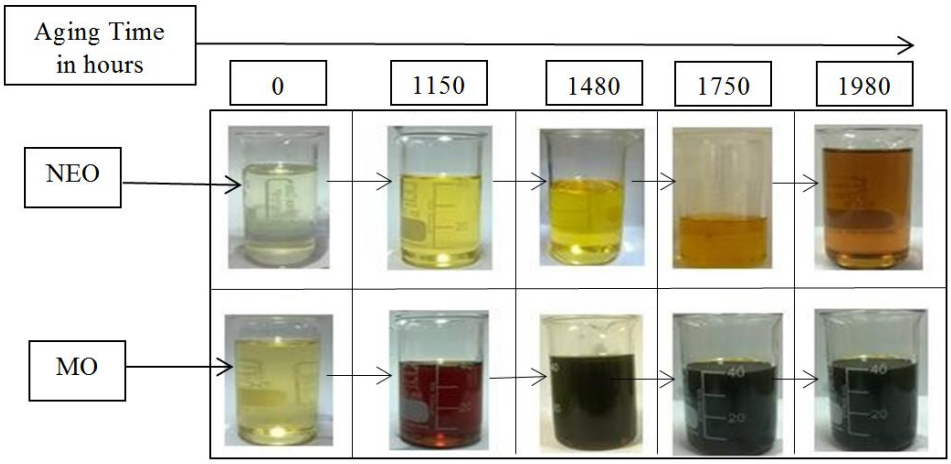

Figure 6. Color changing of NEO and MO with respect to time (hours)

Figure 6 presents the color of oil which shows the visual parameter and reflects the degree of degradation and potential contamination of oil during aging. This performance is more substantial in NE aging such that its color has turned to black after 1480 h of aging whilst color of mineral oil change to amber after 1750 h. There is clear difference between the NEO and MO that NEO after 1980 has good insulating property and also further can be used after 1980 hour while MO has color change (black) and lost his property to insulation and further cannot be used as insulation.

D. DIELECTRIC FLUID FIRE POINT COMPARISION

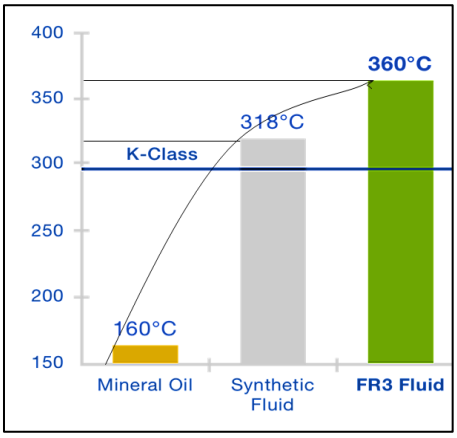

Figure 7. Dielectric fluid fire point comparison between NEO, MO and Synthetic ester

	MO (Typical values)	NEO (Typical values)	NEO (Advantages)
Flash point (°C)	150	> 300	+

Fire point (°C)	160	> 330	+
Auto-ignition temp (°C)	200	>400	+

E. WATER SATURATION

NE liquids are hydrophilic in nature and have a water saturation limit 5 to 8 times more than MO at normal transformer working temperatures (Fig. 8), at 500 ppm moisture content in the oil, the dielectric breakdown strength of natural ester fluids is still within the standard limits.

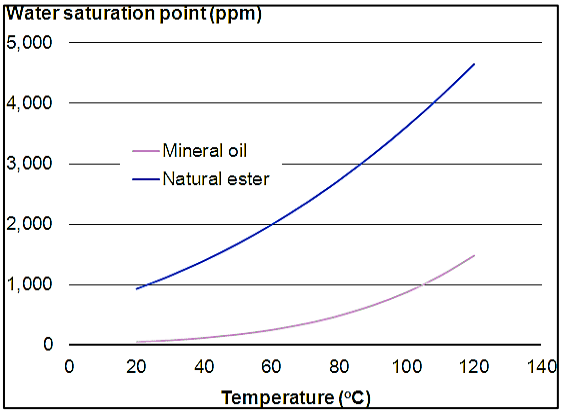

Figure 8. Water saturation vs temperature [14]

The result of this lower moisture content in the insulation paper is a reduction in its degradation rate over time by up to a factor of four as compared to standard mineral oil impregnated paper.

4. CONCLUSION

This paper presents the study and exploration of commercial natural ester oil as insulation oil instead of mineral oil and their physical, chemical and electric breakdown voltage characteristics. This paper conclude that natural ester oil is safe to use, ecofriendly, no toxicity and better breakdown voltage, paper aging of cellulose paper is excellent and extent the life of insulation, strong biodegradability, high-temperature stability, high viscosity index, low temperature flow ability, reduced flammability. There are some issues within natural ester oil that is water content quantity is more than mineral oil and high in cost. Nanoparticles, composite nanoparticles, nano-powder when blended with natural ester oil and mixture of natural ester oil, antioxidants with natural ester can be extended to improve the physical, chemical and electrical properties, acidity, resistivity, loss factor, interfacial tension, pour point, moisture content of nature ester oil.

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