An Auspicious Dielectric in High Voltage Engineering: Vegetable Oil

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***Abstract*—Petroleum based mineral oils have been used for liquid insulation in high voltage equipment since long time ago. Despite the obvious popularity over time, these oils have been found to be lacking in property requirement and most importantly in their negative environmental impacts. Due to the increasing awareness and sensitivity regarding environmental concerns, there is a need for either an alternative or a total replacement since petroleum is one of non-renewable energy source and may be gone one day. In this research, vegetable oils which have been studied in order to investigate the potentiality and suitability which could be a replacement of mineral oil. However, the selection of a typical dielectric fluid depends on its physico-chemical and electrical properties beside the nature of the service it will perform. For the physico-chemical properties, the parameters investigated are density, kinematic viscosity, flash point, fire point and pour point. Then for the electrical properties are breakdown voltage, dielectric dissipation factor and relative permittivity. The study shows that the vegetable oil give preferable performance compared to mineral oil.**

Keywords— environmental impact; physico-chemical properties; breakdown voltage; relative permittivity; dielectric dissipation factor

I. INTRODUCTION

Petroleum products are eventually going to run out leading to serious shortages of mineral oil by the mid-twenty first century [1]. Mineral oil is poorly biodegradable and could contaminate soil and waterways if serious spills occur. Hence, dedicated research is needed to find a suitable alternative to mineral oil-based dielectric fluid.

Vegetable oils are natural products and have renewable sources with plenty of supply as per consumer demand and thus the most suitable candidates for substituting petroleum based fluids. The disadvantage of vegetable oils is that they have lower oxidative stability compared to mineral oils. The most attractive features of vegetable oil-based fluids are that they are 95-100% biodegradable, non-toxic and most environment friendly and thus pose little to no danger to aquatic or terrestrial, offshore or onshore environments [2]. The biodegradability of vegetable oil-based dielectric fluid can be maintained or improved further by purifying and adding environment friendly additives. Cooper Power Systems developed a fire resistant natural ester based dielectric coolant [3]. In addition to fire safety, the natural ester dielectric meet the US Environmental Protection Agency Criteria as having "Ultimate biodegradability" [4]. Vegetable oils biodegrade quickly and completely and also exhibit very low or no toxicity as compared to mineral oils. This is mainly due to the fact that vegetable oils doesn't contain halogens, poly-nuclear aromatics, volatile or semi-volatile organics or other compounds that can be present in mineral oils. Vegetable oils have a much better biodegradation capacity than mineral oil under aerobic as well as anaerobic conditions [5]. Tests carried out by various researchers severally indicate that vegetable oils undergo about 70%-100% biodegradation in a period of 28 days.

II. MATERIALS AND METHODS

The samples of soybean oil, coconut oil, palm oil and rice husk oil have been collected from a local grocery shop located in the market of Rajshahi, Bangladesh to assess the characteristics. The experiments were carried out on the mentioned vegetable oils. Based on the analyses results pertaining to the physical and chemical properties like specific gravity, flash point, fire point, pour point, viscosity and electrical properties like breakdown voltage, permittivity and dissipation factor were investigated. Fig.1 depicts the circuit diagram of electric breakdown test setup.

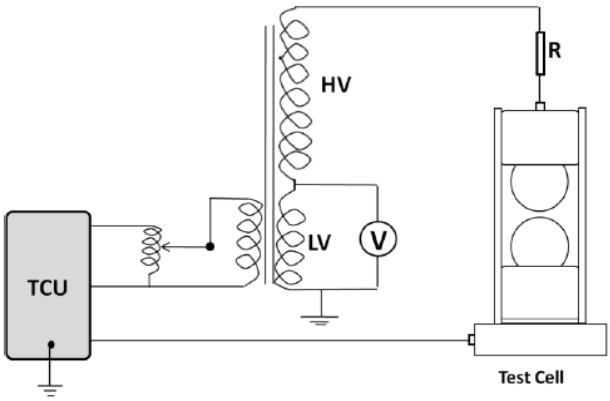

Fig. 1. Schematic diagram of electric breakdown test setup.

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Fig. 2. Image of High Voltage oil Tester (model OTS-E) for breakdown measurement.

Mineral oil used in this experiment is transformer oil collected from Power Development Board, Bangladesh. The breakdown voltage was measured using bi-spherical standard cell with various spacing in Liquid Dielectric Test Set (model OTS-E) as shown in Fig. 2. AC voltage with frequency 50 Hz was applied to certain gap distances between two identical electrodes with increasing rate of 2-3 KV/S till up to breakdown. The temperature of the sample was fixed at room temperature (30□C). Dielectric constant and dissipation factor of oils were measured using Schering circuit test.

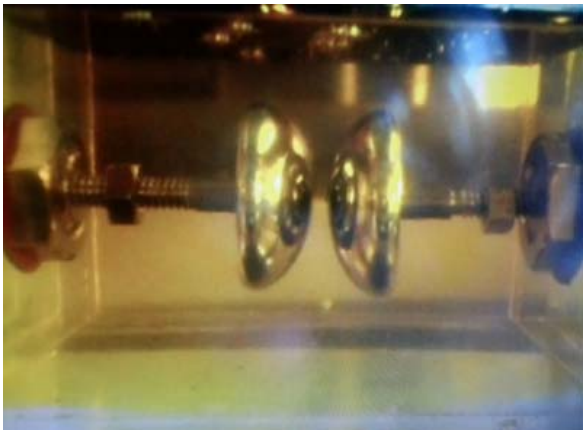

Fig. 3. Schematic diagram of mushroom electrodes used in oil tester.

Fig. 3. Shows the size, shape, configuration and position of the electrodes inside the container of oil tester. The rms value of the breakdown voltage was measured. For each sample of insulating liquid at least 10 minutes after pouring the fluid in to the cell, measurement of breakdown voltages were performed stirring the liquid thoroughly after every breakdown and a minimum wait of 2 minutes in between the measurements.

III. Results and Discussions

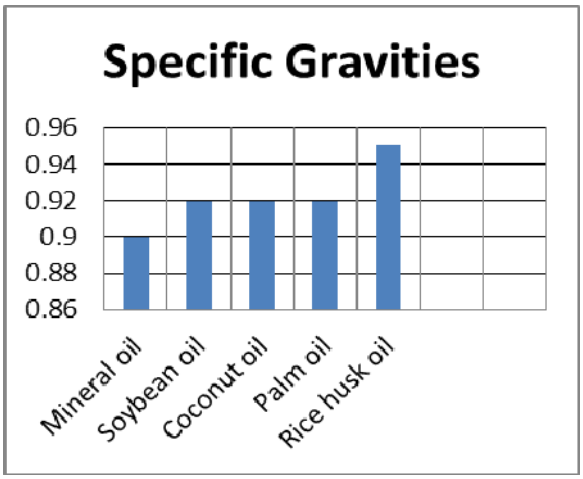

Fig. 4. Comparison of specific gravities of mineral and vegetable oils

The specific gravity of different vegetable oils shown in Fig. 4 indicates that all the vegetable oils have specific gravity higher than the mineral oil. The vegetable oils is very similar or slightly higher than that of ice. Hence, there is a risk of operating problem associated with the floatation of the lighter ice crystals in a cold weather environment. However, the high oil density is not expected to be a factor in hot weather environment. This problem will also disappear if the density of the oil is lowered by proper processing of the oils. The higher the specific gravity of the oil the lower the flow characteristics of the oil. Hence, there could be a lower cooling efficiency in the presence of vegetable oil-based dielectric fluid compared to mineral oil-based dielectric fluid.

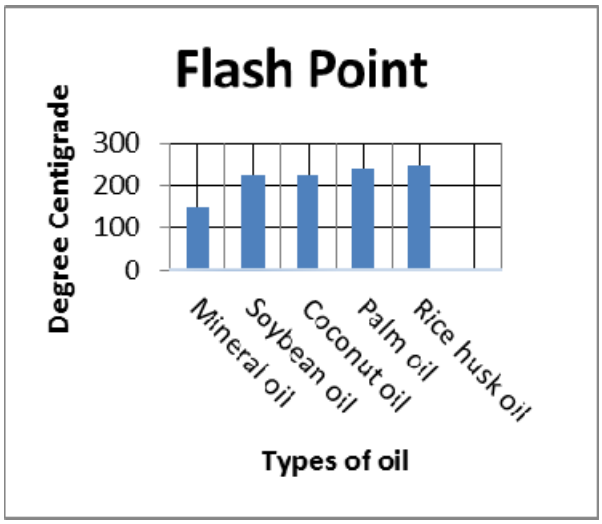

Fig. 5. Comparison of the flash point parameters of mineral and vegetable oils

Flash and Fire points data shown in Figures 5 and 6 indicate that all the vegetable oils have much higher flash and fire points compared to the mineral oil. Higher flash and fire points of vegetable oils compared to the mineral oil indicates better fire resistant capacity in the presence of vegetable oil based dielectric fluid. The data shows that these values (see Figures 5 and 6) are nearly double than those of mineral oils widely used by the power and distribution industry. Hence, a vegetable oil-based dielectric fluid will have minimum chances of causing operational problems associated with low flash and low fire points mineral oil.

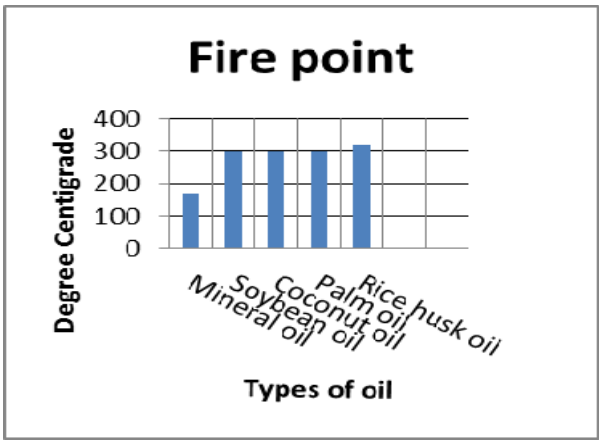

Fig. 6. Comparison of the fire point parameters of mineral and vegetable oils

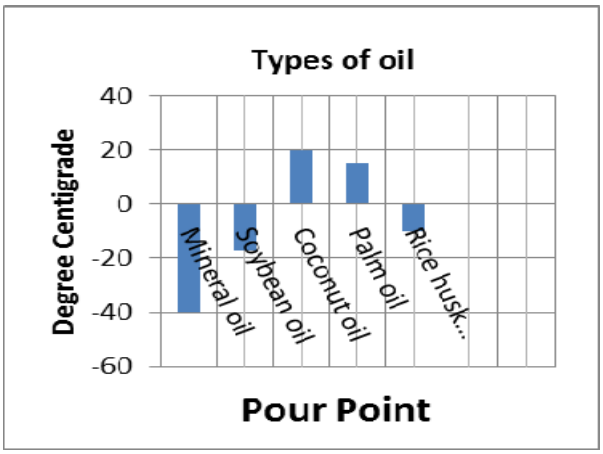

Fig. 7. Comparison of the pour point parameters of mineral and vegetable oils

Pour point data shown in Fig. 7 indicate that all the vegetable oils have lower pour point compared to mineral oil. The pour point values range from -18 ^{o}C to +20 ^{o}C for all the vegetable oils, much higher than -40^{o}C for mineral oil. It can be assumed that Rice husk and Soybean can be used in environment having temperature < -10 ^{o}C without any major interruption in the flow characteristics. The higher pour point parameters of vegetable oils indicate that there is a high risk of operating problems in very cold weather conditions (>-20^{o}C) in the presence of vegetable oil-based dielectric fluids. This parameter needs to be lowered as much as possible to ensure good flow characteristics of the insulating fluids in cold environment.

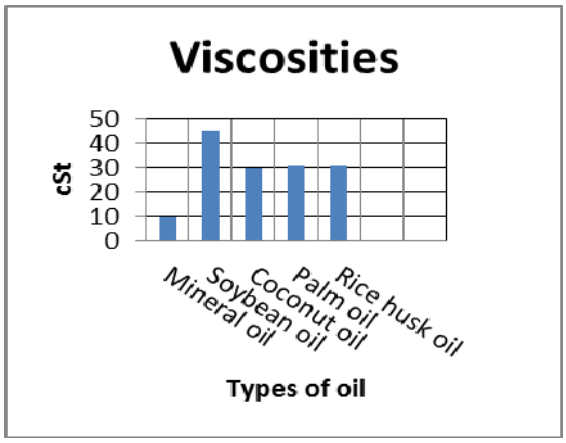

Fig. 8. Comparison of viscosities of mineral and vegetable oils

The viscosity of different oils shown in Fig.8 indicates that all the vegetable oils have much higher viscosity (about 4 to 5 times higher) than the mineral oil. Cooling of transformers is accomplished by convective flow of the insulating fluid. Hence, low viscosity insulating fluid is highly desirable to facilitate convective flow of the insulating fluid. Lower the viscosity of a dielectric fluid higher the efficiency of cooling of the insulating fluid. Hence, this parameter need to improve significantly for safe operation of transformers in the presence of a vegetable oil-based dielectric fluid. The high viscosity of vegetable oil could be a critical issue for safe operation of power and distribution transformers in cold weather countries.

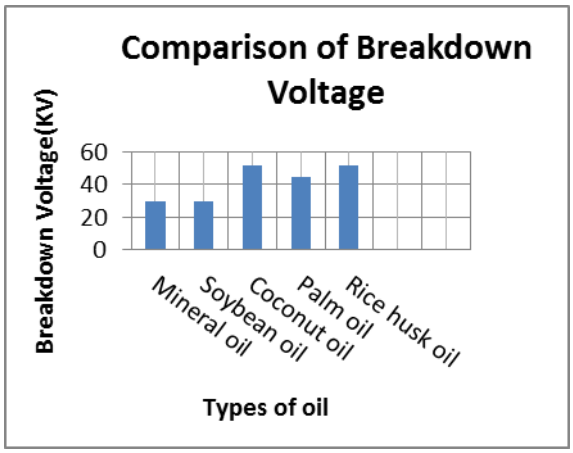

Fig. 9. Comparison of dielectric breakdown voltages of mineral and vegetable oils

Dielectric breakdown voltage data shown in Fig. 9 indicate that most of the vegetable oils have lower dielectric

breakdown voltage compared to the mineral oil. However, Coconut oil, Palm oil and Rice husk oil has higher dielectric breakdown voltage than the mineral oil. The data further indicate that some of the vegetable oils have acceptable dielectric breakdown voltage to consider as a base fluid for vegetable oil-based dielectric fluid development for power and distribution transformers. The good dielectric breakdown voltage of some vegetable oils indicate their ability to handle high voltage load without causing serious problem associated with this property.

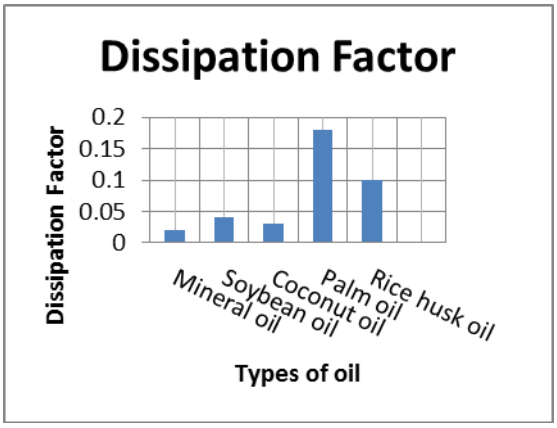

Fig. 10. Comparison of dissipation factors of mineral and vegetable oils

Dissipation factors shown in Fig. 10 indicate that all the vegetable oils have higher dissipation factor compared to mineral oil. Palm and Rice husk oils have drastically higher dissipation factor compared to the mineral oil. This is probably the result of the presence of high amount of conductive contaminants in these oils. As the presence of high amount of contaminants is the cause of higher dissipation factor, it can be improved to acceptable level by further processing and treatment of vegetable oils. Dissipation factor of coconut oil is more or less similar to mineral oil and this is the advantages of possessing lower dielectric losses.

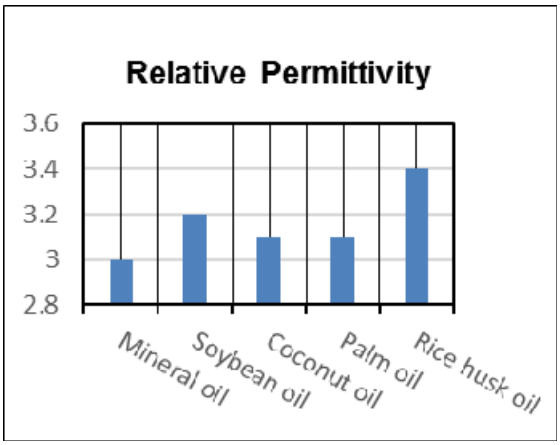

Fig. 11. Comparison of relative permittivity of mineral and vegetable oils

Relative permittivity of any dielectric material is related to the susceptibility which is a measure of how easily a dielectric polarizes in response to an electric field. Application of electric field to a dielectric material directed dipoles inside the material, which is initially random, in the same direction of applied electric field. For the same temperature level, Rice husk oil possesses the highest relative permittivity and then followed by other vegetable oils. The molecule of rice husk oil in the form of dipole is more susceptible to polarize under the influence of an electric field, so that its relative permittivity or dielectric constant is higher than the other oils. This is an advantage as the Rice husk oil would be experiencing the lowest electric field stress compared to other vegetable oils as well as mineral oil.

IV. CONCLUSION

The study reveals that vegetable oils have flash point and fire point much higher than the mineral oil that indicates better fire resistant capacity. Vegetable oils have some physical parameters such as pour point, specific gravity and viscosity which are inferior to the mineral oil and thus needs improvement. The vegetable oils have acceptable level of breakdown voltage compared to mineral oil so that they can be used in high voltage equipment. Though mineral oil has the lowest dissipation factor, vegetable oils show better performance if processed and purified. Rice husk oil shows higher relative permittivity that would be experiencing the lowest electric field stress compared to other tested oils. The properties of vegetable oils which are inferior needs proper research in improving those parameters may lead to the development of highly biodegradable and environmental friendly dielectric fluid suitable for high voltage equipment.

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