# COCONUT OIL AS AN ALTERNATIVE TO TRANSFORMER OIL

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## ABSTRACT

The paper presents a study which has been carried out to use coconut oil as insulation in transformers. Among the important properties considered are the dielectric strength of coconut oil which corresponds to less than 20 kV for a 2.5 mm sphere gap and the *pour point* which is approximately 23°C. To retain the oil in liquid form at low temperatures, several pour point depressants were tried. Some of them depressed the pour point, but also lowered the dielectric strength and proved unsatisfactory.

In order to have improved properties, a purified form of coconut oil was used in the investigation. In this, the free fatty acids have been neutralized (reduced to 0.02%). Deodorization by steam distillation at 200°C has removed odorizing and tasting compounds of lower boiling points. The moisture has been reduced by heating to over 100°C. The demoisturized coconut oil sample showed promising results. The dielectric strength improved to 60kV or even higher dependant on the moisture reduction of the sample. Since the distribution transformer tank (manufactured by Lanka Transformers Ltd) is a sealed container and oil is filled inside a vacuum chamber, moisture inclusion after manufacture is prevented.

As an alternative to reducing the pour point, repeated experiments on the dielectric strength of solidified and partially solidified coconut oil samples were carried out, and it was found that solidification does not appear to have any adverse effect on the dielectric strength. Coconut oil solidifies without creating voids, keeping its dielectric strength unreduced. When exposed to heavy magnetic fields, oil with a higher unsaturated degree of fats may break but coconut oil having a very low degree of unsaturated fats, ensures consistent properties at heavy magnetic fields essential for insulating oils.

An experimental 5 kVA transformer, filled with coconut oil has been constructed and investigated. The study has shown that coconut oil not only appears to possess the necessary electrical properties, but is an environmentally friendly oil and an indigenous resource of Sri Lanka. Thus considering the economic, environmental and social costs, the use of coconut oil for Sri Lanka has become a viable option.

## INTRODUCTION

Transformers have traditionally used mineral oil as insulation, and coconut oil has been used mainly for edible purposes. Transformer oil acts as an insulating and cooling medium in transformers. The insulating oil fills up pores in fibrous insulation and also the gaps between the coil conductors and the spacing between the windings and the tank, and thus increases the dielectric strength of the insulation. Transformer in operation generates heat in the winding, and that heat is transfered to the oil. Heated oil then flows to the radiators by convection. Oil supplied from the radiators, being relatively cool, cools the winding. There are several important properties such as dielectric strength, flash point, viscosity, specific gravity and pour point and all of them have to be considered when qualifying certain oil as transformer oil.

The quality of the oil is very important. A high voltage, highly loaded transformers demands better quality oil than a low voltage, lightly loaded transformer.

Mineral oil, synthetic esters and silicon oil are traditionally used as transformer oils. Mineral transformer oil (hydrocarbons) has Paraffinic, Aromatic or Naphthenic structure, and they are obtained by fractional distillation of crude petroleum. Substitution of chlorine atoms for hydrogen atoms in hydrocarbon molecules makes synthetic oils. Polychlorinated Biphenyl (PCB) which originated from synthetic insulating oils were originally used as insulating oils because of their low flammability and good dielectric properties. However due to their negative environmental impact, their use is now banned in many countries and is not used in Sri Lanka. Silicon has a very high flash point (low flammability) and it is generally used in places where safety is highly desired. It is the most expensive oil of all types.

Apart from those traditional oils, sunflower oil, which is 100% environmental friendly, is used as a transformer oil in some countries [1]. Unfortunately the price of sunflower oil is very high when compared to mineral oil. Further the Nebraska Public Power District is exploring the use of soybean based oil in electric transformers [2]. In our research we have tried to use coconut oil, which is biodegradable and environmental friendly, cheap and available in Sri Lanka as an alternative transformer oil.

Coconut oil is a colorless to pale brownish-yellow liquid. In temperate climates, it appears as greasy, somewhat crystalline, white to yellowish solid fat. Coconut oil is extensively used for edible and industrial purposes. Products derived from coconut oil and its fatty acids find numerous applications in food, soap, textile and synthetic resin industries, and recently even as an auto lubricant [3].

According to the technical specifications of transformer oils and IEC standards[4], the important properties to classify transformer oils[5] are the physical properties, chemical composition, and most importantly, the electrical properties. These were examined. Certain processes were implemented to improve the electrical properties as well as other properties of coconut oil. A coconut oil filled transformer was produced and tested. The Dielectric Strength is the most important electrical property. As per IEC296, transformer-insulating oil must have a dielectric breakdown voltage of 50kV.

## ELECTRICAL PROPERTIES OF COCONUT OIL

Figure 1 - Dielectric Test Equipment

In the dielectric breakdown voltage test equipment, shown in figure 1, a voltage is applied between 2 spherical electrodes separated by a gap of 2.5mm and immersed in oil. The oil sample was agitated and then increasing voltage was applied. Six values of breakdown voltages were taken and its mean and standard deviation were calculated.

Improvement of dielectric strength was observed after heating the oil sample to over 100°C, with sufficient surface area exposed to the atmosphere to allow the moisture to escape from the oil sample.

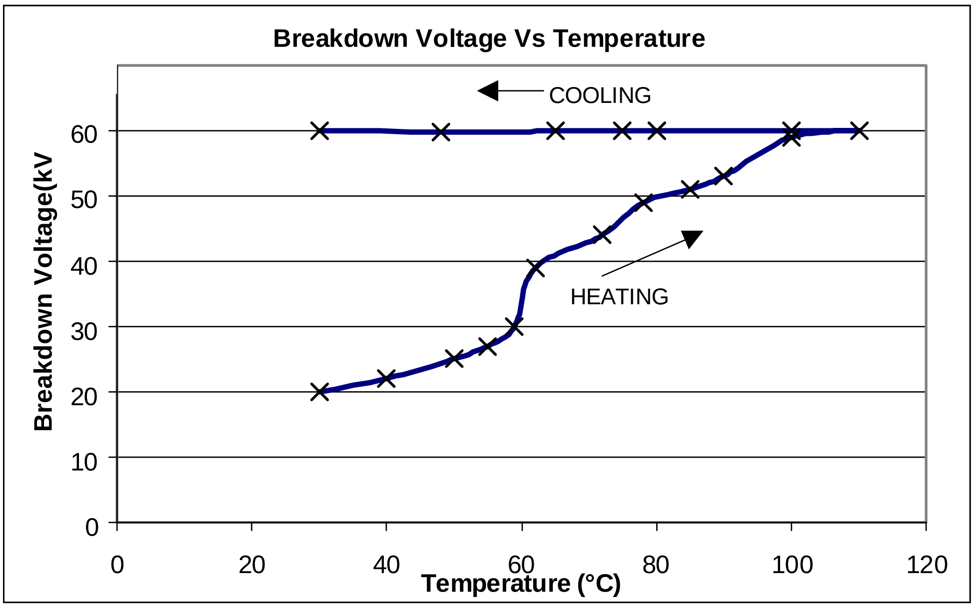


Figure 2 - Heating/Cooling Curve of Coconut Oil.

Dielectric breakdown voltage of the sample at room temperature was 20kV and the sample was heated using a domestic heater of 500W. At different temperatures, a sample was taken and the dielectric breakdown voltage was measured using the testing apparatus. The test results(figure 2) show that the breakdown voltage increases gradually up to 60kV, which is the maximum applicable voltage by the apparatus.

The water content in the sample affects the dielectric strength of oil. Heating evaporates water in the oil sample. When the temperature of the sample is near to the boiling point of water (100°C) the water content is very low, hence it shows the higher dielectric strength.

The heated oil sample, which showed dielectric breakdown voltage of 60kV, was then allowed to cool down back to room temperature. The sample was kept inside the apparatus during the cooling, ensuring no moisture addition to the sample. While the sample was cooling, its dielectric breakdown voltage was measured at several intermediate temperatures. Cooling back to room temperature did not affect the dielectric strength of the oil sample (figure 2).

**Degradation of Dielectric Strength by Moisture Absorption**

Absorption of moisture reduces dielectric strength of coconut oil, because it increases the water content in the sample. When the oil sample is kept open to air for a considerable length of time, a reduction in dielectric strength was observed as a result of moisture absorption. This is a common problem with all types of transformer oils, especially with mineral transformer oil where moisture absorption is one of its inherent properties.

To compare the rate of moisture absorption, one coconut oil sample of 60kV breakdown strength and one mineral oil sample of the same breakdown strength were placed, open to air, in a room where the humidity was 78%. The dielectric breakdown voltages of both the samples were tested at regular intervals and are plotted in figure 3.

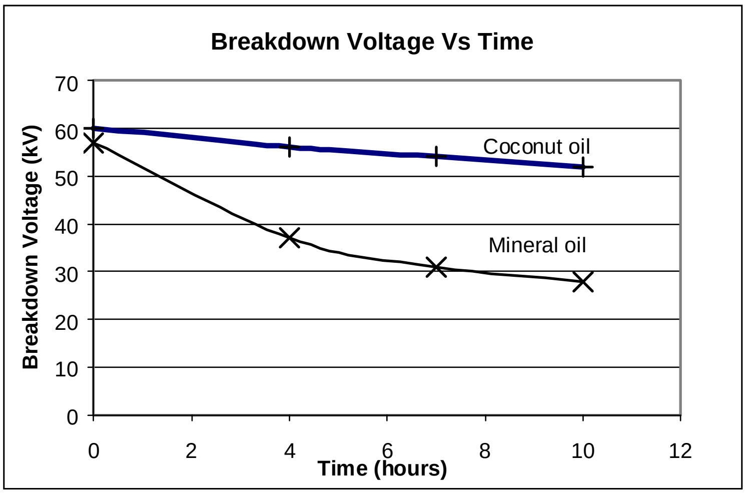


Figure 3 - Moisture Absorption of Oil

The decrease of dielectric strength of coconut oil with time was found to be remarkably lower than for mineral oil. That is, the rate of moisture absorption of coconut oil is very low compared to mineral oil, under similar conditions of exposure to the atmosphere.

The insulating oil should impregnate the layers of paper that insulate the coils in a transformer winding. Thus the paper impregnation ability of coconut oil was considered as an important property and obtained from a comparative test with mineral transformer oil.

**Paper Impregnation Test**

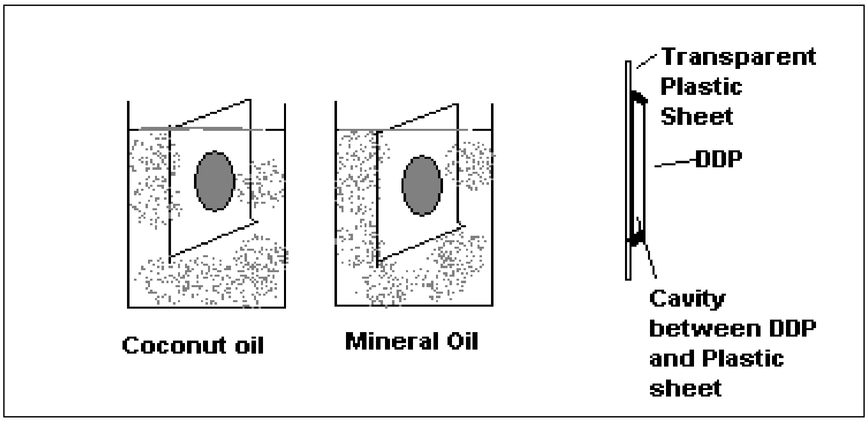


Figure 4 – Impregnation Test for Oil

Two circular pieces of *Diamond Dotted Paper* (DDP), a material commonly used in transformer winding insulation; of similar dimensions (thickness and diameter), were fixed using "silicon sealant" on two transparent plastic sheets creating even cavities between the DDP and the plastic sheet.

The two sheets were immersed, one in coconut oil and the other in mineral oil, at the same time and the time taken to fill the cavity was compared (figure 4).

It was found that while the time taken to fill the cavity was 41 hours for mineral oil, it was 58 hours for coconut oil. It is seen that coconut oil impregnates insulating paper, but it takes relatively more time than mineral oil. By this result we can conclude that while the level of paper impregnation of coconut oil is lower than mineral oil, it has an acceptable level.

Impregnation Process.

Moisture reacts with cellulose in paper insulators and results in paper degradation. The production process of transformers minimize the contact of moisture with oil. It also increases the level of paper impregrnation.

The core and windings assembly is shown in figure 5, and it is kept inside an oven for approximately 36 hours to make it dry and free of moisture.

Figure 5-Core and Winding Assembly

Figure 6-Vacuum Impregnation

This improves the paper impregnation level of oil, because paper impregnation is very high when the paper is dry. After taking from the oven, the core is tanked and placed inside a vacuum chamber immediately (figure 6). Creation of the vacuum vaporizes any remaining moisture in the tank and at approximately 0.5 bar, oil filling is started. After filling, the vacuum is released. At the release of the vacuum, impregnation boosts-up, ensuring better impregnation.

**PURIFICATION OF COCONUT OIL**

To improve certain properties desired, for use coconut oil as transformer oil, the coconut oil sample was subjected to the following purification processes:- De-moisturizing, Neutralization, Bleaching, Deodorization. (Some of these processes were carried out by the manufacturer of the coconut oil).

De-moisturizing was done by heating the oil sample above the boiling temperature of water. It improved the dielectric strength of both purified coconut oil and normal coconut oil (oil without purification). This process was carried out after other three processes.

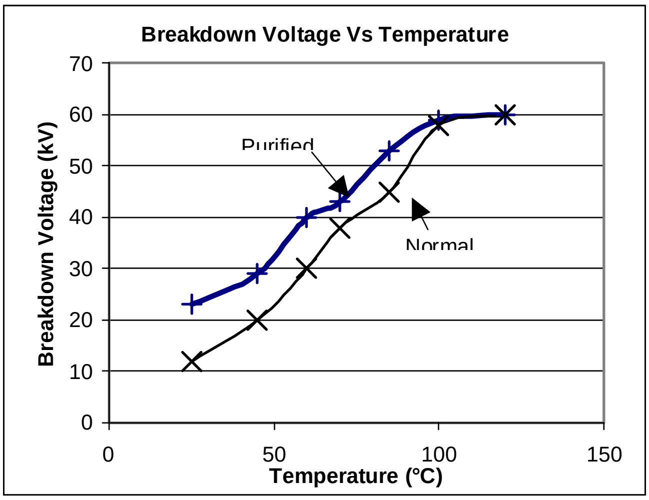


Figure 7- Heating of Coconut Oil.

Coconut oil contains free fatty acids and that makes coconut oil corrosive. Free fatty acids (FFA) are a combined result of oxidation and reaction with bacteria in the atmosphere. Before purification, the FFA content in coconut oil is approximately 5%. By adding NaOH, free fatty acids were neutralized and the FFA percentage of the tested sample was reduced to approximately 0.01~0.04%.

Coconut oil contains odor and tasting compounds, which are actually low boiling compounds. Inclusion of such compounds with low boiling point builds a pressure in the transformer at operation where the temperature rises normally above 60°C. Deodorization removes odor and taste of coconut oil and is done by steam distillation at 200°C.

To remove saponificable matter and colorings in coconut oil, a bleaching process was carried out by using activated clay.

## A COMPARISON WITH TRANSFORMER OIL STANDARDS

Several important properties, specified in transformer oil standards were compared with the relative values of coconut oil (table 1).

| Property | Coconut Oil | Standard Oil (IEC296) |
|---|---|---|
| Dielectric Strength (kV) | 60 | 50 |
| Pour Point (°C) | 20 | -40 |
| Flash Point (°C) | 225 | 154 |
| Moisture Content (mg/kg) | 1.0 | 1.5 |
| Viscosity (cSt) at 40°C | 29 | 13 |
| Density (kg/dm$^3$) at 20°C | 0.917 | 0.895 |

Table 1- Comparison of Properties of Oils

The dielectric strength of purified coconut oil satisfies the value given in the standard and has a sufficient tolerance to make it practically feasible.

The Flash point of coconut oil is higher than the standard value[6]. The flash point of oil is specified for safety reasons. Higher flash point ensures safety of a transformer operating at high temperatures and allows its use in same adverse conditions.

Cooling of a transformer is mainly governed by convection, so it is important to have a low viscosity to facilitate convection: the lower the viscosity, the better the cooling. Increase in temperature reduces viscosity, and as can be seen from figure 8, the desired range of viscosity is reached at about 80°C rather than at 40°C. However if used in a tropical country like Sri Lanka, this is unlikely to cause any adverse effect.

Specific gravity of coconut oil is 0.917 (at 20°C) and it is higher than the specified value. Lower the specific gravity better the flow of oil and it facilitates convection.

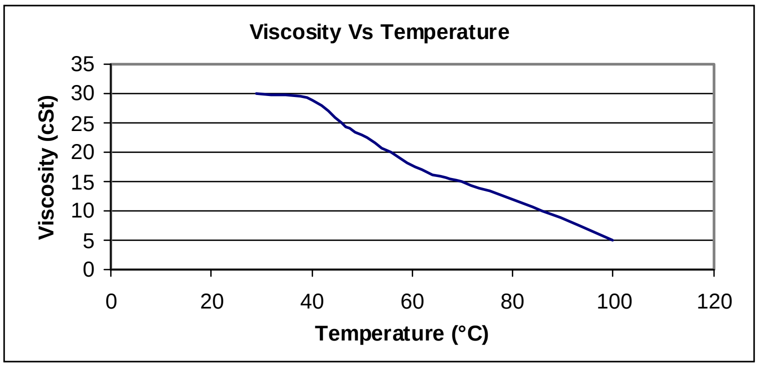


Figure 8- Variation of Viscosity of Coconut Oil.

## COCONUT OIL IN COLD WEATHER CONDITIONS

Pour point of coconut oil is approximately 20°C and much higher than the standard value of –40°C. It should be lowered as much as possible to achieve a good flow of oil at cold environmental conditions. The transformer in operation generates heat which results in the temperature rise in oil. But in cold weather conditions, when the power supply is disconnected for a long time and re-energizing of the transformer, coconut oil can solidify due to its higher pour point. It may cause a failure in the transformer due to creation of low creepage distances or voids.

The standard pour point value is –40°C. In an attempt to reach that value, coconut oil was subjected to a "winterization process" and several pour point depressants were also added to coconut oil.

### Winterization Process

The Winterization process was carried out to remove the higher melting glycerides, which cause liquid oils to become cloudy and more viscous at low temperatures. In that process, a 200ml sample of coconut oil was quickly chilled to 10°C. Crystallized particles were filtered-out and the remaining liquid sample was found to be 50ml. This 50ml liquid oil sample was again gradually chilled to 10°C, starting from room temperature. Partially crystallized particles were found even before 14°C.

(Crystallization started approximately at 15°C). This experiment proved that the winterization process was not economical and did not achieve the desired result.

Pour Point Depressants

Coconut oil was mixed with pour point depressants (such as Glycerin, Unified Naphtha, and Ethyl Acetate) in different proportions. Other than for Ethyl Acetate, none of the others had any affect on the pour point. Although Ethyl Acetate depressed the pour point, when added 10% by volume, the depression was only to 10 $^{o}$C, and then too the dielectric strength was reduced drastically to less than 20 kV on the 2.5 mm standard gap (compared to 60 kV normally). Thus the pour point depressants did not prove to be a success.

Dielectric Strength of Solidified Coconut Oil

Dielectric breakdown voltage of partially solidified and fully solidified coconut oil samples was tested as an alternative to reducing the pour point. The testing vessel of the dielectric test apparatus was filled with purified coconut oil and chilled. At different states of oil (ex: fully solidified, partially solidified…. etc.) the dielectric test was carried out.

The test results showed that solidification does not appear to have any adverse effect on the dielectric strength. Coconut oil solidifies without creating voids, keeping its dielectric strength unreduced.

Comparison with Sunflower Oil

Pour point of sunflower oil is approximately –18°C and that of coconut oil is 20°C. The unsaturated acid (Linoleic & Oleic) percentage in sunflower oil is 91% while saturated acids accounts for about 9%. Coconut oil consists of only 9% of unsaturated acids and 91% of saturated acids. Pour point of unsaturated acids is very low compared to pour point of saturated acids. Hence, sunflower oil has a low pour point, and coconut oil has a high pour point. Unsaturated fatty acids contain double bonds. Inside the transformer, oil is subjected to heavy electro-magnetic fields. There is a possibility that double bonds may break due to polarization. Coconut oil is far better than sunflower oil from this point of view.

Oil Contamination

The modern distribution transformer tank is a sealed vessel, where contact of air with oil is virtually impossible. But there can sometimes be very small leaks in the tank that will allow air into the tank and oxygen in air to react with oil. Oxidation products are water and free fatty acids. Water contaminates insulation oil and paper.

To figure out the possible level of contamination due to tank leaks, a coconut oil sample of 58kV dielectric breakdown voltage was placed in a barrel where the seal cap was left open (figure 9), allowing air contact with the oil surface. The oil was tested for breakdown voltage daily by extracting at the sampling valve. Negligible degradation of the oil was observed even after 40 days (figure 10).

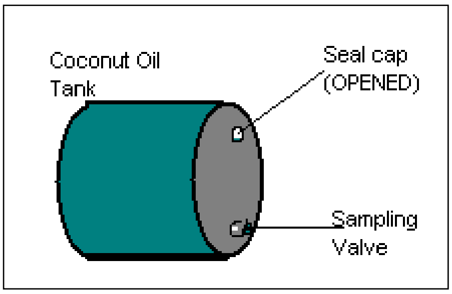


Figure 9 - Tank with seal cap opened

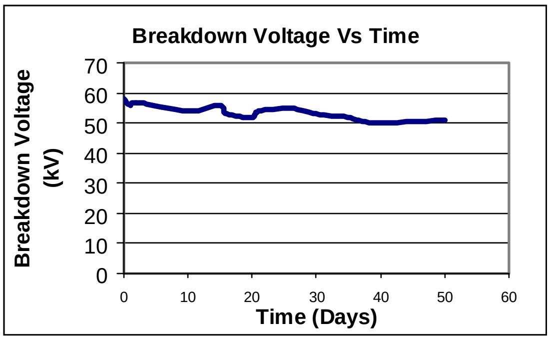


Figure 10 - Degradation of oil

## COCONUT OIL FILLED TRANSFORMERS

To test the oil in real conditions, a 5kVA, 33kV/240 V single-phase transformer was filled with purified coconut oil, and tested in LTL testing laboratory (figure 11).

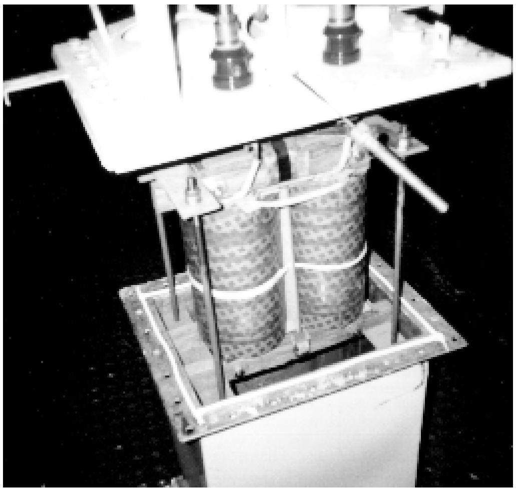

Figure 11 - Single Phase Coconut oil filled transformer

Coconut oil was Neutralized, Bleached, and De-odorized at BCC. Oil capacity of the transformer was 55litres. A special boiler was used to heat purified coconut oil before filling the transformer. Dielectric breakdown voltage of oil was 58kV after heating above 100°C. Oil was filled under vacuum and after top-up; the transformer was tested with the seven routine tests that all the LTL transformers face before dispatch. All the tests were passed by this transformer.

The No load test and the load test showed that the losses in the transformer was not affected by the use of coconut oil. The voltage withstand tests showed that adequate insulation existed in the transformer.

<u>Heat Run Test</u>

When the transformer is overloaded, the winding tends to overheat. At this moment, the cooling capability of the oil is critical. The oil must be capable of stopping the heating of the winding over its safe limits. The maximum temperature of the winding when the transformer is overloaded can be calculated by using the results of heat run test. Coconut oil filled 5kVA, 33kV/240V transformer was loaded by 125% and the temperature difference between the top oil and ambient was measured at regular intervals. This difference became constant at steady state. By using that value and winding resistance at steady state, the maximum temperature rise of the winding was calculated (58 $^{o}$C). This was below the maximum allowed limit.

## TESTING TRANSFORMERS IN A COLD ENVIRONMENT

Figure 12 - Transformer immersed in the fibreglass vessel surrounded by ice.

To test the insulation properties of 5kVA, 33kV/240V transformer in a cold environment, an extremely cold climate was achieved by placing the transformer in a fiberglass vessel filled with ice cubes (figure 12). It took approximately 40 hours to completely solidify the full amount (55 liters) of purified coconut oil in the transformer. Then it was allowed to settle down back to room temperature.

During this process the transformer was tested with high voltage and power frequency tests four times at four different states of oil.

1. Semi solidified state before full solidification.
2. Completely solidified state.
3. Semi solidified state after full solidification during liquification
4. Liquid state (Ambient temperature)

Although the power frequency and high voltage tests are not recommended several times for a single transformer, this was done as our objective was to observe insulation properties of the transformer at different stages. The transformer passed both the tests at all four states.

Considering all the above facts, we can conclude that coconut oil can be used as transformer oil. However further tests need to be done under actual operating conditions. Coconut oil is freely available in Sri Lanka and it may become cheaper than other transformer oil. Most importantly it is 100% environmental friendly, hence it can be easily used as an alternative to traditional transformer oil.

## ACKNOWLEDGEMENTS

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