Coconut Oil Insulated Distribution Transformer

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ABSTRACT

This paper presents the evolution of a coconut oil filled distribution transformer for use in tropical countries where the temperatures rarely go to sub-zero temperatures and where there is an abundance of environmentally friendly coconut oil available.

Initially, tests have been carried out to establish that it is feasible to use coconut oil in transformers as an insulating oil. A 5 kVA single phase transformer, filled with purified coconut oil, has then been tested under adverse conditions in the laboratory. Finally a full scale 160 kVA, 3 phase, 50 Hz distribution transformer has been constructed filled with purified coconut oil under factory conditions and is being tested under practical conditions in the field.

Initial tests have indicated that the use of coconut oil as an insulating oil in sealed distribution transformers is a viable alternative to mineral oil. Its indigenous and environmentally friendly nature and the higher operating temperatures possible also make it ideal as an insulating oil for Sri Lanka in the future.

1.0 INTRODUCTION

Transformer oil acts as a cooling and insulating medium in transformers. This insulating oil not only fills up the pores in the fibrous insulation such as paper, but also the gaps between the turns of the winding and the spacing between the winding and the tank. The oil, in addition to functioning as a dielectric also serves as a cooling medium.

Traditionally, mineral oil, synthetic esters and silicon oils have been used in transformers. More recently, the environmentally friendly sunflower oil has been used as a transformer oil for special purposes [1]. Unfortunately the price of specially treated sunflower oil is very high compared to mineral oil.

In the present study, the properties of coconut oil, which is an indigenous product of Sri Lanka, has been investigated to decide whether it can be used as an insulating oil in distribution transformers.

2.0 Properties of Coconut Oil

Coconut oil is a colourless to pale brownish-yellow liquid. In temperate climates, it appears as greasy, somewhat crystalline, white to yellowish solid fat.

In order to avoid problems caused by impurities present in Coconut oil available in the ordinary market in barrel-form, only commercially available purified coconut oil was examined. Ordinary coconut oil could also be purified to reach the required level.

Although coconut oil may come from diverse sources, there is a good agreement as to its properties. [The Appendix give the Chemical and Physical Properties of Coconut Oil]

2.1 Dielectric Strength

The dielectric strength of coconut oil is the most important of its electrical properties. The dielectric strength of normal purified coconut oil was found to be about 18 kV to 31 kV and differed from sample to sample dependant on the inherent moisture content of the sample. In order to reduce the moisture content, the oil was heated to around 110^{o} C and tested again at several temperatures while heating and cooling. Sufficient area was exposed to the atmosphere during the heating process to allow the moisture to escape from the oil sample.

In a particular sample of coconut oil, the dielectric strength was found to gradually improve from about 20 kV (for an electrode gap of 2.5 mm) at room temperature of 30^{o}C to about 60 kV at 110^{o}C. The dielectric strength did not deteriorate even when the sample was allowed to cool down to room temperature (figure 1).

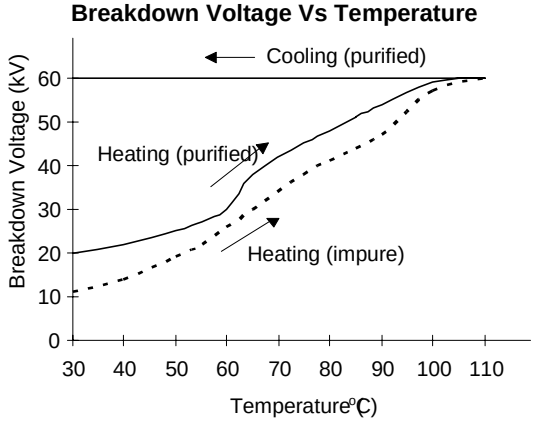

Figure 1 - Heating/Cooling Curve of Coconut Oil

In order to determine the improvement to the dielectric strength of commercial (impure) coconut oil, the heating experiment was repeated with this oil. It was found that even the impure coconut sample which had an initial breakdown strength of about 11 kV improved to the same high value of 60 kV when the temperature was increased to above 100^{o}C.

Thus it can be easily concluded that the dielectric strength of coconut oil is highly dependant on the moisture content of the sample. It is to be noted that this is also true for the traditional mineral oil used as transformer insulation.

The dielectric strength required for standard mineral oil as per the IEC296 standard [2] is 50 kV for the standard 2.5mm gap. Treated coconut oil adequately meets this standard value.

2.1.1 Degradation of Dielectric Strength

In order to compare the ingress of moisture with that of mineral oil, on exposure to the atmosphere, a sample of treated coconut oil (of approximately 60 kV dielectric strength) and a sample of mineral oil (of similar dielectric strength) was placed open to air in a room where the humidity was 78%. The breakdown voltages of both samples were tested at regular intervals (figure 2).

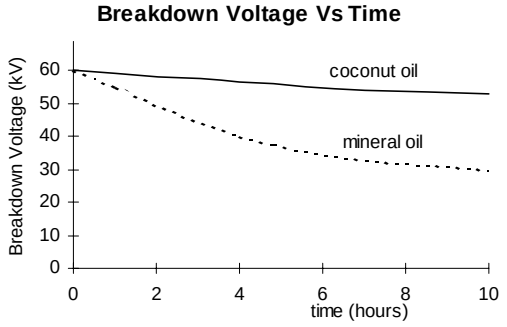

Figure 2 - Degradation due to moisture absorption

The decrease in dielectric strength of coconut oil is seen to be remarkably lower than that of mineral oil. Moisture absorption is quite a common problem to all transformer oils and is an inherent property of mineral oils.

The distribution transformer tank is usually a sealed vessel, where contact of air with oil is virtually impossible after assembly. However under exceptional circumstances small leaks in the tank could allow air into the tank and oxygen in air to react with oil. Oxidation products are water and free fatty acids. The water contaminates insulation oil and paper.

An additional test was thus done to determine the possible long term contamination of the oil due to a small leak. This situation was simulated by placing the coconut oil in a barrel with the seal cap left open (figure 3) allowing air contact with the oil surface.

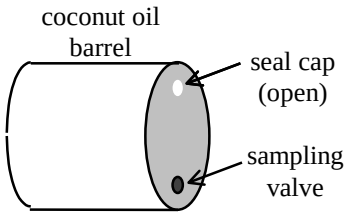

Figure 3 - Barrel of oil with seal cap left open

Samples of oil, taken through the sampling valve at the bottom, were tested for breakdown daily over a period of almost 2 months (figure 4). Negligible degradation of the oil was observed even at the end of the period.

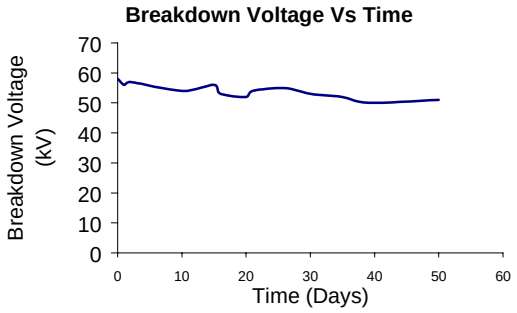

Figure 4 - Degradation of oil due to small leak

2.1.2 Dielectric strength of solidified coconut oil

Since the pour point of coconut oil is much higher than what is specified for mineral oils in the IEC296 standard, the possibility of solidification of the coconut oil during operation under cold environmental conditions was investigated.

Thus the dielectric strength of partially solidified and fully solidified oil samples was tested.

The testing vessel of the dielectric test apparatus was filled with purified coconut oil and chilled.

At different states of oil (fully solidified, partially solidified and liquid) the dielectric test was carried out.

State of solidification	Breakdown voltage (kV) of 2.5 mm gap
liquid	60.00, 60.21, 60.07, 60.07, 60.00
partially solid	59.65, 59.79, 60.07, 60.21, 60.21
solid	60.00, 58.33, 60.00, 60.00, 60.07

Table 1 - Breakdown strength of Coconut Oil

It is seen from table 1 that the breakdown strength of Coconut oil appears to be independent of the state of solidification. This is probably because Coconut oil solidifies without creating voids, keeping its dielectric strength unreduced.

Solidification is known to contract the volume of coconut oil and it reduces the oil level of the transformer. Volume contraction of coconut oil at low temperatures was thus studied.

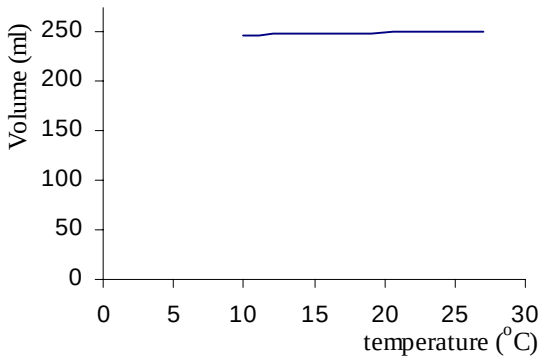

Figure 5 - Volume reduction on cooling

250 ml of coconut oil at room temperature (27^{o}C) was gradually cooled observing the reduction in volume. It was observed that the volume reduced to 247 ml at 10^{o}C indicating a reduction in volume of about 1.2%. This reduction in volume is not considered to be significant.

2.2 Relative Cost of Coconut Oil

Mineral transformer insulating Oil costs US$ 0.65 per litre (approximately Rs 60 per litre), while purified coconut oil available in the retail market is Rs 120/= per litre and the impure form is retailed at Rs 60/= per litre. It is seen that even at the retail market rates, coconut oil is only marginally more expensive than Mineral Oil

2.3 Permittivity of Coconut Oil

The relative permittivity of the coconut oil used was measured using a comparison method and was found to be 3.04, the same measurement method gave that of mineral transformer oil to be 2.20 confirming the reliability of the method of measurement.

2.4 Oil Impregnation of Paper

Two circular pieces of Diamond Dotted Paper (DDP), used as insulation in transformers, of similar dimensions were fixed using "silicon sealant" on two transparent plastic sheets creating even cavities. One sheet was immersed in coconut oil and other in mineral oil (figure 6)at same time and the time taken to fill the cavity was compared (table 2).

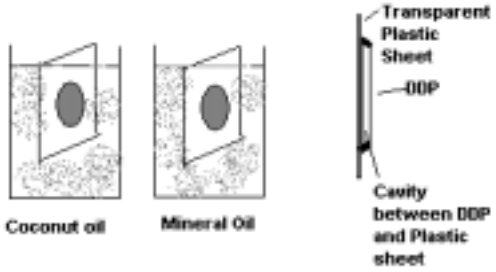

Figure 6 - Oil Impregnation Test

	Coconut oil	Mineral Oil
Time to fill cavity (hr)	58	41

Table 2 - Impregnation time of Oils

The results show that the rate of impregnation of paper with coconut oil is marginally lower than that with mineral oil, but that it is at an acceptable level. In practical situations, the Transformer is normally filled with oil under vacuum with the core dry and free of moisture. Under these conditions, at the release of the vacuum, impregnation boosts up, ensuring good impregnation.

3. COCONUT OIL TRANSFORMERS

3.1 Single Phase Transformer

To test the behaviour of coconut oil in an actual transformer, a 5 kVA, 33 kV/240 V single phase transformer (figure 7) was first produced. Oil capacity of the 5kVA transformer is 55 litres. A special boiler was used to heat the previously purified coconut oil before filling the transformer. 60 litres of oil was heated to around 120°C to exceed the boiling point of water. Sample of heated oil was taken from the boiler and its dielectric strength was measured to be 58kV. The transformer was filled with this treated coconut oil under vacuum conditions and tested at the LTL Testing Laboratory.

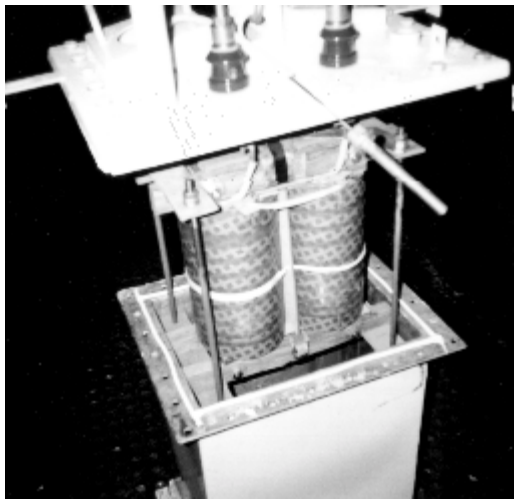

Figure 7 - Single phase coconut oil filled transformer

3.1.1 Routine Tests

The transformer was tested with the seven routine tests that all of the LTL transformers face before dispatch.

These are (a) Meggar test, (b) High Voltage test, (c) High frequency test, (d) No load test, (e) Full load test, (f) Dielectric test and (g) DC resistance test

The transformer passed all the routine tests. It was also observed that the losses and other parameters of the transformer were not noticeably changed by the replacement of mineral oil by coconut oil.

3.1.2 Heat Run Test

The Heat Run Test was carried out to determine possible overheating of the insulation above design value. The Transformer was loaded 1.25 times full load (to simulate an overload condition) and the maximum temperature rise was found. This value is well below the maximum allowable limit.

3.1.3 Testing in a cold environment

To test the insulation properties of the 5kVA single phase transformer under adverse conditions, a cold environment was simulated in the testing laboratory.

The extremely cold climate was achieved by placing the transformer in a fibreglass vessel filled with ice cubes (Figure 8).

Figure 8 - Transformer cooled using ice cubes

It took approximately 40 hours to fully solidify all the oil in the transformer. Then it was allowed to settle down back to ambient temperature.

During this process the transformer was tested with High Voltage and Power Frequency tests four times at the four following states.

1. Semi solidified state before full solidification.
2. Fully solidified state.
3. Semi solidified state after full solidification.
4. At ambient temperature after liquification.

The High Frequency and High Voltage withstand tests are not recommended to be done several times, but had to be done as our objective was to observe the insulation properties of the same transformer at different states of solidification. The 5kVA single phase transformer passed both the tests at all four states.

3.2 Three Phase Distribution Transformer

The next requirement was to test the behaviour of a coconut oil filled three phase distribution transformer under field conditions.

Figure 9 - Three phase coconut oil filled transformer

For this purpose, a conventional 160 kVA, 33 kV/415 V three phase transformer (figure 9) was produced but filled with treated coconut oil.

The Oil capacity of the 160kVA transformer is 290 litres. By using a conventional transformer oil filter, coconut oil was filtered. The dielectric strength of the oil before filtering was 38kV and, after filtering its dielectric strength improved to 58kV.

The 160kVA transformer was filled under vacuum conditions and the routine tests were conducted at the LTL Testing Laboratory. The transformer also passed all the routine tests. A heat run was also conducted and the temperature rise at steady state was found to be 30^{o}C, which is well within the maximum allowable limit.

This transformer has been dispatched to the field for on site testing in a natural environment. Initial testing will be carried out in or around Piliyandala where temperatures do not normally go below the pour point of the coconut oil.

It is also planned to continue the testing at a later date in a cold climate such as Nuwara Eliya to study the behaviour under cold environmental conditions.

4. CONCLUSION

The study has shown that purified and de-moisturised coconut oil can be used satisfactorily in sealed distribution transformers as an insulating oil in tropical climates. Tests have also shown that they may even be suitable in temperate climates although coconut oil freezes at about 23^{o}C. The main advantage however is that coconut oil is environmentally friendly and costs almost the same as mineral oil.

5. ACKNOWLEDGEMENTS

The authors wish to thank Mr U D Jayawardena, General Manager of Lanka Transformers Ltd for the ideas, encouragement and facilities provided to undertake the study.

They would also like to thank their colleagues for their helpful suggestions.

6. REFERENCES

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2. IEC Publication 296:1982 - Specification for unused mineral insulating oil for transformers and switchgear (incorporating amendment 1:1986)
3. NYNAS Transformer Oil Handbook, NYNAS Naphthenics AB, Stockholm, Sweden

APPENDIX - PROPERTIES OF COCONUT OIL

A1 - Chemical Properties

A1.1 Chemical Composition

The Constituent fatty acids of coconut oil are

Lauric	44.1-51.0
Myristic	13.1-18.5
Palmitic	7.5-10.5
Caproic (hexoic)	0.2- 0.5
Caprilic (octoic)	5.4- 9.5
Capric (decoic)	4.5- 9.7
Stearic	1.0- 3.2
Arachidic	0.2- 1.5
Total saturated acids ~ 91%	
Oleic	5.0- 8.2
Linoleic	1.0- 2.6
Total unsaturated acids ~ 9%	

A1.2 Glyceride Composition.

Trisaturatedglycerides	84%
Disaturated-monounsaturated	12%
Monosaturated-diunsaturated	4%

A13 Iodine Value

The Iodine value is defined as the amount of iodine (gram) absorbed by 100 gram of fat and is a measure for determining the unsaturation degree of fats and fatty acids. Unsaturated fats, which *consist* of double bonds may polarize and break in heavy electro-magnetic *fields*.

Coconut oil has the Lowest Iodine value of all the vegetable oils.

Iodine value of coconut oil is 81 and its unsaturated fatty acid percentage is only 9%.

A1.4 Saponification Value

The Saponification Value is the number of milligram of potassium hydroxide needed to saphonify (or convert into soap) 1 gram of fat.

Saponification value of coconut oil is 250.

A2 - Physical Properties

A2.1 Viscosity.

The cooling of a transformer is mainly governed by convection, so it is important to have a low viscosity to facilitate convection. Increasing temperature reduces viscosity.

Viscosity of coconut oil is 29 cSt at 40^{o}C.

Value as per IEC296 is 13 cSt at 40^{o}C.

A2.2 Pour Point.

The Pour Point is the temperature at which the oil just ceases to pour (or flow). The Pour point of an oil should be as low to achieve good flow of oil in a cold environment.

Pour point of coconut oil is around 23°C

Value as per IEC296 is -40^{o} C

A2.3 Flash Point.

The flash point of an oil is specified for safety reasons.

Flash point of coconut oil is around 170-225°C

Value as per IEC296 is 154^{o}C

A2.4 Specific Gravity.

Specific gravity of coconut oil is 0.917 at 20°C

Value as per IEC296 is 0.895 at 20^{o}C

A2.5 Moisture Content.

The moisture content of coconut oil varies from sample to sample.

Average moisture content of coconut oil is 1.0 mg/kg

Value as per IEC296 is 1.5 mg/kg