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REVIEW OF ADVANCES IN TRANSFORMER DIELECTRIC INSULATING FLUIDS

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RINGKASAN : *Kertas ini membincangkan ringkasan kerja yang dilakukan terhadap kajian cecair dielektrik berteraskan minyak-biji benih yang boleh dimakan. Bukti menunjukkan adanya kekurangan beberapa ciri dengan penggunaan petroleum dan minyak mineral untuk penyejukan pengubah. Usaha pengkaji pada masa sekarang untuk membangunkan dan memberikan pilihan cara penyejukan dan penebatan pengubah adalah dengan mengalih perhatian kepada kepentingan menyeluruh terhadap pengubah di dalam rangkaian pembekal kuasa elektrik. Yang penting sekali ialah kebolehan cecair dielektrik sayuran asli untuk mematuhi peraturan undang-undang kesihatan dan alam sekitar di dalam kes-kes tumpahan.*

Minyak sayuran asli yang diproses telah dijumpai dapat memenuhi spesifikasi kerana ia mempunyai titik sinaran yang tinggi (sehingga 300°C), titik api yang tinggi (sehingga 250°-300°C), titik mengalir yang rendah (< -10° C) dan mempunyai voltan kerosakan dielektrik yang tinggi (>50KV). Keadaan ini memenuhi piawai EEE C57, IEEE 637, ASTM D6781 dan 60296. Akhir sekali kebolehan terbiodegrasi membuatkan ianya selamat untuk digunakan di dalam kawasan penduduk yang padat dan berdekatan dengan laluan air. Kini bukan sahaja perlaksanaan teknikal menjadi asas di dalam pemulihan bahan tetapi juga keseluruhan alam semulajadi dan kos jumlah kitaran hidup menjadi sebahagian daripada analisis tersebut.

ABSTRACT : This paper discusses a summary of recent work on a natural edible seed-oil-based dielectric fluid. Evidence has shown some property deficiencies with the presently used petroleum and mineral oils for transformer cooling. The present efforts by researchers to develop and provide alternative means of cooling and insulating transformers is pivoted around the obvious importance of transformers in electrical power supply network. Most important is the ability of natural vegetable dielectric fluids to comply with environmental and health regulation laws in cases of spillage.

The treated natural vegetable oils have been found to meet specifications since they have high flash points (up to 300°C), high fire points (250°-300°C), lower pour points (<-10°C) and have high dielectric breakdown voltage (>50KV). These conditions comply with IEEE C57, IEEE 637, ASTM D6781 and IEC 60296 (standards). Finally, its biodegradability makes it safe for use in densely populated areas and close to waterways. Today, not only technical performance is of essence in material selection, but also the overall environmental and total life-cycle cost is becoming part of the analysis. Malaysia stands to gain a lot from this type of research, since it is one of the world leaders in palm oil production.

Keywords : Transformer oil, insulating vegetable fluid, vegetable oil coolant

INTRODUCTION

Transformers form an important part of an electrical network. Without transformers, utility companies would not be able to transmit and distribute electricity generated at remote power stations. Oil is used as an insulator and coolant in transformers and by monitoring its condition the transformer's overall health is determined. Electromagnetic devices like transformers heat up during operation due to various losses in its electrical and magnetic components. The rejection of heat is critical since excessive temperatures can damage insulation. Failures of transformers cost millions of dollars to replace, require months to repair and can leak toxic fluids. Cooling capability ultimately determines the amount of power that can be reliably handled by a transformer. As a result, transformers are designed to maximise heat rejection and this often means bulky and expensive designs (Maulbetch, 1997).

The function of dielectric fluid in an appliance is that of cooling and insulation. 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 transferred 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 to be considered when qualifying certain oil as transformer oil. The quality of the oil is very important. At high voltages highly loaded transformers demand better quality oil. While at low voltages highly loaded, transformers demand for high quality oil is not critical (Abeysundara *et al.*, 2001).

For more than a century, petroleum-based mineral oils purified to "transformer oil grade" have been used in liquid-filled transformers. Synthetic hydrocarbon fluids, silicone and ester fluids were introduced in the latter half of the twentieth century, but their use is limited to distribution transformers. Several billion litres of transformer oil are used in transformers worldwide.

The popularity of mineral transformer oil is due to availability and low cost, as well as being an excellent dielectric and cooling medium. Petroleum-based products are so vital in today's world that the consequence of its unavailability cannot be imagined. Transformers and other oil-filled electrical equipment use only a tiny fraction of the total petroleum consumption, yet even this fraction is almost irreplaceable (Oommen, 2002).

However, recent findings have made the use of mineral and petroleum oils in electric equipment rather unfit therefore there is the need for either an alternative or a total replacement. These oils suffer problems like low fire and flash points, low breakdown voltage and most importantly is the difficulty of disposal after usage. In cases of equipment failure or spillage, their decomposition is very slow, since they are not biodegradable. This is a very serious issue that poses environmental concern.

In view of these issues, research is currently going on to find replacements or alternatives to mineral and petroleum oils from natural vegetable oils, for electrical equipment maintenance.

VEGETABLE BASED DIELECTRIC FLUIDS

The paper aims to highlight the research efforts in transformer cooling and the developments of alternative dielectric fluids. It offers a summary of development work on a natural edible seed-oil-based dielectric fluid. It includes a background discussion of oils used, key properties comparison with other major dielectric fluid types, and details of field trials.

Conventional mineral oils in transformer can pose a threat to environment if spilled due to its negative environmental impact; its use is now banned in many countries. 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 and is also non biodegradable (Lucas *et al.*, 2001).

Most transformers and capacitors use a dielectric fluid based on polychlorinated biphenyls (PCBs). These products, although having fire-resistant and other properties required for use in electrical equipment, present some major disadvantages. These disadvantages are linked to the toxic nature of PCBs and their potential contamination. Negative biological effects have been coming to light over many years and are now well established. Unfortunately PCBs have already been in widespread use for about 40 years in transformers and it is now necessary to put forward practical solutions for eliminating them wherever they are used. The first problem that countries with PCB transformers still in operation have to face is how to locate and identify this equipment. A decision will then have to be taken as to when, and how, the contaminated equipment will be managed, reclassified and eventually eliminated. It is the purpose of this publication to assist people responsible to take the appropriate decisions enabling their country to comply with the provisions of the Stockholm Convention.

RESEARCH EFFORTS

In line with the myriad of problems stated above there is then the need to look for alternative solutions. The solutions should not be merely that of managing what is now apparent, but we should come up with alternative means of cooling electrical equipment. Along this line biological or plant based oils are handy. Recent industrial research and development have found that vegetable oils termed as "biodegradable oils" can be used for industrial applications. Its engineering applications have been proven by researchers (Oommen, 2002).

HISTORICAL PERSPECTIVE OF VEGETABLE OILS AS DIELECTRIC FLUIDS

Historically vegetable oils have found applications in the maintenance of electrical equipment. In 1892, experiments with liquids other than mineral oils included ester oils extracted from seeds. None made operational improvement over mineral oil, and none were commercially successful. A particular problem with seed oil-based coolants were its high pour points and inferior resistance to oxidation relative to mineral oil (Lucas and Rhee, 1992). Nevertheless, due to operational and economical reasons there was a decline in their usage along the line. Except for occasional applications in capacitors and other specialties, renewed interest in ester -based coolants did not occur until after the infamous issue of the PCB arose in the 1970's.

In 1984, the first transformer applications of these synthetic esters were railroad rolling stock transformers with very high duty requirements. Due to their compact dimensions, such transformers had forced circulation flow to remote heat exchangers. Therefore excellent lubricity, very low pour point temperature and a high fire point were important fluid characteristics for their application. Market acceptance of synthetic esters was limited to spatiality applications, primarily due to their high cost compared to other dielectric fluids (McShane and Oommen, 2003).

Presently environmental and health reasons have seen a total reversion to these oils. As a result of environmental regulations and liability risks involving non-edible oils, an extensive R&D effort begun in 1990's which led to revisiting the natural esters. They share many of the excellent dielectric and fire safety properties of synthetic polyol esters and they are classified as edible oils. In addition, they are biodegradable since they have organic composition and most importantly, they are much more economical than synthetic esters (McShane, 2001).

CHEMICAL COMPOSITION OF VEGETABLE OILS

For a vegetable oil to fully qualify as a dielectric fluid, its chemical composition is crucial. The vegetable oils suitable for engineering applications have common molecular arrangement. Crude vegetable oils extracted from oil seeds have a dark colour and contain solid constituents such as proteins and fibres, and liquid (fats and oil). Both fats and oil are triglyceride esters of fatty acids, but fats contain a relatively high percentage of saturated triglycerides and would freeze to solid state below room temperature. The oily part usually remains as liquid above 0º C, oils with high unsaturation may remain as liquid at 15-30º C.The triglyceride ester molecule may be represented as follows (Oommen, 2002).

CH_2-$OOCR_1$
CH -$OOCR_2$
CH_2-$OOCR_3$

Where R_1, R_2, and R_3 are fatty acid chains of same or different types. Saturated fatty acids with eight to 22 carbon atoms are found in oils. Fatty acids with one unsaturated bond have carbon atoms ranging from 10 to 22. Fatty acids with di-and tri-unsaturation mostly contain 18 carbon atoms (Linoleic and Linolenic acids). The fatty acid composition of some vegetable oils is shown in Table 1 (Lucas and Rhee , 1992).

SYNTHESIS, PURIFICATION AND TESTING

This section describes how the dielectric fluid is produced and the product tested. The BIOTEMP® and the Envirotemp FR3® are used as examples and the details about these fluids will be presented. In general, the following are the required tests according to international regulations ASTM and IEC and some local regulatory and standardisation :

Appearance, Colour and Colour number, Viscosity and Viscosity Index, Flash and Fire Points, Pour Points, Thermal Conductivity, Interfacial Tension, Dielectric Breakdown Voltage, Dielectric Constant, Dissipation or Power Factor, Acidity, Oleic Content, Moisture Content, Gassing Tendency, Neutralisation Number, Oxidative Stability, Turbidity, PCB and Furan Content and Biodegradability Test.

The starting point in the production of vegetable oil based dielectric fluid is the vegetable seeds collected from trees. After separation of solid matter, the oil is treated with special solvents to remove unwanted components. Bleaching is usually done by clay filter press, which further purifies the oil. Deodorisation by steam removes volatiles that produce odours. The RBD oil varies in electrical purity over a wide range with conductivities ranging from 5-50 pS/m. For transformer use, it is desirable to have conductivity of 1 pS/m or below. To achieve this, special clays with improved absorbing power are used (Oommen, 2002).

Table 1. Typical fatty acid composition of some vegetable oils (Oommen, 2000)

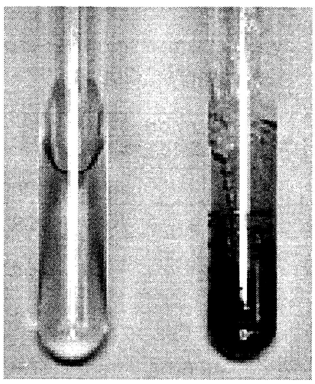
Vegetable Oil	Saturated Fatty Acids, %	Unsaturated Fatty Acids, %		
		Mono	Di-	Tri-
Canola oil*	7.9	55.9	22.1	11.1
Corn oil	12.7	24.2	58	0.7
Cottonseed oil	25.8	17.8	51.8	0.2
Peanut oil	13.6	17.8	51.8	0.2
Olive oil	13.2	73.3	7.9	0.6
Safflower oil	8.5	12.1	74.1	0.4
Safflower oil, high oleic	6.1	75.3	14.2	-
Soybean oil	14.2	22.5	51	6.8
Sunflower oil	10.5	19.6	65.7	-
Sunflower oil, high oleic	9.2	80.8	8.4	0.2

* Low erucic acid variety of rapeseed oil; more recently canola oil containing over 75% monounsaturate content has been developed.

A conductivity meter, such as the Emcee meter described in ASTMD4308, may be used to monitor the purity of the oil. The final stage is the degasification and dehumidifying of the oil. Vegetable oils are hygroscopic; hence, they may absorb water at as much as 1200 ppm or more, at saturation and at room temperature. It is desirable to lower this to 100 ppm.

To stabilise the oil, it is necessary to add suitable antioxidants. Commonly used inhibitors such as DBPC and food-grade antioxidants are not powerful enough to produce oil that will pass the ASTM oxidation tests, such as D-2440. A special antioxidant package that uses complex phenols and amines is used in the BIOTEMP® fluid. Care should be taken not to add too much because the conductivity would rise to unacceptable levels. It is desirable to keep the level of the additive to below 1%. The approach used for the Envirotemp FR3® fluid is to avoid contact with air by careful sealing of the transformer and using an oxygen-scavenging powder above the oil level. The oxidation stability of vegetable oils is greatly dependent on the monounsaturate content, which should be over 80% for long-term transformer use (Oommen, 2002).

Proper inhibitors are still needed. The percentage of tri-unsaturates should be negligible in these oils. Figure 1 shows how poorly stabilised and inferior oil (1b) will gel during a standard oxidation test, ASTM D 2440, while a well-stabilised superior fluid (1a) will not (Oommen, 2000) . The gel test is perhaps much more meaningful than the acidity values for vegetable oil after the oxidation test.



(a) (b)

Figure 1. *(a) Properly stabilised and*
(b) poorly stabilised/inferior oils

PRODUCTS PATENTED

As stated earlier, dielectric coolants from vegetable sources are already in the market and their field performance have proved to be much superior to the mineral, petroleum or even synthetic esters. So far about five products have received patents in the United States. Examples of two of these products are presented here.

BIOTEMP®

This is the first commercial product that was patented in the U.S. in September 1999 by ABB and developed at its Raleigh, NC-based transformer lab (U.S. Patent, 1999). The base fluid was high oleic oil with over 80 percent oleic content. These oils are produced mostly from seeds that have been developed by selective breeding; more recently, gene manipulation techniques have been used. Partial hydrogenation is an added step that may be used to minimise the very unstable tri-unsaturates. The high mono-unsaturated oils are in demand in the food and lubrication industries. The BIOTEMP® fluid, also from high oleic oils, is now used in some distribution and network transformers in critical areas (Oommen, 2000). Table 2 shows some properties of BIOTEMP® compared to that of mineral oil and the ASTM method used to test property.

ENVIROTEMP FR3®

In March 2000, another U.S Patent was granted to Cooper Industries, Inc in Milwaukee, under the trademark Envirotemp FR3® (U.S. Patent, 2000). This fluid is from standard- grade oleic base-oils and is used commercially in some distribution transformers.

Envirotemp FR3® is a unique dielectric coolant whose base oil comes from renewable natural resource-seeds. Specially formulated with performance -enhancing food-grade additives, non-toxic, readily biodegradable insulating fluid is the first truly green fluid (Bertrand and Hoang, 2003). Table 3 shows the properties of Envirotemp.FR3®.

PRESENT RESEARCH EFFORTS

Currently researchers are continuing their efforts to produce more natural coolants from available trees in nature. Some of the oils mentioned below can be directly used as dielectric coolants after extraction from their seeds, whilst others have to undergo some treatment.

RAPESEED OIL

Blended oils based on semi-refined rape-seed oil and derivatives have been prepared by Bertrand and Hoang (2003) in France, that satisfy operation requirements in transformers (Shinke *et al*, 2003). The work involves investigations on food quality vegetable oils; the oils show favourable dielectric characteristics as insulating material for electrical devices. In order to comply with possible applications, characterisation of different seed oils (and some chemical derivatives) has been carried out. Results are compared to specified values for unused mineral oils (IEC 60296), the electrical properties of vegetable products are close to the

Table 2. Properties of Biotemp®

Test	Biotemp®	Mineral Oil	ASTM Method
(3) Flash Point	**300**	145/285	D92
(6) Specific Gravity	**0.91**	0.89	D1298
(7) Viscosity **100ºC** **40ºC** **0ºC**	 **10** **40** **300**	 3/13 12/120 76/200	D445, D2161
(14) Dielectric Breakdown Voltage, KV	**45** **32** **65**	30/42 22/30 56/61	D877, D1816 2.5mm, 1.02mm 2.03mm
(15) Dissipation Factor 25ºC 100ºC	 **0.05** **2.0**	 0.01 0.3	D924
(10) Water Content, ppm (as received)	**150**	35/25	D1533
(11) Neutralisation Number, KOH/g	**0.075**	0.03/ 0.01	D974, D1534
(9) Oxidation Stability RBOT, minute	**200**	195/ 1000	D1473, D2668
(12) Oxidation Stability Sludge	**Pass**	Pass	D2112, D2440

Table 3. Properties of Envirotemp FR3®

Test/Oil Type	Enviro-temp FR3®	R-temp fluid temp	Mineral Oil	Silicon Oil
Electrical				
Breakdown Voltage, KV ASTM D 77	56	52	45	40
Physical				
Viscosity 40ºC 100ºC ASTM D445	 33 8.0	 113 12	 9.2 23	 39 17
Flash Point, °C ASTM D 92	324	276	147	300
Fire Point, °C ASTM D92	300	312	185	343
Specific Heat, cal/g. °C ASTM D2786	0.5	0.45	0.3	0.36
Pour Point, °C ASTM D97	-21	-21	-50	-55
Specific Gravity ASTM D1289	0.92	0.87	0.87	0.96
Environmental				
Biochemical Oxygen Demand, ppm 5-Day SM452100	>200	63	<6	0
BOD/COD Ratio (%)	45	17	7	0
Biodegradation Rate (%) 21-Day CEC-33	>99.0	27.1	25.7	0.0

properties of conventional mineral oils. Today not only technical performance is of essence in material selection, the overall environmental and total life-cycle cost is also becoming part of the analysis. The minimum health and environmental related requirements for applying a liquid as dielectric insulating fluid are:

- Non-toxicity
- Biodegradability
- Production of only acceptable and low-risk thermal degradation by-products
- Recyclable and readily disposable

Their findings concluded that alternative non-petroleum liquid meets all these criteria and in addition these fluids are derived from renewable resources, unlike mineral that come from depletable and environmentally unsafe sources. Nowadays, it is increasingly important that a dielectric fluid should give high technical performance in transformer tanks and low environmental impact in the event of release. Table 4 shows their findings against standard and in comparison with other insulating fluids.

Table 4. Comparison of properties between vegetable and non-vegetable oils

Properties /Oils	Mineral Oil	Silicone Oils	Synthetic Ester	Vegetable Oil	Test Method
Dielectric Breakdown, KV	30-85	35-60	45-70	82-97	IEC-60156
Relative permittivity @ 25ºC	2.1-2.5	2.6-2.9	3.0-3.1	3.1-3.3	IEC-60247
Viscosity @, $mm^2 s^{-1}$ 0ºC 40ºC 100ºC	 <76 3-16 2-2.5	 81-92 35-40 15-17	 26-50 14-29 4-6	 143-77 16-37 4-8	ISO-3104
Pour Point	-30 to -60	-50 to -60	-40 to -50	-19 to -33	ISO 3016
Flash Point, ºC ASTM D 92	100-170	300-310	250-270	315-328	ISO 2592 (1)
Fire Point, ºC ASTM D92	110-185	340-350	300-310	350-360	
Density @ 20ºC Kg/dm^3	0.83-0.89	0.96-1.10	0.90-1.0	0.87-0.92	ISO-3675
Specific Heat, J/g/K	1.6-2.0	1.5	1.8-2.3	1.5-2.1	ASTM E-1269

COCONUT OIL

Abeysundara *et al* (2001) reported using coconut oil as an alternative dielectric fluid in transformer cooling. The project was jointly embarked upon by the Electrical Engineering Department of the University Moratuwa Sri Lanka and the Lanka Transformers, which is a subsidiary of the Sri Lankan Electricity Supply Company charged with responsibility of manufacturing transformers (Lucas *et al.* 2001).

The IEC 60296 standard was used to first verify, in the laboratory, the property requirement of the coconut oil. The initial test result showed that the primitive form of the oil has a dielectric breakdown voltage of 20KV, but after refining the oil the breakdown voltage was raised to 60KV. The refining involves neutralisation of free fatty acids in the oil, deodorising and demilitarisation. Removal of moisture was achieved by heating the oil to 100°C. Figure 2 shows the breakdown voltages obtained during the heating of the oil and the breakdown voltage. The use of coconut oil for Sri Lanka has become a viable option. Table 5 shows the properties of coconut oil measured against IEC 60295 (Oommen, 2002).

Figure 3 compares the absorption of moisture between coconut oil and the traditional mineral transformer oil. The aim is to measure the breakdown voltage after oil has been left outside for some time to free absorb moisture form the atmosphere. The treated coconut oil has proved far more superior than the mineral oil in this regard.

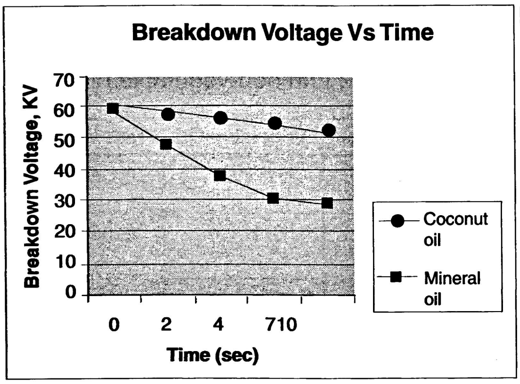


***Figure 2.** Heating and cooling of coconut oil*

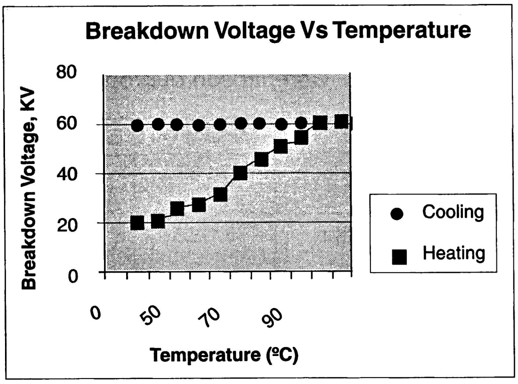


***Figure 3.** Breakdown of coconut and mineral oil*

Table 5. Coconut Oil being measured against IEC

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/dm³ at 20°C	0.917	0.895

Table 6. Non-electrical properties of RAPSOL .T

Property	VDE 370	RAPSOL.T	Shell Delta
Density, g/ml	≤ 0.895	0.917	0.872
Kinematic Viscosity, $mm^2\ s^{-1}$ at 20ºC	≤ 25	72.5	18
Flash Point, ºC	≥ 130	>220	138
Neutralization No., mg koh/g	<0.03	<0.1	Not present
Sulphur Content , mg koh/g	Not present	< 1.0	Not present

INHIBITED RAPESEED OIL

Badent *et al* (2002) reported the development of transformer insulating fluid from an inhibited rapeseed oil. The Institute of Electrical Energy System and High Voltage Technology Germany developed the oil in collaboration with German oil mills. Realising the ageing problem of non-inhibited rapeseed oil in the transformer, they developed an inhibited oil to be able to cope with 30-40 years sealed in the transformer tank. This problem is mainly caused by deficiency in oxidative stability.

The new oil developed, named RAPSOL was enhanced in the laboratory using additives to the base oil, which is rapeseed oil of edible grade. These additives are in the form of oxidation inhibitors and metal passivators to prevent both oxidation instability and unwanted conduction in transformer tank. The physical and chemical properties of the oil were then tested. Table 6 shows the record of the non-electrical properties of the oil compared with other insulating fluids.

The dielectric breakdown voltage was found to be above 50KV, which conforms to the requirements. Likewise, the dissipation factor and dielectric constant was also within acceptable limits. After satisfying dielectric tests, a virgin triple-phase rated 250KVA, 20/0.4KV customary distribution transformer with hermetically sealed tank was filled with the vegetable RASOL.T stabilised oil as dielectric fluid. In order to qualify for this new insulation combination, type tests and routine tests were carried out according to IEC 60076. In detail, lightening impulse withstand voltage test, separate-source voltage withstand test and short duration induced over voltage withstand test, as well as measurement of temperature raise test were carried out on the transformer.

The results show a modest conformity of the vegetable oil filled transformer with the standards. In summary, the electrical properties of inhibited rapeseed oil RAPSOL.T are not influenced negatively by the addition of oxidation stabilisers and metal passivators. Investigation shows that AC strength and impulse voltage is as high as that of Shell oil and mineral oil. Based on the results of this work, life testing of vegetable rapeseed oil in the laboratory is the subject of current research. If completed successfully, a new perspective of insulating materials of state-of- the art is opened.

INDIAN BEACH OIL

An alternative transformer cooling fluid was developed from Indian beach oil in 2001. The beach oil is extracted from the Pongamia glabara tree and used for edible purposes. The tree is native to India and Sri Lanka. The oil was chosen for this work because of initial good properties (Thomas *et al.* 2001). The first part of their work involved the conversion of beach oil into methyl ester, employing the process of trans-esterification. The ester was named Methyl Ester of Karanji Oil (MEKO); the name Karanji comes from one of the major oils making up the Indian Beach oil. The ester was refined by passing it through alumina and earth material.

The researchers used the Bureau of Indian Standards (BIS) 335 1993 to test the physical, chemical and electrical properties of the MEKO. Table 7 shows their results compared with three other insulating fluids. They also measured the effect of moisture, dissolved gases and particulate matter on the dielectric strength of the ageing oil. The ageing was measured using open beaker and glass tube methods. Figure 4 shows the properties of MEKO plotted in comparison with three other fluids.

Table 7. Properties of MEKO compared with other insulating fluids

	Properties	MEKO	Mineral oil	Midel 7131	R.Temp. Oil
1	Density @ (29.5°C)	0.87	0.89	0.95	0.87
2	Kienematic Viscoscity @(27°C) Cst	8	27	53	253
3	Flash Point	295	140	233	253
4	Neutralization Value (mgKOH/g)	Nil	0.03	Nil	Nil
5	Electric Strength	65	60	75	65
6	Power Factor DDF@(90°C)	0.0014	0.002	0.0023	0.00025
7	Dielectric Constant @(27°C)	3.0	2.2	2.2	2.2
8	Specific Resistance @ (90°C) x 10E-12	5.0	35	30	40
9	Oxidation Inhibitor	Nil	Nil	Present	Present

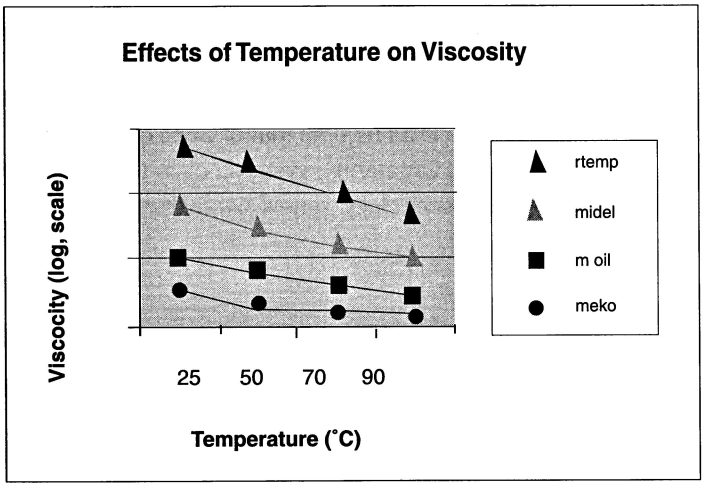


***Figure 4.** Properties of Karanji (MEKO) compared with other oils*

In conclusion, it was found that:

- Physical and chemical properties of MEKO are comparable to Midel 7131 and R.temp fluid.
- Accelerated ageing studies performed on ester reveals that the Methyl ester has more chemical stability even without inhibitors to oxidation and the extent of ageing is much less compared to mineral oil, Midel 7131 and R.temp fluid.
- Alternative source of liquid dielectric from vegetable origin has been developed.

THE FUTURE

Vegetable oil coolants and lubricants indeed, have become a dominant future in research, academia and the industry. This development is preparing them to be the resources of tomorrow. In the near future they are going to replace completely the use of petroleum and mineral oils, because of their high performance and obvious advantage to the environment.

U.S. farmers are beginning to move towards specialisation of crops, specifically growing specialty crops for specific end-uses. These specialty crops often bring in higher premiums and are more profitable than growing the same crops when there is a surplus. The use of genetic modification will create specialty crops with pharmaceutical and health benefits, as well as crops suitable for machinery lubricants and coolants. Most importantly, the development of enhanced and naturally more stable oilseeds is reducing the prices of some of these lubricants.

In Europe, environmental mandates have expanded the use of these products. In the United States, the lack of regulatory mandates and higher prices has hindered the growth in usage. But long-term liability for the management of and the increasing prices for petroleum are changing the picture.

The soybean market has the infrastructure to meet quality and quantity requirements for the lubricants industry. The worldwide supply of soy oil is approximately 6.2 billion gallons, half of which is produced in the United States. Other vegetable oils must be imported and are generally much more expensive than soybean oil.

With the US government's lead-by-example initiative, advocacy by growers associations and advances in lubricant research and biotechnology of oilseeds, the U.S. market will progressively see more biobased lubricants. As industrial users learn of and use these products, vegetable oil-based lubricants, also called biodegradable lubricants or biobased lubricants, will become an important addition to the existing lubricant industry. Due to their benefits, they will be become more prevalent in applications where environmental and safety concerns are high, and they will be less prevalent where petroleum products offer price and performance beyond those possible by biobased products. Rest assured that environment-friendly bio-based lubricants and greases are here to stay.

The world is going to witness the arrival of more coolants from vegetable origin. There will be a break of monopoly in transformer oil manufacture and the transformer itself. Much cheaper and within reach transformers will be in the markets.

CONCLUSION

Today the world is witnessing the period of a shift from the petroleum and mineral oils that are depleting and environmentally unfriendly in transformer cooling to vegetable oils that are renewable and environmentally friendly. These renewable resources have wonderful dielectric properties and are compatible for use without any risk. The market and regulatory pressures to reduce liability risk exposure of mineral-oil-filled distribution and power transformers are increasing. In addition, there are demands to improve equipment efficiencies and adopt more "earth-friendly" options. Considering these paradigm shifts, the industry has been developing new transformer concepts.

Based on data obtained from laboratory and field trials, a practical edible-oil-based dielectric coolant using food-grade additives can be successfully incorporated into transformer insulation systems with minimal modifications. Testing indicates that they can offer a significant reduction in fire and environmental risks compared to conventional mineral oil. Compared to all commercially available fire-resistant non-ester dielectric coolants, testing indicates a most favourable environmental profile.

Preliminary studies indicate that the concept is a competitive alternative to all existing transformer types based on total life-cycle cost, and with several fire-resistant types on both a first and total life cycle cost basis.

The endeavour will place Malaysia in this raising trend and provide it with a means of earning foreign exchange, save it from foreign spending and shift the country to using products that will be environmentally friendly and ensure sustainable development.

Epilogue

The authors are currently carrying out studies on yet another biobased dielectric coolant. The base oils selected are *Moringa Oleifera* seed oil, palm oil and coconut oil. The method will first involve individual oil testing, and then by the process of selective breeding and membrane ultra-filtration refining, a new dielectric coolant will emerge. In this way, a new method of refining is introduced and a new fluid will be added to the ever-increasing list of vegetable oil based transformer cooling and insulating fluids.

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