NATURAL ESTER DIELECTRIC LIQUIDS FOR TRANSFORMERS AND OTHER HV APPARATUS

Whilst mineral oils are still used extensively in electrical devices, the use of natural esters as insulating and heat transfer liquids is on the rise due to their improved fire safety, asset life extension and non-toxicity and biodegradability.

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A range of new natural ester dielectric liquids for application in transformers and other high voltage apparatus has been formulated by Biolectric Pty Ltd and is distributed by IMCD Australia Ltd. Research undertaken by Biolectric has reduced vegetable oil's susceptibility to oxidation and developed a range of vegetable oil based dielectric fluids, NeuGen. The NeuGen range of products is a proprietary formulation using high oleic vegetable oil combined with performance-enhancing additives which have been determined to be non-toxic and readily biodegradable.

This paper details technical data available to date for one of the insulating liquids, NeuGen Plus, which is Biolectric's second generation dielectric liquid.

NeuGen Plus has all the properties required for a less flammable dielectric insulating fluid to be used in modern HV equipment including distribution, mobile and power transformers: it has the flash and fire points exceeding

300 °C. Table 1 below compares some key physical properties of NeuGen Plus with those of other dielectric liquids.

DIELECTRIC PROPERTIES

The dielectric strength is a major parameter when choosing dielectric liquids for the use in oil-filled electrical apparatus. The lighting impulse breakdown voltage for NeuGen Plus is 138 kV, which is above the minimum of 130 kV specified by ASTM D6871. According to IEEE Std C57.106 and IEEE Std C57.147, the minimum AC breakdown voltage limit per ASTM 1816 (2 mm gap) is 35 kV for shipments of new insulating mineral and vegetable oils as received from the supplier. The average AC breakdown voltages for three natural esters are shown in Figure 1.

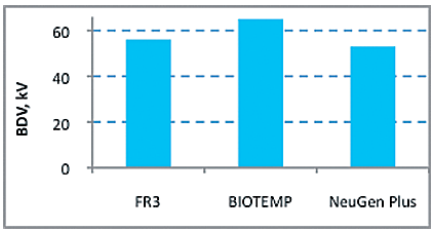

Figure 1 *Average AC Breakdown Voltages (BDV) for Three Natural Esters (ASTM 1816, 2 mm gap)*

The other important parameter of dielectric fluid is its dielectric constant (relative permittivity). In a transformer, the electrical stress distributes inversely proportional to the permittivity of the material. The weakest material in the solid-liquid insulation structure of a transformer is the liquid. The use of a liquid with a higher dielectric constant brings the dielectric constants of the liquid and solid insulation closer together, thus reducing the stress in the liquid. Figure 2 shows that the dielectric constants of natural esters are higher than that of mineral oil.

The dielectric dissipation factor (DDF) is also an important dielectric parameter of insulating

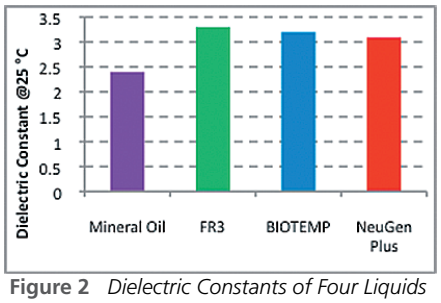

Figure 2 *Dielectric Constants of Four Liquids*

fluid. New natural ester fluids have inherently higher dissipation factors than mineral oils. The standard maximum acceptable DDF values for receipt of shipments of new natural ester fluids are specified as follows: in IEEE C57.147 as 0.2% at 25 °C and 4% at 100 °C; in IEC 62770 as 5% at 90 °C. The DDF of NeuGen Plus is 0.05% at 25 °C and 1.74% at 100 °C, well below the limits specified. Figure 3 shows the DDF values for the four dielectric liquids at different temperatures.

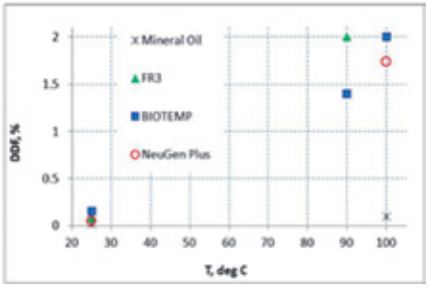

Figure 3 *DDF of Four Liquids (updated)*

GASSING

Natural esters have inherently lower gassing tendency under electrical stress than mineral oils, and generally fairly negative or gas absorbing – see Figure 4. The gas absorbing feature of natural esters makes them attractive for applications in sealed systems.

Stray gassing is an unexpected gas formation from some oils at relatively low transformer operating temperatures in the range from 80 to 250 °C. These are not considered a fault or a concern with the transformer. Insulating liquids with low gas concentrations are considered to be less stray gassing.

TABLE 1: SOME PROPERTIES OF DIELECTRIC LIQUIDS (UPDATED)

PARAMETER	MINE-RAL OIL	FR3	BIOTEMP	NEU GEN PLUS
Flash Point, ˚C	150	320 … 330	330	318
Fire Point, ˚C	170	350 … 360	360	360
Pour Point, ˚C	-57	-18 …-23	-15 …-25	12
Density (20˚C), g/mL	0.88	0.92	0.91	0.91
Viscosity (40˚C), cSt	9.1	36	42	39.3

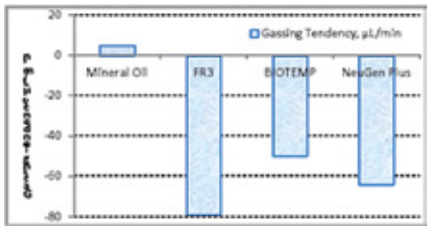

Figure 4 *Gassing Tendency of Four Liquids at 80 °C under Electrical Stress (ASTM D2300)*

Testing was performed according to ASTM D7150, in which the natural ester sample was sparged with air/nitrogen for 30 minutes in syringes, sealed and aged for 164 hours at 120 °C, and then the DGA analysis was performed. The test results for the combustible gases of the three natural esters are provided in Figures 5 and 6. For comparison, the values of Not to Exceed Limits (NTEL) for mineral oil (MO) are shown.

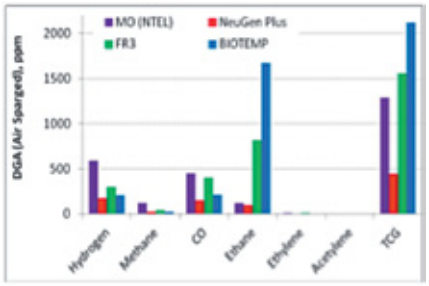

Figure 5 *Stray Gassing Results under Air Sparging Conditions (ASTM D7150)*

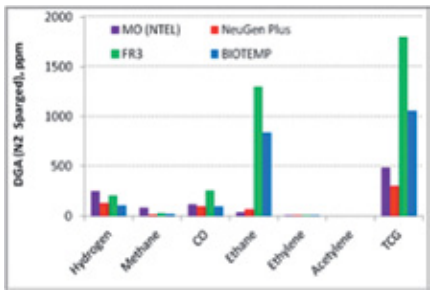

Figure 6 *Stray Gassing Results under Nitrogen Sparging Conditions (ASTM D7150)*

Unlike the other two natural esters, the NeuGen Plus did not exceed the NTEL for most of the combustible gases.

VISCOSITY

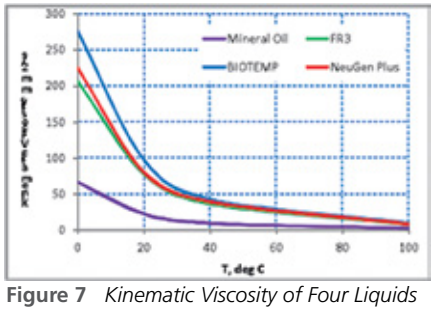

Figure 7 *Kinematic Viscosity of Four Liquids vs. Temperature*

Kinematic viscosity is the most influential parameter for the heat transfer. Viscosity is the measure of the resistance of a fluid to flow. Natural esters typically have higher viscosity than mineral oils. Figure 7 compares kinematic viscosity of the three natural esters with that of mineral oil.

TABLE 2. IEC 62770 OXIDATION STABILITY TEST RESULTS

PARAMETER	IEC 62770 LIMITS	NEUGEN PLUS
Volatile Acids	-	0.07
Soluble Acids	-	0.01
Total Acids	≤ 0.6	0.08
Total Sludge	No requirement	0.01
DDF at 90°C	≤ 0.5 absolute	0.0782
Viscosity Increase	< 30%	12.5%

Table 2 shows that after this oxidation test NeuGen Plus was still well below the IEC 62770 specified limits.

WATER SATURATION SOLUBILITY

A high water saturation solubility (or water-in-oil solubility limit) of natural esters is a great advantage of the fluids. Ester fluids can hold considerably more water than mineral oil.

Ester liquid has an excellent ability to dry the solid insulation when they are partnered. At elevated temperatures, ester fluids can undergo hydrolysis, consuming available water from the paper and improving paper ageing characteristics. Figure 8 compares water saturation solubility of the three natural esters with that of mineral oil.

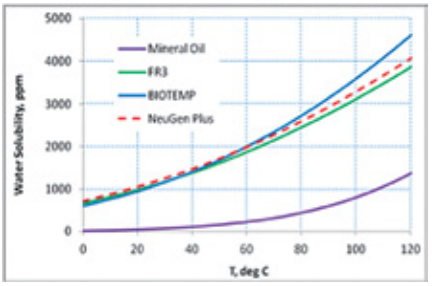

Figure 8 *Water Saturation Solubility of Four Liquids vs. Temperature*

Knowledge of the water saturation solubility of the oil allows constructing a moisture equilibrium chart relating the water content of paper (WCP) to the water content of oil (WCO) at various temperatures for this particular oil. Figure 9 shows such chart constructed for NeuGen Plus.

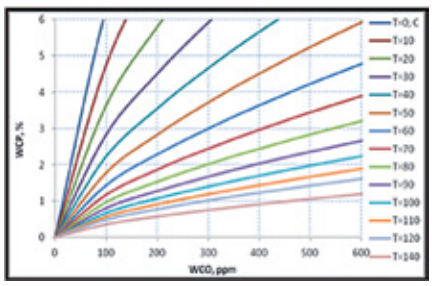

Figure 9 *Moisture Equilibrium Chart for NeuGen Plus*

OXIDATION STABILITY

NeuGen Plus and another natural ester product have been subjected to a test conducted at 120 °C with oxygen bubbled through each fluid as per the standard test method IEC 61125B. The test was stopped after 48 hours, when the other natural ester fluid had polymerised while NeuGen Plus was still viscous (Figure 11), demonstrating its high oxidation stability.

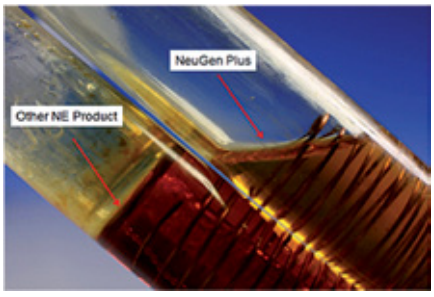

Figure 11 *NeuGen Plus and Other Natural Ester Fluid after Testing at 120 °C with Oxygen*

Another oxidation stability test has been conducted as per IEC 62770 using a modified IEC 61125C test method. NeuGen Plus has been subjected to 120 °C with air bubbled through it for 48 hrs; see results in Table 2 above.

MATERIALS COMPATIBILITY

The materials compatibility test has been conducted in NeuGen Plus with nitrogen and air per ASTM D3455 (164 hrs at 100 °C). The materials tested included:

- copper
- aluminium
- brass
- lead
- core steel
- steel tubing
- pressboard (cellulose)
- water soluble glue
- high density polyethylene
- nylon
- varnish (glyptal)
- PVC
- PEI
- PFTE, and
- viton and buna-n gaskets.

Test results have shown that no material of the 16 materials tested has been compromised by the fluid.

MISCIBILITY

Mixtures containing NeuGen Plus and 10% and 50% of mineral oil (MO) have been tested. Comparisons for the mixtures and non-mixed liquids are shown in Figures 12-16 overleaf.

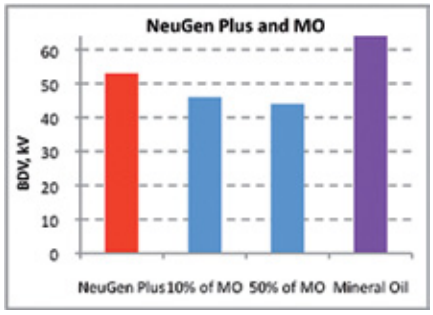

Figure 12 *AC Breakdown Voltages (BDV) for Mixtures and Non-Mixed Liquids*

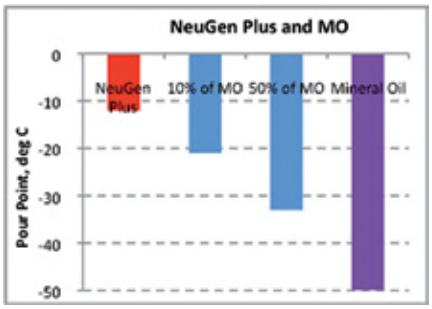

Figure 14 *Pour Point for Mixtures and Non-Mixed Liquids*

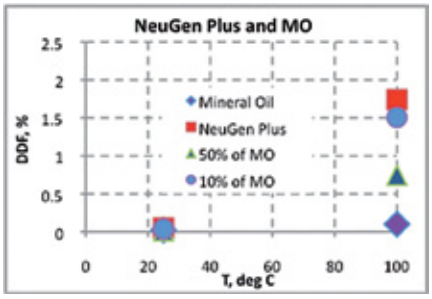

Figure 16 *DDF for Mixtures and Non-Mixed Liquids*

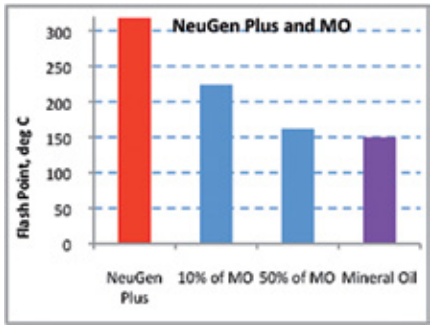

Figure 13 *Flash Point for Mixtures and Non-Mixed Liquids*

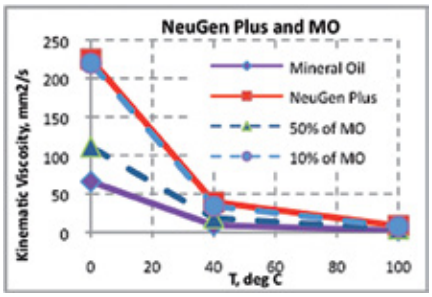

Figure 15 *Kinematic Viscosity for Mixtures and Non-Mixed Liquids*

CONCLUSIONS

NeuGen Plus is a new bio-based nontoxic dielectric fluid that has the flash and fire points exceeding 300 °C. Its dielectric properties comply with the IEEE and IEC standards. NeuGen Plus is a gas absorbing fluid, which makes it attractive for sealed applications. It produces much less stray gasses compare to the other natural ester liquids considered. A new moisture equilibrium chart has been constructed for NeuGen Plus. NeuGen Plus demonstrates high oxidation stability. NeuGen Plus is compatible with the materials tested. It demonstrates good miscibility with mineral oil.