Conduction Characteristics of
MIDEL eN 1204 insulating liquid
under DC non-uniform conditions

DC non-uniform field conditions | Comparison with MIDEL 7131 & Diala D

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Research Motivation

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In recent years, the advancement of high voltage applications such as plasma drilling, HVDC (high voltage direct current) power networks and subsea HV transmission lines has dramatically increased the demand for environmentally friendly, non-flammable dielectric liquids. Therefore, research into dielectric fluids and their breakdown mechanisms has rapidly increased [1]. Previous studies [2] have been done to evaluate natural ester liquids and vegetable oil suitability for such applications.

MIDEL eN 1204 by M&I Ltd is a new, rapeseed based, biodegradable dielectric fluid which boasts similar properties to existing industry standard transformer oils; at no cost to the environment. The aim of this study is to further test MIDEL eN 1204 for its electrical properties, and compare them with well-known dielectric oils MIDEL 7131 and Diala D mineral oil. Characteristics under test will be the **mobility of charge carriers under HVDC stress** in a **point-plane electrode** configuration, and **low-field conduction temperature dependence**. The **effect of aging** on the above characteristics have also been investigated.

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Testing Configurations

High Voltage point-plane configuration [0 - 10 kV]

Obtaining IV curves at high voltage consisted of a **cylindrical test cell** containing a **point-plane electrode configuration**; whereby a grammarphone needle with tip curvature of r ~14 μm acted as the high voltage electrode, combined with a circular brass plane of diameter 30 mm as ground, as shown in **Fig. 1**. A High Voltage probe measured the input voltage. The plane electrode was connected to an electrometer to measure the current through the dielectric. The test cell contents were subjected to high voltage stress from **0 to 10 kV in 500 V steps**. Readings were taken in triplicate, allowing a standard error to be calculated for each current.

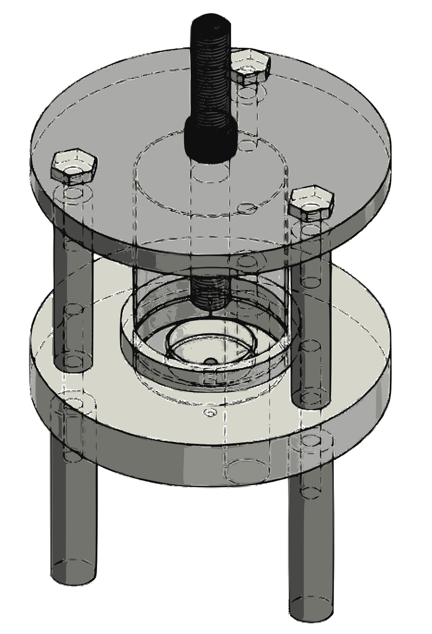


Fig. 1. *- HV point-plane test cell*

Low Voltage cylindrical cell configuration [0 - 70 V]

Obtaining IV curves at low voltage consisted of a **type 4536A cylindrical test cell**, **Fig. 2.** topology and dimensions of which can be found in [3]. 10 ml fluid samples were inserted into the test cell via a syringe. At an electrode gap separation of d = 1 mm, the internal surface area in which the fluid covered was estimated at A = 84.13 cm². The test cell contents were subjected to **low-field conditions** in the range of **0 to 70 Vdc** through the use a programmable electrometer, with the conduction current measured with a secondary electrometer. **Temperature dependence** for each oil was found by submerging each sample within a water bath and repeating the above procedure, at **room temperature, 45 degrees C and 65 degrees C.** Once again readings were taken in triplicate to allow for a standard error to be computed.

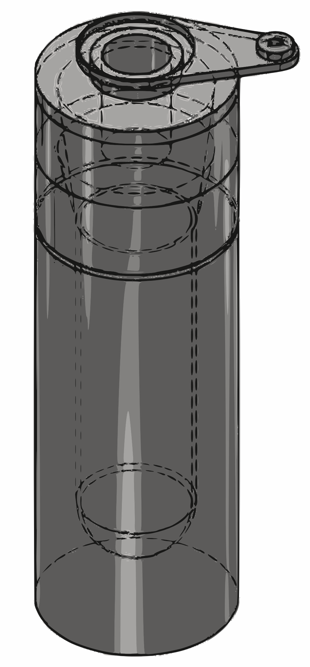
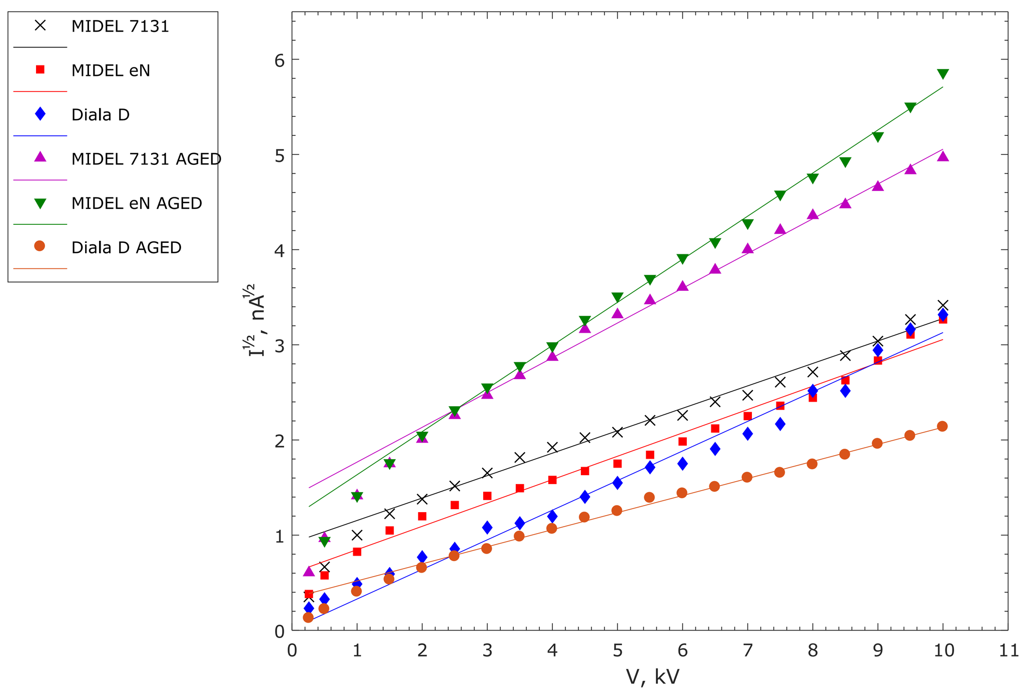


Fig. 2. *- LV Cylindrical test cell*

Results and Analysis

High Voltage Carrier Mobility Measurements



	Slope, B [nA½/kV]	Carrier Mobility, μ *[cm²/Vs]*
MIDEL 7131	0.2352	0.00009766
MIDEL eN 1204	0.2426	0.00010726
Shell Diala D	0.2989	0.00022943
MIDEL 7131 AGED	0.3723	0.00024471
MIDEL eN AGED	0.4564	0.00037962
Diala D AGED	0.1821	0.00008515

Fig. 3. *- I½-V curve for all six fluids under test. Solid points show experimental data, linear fit is solid line.*

Assuming complete saturation of space charge, and that the carrier mobility, μ, is constant, a relationship has been found in previous studies, where the governing IV relationship was solved to be:

$$I = \frac{2\mu\varepsilon_0\varepsilon_l}{d}(V - V_0)^2$$

where ε_0 is the permittivity of free space, ε_l is the relative permittivity of the dielectric, I is the measured conduction current, V is the applied voltage, d is the gap between the needle and plane, V_0 is a constant with dimension of Volts.

Hence, the carrier mobility values seen in the table above were calculated from the gradient of *I½-V* curves in **Fig. 3.**, and applying the following analytical expression:

$$\mu = \frac{B^2 10^{-15} d}{2\varepsilon_0\varepsilon_l}\left[\frac{cm^2}{Vs}\right]$$

Low Voltage Conductivity Measurements

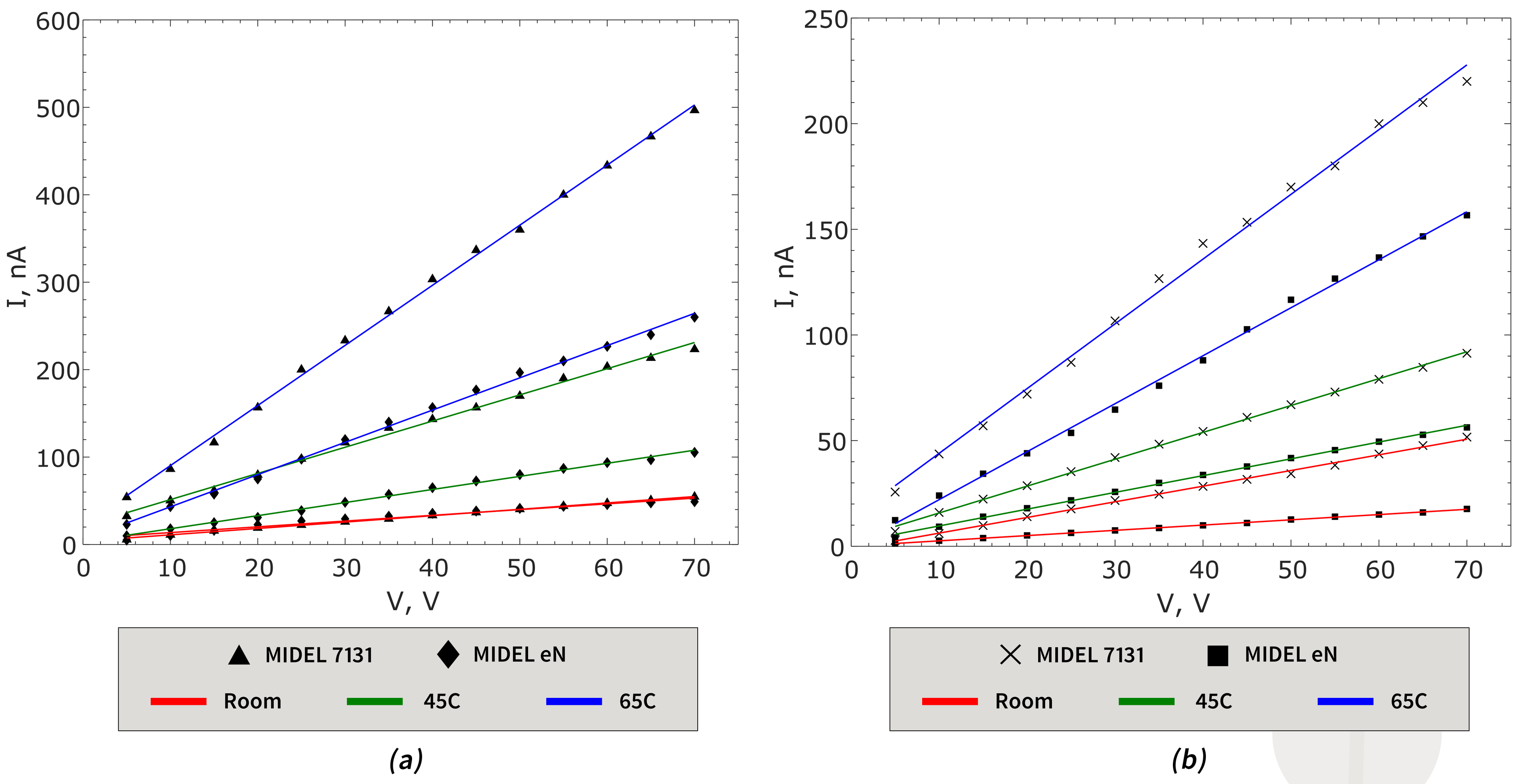


Fig. 4. *- IV curves for (a) aged (b) unaged dielectric fluids under test. Solid points show experimental data, linear fit is solid line.*

In the low voltage regime, conduction is dominated by Ohmic mechanisms and therefore the IV curves will follow a linear relationship, where the conduction, G is given by the slope, allowing for the conductivity, σ to be calculated with use of the surface area A. Measurements of Diala D proved to be extremely unstable, rendering it inappropriate to use as a means of comparison due to the very large uncertainty. However, MIDEL eN and 7131 were highly stable in all tests. **Fig 4**a and **4b** shows the comparison between MIDEL eN and the widely used MIDEL 7131 for low-field temperature dependence. Conductivities in tabulated form *[S/cm²]*.

	Room	45 C	65 C
MIDEL 7131	8.81×10-12	1.51×10-11	3.64×10-11
MIDEL eN 1204	2.96×10-12	9.49×10-12	2.70×10-11
Shell Diala D	*Too turbulent*	*Too turbulent*	*Too turbulent*
MIDEL 7131 AGED	8.67×10-12	3.56×10-11	8.17×10-11
MIDEL eN AGED	7.82×10-12	1.78×10-11	4.45×10-11
Shell Diala D AGED	*Too turbulent*	*Too turbulent*	*Too turbulent*

Conclusions

Hence, it is found that MIDEL eN 1204 possesses a **similar carrier mobility in the 0-10 kV range when compared to MIDEL 7131**, but reacts with a **much higher mobility increase with aging**. In the **low-field region**, it is found that MIDEL eN possesses a **lower conductivity across the temperature ranges**, and a **lower conductivity increase with aging** compared with the other two fluids. Diala D is found to be **turbulent** and **unstable under low-field conditions**, with potential **viscous** and **electrohydrodynamic** processes being dominant, rendering results highly uncertain and difficult to use as a means of comparison in this study.

References

[1] *M. Butcher, A. Neuber, M. Cevallos, J. Dickens and H. Krompholz, "Conduction and breakdown mechanisms in transformer oil", IEEE Trans. Plasma Sci., Vol. 34, No. 2, pp. 467-475, 2006.*

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