BREAKDOWN OF ENVIRONMENTALLY FRIENDLY INSULATING LIQUIDS

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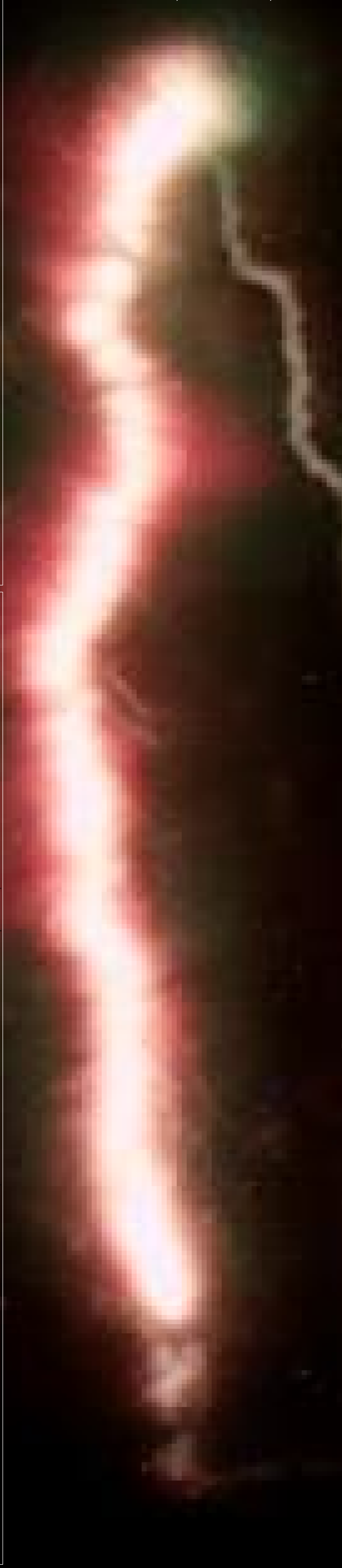


Motivation

For many years now the power and pulsed power industries have been searching for ways to reduce the environmental impact of operations. One area which has drawn attention within both industries is the use of mineral oils as insulating liquids within high voltage electrical machines and apparatus. The use of such non-biodegradable, low-flash point naphthenic oils presents both great risk to personnel, electrical systems and the surrounding environment in the event of catastrophic failure. This has focused efforts on the search for alternatives to the use of these insulating oils; with particular attention given to liquids derived from readily available natural sources. This is due to the advantageous characteristics these, predominately, ester based fluids offer; such as high biodegradability, high flash and fire points, low toxicity and high availability of raw material with most derived from soybean or rapeseed. Such characteristics will help in improving the safety of high voltage pulsed power machines while also reducing the environmental risks associated with their operation. In order to facilitate their use in pulsed power machines and systems, characterisation of ester insulating liquids when stressed with high voltage impulses is required. Therefore, this research programme has focused on how these new fluids and fluid/solid interfaces perform under impulsive electrical stress.

Materials & Methods

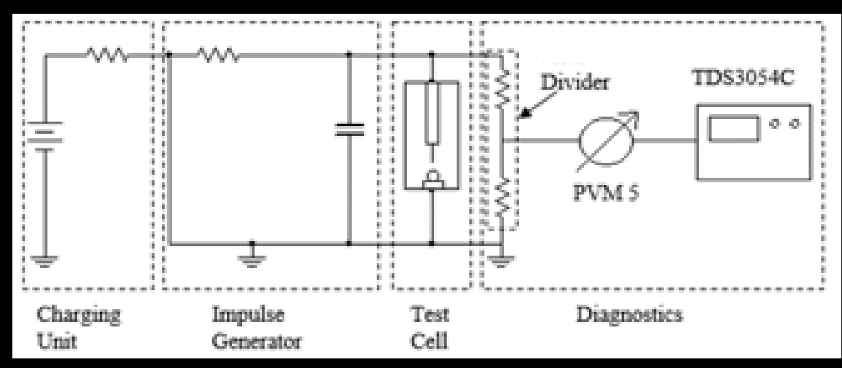
Two ester liquids and a mineral oil in three discrete states of relative moisture content; the level of relative humidity as provided by their manufactures (~20%); the ambient relative humidity of the laboratory environment (~35%) and an elevated relative humidity ~70% were investigated. Samples of natural ester Envirotemp FR3 (Cargill Ltd, USA), synthetic ester MIDEL 7131 (M&I Materials Ltd, UK) and mineral oil Diala S4 ZX (Shell Ltd) in each state of relative humidity were exposed to standard (1.2/50us) and non-standard (7/170us) high voltage impulses of both positive and negative polarity.

	Shell Diala S4 ZX	*MIDEL 7131*	*Enivrotemp FR3*
Composition	Mix of hydro-carbons	Pentaerythritol tetra ester	Plant based ester
Degree of biodegradability	Non	Highly	Highly
Oxidisation	Mildly susceptible	Non-susceptible	Susceptible
Water Saturation	70ppm	2600ppm	1100ppm
Flash Point	191°C	260°C	316-330°C
Permittivity	2.2	3.2	3.2
Dielectric strength (AC power frequency)	60 kV	75 kV	56 kV

The breakdown voltage, V_{bk}, and time to breakdown, t_{bk}, were obtained in an overstressed regime, i.e. each applied HV impulse resulted in breakdown of the insulating liquid. All breakdown events were registered on the rising slope or around the peak of each applied HV impulse. To more accurately represent the types of electrical stress experienced by pulsed power machines, a multi-shot testing methodology was applied during all breakdown experimentation. That is to say that each liquid sample was been exposed to a 11 individual breakdown events with the first breakdown logged creating a dataset of "first breakdown events" for each of the test liquids (n=3). Then, V_{bk} and t_{bk} associated with the next 10 breakdown events were recorded (n=30) before replacement of the liquid sample as well as the HV and ground electrodes.

Experimental system

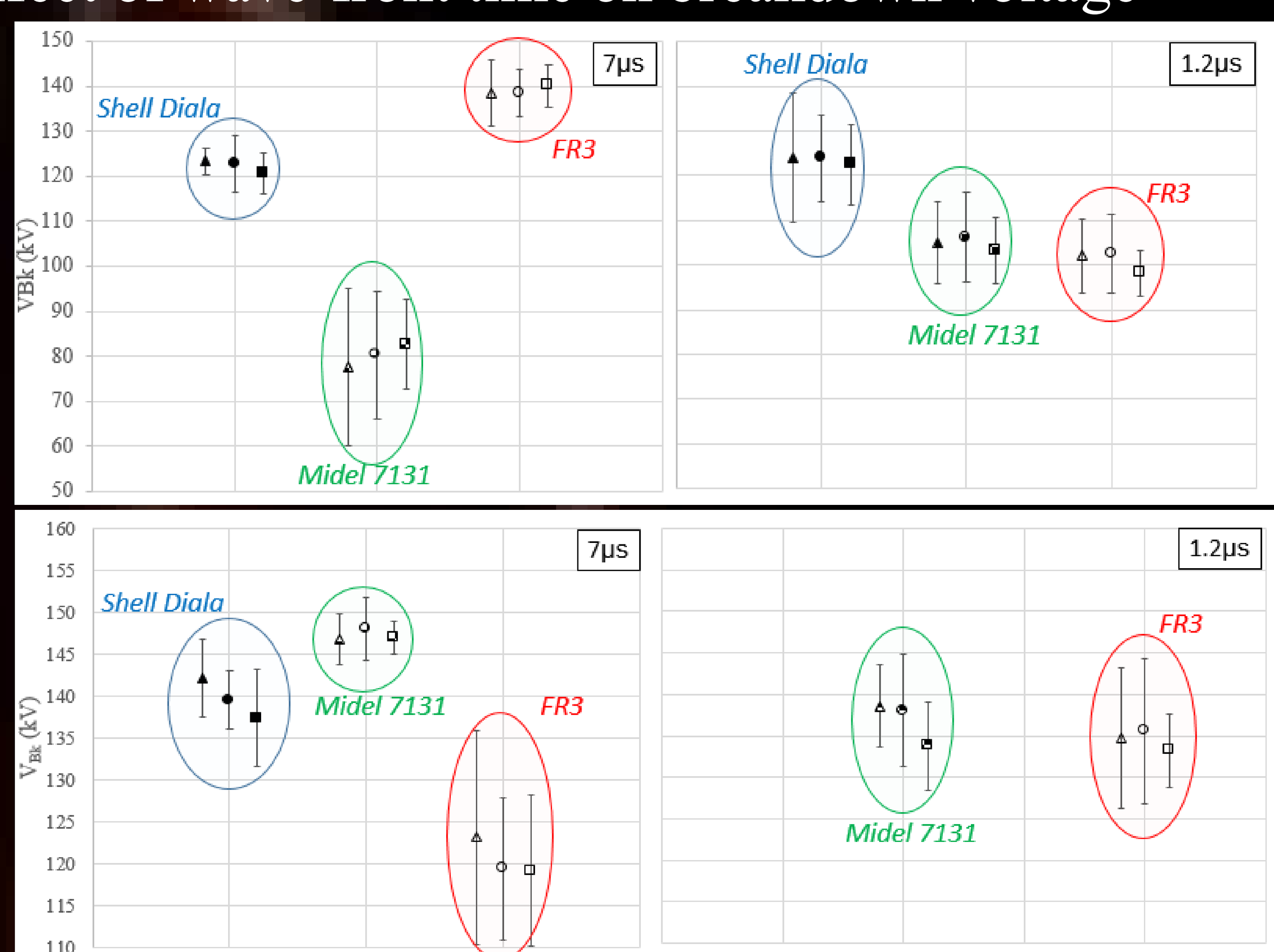
The breakdown tests were conducted in a needle-sphere electrode configuration. A gramophone needle with a nominal tip radius of ~35 µm was used as the HV electrode, and a 12.7 mm diameter spherical mild steel ball bearing was used as a ground electrode. A fixed 8 mm inter-electrode gap distance was used in the tests; achieving a Schwaiger factor of η ~ 0.01



The voltage impulse used for the breakdown measurements was generated with a Marx-type pulsed power generator. A high voltage direct current power supply (Glassman, USA) was used to charge a five-stage air insulated inverting Marx generator through a series configured protection resistor stack. A charging DC voltage of 30 kV was used in all tests, allowing production of HV impulses with a peak nominal amplitude of 150 kV. Triggering of the impulse generator was achieved through a pneumatic process in which closing of the spark switches occurred as a result of a reducing the pressure within the spark column. To measure the HV wave-forms during the breakdown tests a HV divider was connected in parallel with the test cell. This custom built divider, a CuSO4 water solution filled column, was coupled to a commercial HV probe, NorthStar PVM5, with a nominal bandwidth of 80 MHz. All experimental voltage signals were captured and recorded using a Textronix TDS3054C digitising oscilloscope (500 MHz, 5 Gs/s).

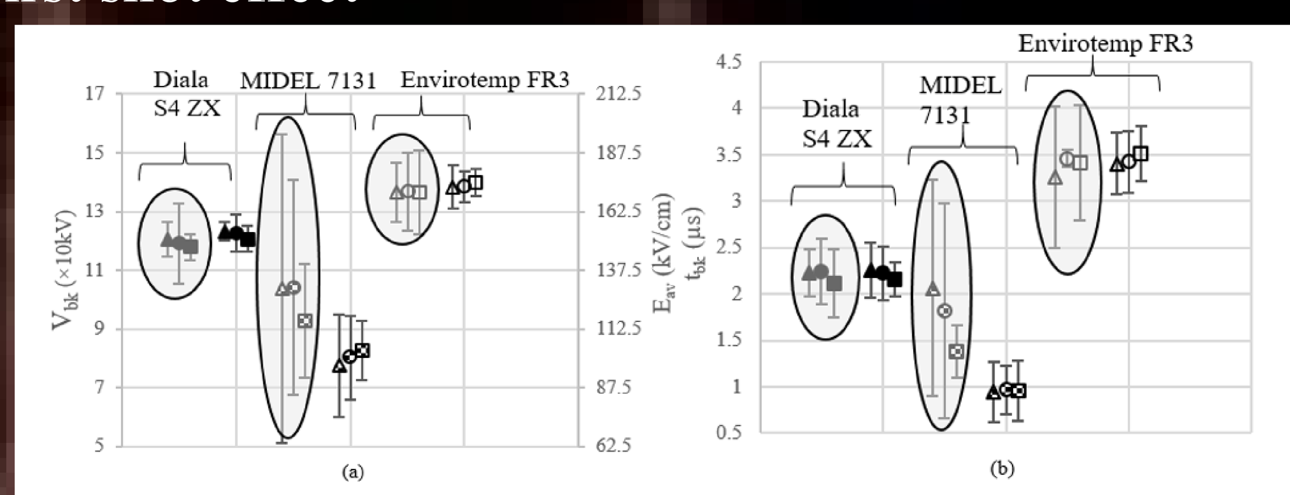
Experimental results

Effect of wave-front time on breakdown voltage



Breakdown voltage for positive (upper figure) and negative (lower figure) HV impulses. Δ: 'As Received' condition, ○: 'Ambient RH' and □: 'Elevated RH'. Open shapes, EnvirotempFR3; solid shapes, Shell Diala S4 ZX, patterned shapes MIDEL 7131. Error bars represent 95% confidence intervals.

'First shot effect'



Breakdown voltage and average breakdown field (a), and time to breakdown (b) for positive HV impulses. Δ: 'As Received' condition, ○: 'Ambient RH' and □: 'Elevated RH'. Open shapes, Envirotemp FR3; solid shapes, Shell Diala S4 ZX; patterned shapes, MIDEL 7131. Circled areas denote 'first breakdown'. Error bars represent 95% confidence intervals.

Conclusions

- Clear sensitivity of breakdown parameters to signal rise time has been observed
- The breakdown voltage, and time to breakdown, of the examined ester dielectrics is seen to increase with wave-front time; irrespective of impulse polarity
- Varying polarity phenomena manifest as a result of the specific rise-time applied to the voltage signal
- Atypical behaviour exhibited by the natural ester when stressed with the non-standard voltage signal (7µs)
- Dissimilarity in breakdown voltage of the ester fluids and mineral oil observed to worsen as rise-time is increased
- Water content of the dielectric fluid exerts negligible influence over breakdown dynamics