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HyVolt

/ Dielectric Fluids

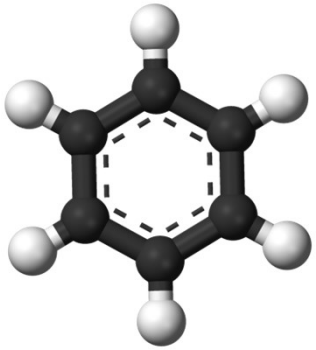
Key aspects of insulating liquids for Power Transformers; today and future landscape

Dr Bruce Pahlavanpour

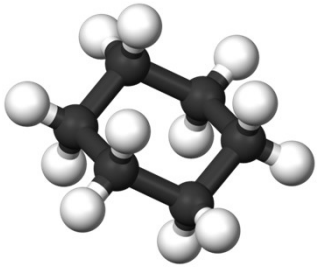
Content

- Chemistry
- Dielectric design
- Electrical properties
- Streamer behaviour
- PD

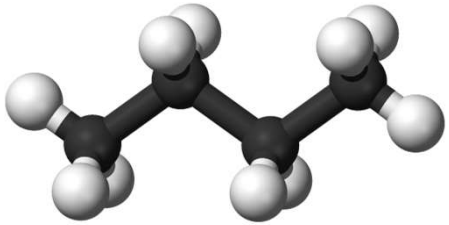
Mineral Insulating Oil - components



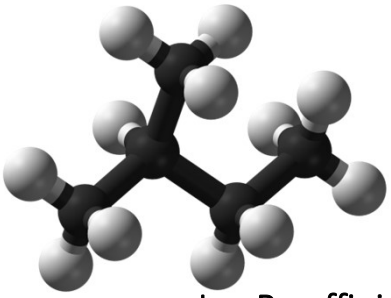
Aromatic



Naphthenic



Paraffinic



Iso-Paraffinic

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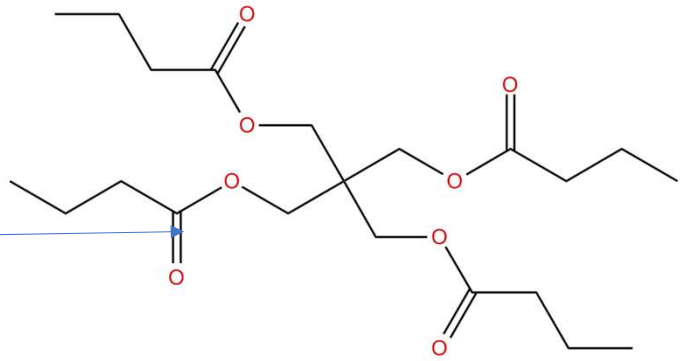
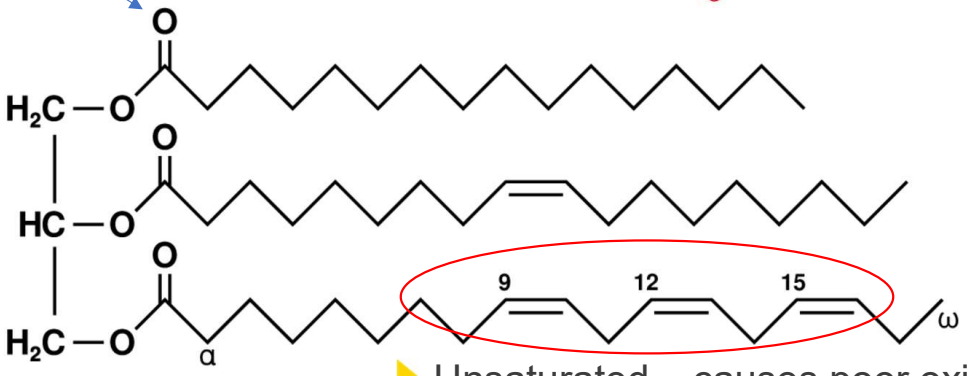
Some chemistry of Esters

Synthetic Ester



Polar

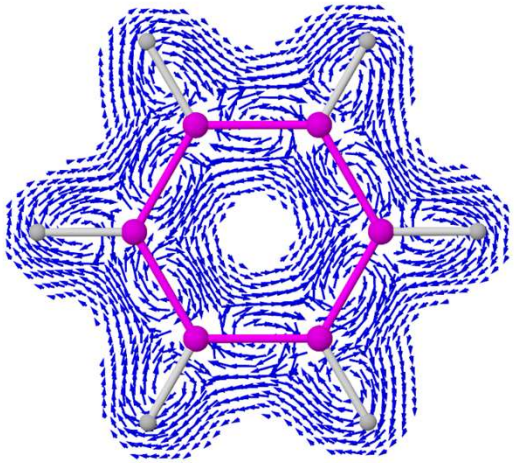


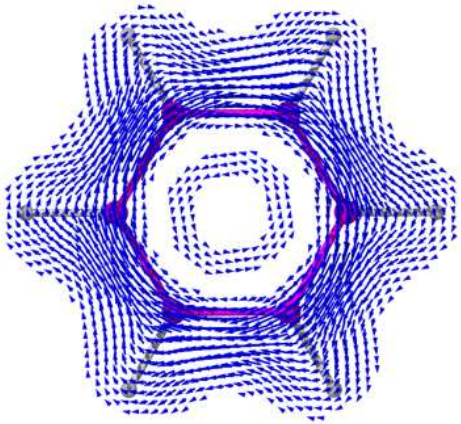
- Unsaturated – causes poor oxidation stability

Natural Ester

Aromaticity – refining degree

- Too many aromatics (in the wrong place) can lead to poor oxidation stability.
- An optimal amount & type of aromatics can lead to favorable dielectric properties & solvent power.





SOURCE: Hoferaanderl , Wikipedia

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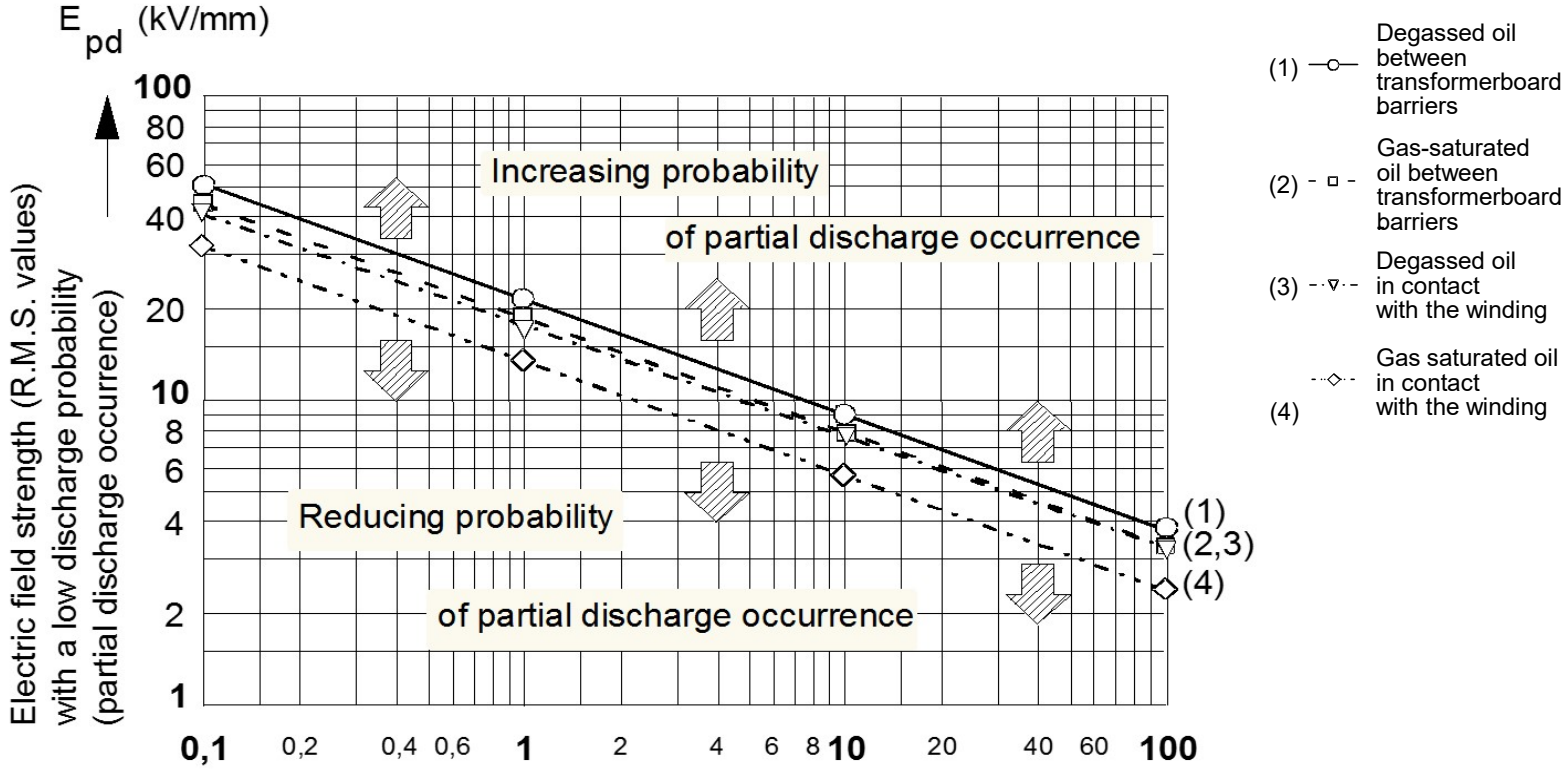
Dielectric Strength of oil with gap size



SOURCE: **Weidmann**

Permittivity

- Relative permittivity – ≈polarizability.
- Depends on polar species and species that can have temporary dipoles.
- Effects the field distribution in insulating systems.
- Matching is favourable but need to consider surface effects as well

	ε liquid	ε Impregnated cellulose
Mineral Oil	~2 - 2.4	~4 - 4.5
Esters	~3 – 3.5	~4.5 - 5
Silicone Oils	~2.2 – 2.8	~4 – 4.9

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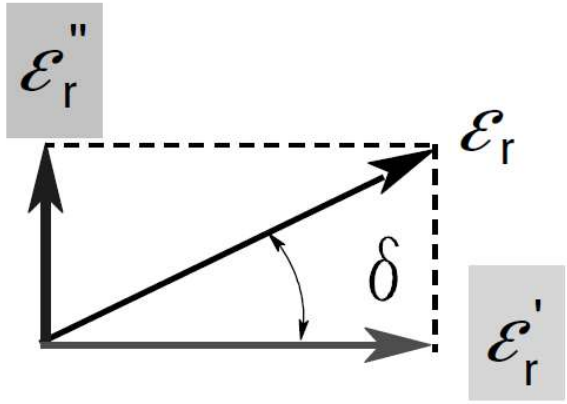
Dielectric Dissipation Factor (DDF / TAN DELTA)

- IEC 60247
- 50Hz, 90°C

- DDF closer to 0 = better dielectric

$$\tan \delta = \frac{\varepsilon_r''}{\varepsilon_r'} = D = \frac{1}{Q}$$

$$= \frac{\text{Energy Lost per Cycle}}{\text{Energy Stored per Cycle}}$$



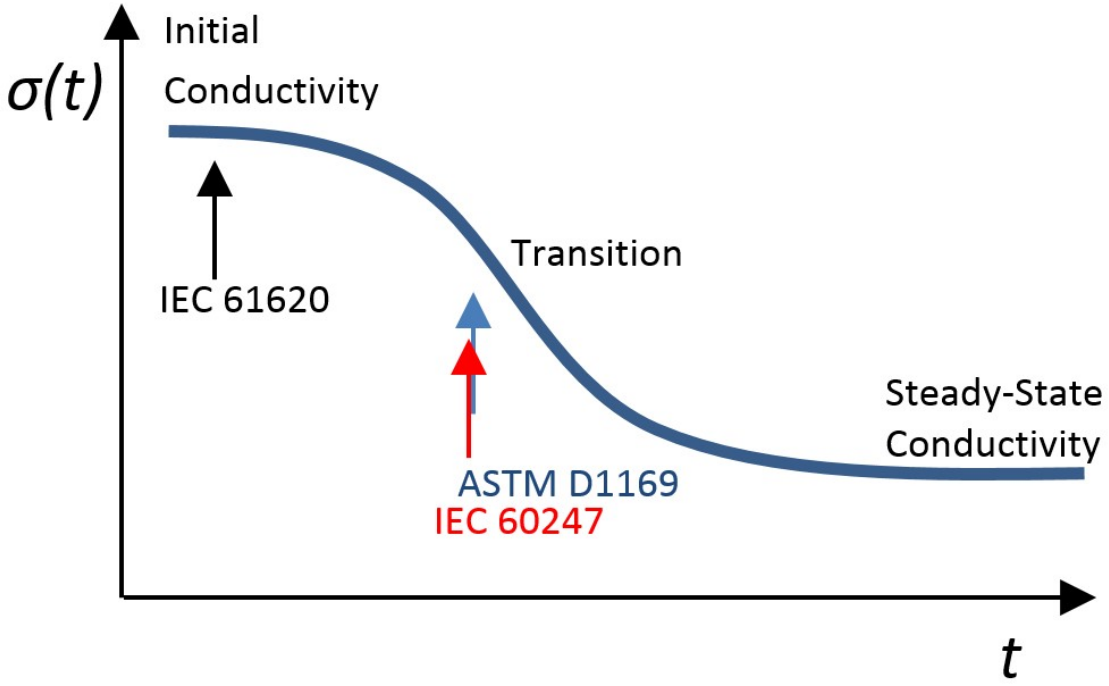
IEC 60247	Treated new virgin oil	IEC 60296	IEC 60422 Prior Energisation	IEC60422 "Good"	IEC60422 "Fair"	IEC60422 "Poor"
DDF 50Hz@ 90°C	<0.001	<0.005	<0.01	< 0.1	< 0.5, <0.2*	>0.5, >0.2*
DDF 50Hz@ 90°C (IT)				<0.01	<0.03	>0.03

IT = Instrument Transformers * Power Transformers (>170 kV)

Volume Resistivity/Conductivity

- Reciprocal of conductivity.
- Common standards (IEC 60247, ASTM D1169) have notoriously poor repeatability.
- This is because DC conductivity is more time and field dependent
- More relevant for HVDC applications (conductivity matters most in polarity reversal test)
- Not recommended as a primary oil condition indicator.
- New oil ≈> 1000 – 2000 G.Ω.m
- IEC 60422, after filling, prior energisation > 60 G.Ω.m

Time Dependent Conductivity



Time-dependent conductivity at low field strengths

SOURCE: Cigre TB 646

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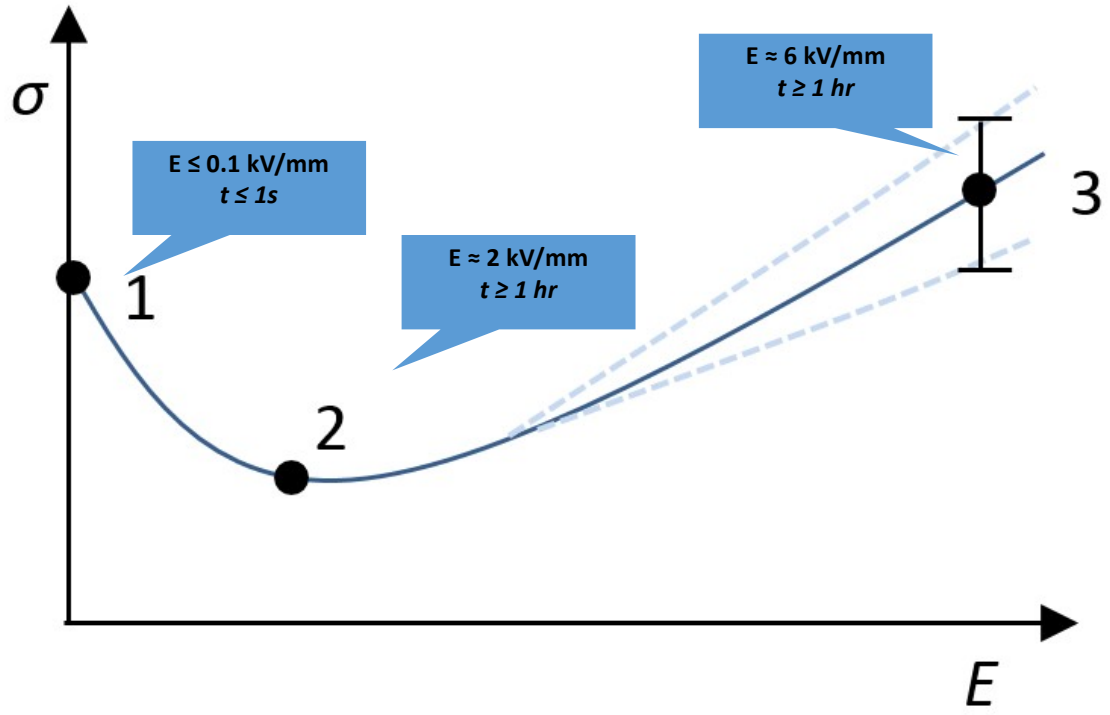
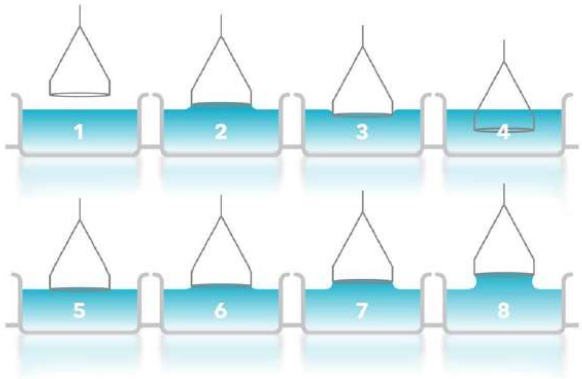
“3 Point characterisation” Conductivity [HVDC]



SOURCE: Cigre TB 646

Inter-Facial Tension (IFT)

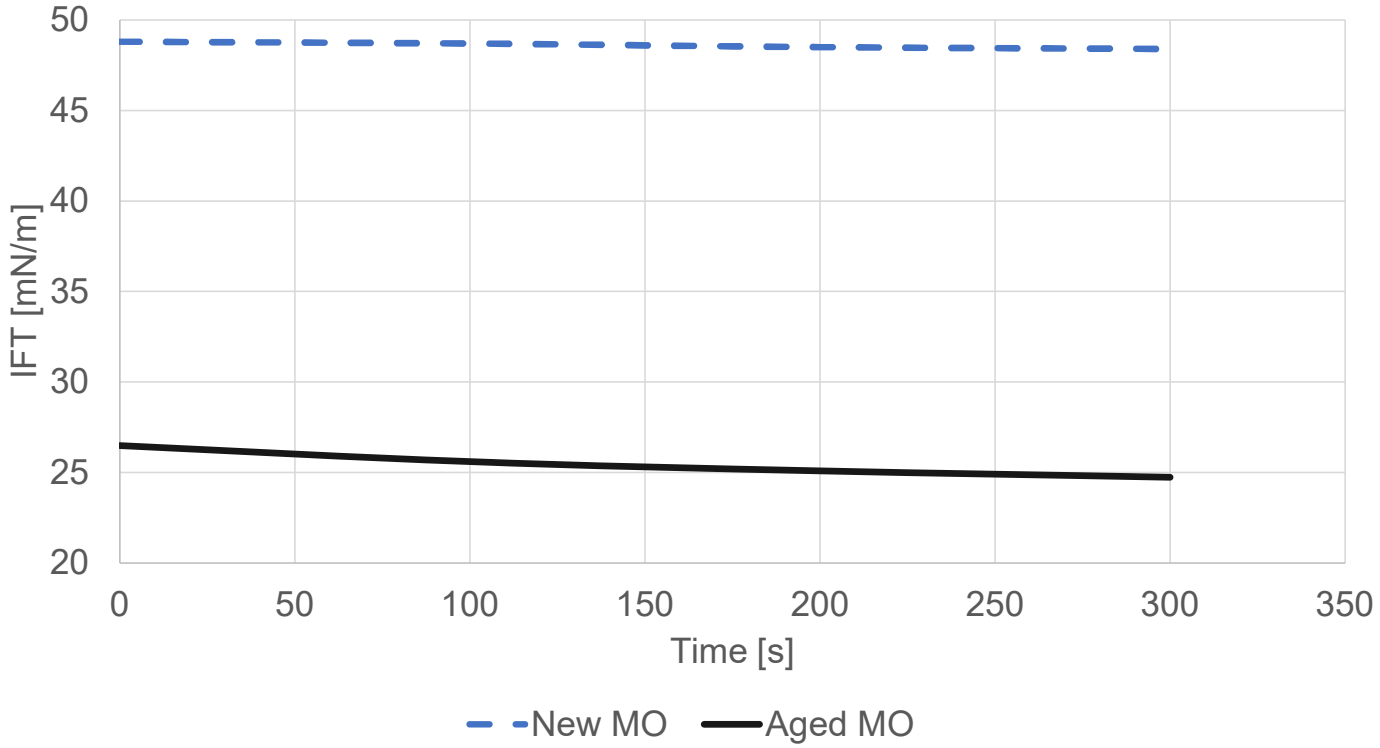
- Very sensitive to surface active species.
- These are normally polar.
- Very useful for detecting contamination and material incompatibility.
- Early warning to early oxidation when complemented with DDF and others.
- IFT >40mN/m for new mineral oil



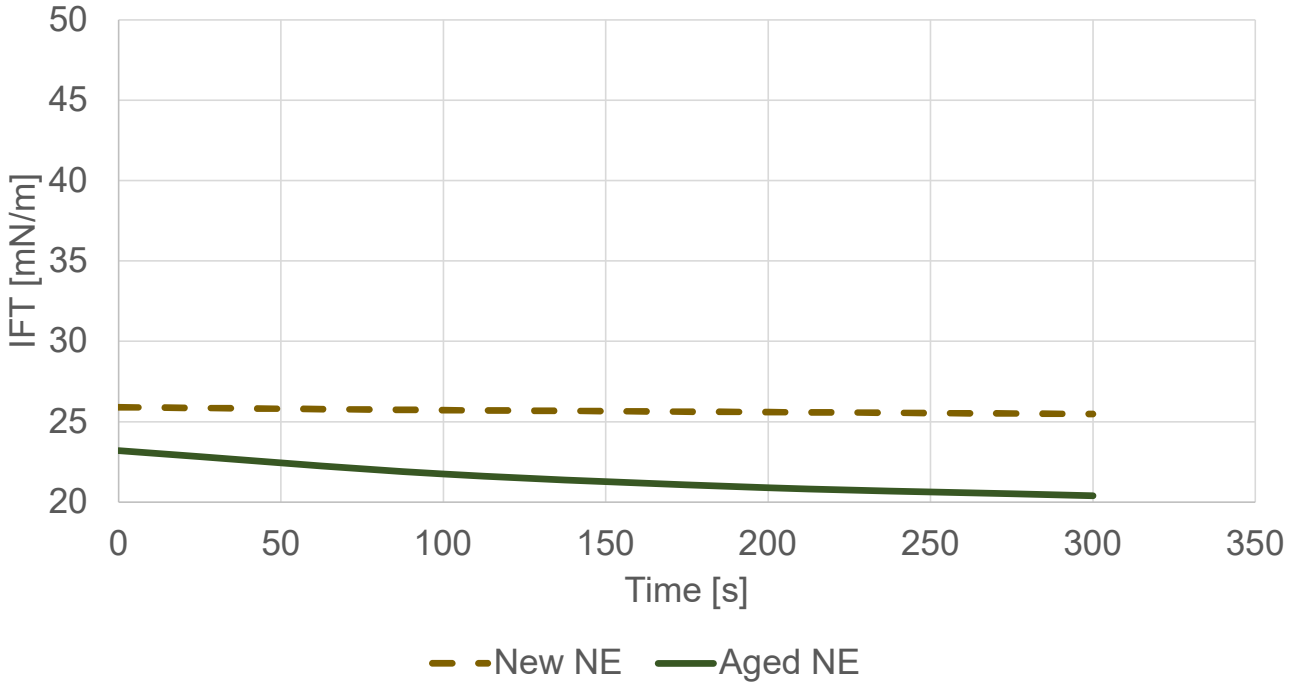
IFT method update

- IEC 62961 is published recently
- It takes time for equilibrium to be reached
- Aged samples and esters necessary to increase test time to 400 seconds

IFT – Mineral Oil



IFT – Natural Esters



Impregnation of Insulation

- Complete impregnation of solid insulation is vital to ensure no voids etc.
- Viscosity of oil is the key decider in terms of impregnation times.
- Optimise temperature and times for effective impregnation.
- Impregnating pressboard is most difficult due to high density.

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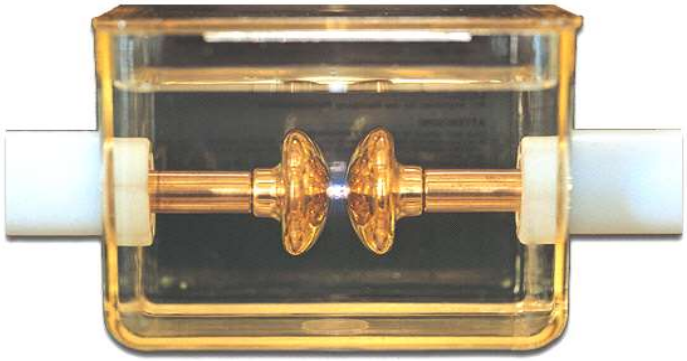
Breakdown Voltage

IEC 60156

Spherical Electrodes



VDE “Mushroom” electrodes

Disk Electrodes

ASTM D877

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Breakdown Voltage

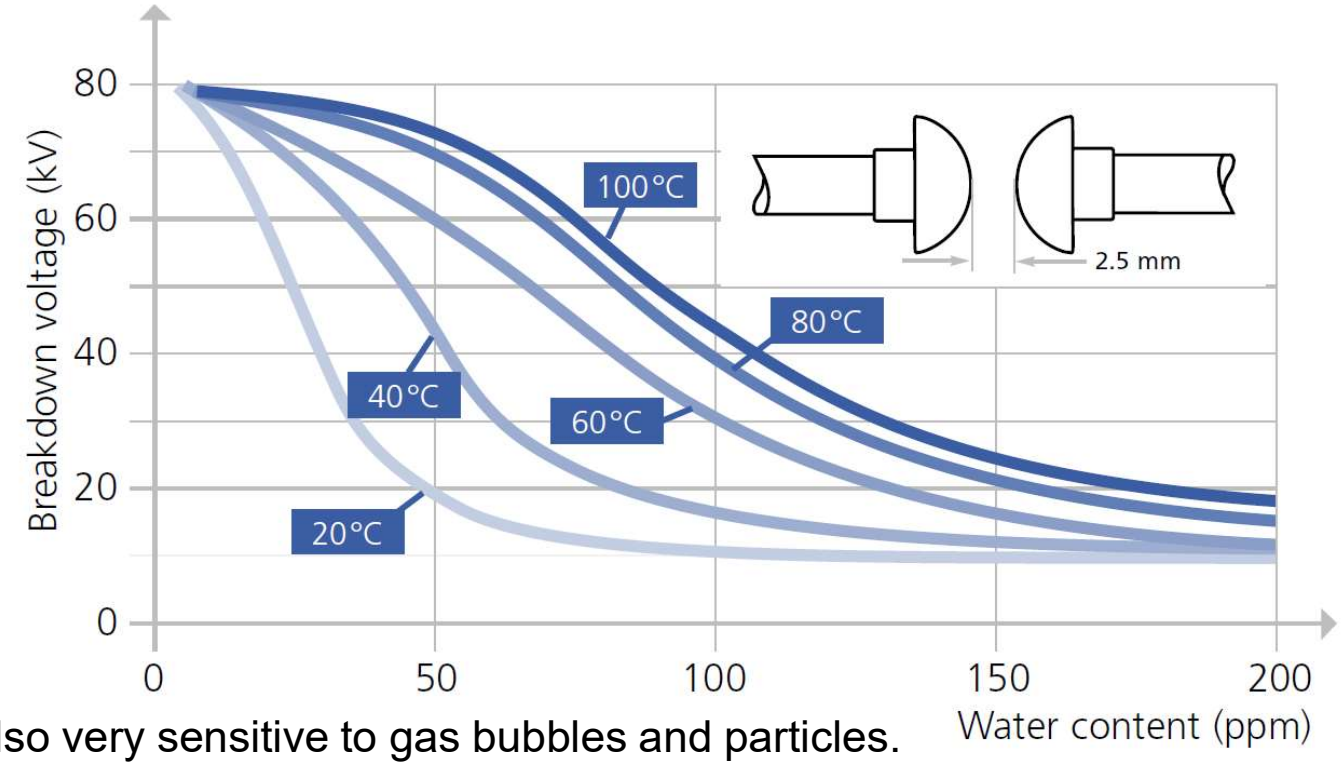
- Liquid Condition is primary factor.
- Relative water saturation, gas content & particles.
- Differences between methods are mainly due to electrodes, and test conditions.

Test	Mineral Oil	Synthetic Ester	Natural Ester
IEC 60156 2.5mm	>70 kV	>70 kV	>70 kV
ASTM D877	>50 kV	>40 kV	>45 kV

These tests do not easily reveal the differences in intrinsic insulating capability of the liquids

BDV / Water Content

Typical Naphthenic mineral oil



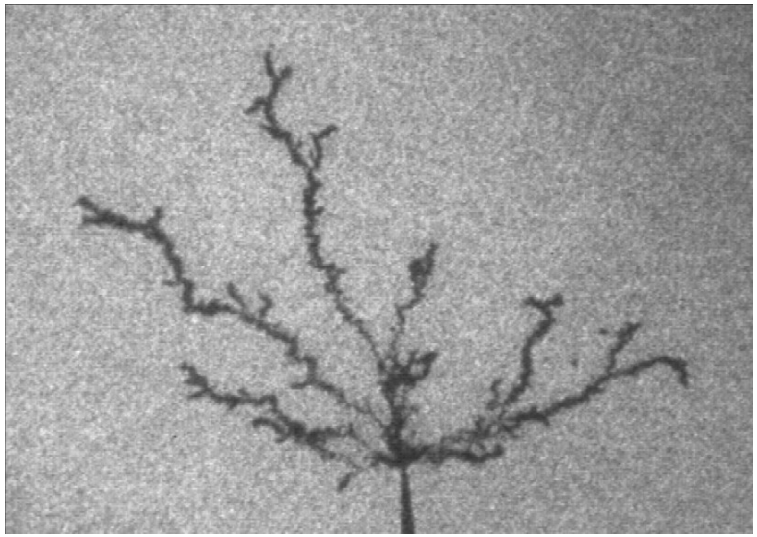
- BDV also very sensitive to gas bubbles and particles.
- Degassing, Filtration and Drying normally yields >70kV.

Breakdown in Liquids

- Not yet fully understood.

- Have been categorised mostly by average propagation velocity.

- Progressive part ionised gaseous filaments known as *streamers.*



- In most liquids, steps by which the streamer propagation velocity increases with increasing voltage

–streamer ***modes.***

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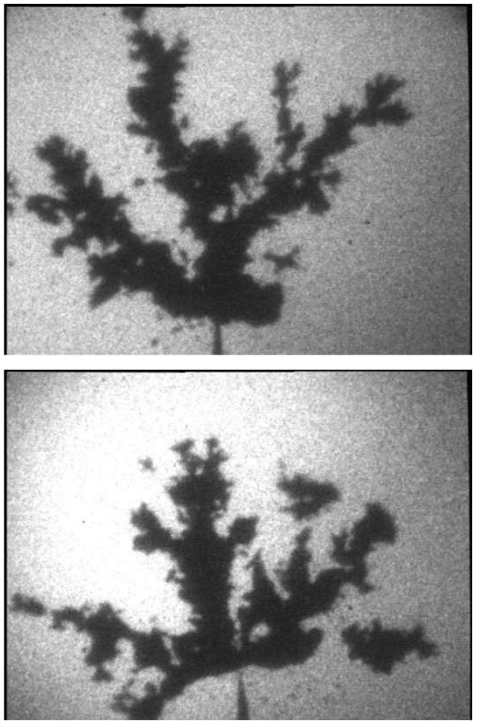
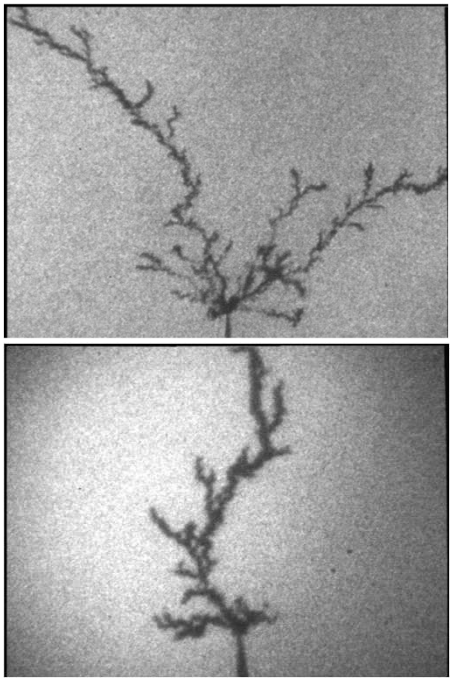
Streamers in Oil –

Representative of mineral oil behaviour



Negative



Positive

SOURCE: SINTEF 2010 Investigation Project for Nynas (applied impulse)

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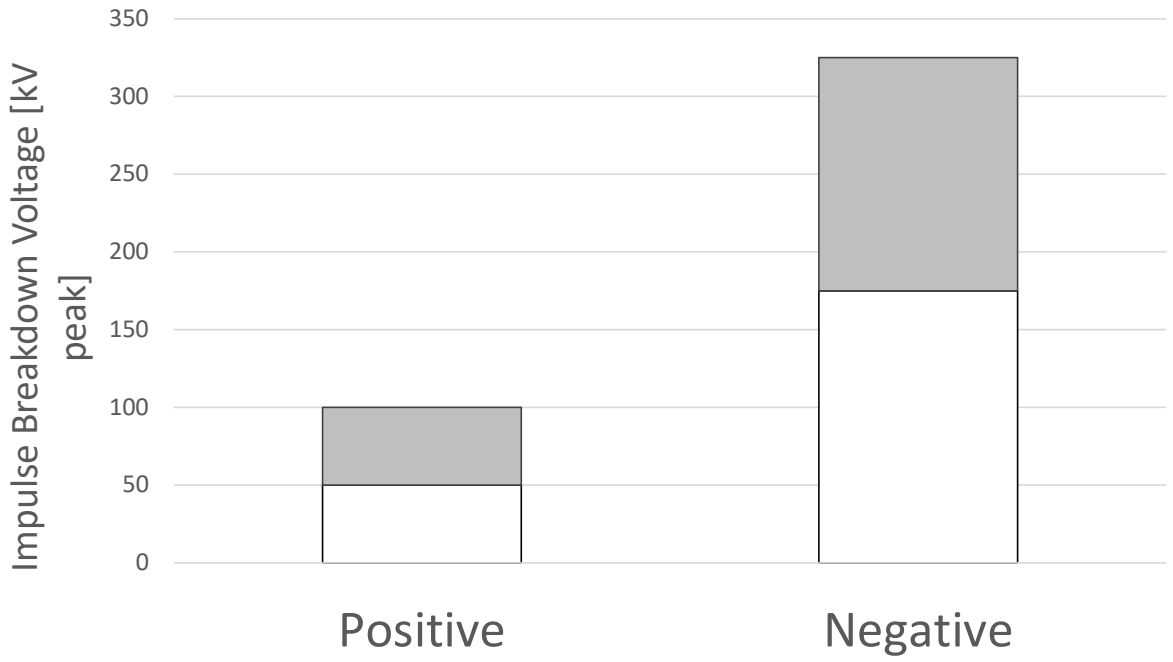
Positive vs Negative Impulse Breakdown Voltage
(point/sphere electrodes – ASTM D3300, IEC 60897)



Approximate range for mineral insulating oils.

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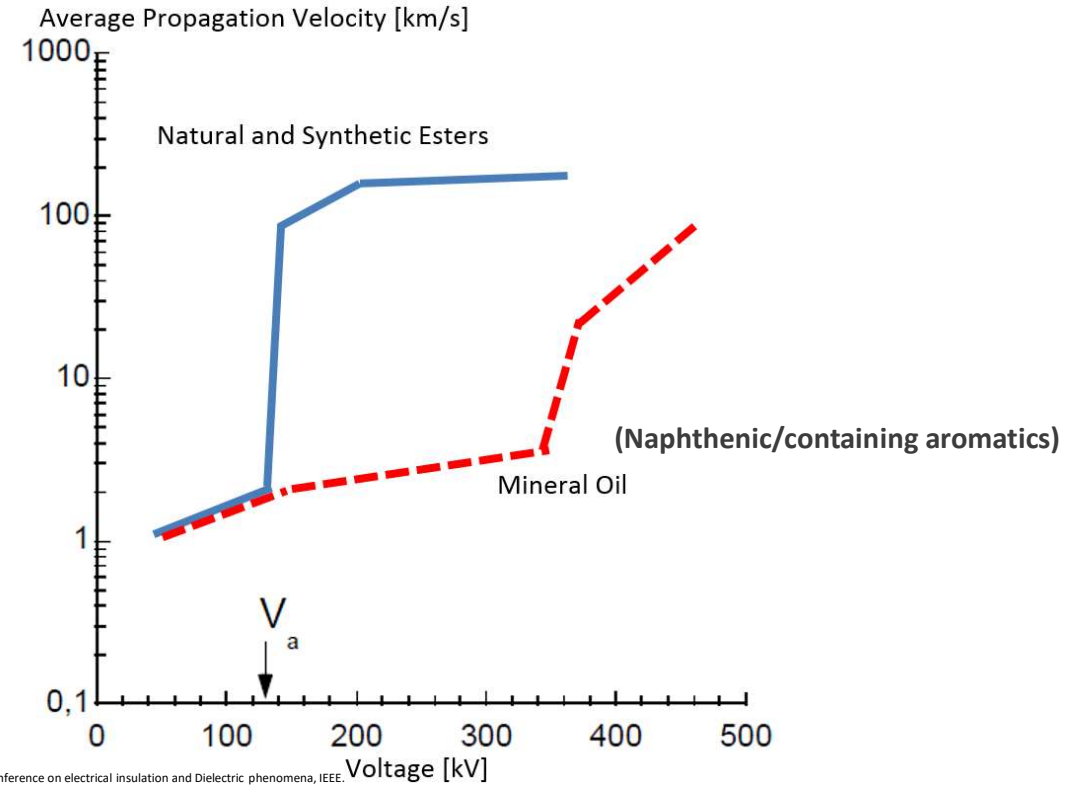
Acceleration Voltage

Impulse applied divergent fields, Positive Streamers – Esters versus Naphthenic Mineral oils



SOURCE DATA: N. Ngoc Et. Al. "2010 annual report conference on electrical insulation and Dielectric phenomena, IEEE.

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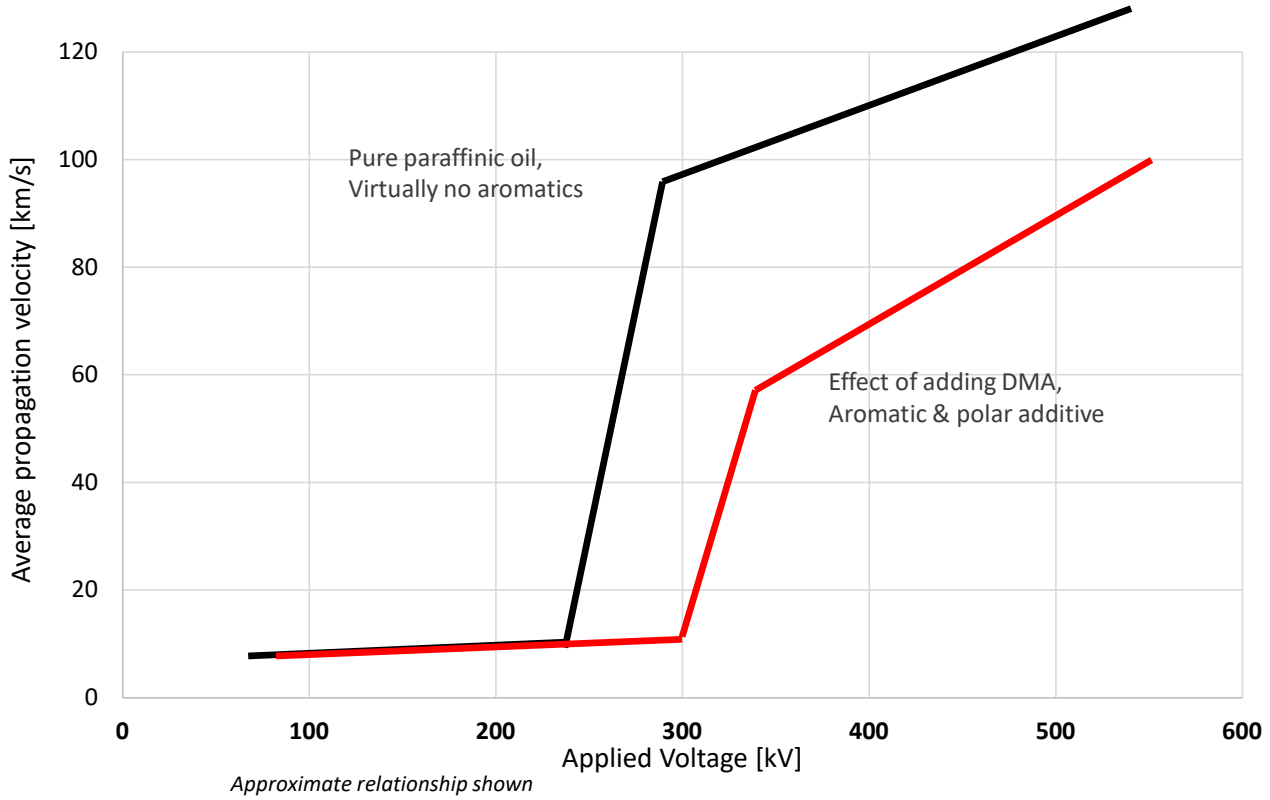
Acceleration Voltage

Impulse applied divergent fields, Positive Streamers – illustration of influence of aromatics



Approximate relationship shown

Source data & original work in: "Streamers in Large Paraffinic Oil Gap" N. V. Dung et. Al.

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Test Method – PD investigation of insulating liquids

- Point-sphere electrode configuration AC 60kV 50Hz RMS (IEC TR61294 – 50mm gap)

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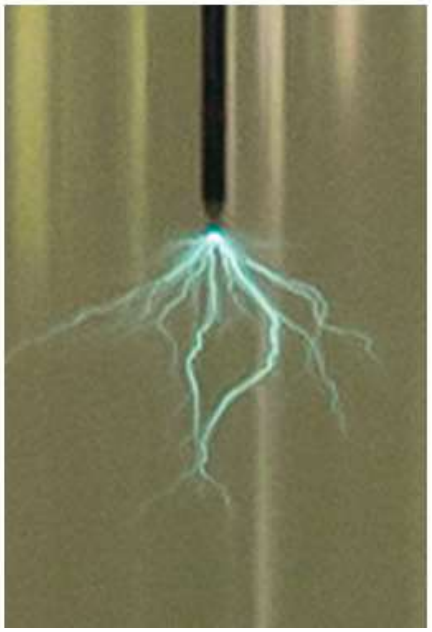
PD Behaviour

- Point-sphere electrode configuration AC 60kV 50Hz RMS (IEC TR61294 – 50mm gap)

Synthetic Ester



Natural Ester

Inhibited Naphthenic

Same exposure time used, indicative photographs, EIMV Slovenia

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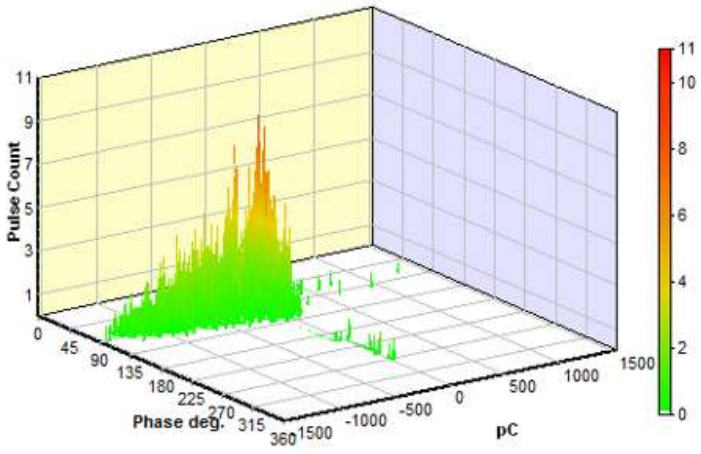
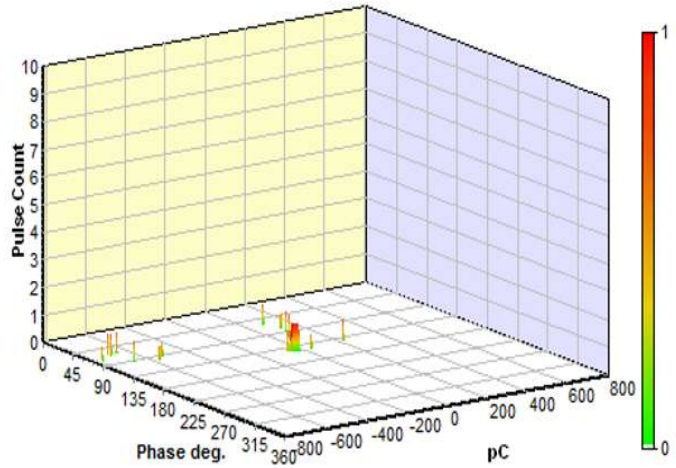
PD behaviour

Differences in HV behaviour between different liquid chemistries are observed when doing comparative Partial Discharge testing.

Ester liquids generally exhibit higher PD activity.



Synthetic Ester, 35kV, 1 min



Naphthenic, 35kV, 1 min

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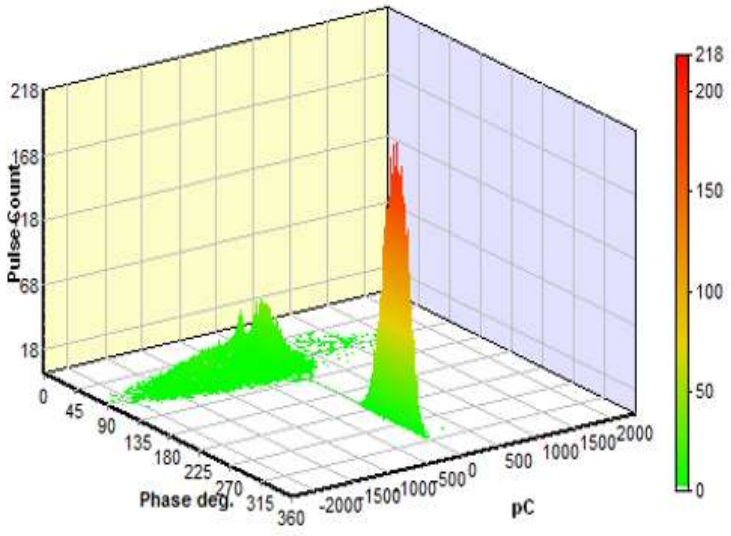
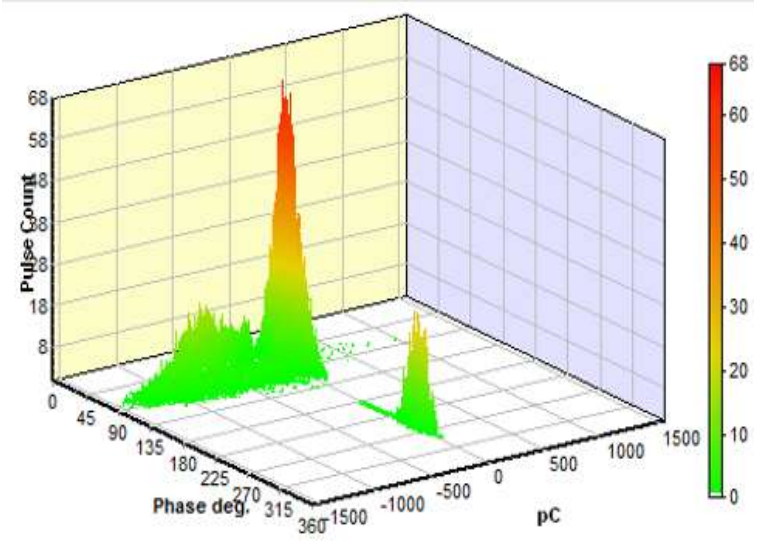
PD Behaviour



Synthetic Ester, 40 kV, 5 min



Natural Ester, 40 kV, 5 min

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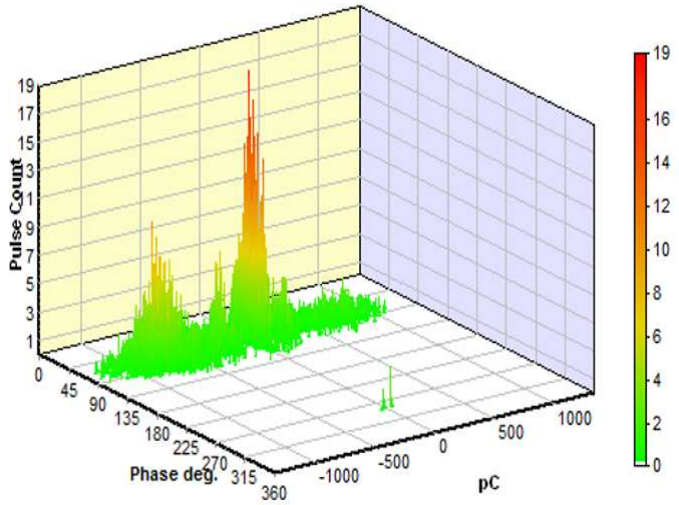
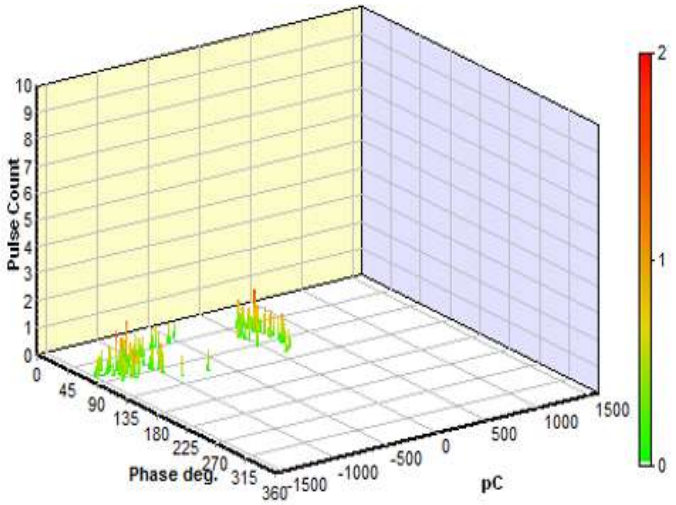
PD behaviour

- Iso-Paraffinic liquids typically show higher PD repetition rates than typical naphthenic oils.
- Believed to be due to lower density and absence of aromatics.
- Topic under further investigation.



Iso-Paraffinic - 40kV 5MIN



Naphthenic - 40kV 5MIN

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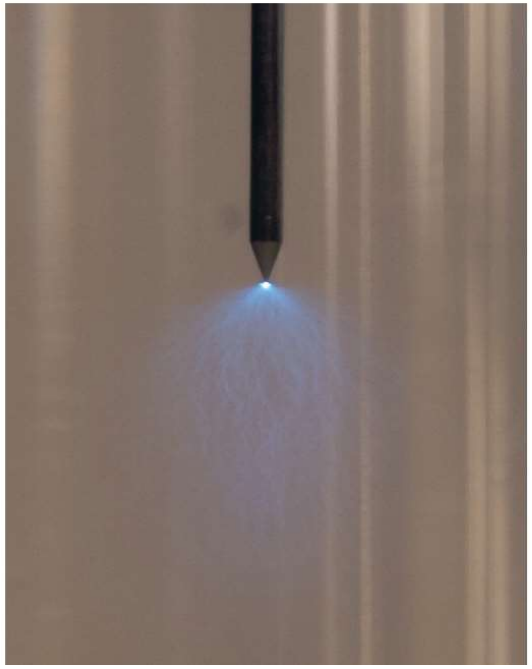
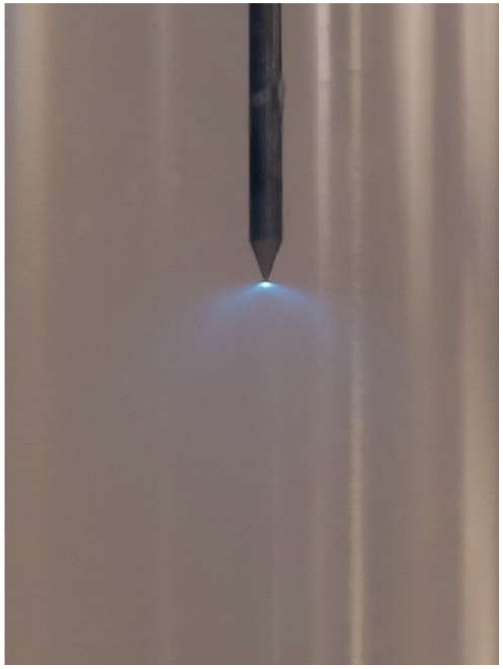
PD Comparison

- Point-sphere electrode configuration 60kV 50Hz RMS applied voltage.



Iso-Paraffinic



Naphthenic

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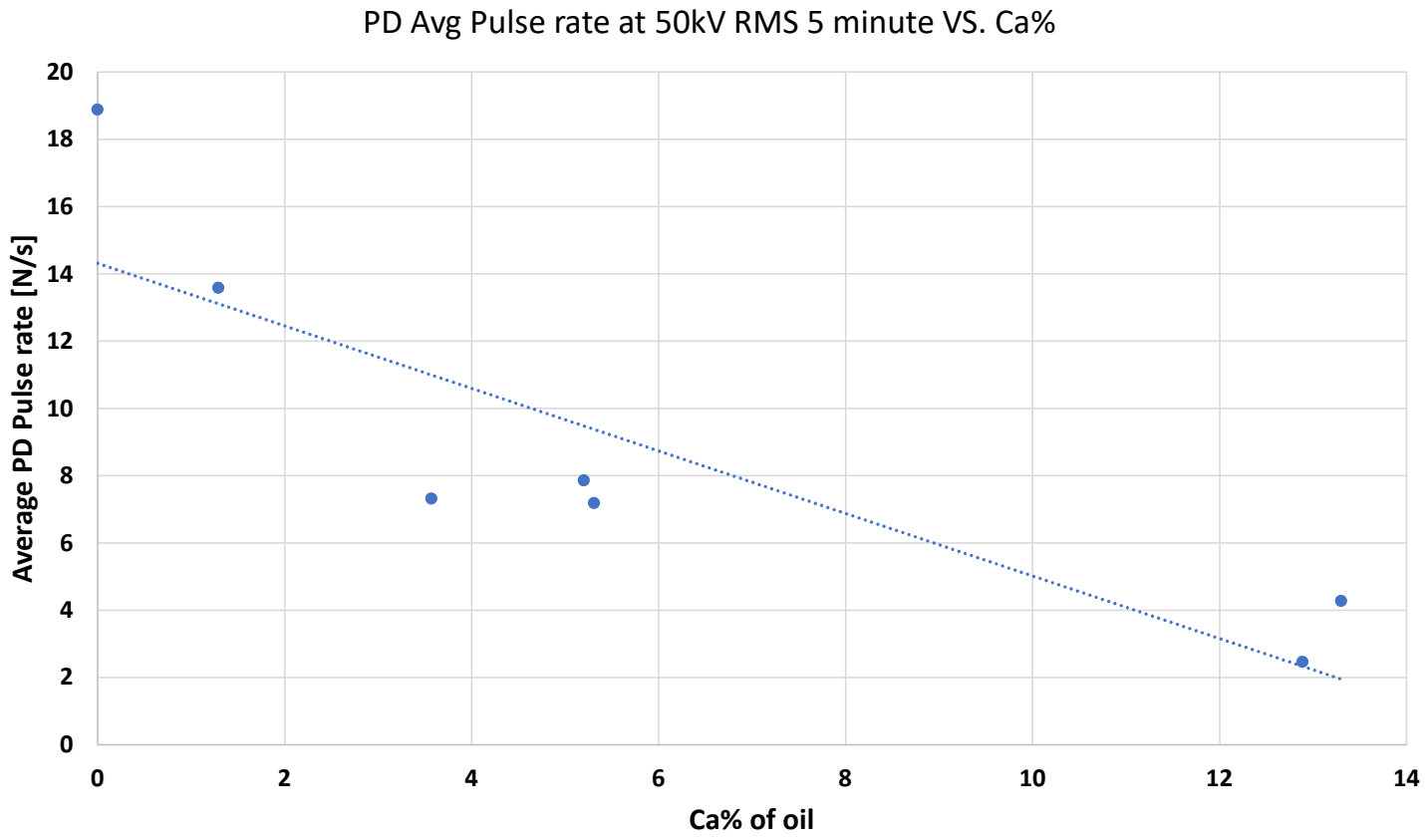
Prelim. relationship? - PD Pulse rate to aromatics



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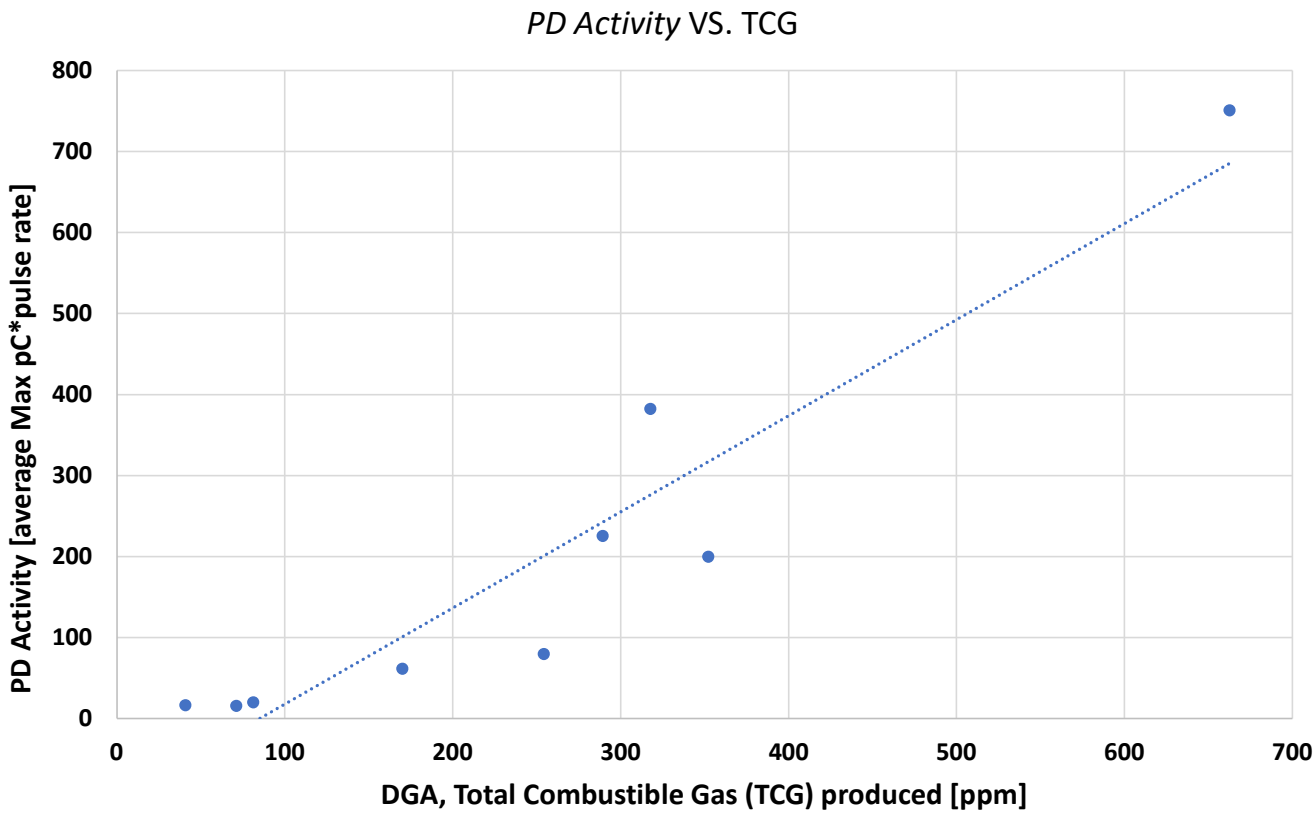
Prelim. relationship? - PD activity to gas production



Conclusion

- Insulating liquids insulating capability are governed by both composition and condition (impurities, moisture, gases)
- Streamer propagation behaviour of a particular liquid is intimately linked to its HV performance (PD, time to breakdown, polarity sensitivity).
- In mineral oil - aromatics play a role.
- Esters have inferior HV behaviour – design considerations & adjustments are necessary.

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Thank you.