An Overview of the Suitability of Ester Oil Dielectrics for use in Large Power Transformers

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M&I Materials

United Utilities

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ScottishPower

EDF ENERGY

TJ H2b

nationalgrid

Contents

- Overview of use of ester oils
- Technical challenges of ester transformers
- Dielectric performance of ester oils
- Dielectric performance of ester impregnated cellulose
- Condition monitoring - DGA

Background

- Both synthetic and natural types of ester oils available
- Synthetic ester oils, petroleum product origin, far more chemically stable
- Natural ester oils, agricultural product origin

Background

- Synthetic ester oils used in speciality and distribution transformers since 1970s with no reported problems
- Natural ester oils have been in small transformer use since the mid 1990s, and are used by over 100 companies in the US.

Power transformer – current state of play

- Synthetic ester oil used in 238kV power transformer located in Sweden
- Natural ester oil to be used in 242kV Brazilian shunt reactor
- Natural ester oil being used to develop a 132kV 90MVA transformer by EdF Energy and AREVA T & D

Proposed power transformer benefits

- Environmentally friendly – biodegradable
- High flash / fire point – fire safety

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Proposed power transformer benefits

- Transformer life mainly depends on life of cellulose, as this cannot easily be replaced or reconditioned
- Ester oils “drying” cellulose preserve cellulose life
- Products of ester oil aging less aggressive than mineral oil so do not attack the cellulose

Challenges in power transformer design/manufacture/operation

- Dielectric performance of ester and ester impregnated cellulose insulation system under rms and transient voltages

- Viscosity of ester oil affects impregnation during manufacturing

- Condition assessment tools – the experience with mineral oil transformer can still be used ?

Technical aspects of ester oils

Investigation into effects of moisture

Aim: Establish comparatively how moisture affects oil dielectric strength

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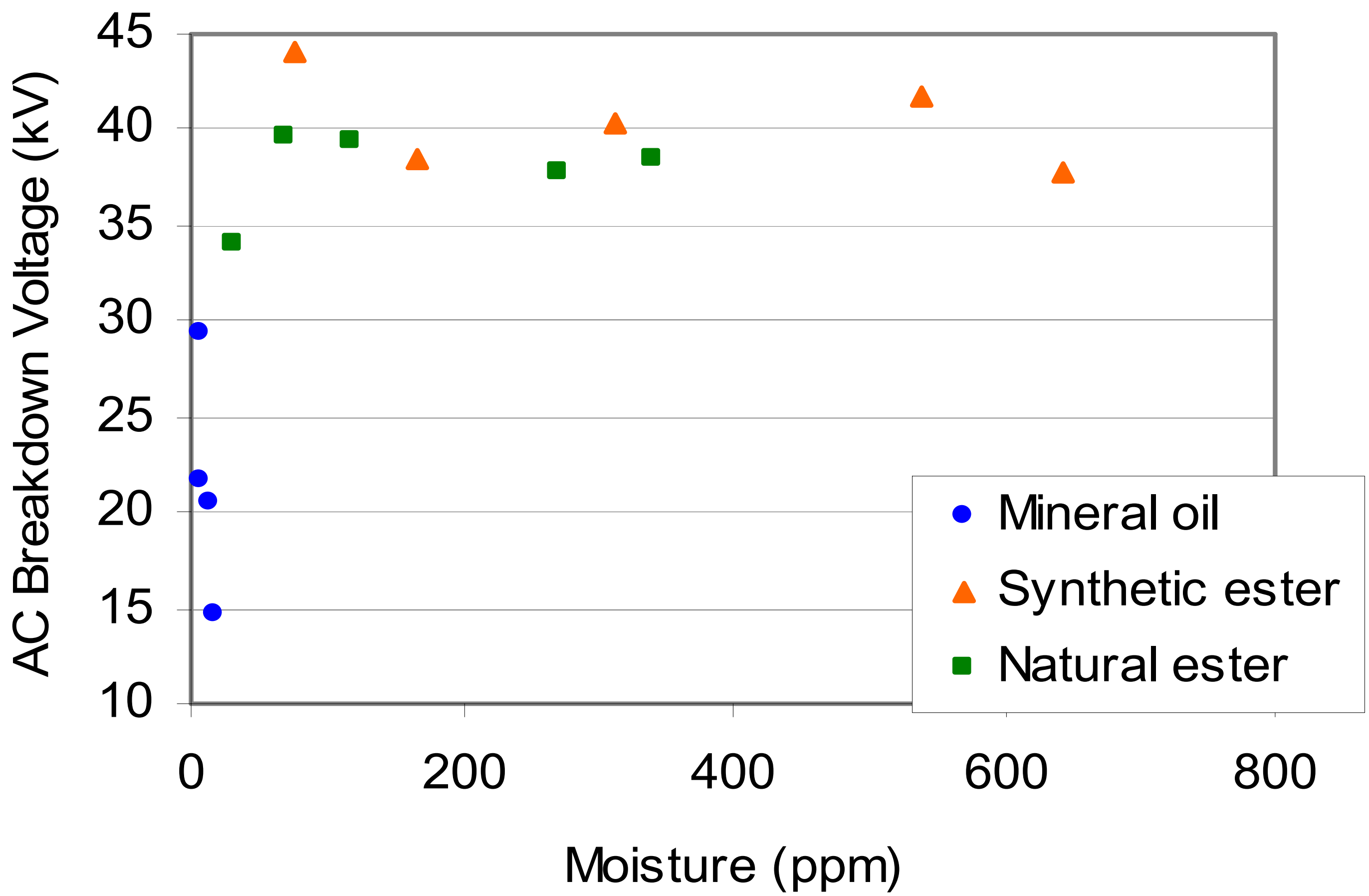
AC and impulse dielectric strengths

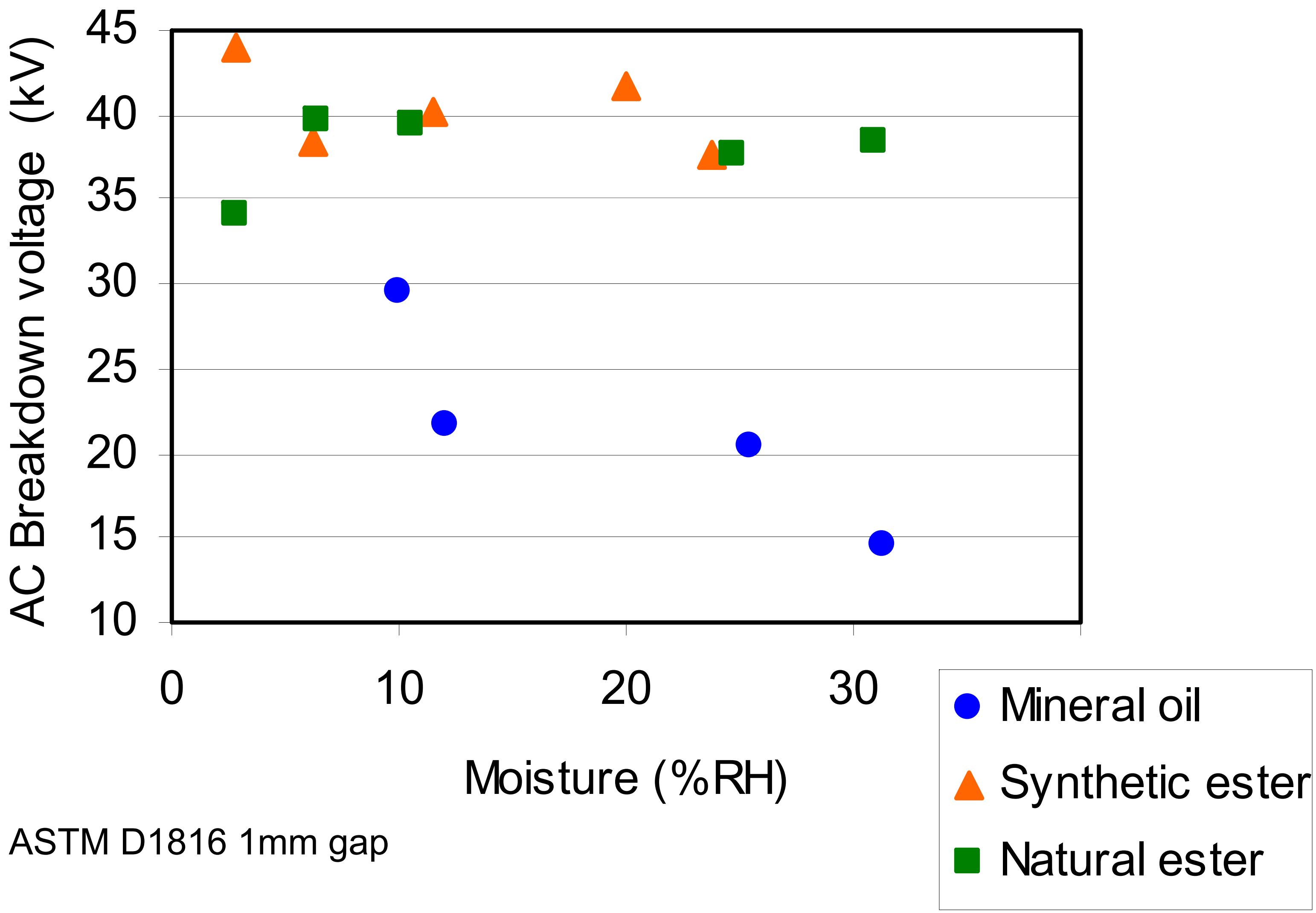
- High working transformer voltages require retention of dielectric strength
- Water often described as number one enemy of insulation
- Sealing transformer does not prevent increase of water

Investigation into effects of moisture

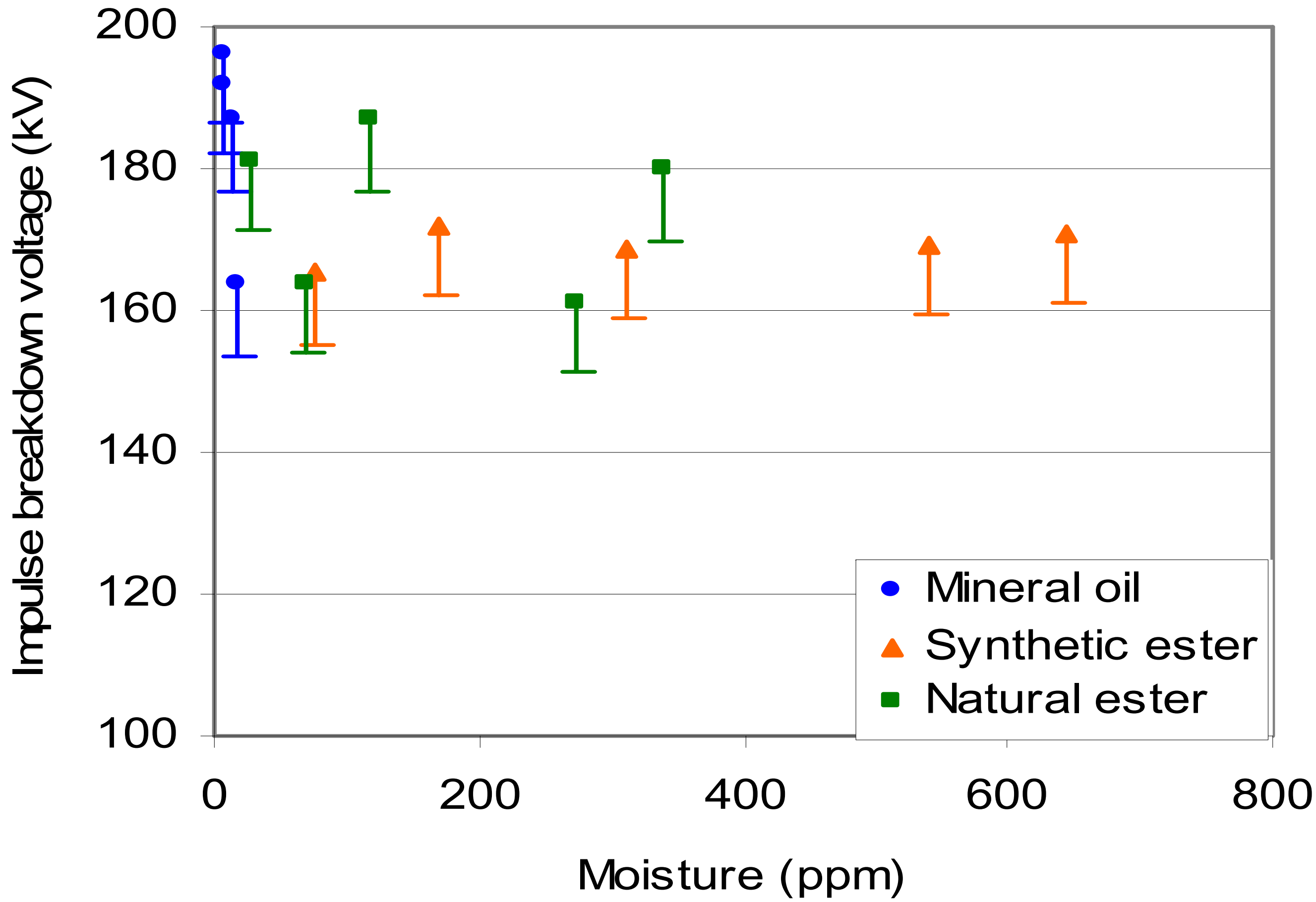
Glycerol solution and desiccator used to vary oil moisture content



ASTM D1816 1mm gap



ASTM D1816 1mm gap



200
180
160
140
120
100
Impulse breakdown voltage (kV)
0
200
400
600
800
Moisture (ppm)
Mineral oil
Synthetic ester
Natural ester

ASTM D3300

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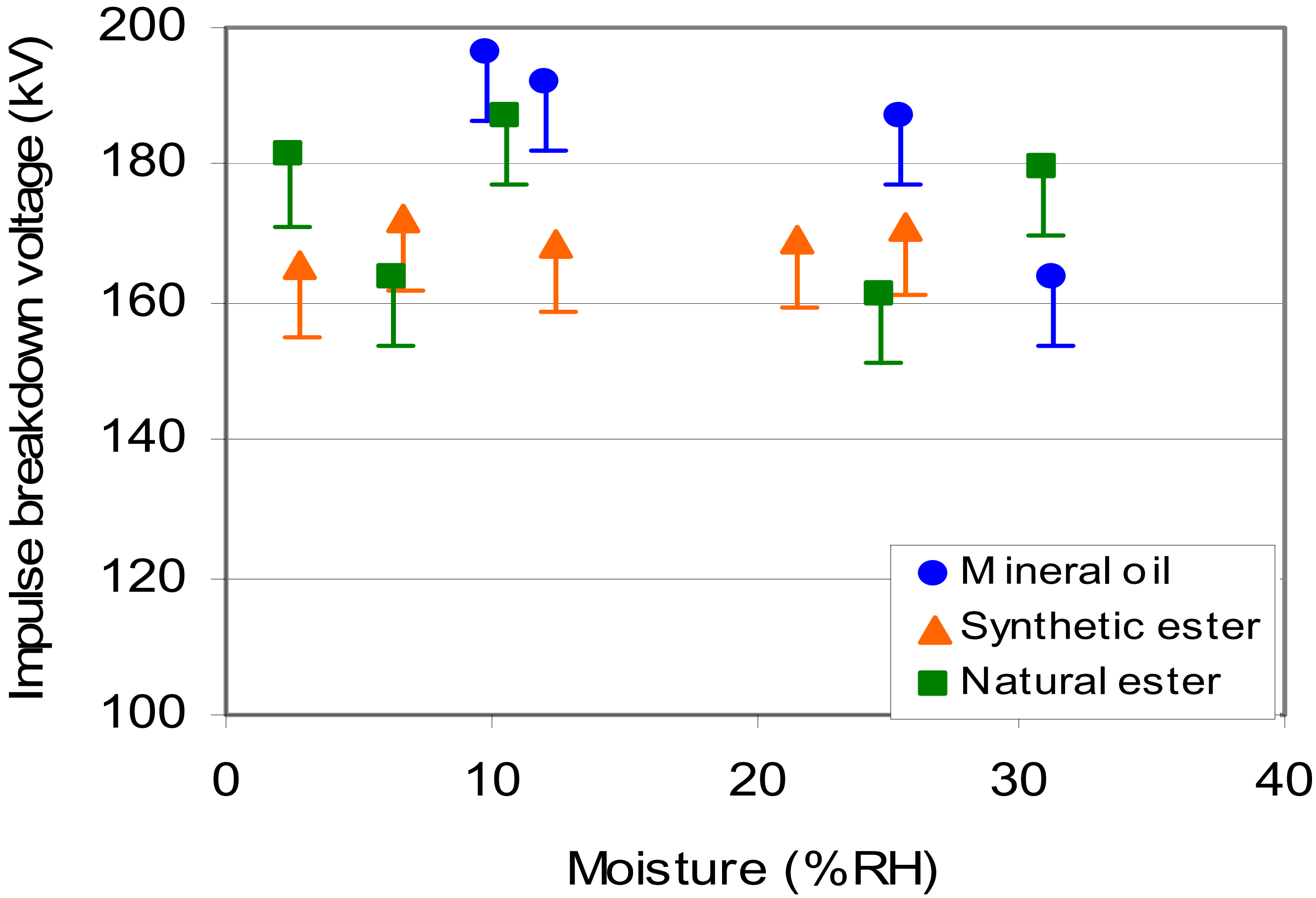

ASTM D3300

Conclusion

Dielectric strength of ester oils less affected by moisture than mineral oil

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Laboratory based investigations into the chemical stability of synthetic and natural ester oil dielectrics

Chemical stability – Investigation

Aim: Establish how various parameters of oils change during aging

Hypothesize how changes in parameters may affect overall transformer performance

Chemical stability – Aging standards

Why do we use them?

Simulate how oil is likely to perform in use

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Chemical stability – Aging standards

Must be careful interpreting applicability of aging standards

Standards may not be realistic of the transformer environment or consider the effect of oil aging on transformer life

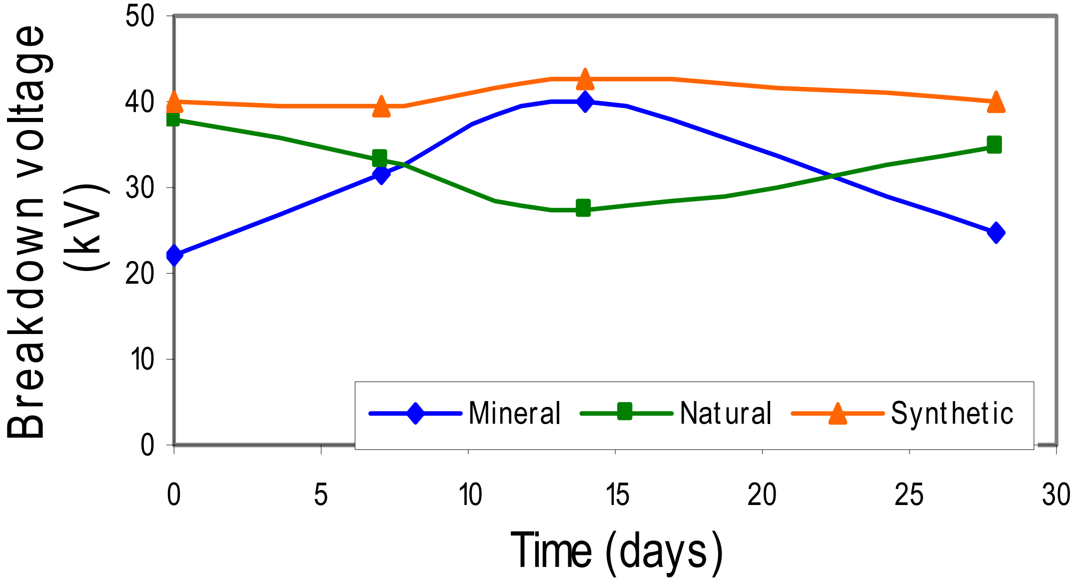
Chemical stability – In use

Synthetic esters have been in use since the 1970s

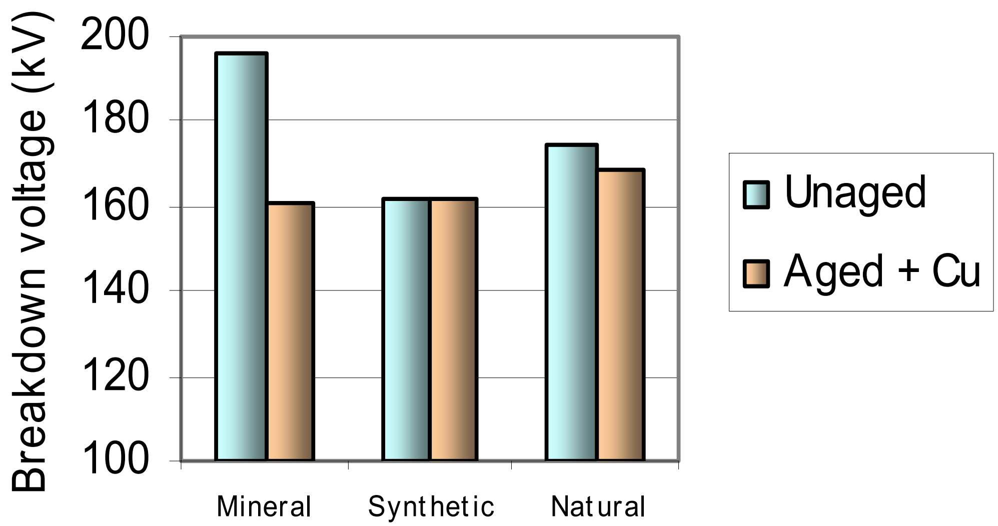
Natural esters have been in use since the mid 1990s

Chemical stability – Investigation

- Aging performed to monitor how oil changes
- Open beaker method
- 115°C
- Up to 28 days
- Included catalytic items



AC dielectric strength



Lightning impulse dielectric strength

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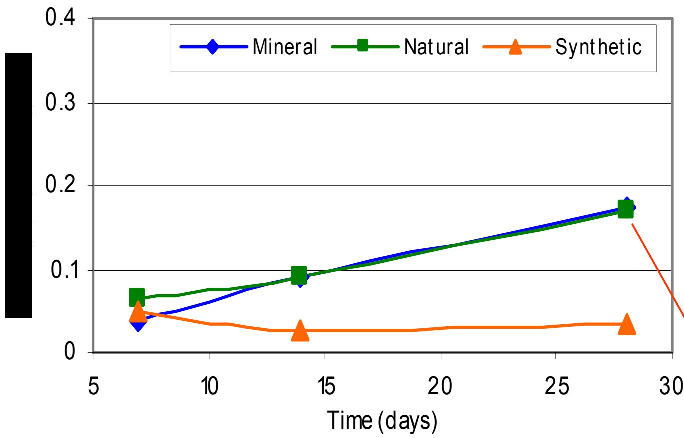
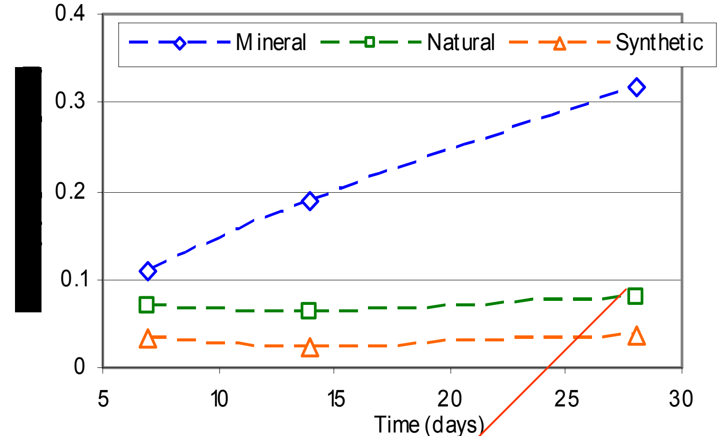
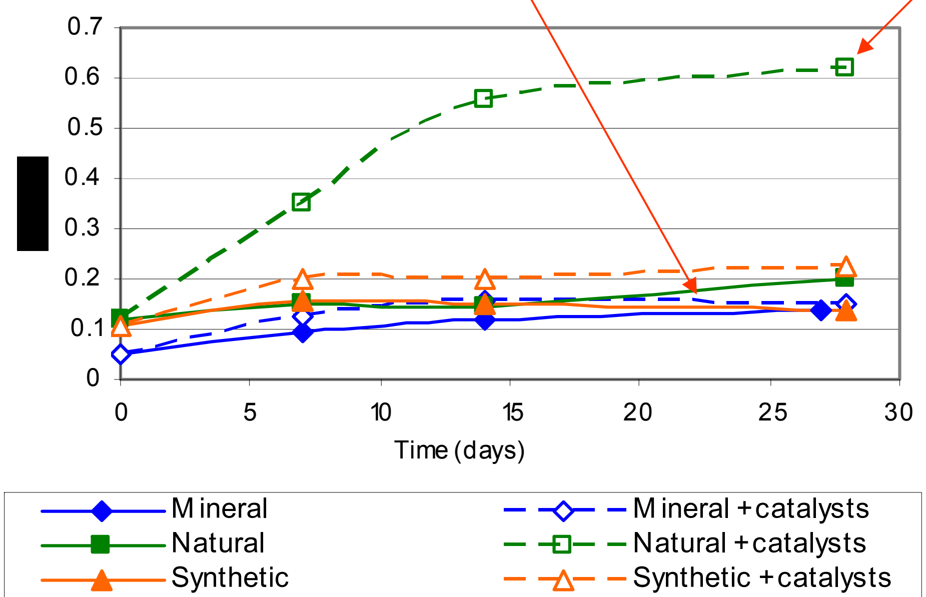
Acidities



Without copper



With copper



Mineral oil

Natural ester

Synthetic ester

Sludging

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Conclusions: Synthetic vegetable oil

- Highly stable towards oxidation
- Backs up manufacturer claim that these can be used in a free breathing transformer environment

Conclusions: Natural ester oil

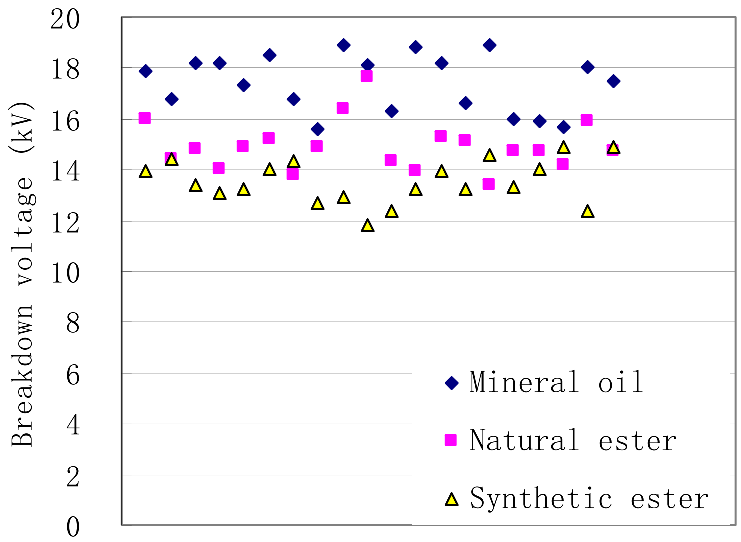
- Must be careful when applying aging standards
- Aging products are considered less aggressive than mineral oil
- CPS have 10 years of data to conclude natural esters are suitably stable in sealed transformer

Technical aspects of ester oil impregnated cellulose

Dielectric capability

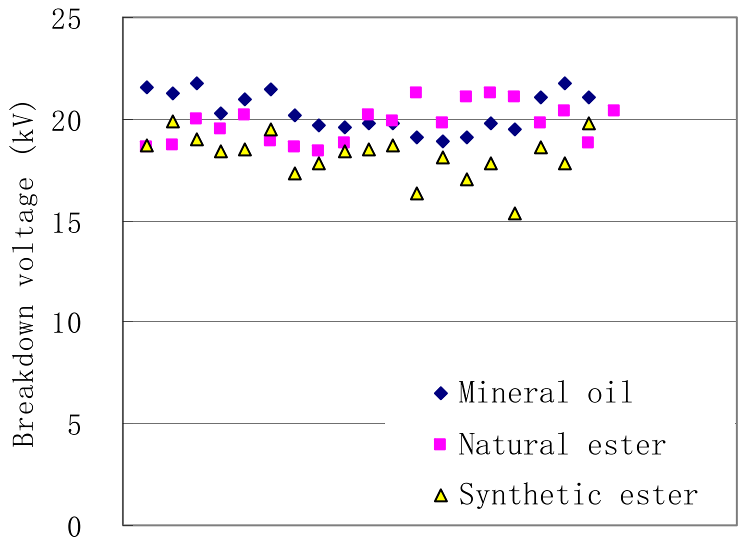
- AC test on ester impregnated paper
- Impulse test on ester impregnated paper

Rms breakdown voltages of ester impregnated paper



Breakdown voltage of layer insulation paper (0.25mm)

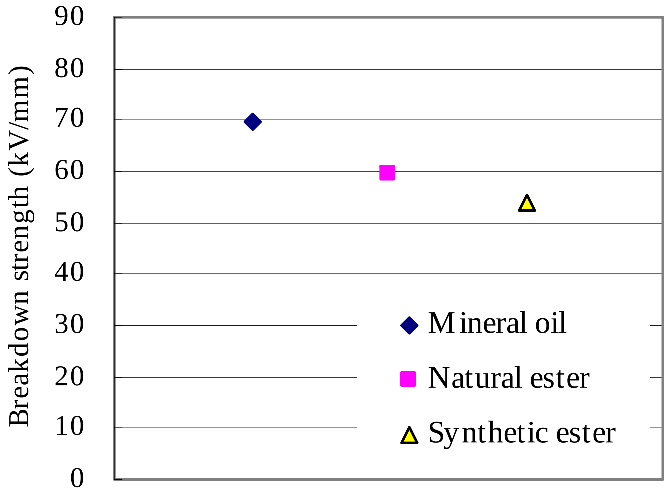
(Paper density= 0.75g/cm3;
Sample thickness= 0.25mm)



Breakdown voltage of conductor insulation paper (0.26mm)

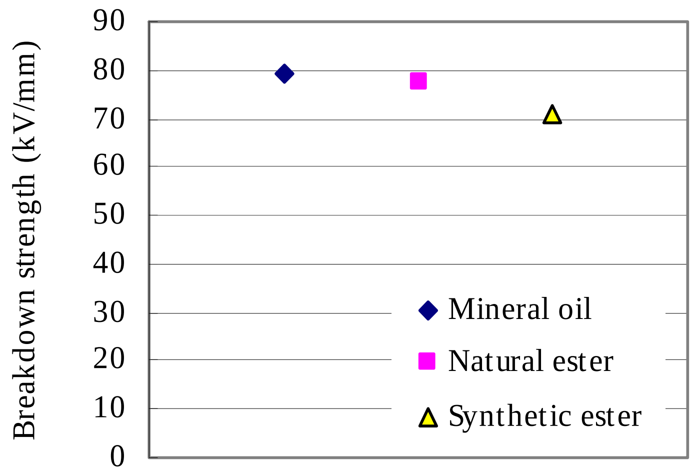
(Paper density=0.93g/cm3;
Sample thickness=0.26mm)

Rms breakdown strength



Layer insulation paper

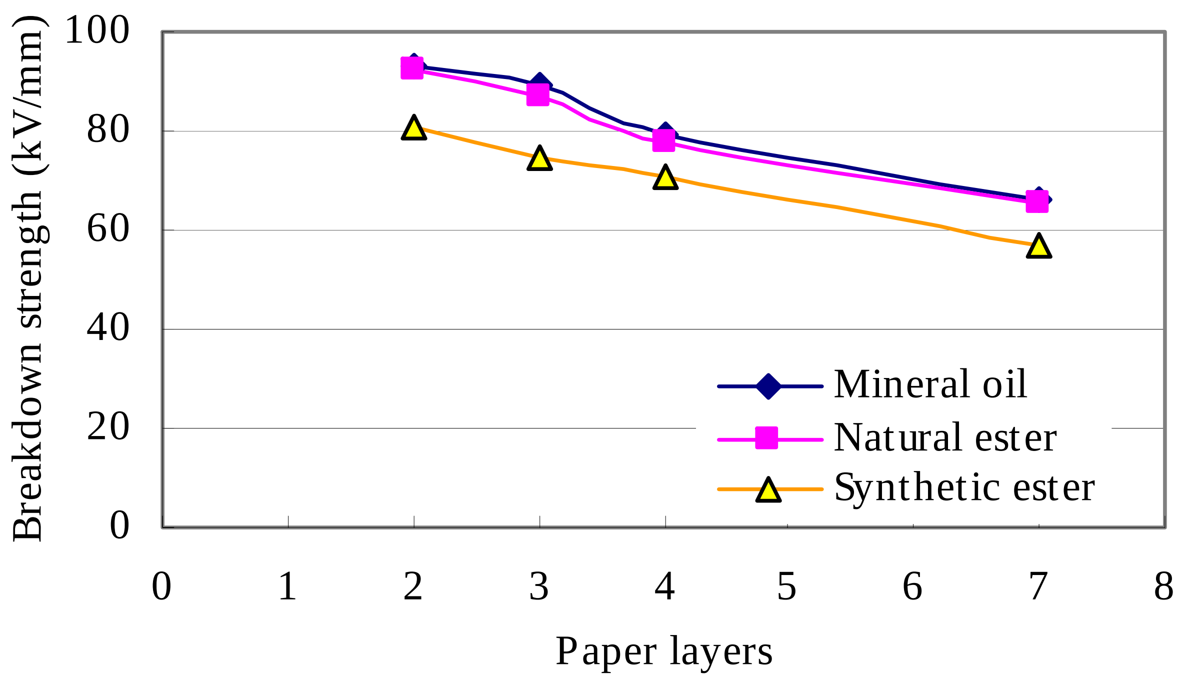
Breakdown strength
(Paper density= 0.75g/cm3;
Sample thickness= 0.25mm)



Conductor insulation paper

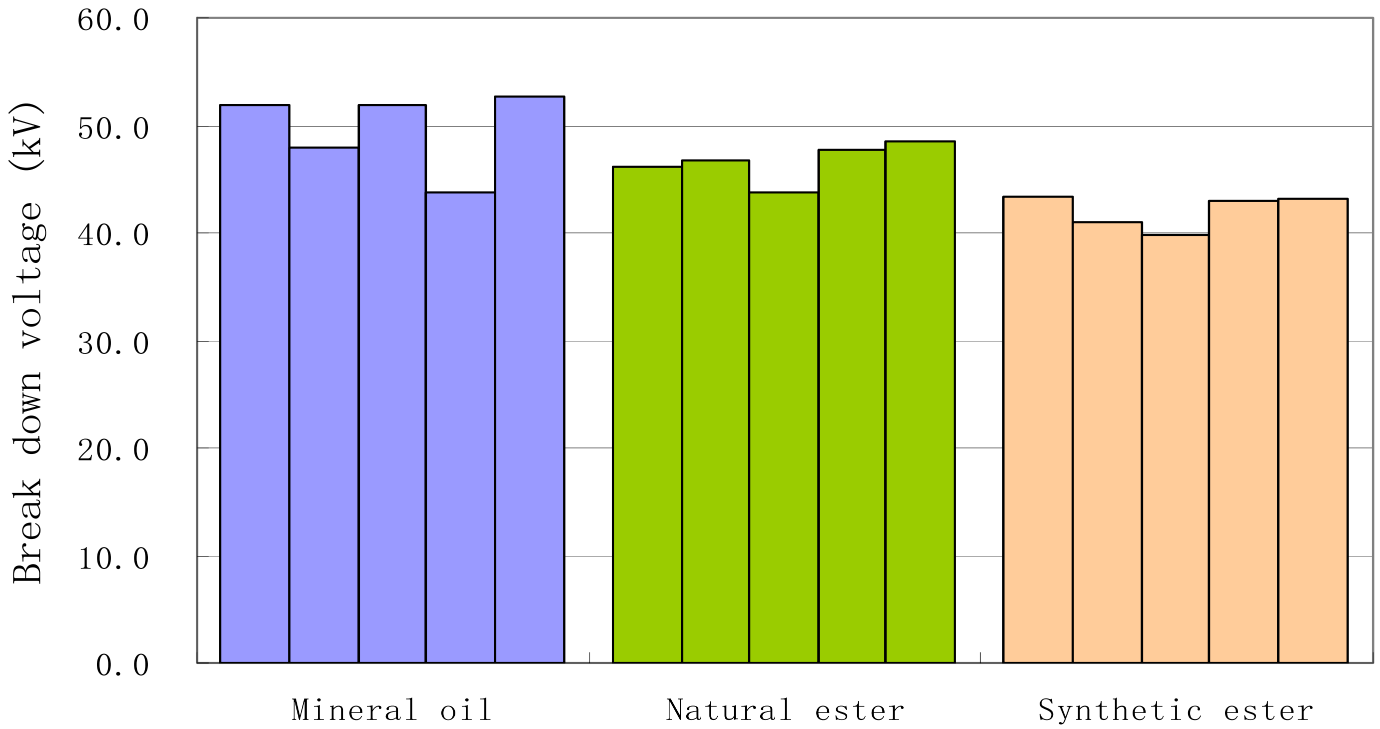
Breakdown strength
(Paper density=0.93g/cm3;
Sample thickness=0.26mm

Rms breakdown strength VS. thickness



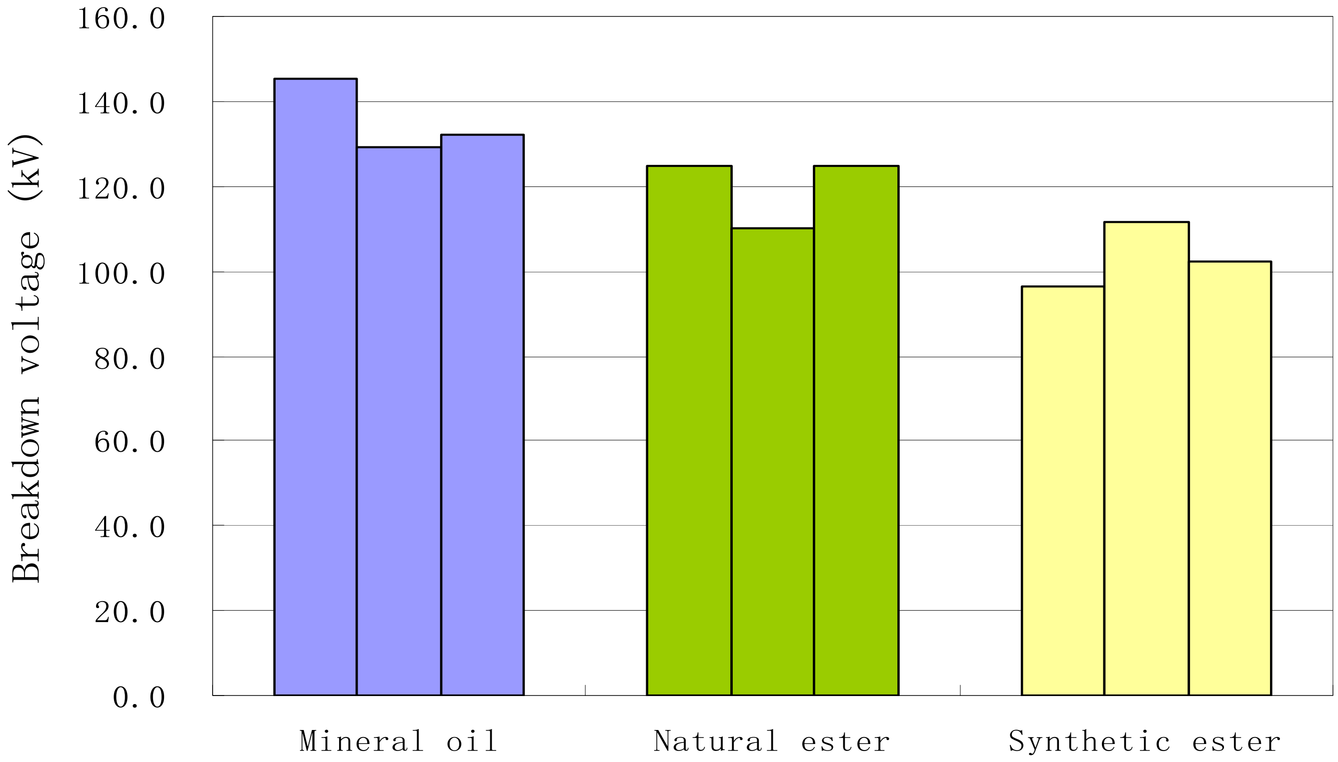
Paper density= 0.93 g/cm3; moisture< 0.2%

Impulse breakdown voltage of ester impregnated paper



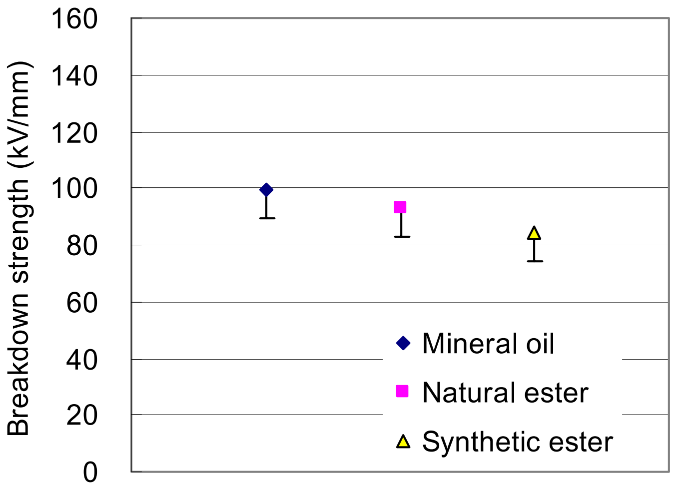
Paper density= 0.75 g/cm3, thickness= 0.5mm
moisture< 0.2%

Impulse breakdown voltage of ester impregnated paper



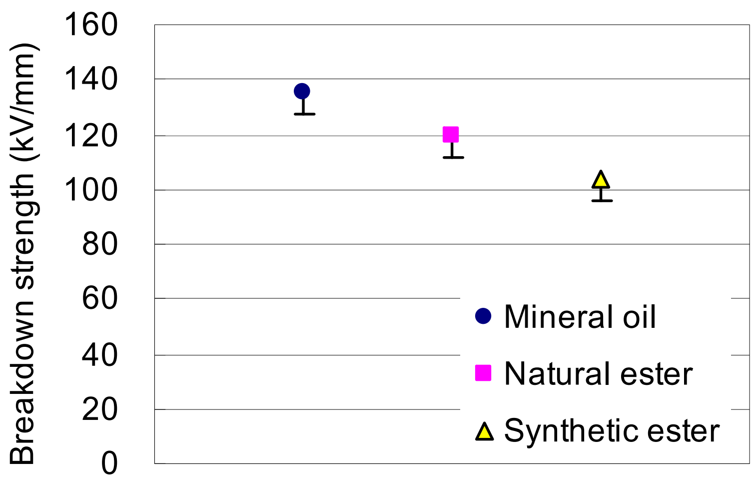
Paper density= 0.93 g/cm3, thickness= 0.64mm
moisture< 0.2%

Impulse breakdown voltage of ester impregnated paper



Layer insulation paper

Breakdown strength



Concoctor insulation paper

Breakdown strength

Dielectric capability of ester impregnated paper

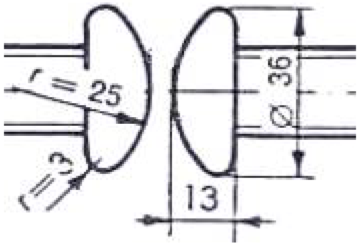
Conclusion:

- Dielectric strength of paper increases with density and decreases with thickness
- Natural ester impregnated paper is comparable to mineral oil impregnated paper, while the dielectric strength of synthetic ester impregnated paper is relatively lower
- Breakdown mechanism is being studied to explore the reason behind the differences

AC stress test (ester-pressboard VS mineral-pressboard)

- Test description:

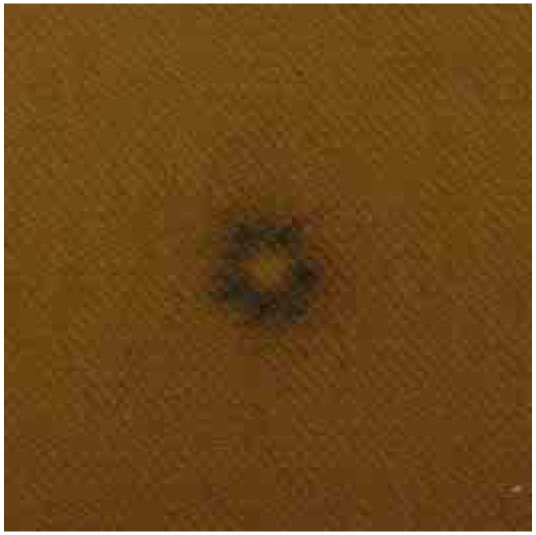
  - Partial sphere electrodes were used:



  - AC voltage was raised up to 75kV with increasing speed of 0.5kV/s.

AC stress test (ester-pressboard VS mineral-pressboard)

Test result:



Mineral oil impregnated pressboard

Ester impregnated pressboard

AC stress test (ester-pressboard VS mineral-pressboard)

Conclusion:

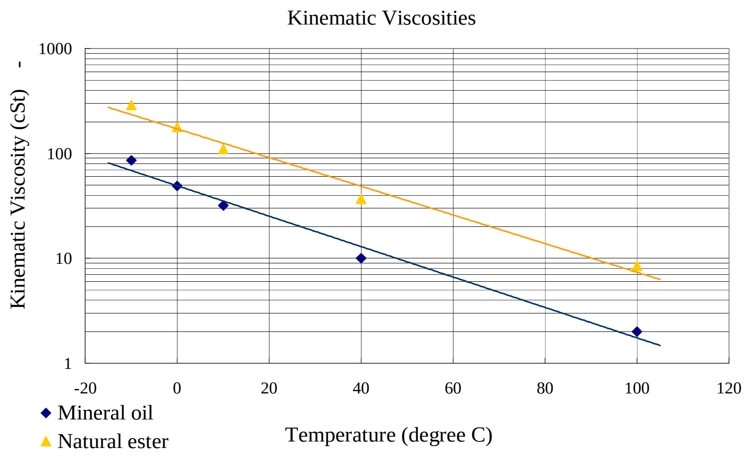
- Results are in favour of the ester impregnated pressboard, but the breakdown strength is not comparable in different oil medium.
- The lower permittivity ratio of ester-impregnated pressboard to ester fluid helps to deter surface discharge
- More work need to be done to study the intrinsic dielectric strength of pressboard impregnated by different oil

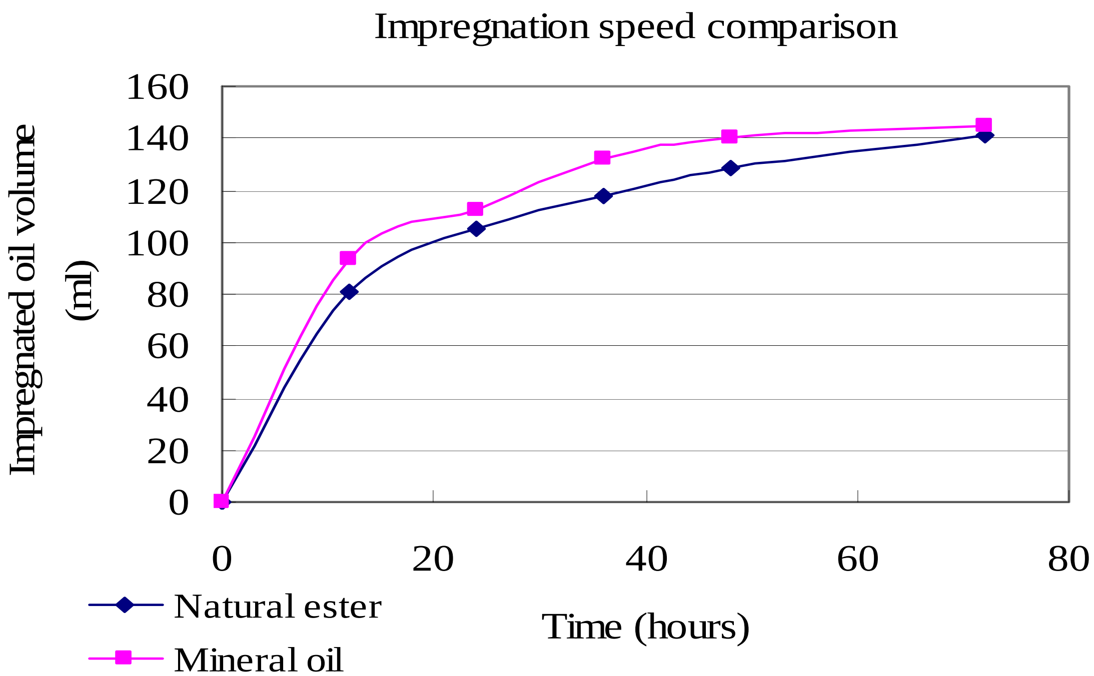
Impregnation of solid insulation by ester fluid

Impregnation by ester

- Higher viscosity of ester fluids is a disadvantage during impregnation process
- Impregnation of both paper and pressboard brings no technical problem due to their thin thickness.
- Impregnation of laminated blocks brings more engineering challenges

Higher temperature may help





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Dissolved gas analysis (DGA) for ester oils

Transformer faults

- DGA is still the most effective condition monitoring and assessment tool for incipient faults

- Two types of faults: thermal and electrical,

- Thermal fault: - overheating of oil, oil/cellulose

- Electric fault: PD, low energy/high energy discharges

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Laboratory simulated faults

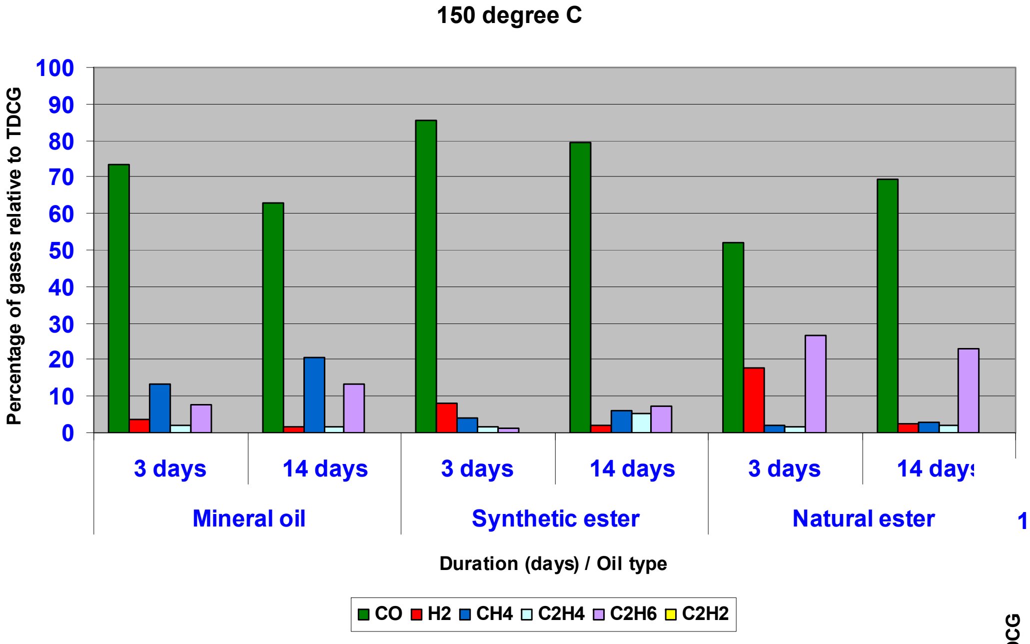
- Seal oil or oil/cellulose samples in bottles
- Overheating in oven at controlled temperature for a period of time
- Ester oils subjected to PD
- Ester oils subjected to low energy discharges, controlled arcing using overcurrent relay

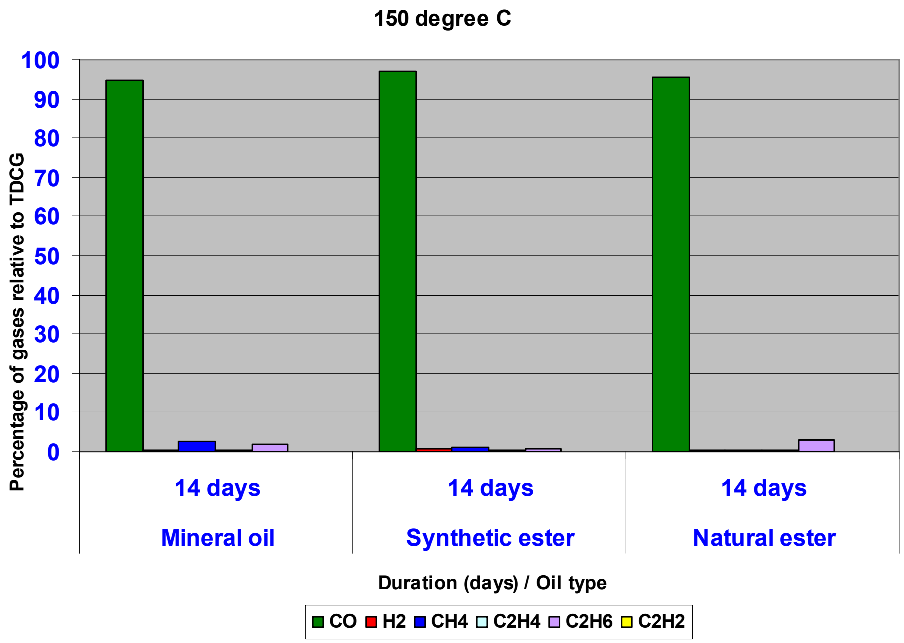
Thermal tests at 150°C

- Thermal tests at 150°C with & without paper

- DGA Results are the average of 3 samples

Thermal tests with oil only, oil/cellulose





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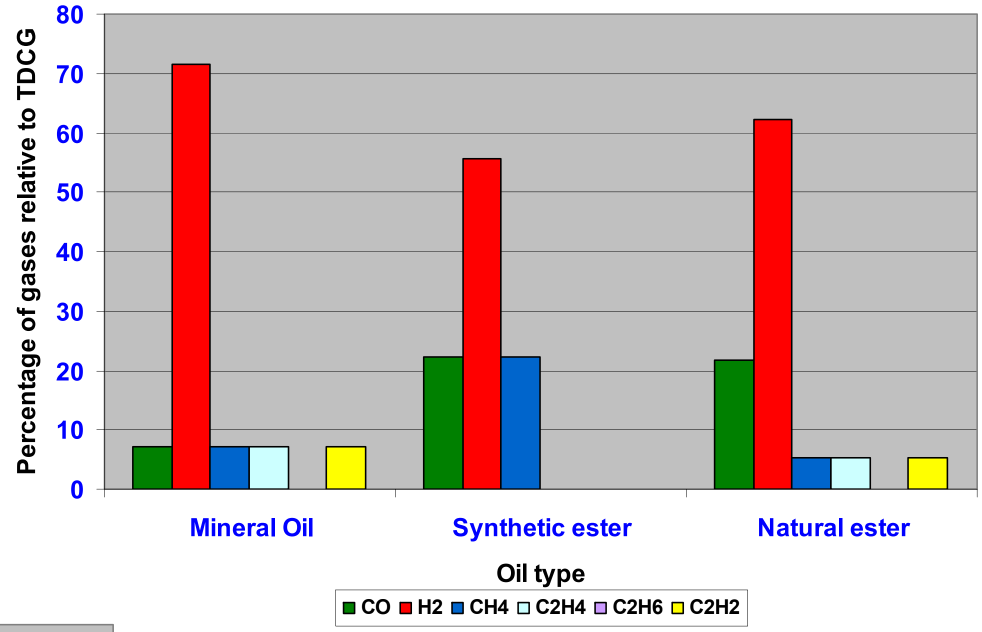
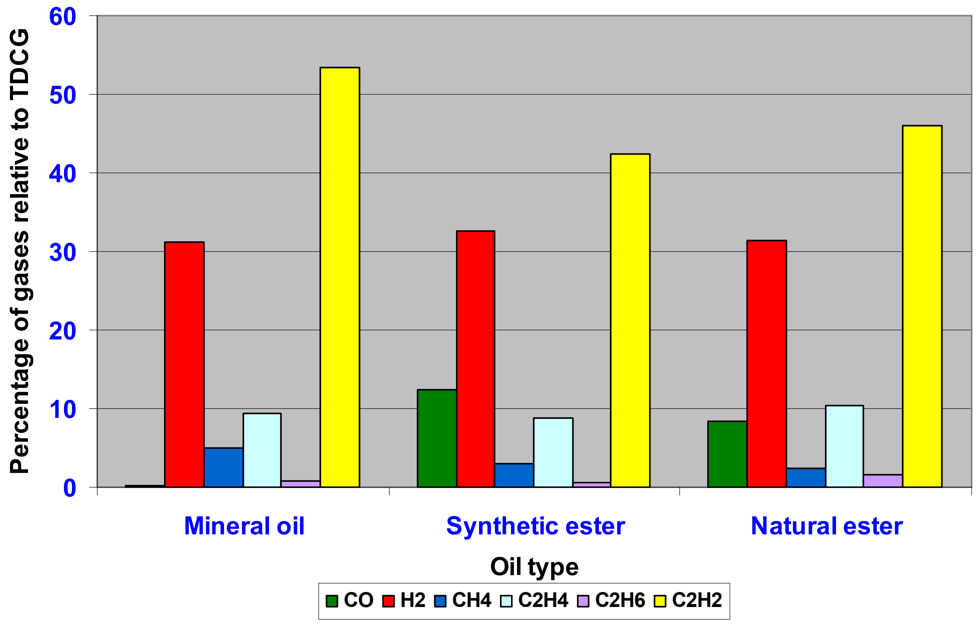
Electrical tests

- Cold corona type discharge tests
- Low energy discharge tests

Cold corona type discharge



Low energy discharge



Fault diagnosis methods

- IEC60599

- Duval Triangle method

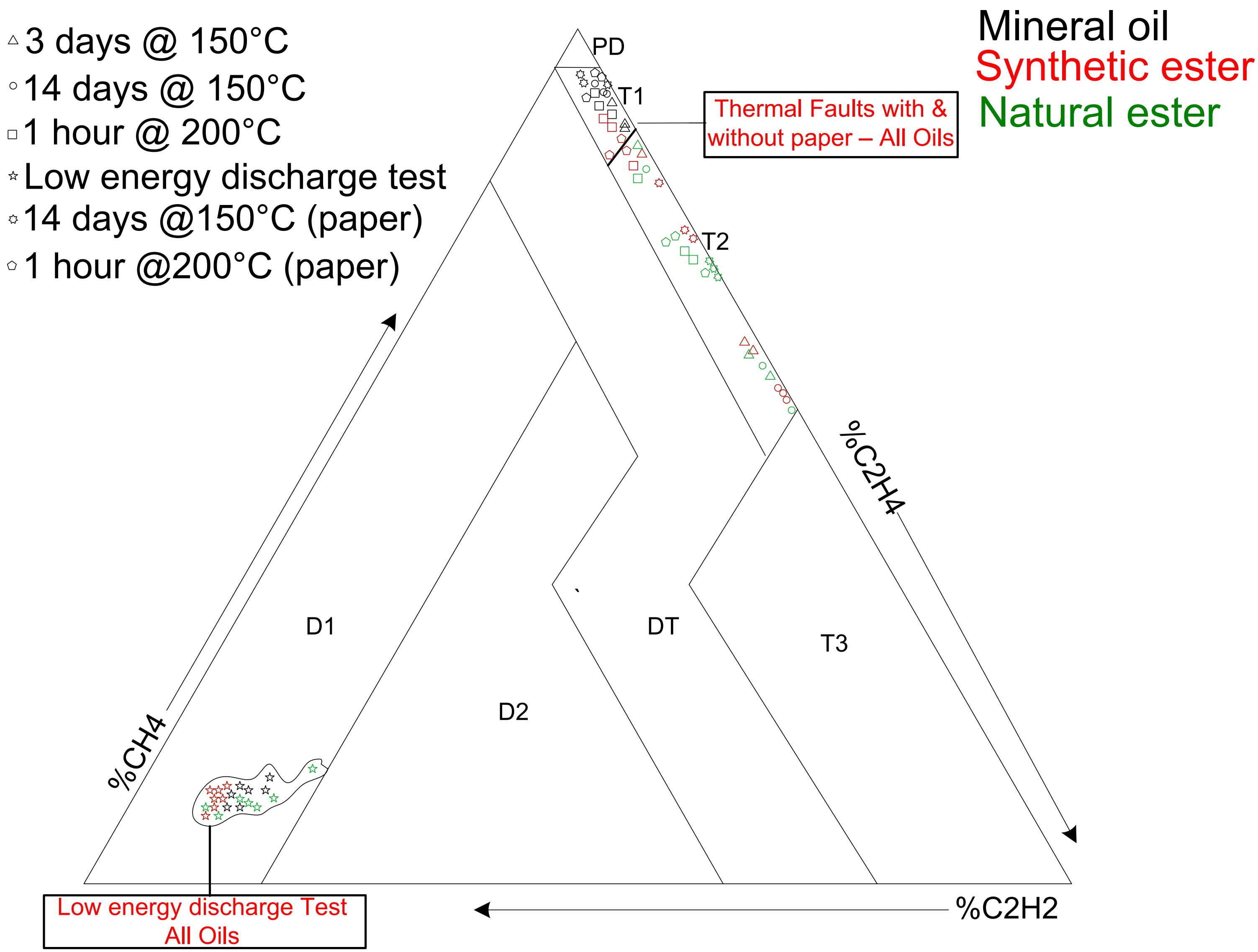
IEC60599

Thermal tests			
Test method	Oil type	Diagnosis result (oil only)	Diagnosis result (oil and paper)
14 days at 150°C	Mineral oil	Thermal Fault of Low temperature range (150-300 °C)	Thermal Fault of Low temperature range (150-300 °C)
	Synthetic ester	Thermal Fault of Low temperature range (150-300 °C)	Thermal Fault of Low temperature range (150-300 °C)
	Natural ester	Thermal Fault of Low temperature range (150-300 °C)	Thermal Fault of Low temperature range (150-300 °C)

IEC60599

Electrical tests		
Test method	**Oil type**	**Diagnosis result**
Cold corona type discharge	Mineral oil	Discharge of low energy
	Synthetic ester	Normal (No fault)
	Natural ester	Not Applicable
Low energy discharge	Mineral oil	Discharge of low energy
	Synthetic ester	Not Applicable
	Natural ester	Not Applicable

Duval triangle



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Conclusions

- Comparable dielectric performance under rms and transient voltages

- Due to high viscosity, higher temperature impregnation and longer time may be needed Impregnation

- DGA can be still used as a condition assessment tool, but the diagnosis criteria need to be adjusted

Future work

- Volume effect need to be studied under rms and transient voltages

- Suitability will be further confirmed through operating experience

The end

Thank you !

Research team in Manchester:

PhD students: Dan Martin, Imad Khan, Jie Dai

Lecturers: Zhongdong Wang, Ian Cotton