TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

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Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

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Mineral based Transformer oil is used for over 100 years in transformers

It fulfills different tasks and properties

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Functions of an insulating liquid

- Insulation
- Impregnation
- Heat transfer (cooling)
- Fire Extinguishing
- Dielectric
- Diagnostic

Requirements of insulating oils

1. To meet the Insulation function, the oil must have high dielectric strength and low dielectric dissipation factor to withstand the electric stresses imposed in service.

2. To meet the Heat transfer and Cooling functions, the oil must have viscosity and pour point that are sufficiently low to ensure that oil circulation is not impaired at the most extreme low temperature conditions for the equipment.

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Requirements of insulating oils

3. To meet the Arc quenching function, the oil requires a combination of high dielectric strength, low viscosity and high flash point to provide sufficient insulation and cooling to ensure the arching is extinguished.

Requirements of insulating oils

4. To have low viscosity to enable Optimum impregnation of the solid insulation in transformer

5. Measuring different parameters of the oil such as Gas in Oil analysis allows a Diagnostic of the condition of transformer

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IfES Different Kinds of insulating liquids

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Mineral oils

Paraffins	(40 % - 60 %)	saturated
Naphtenes	(30 % - 50 %)	Hydrocarbons
Aromates	(5 - 20 %)	unsaturated
Olefines	(bis 1 %)	hydrocarbons

Thermal and electrical aging increases the loss tangent and lowers the breakdown voltage

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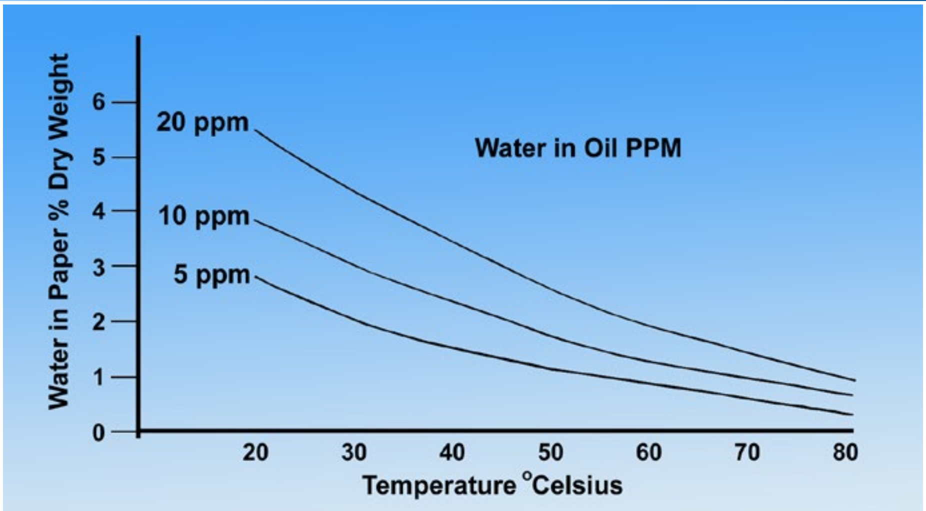

Moisture equilibrium in oil paper system

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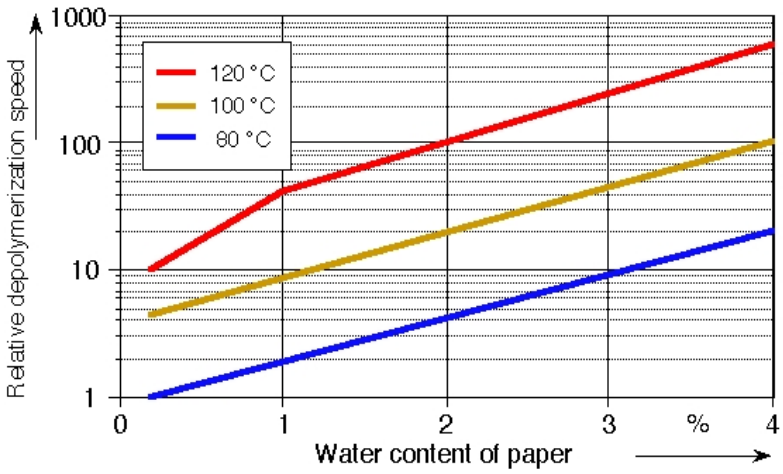
Relative depolymerisation speed



Bouvier, D(80°C and moisture of cellulose 0,2%) = 1

THE EFFECT OF MOISTURE ON CELLULOSIC INSTULATION	
Transformer H_20 Content By Percent Dry Weight in Cellulose	Aging Rate (Reduction in Tensile Strength)
0.3% 2.0% 4.0%	1.0 6-16x 12-45x
A. Stannett (1965)	

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Sludge Formation in Oil

Oxidation begins as soon as the oil is placed in the transformer.

Deterioration results from the effects of oxidation.

Unstable hydrocarbons plus oxygen, moisture, heat, vibration, and electrical stresses result finally in the terminal stage of oil degradation as an insulating medium, that is the formation of sludge.

Sludge precipitates out of the oil where it attacks solid insulation and can reduce effective cooling.

Sludge Formation in Oil

The sludge builds up in layers whose hardness depends on how the unit has been operated and how long maintenance has been ignored.

Sludge formation depends on the presence of oxygen in an energized transformer.

This oxygen may come from outside air, but also comes from the breakdown of the Kraft paper insulation.

The probability of sludge accumulation increases if the oil shows an increase in neutralization (acid) number, a drop in interfacial tension, deepening of color.

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TRANSFORMER OIL CLASSIFICATIONS

Color no	Class	NN	IFT	Colour	M.I.N.
	1. Good Oils	0.00 - 0.10	30.0 - 45.0	(Pale Yellow)	300 - 1500
0.5-1.0	2. Proposition A Oils	0.05 - 0.10	27.1 - 29.9	(Yellow)	271 - 600
1.0-2.5	3. Marginal Oils	0.11 - 0.15	24.0 - 27.0	(Bright Yellow)	160 - 318
2.5-4.0	4. Bad Oils	0.16 - 0.40	18.0 - 23.9	(Amber)	45 - 159
4.0-5.5	5. Very Bad Oils	0.41 - 0.65	14.0 - 17.9	(Brown)	22 - 44
5.5-7.0	6. Extremely Bad Oils	0.66 - 1.50	9.0 - 13.9	(Dark Brown)	6 - 21
7.0-8.5	7. Oils in Disastrous Condition	1.51 or more		(Black)	

Ref:
Oil condition based on ASTM D 1500 color testing comparisons

	Symptoms	Diagnosis	Treatment
1.	Breakdown voltage low	Moisture or solids in oil	Oil purification
2.	Oil colour orange/brown	Oil deterioration	Oil regeneration
3.	Visible sludge in oil/transformer	Insulation deterioration	Transformer desludging
4.	Free water in oil or oil cloudy	Insulation Saturated	Transformer dry-out

Oil Parameters (IEC 60422, VDE 0370-2)

- Colour
- Particle
  - General status
- water content
  - Important parameter
- breakdown voltage
  - Important parameter

Oil parameters

- Tan-Delta
  - Leads to increased thermal stress
- Interfacial tension
  - Oil aging, degradation products
- Acidity (total acid number)
  - Acid aging products degrade paper insulation
- Inhibitor content
  - Consumption is a measure for aging
- PCB-content
  - Is not more permitted
- Density, flashing point, viscosity

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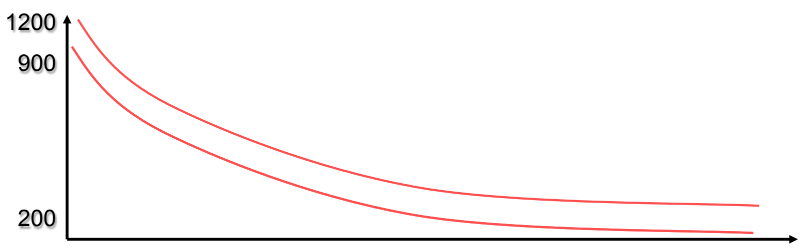
Furan analysis

- 5-Hydroxylmethyl-2-Furfurol (5HMF)
- 2-Furfurylalcohol (2FOL)
- 2-Furfurol (2FAL)
- 2-Acetylfurane (2ACF)
- 5-Methyl-2-Furfurol (5MEF)



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DGA (Dissolved Gas Analysis)

- Nitrogen N2
- Oxygen O2
- hydrogenH2
- carbon monoxide CO
- carbon dioxide CO2
- Methane CH4
- Ethane C2H6
- Etylene C2H4
- Acetylene C2H2

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DGA Diagnostic Tools

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DGA (IEC 60599 VDE 0370-7)

Electrical fault

- Partial discharge
- Low energy discharge
- High energy discharge

Thermal Fault

- Lower than 300°C
- Between 300 and 700°C
- Above 700°C

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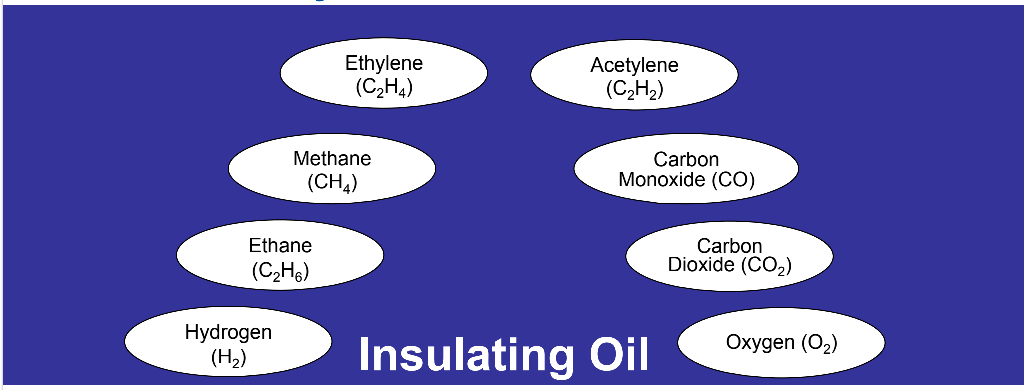
Which Gases are Generated?

Eight key gases in transformer oil are associated with fault conditions.

DGA detects the level of gases indicative of various faults that may lead to transformer failure.



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Most severe faults:

Faults D2 in paper and in oil (high-energy arcing)
Faults T2-T3 in paper (>300 °C)
faults D1 in paper (tracking, arcing)
faults T3 in oil (>700 °C)

Less severe faults:

Faults PD/ D1 in oil (sparking)
Faults T1 in paper (<300 °C)
Faults T2 in oil (<700 °C)
Are difficult to find by inspection

A fault in paper is generally considered as more serious than a fault in oil because paper is often placed in a HV area (windings, barriers)

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IEEE Std. C57.104 2008 IEEE Guide for the Interpretation of Gases Generated in Oil Immersed Transformers

IEC 60599-1999 Mineral Oil Impregnated Electrical Equipment in Service: Guide to the Interpretation of Dissolved and Free Gas Analysis.

IEC 60599-1999, Amendment 1, 04/2007

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CO_2 vs. CO Ratio

This ratio may be used as an indicator of thermal decomposition of cellulose.

Levels should exceed minimum values for the ratio to be valid

CO ≥500 ppm

CO_2 ≥5,000 ppm

Best used as a complement to other diagnosis methods for a more accurate assessment

CO_2/CO Ratio	Thermal decomposition state
<3	Excessive
>7	Normal
<10	Normal
>10	Excessive

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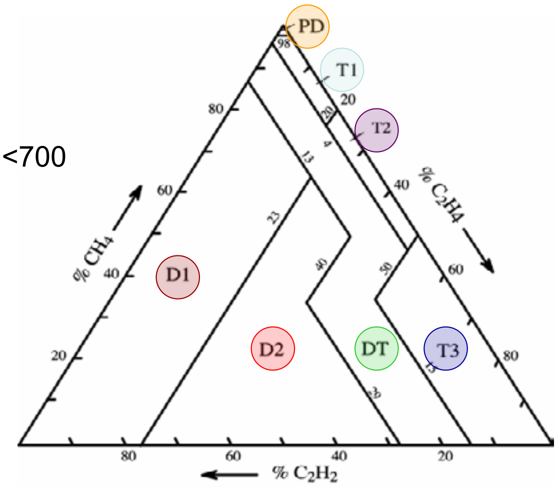
The Duval Triangle: (per IEC 60599 Guidelines)

PD = Partial Discharges
D1 = Discharges of low energy
D2 = Discharges of high energy

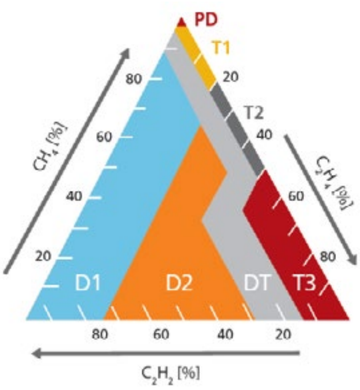
T1 = Thermal fault, < 300 °C
T2 = Thermal fault, >300 °C and <700 °C
T3 = Thermal fault, >700 °C

DT = Discharge or Thermal indeterminate zone

Gas percentages add to 100%
- 2 gases indicates problem
- 3[rd] gas confirms



Using the Triangle Method

DUVAL TRIANGLE (IEC 60599-2007-05)		
	**ZONE**	**FAULT INDICATION**
	T1	Thermal fault, ≤300 °C
	T2	Thermal fault, >300 °C, ≤700 °C
	T3	Thermal fault, >700 °C
	D1	Discharges of low-energy
	D2	Discharges of high-energy
	DT	Combination of thermal faults and discharges
	PD	Partial discharge

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Alternative Liquids

Gas to Liquid (GTL)

Synthetic Ester
Midel 7131
Beckfluid

Natural Ester

Silicon Fluid Basilone M50

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Gas to liquid (GTL) based inhibited transformer oil

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Inhibited GTL versus conventional inhibited oils oxidative stability

	Limits IEC 60296	IEC 60296 – sect 7.1 Higher oxid stab & low sulphur	Inhibited Shell Diala S3 ZX-I	Inhibited Shell Diala GTL
Oxidation Stability IEC 61125 C	164/500 hours	500 hours	500 hours	500 hours
Total acidity, mgKOH/g	**max 1.2**	**max 0.3**	**0.02**	**<0.01**
Sludge, weight %	**max 0.8**	**max 0.05**	**0.01**	**<0.01**
Dielectric dissipation factor (DDF) at 90 °C	**max 0.5**	**Max 0.05**	**0.009**	**<0.001**

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GtL inhibited Oils - Exceptional resistance to degradation

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Comparison of different liquids

Characteristics	Ester liquid	Silikon liquid	Mineral oil	PCB
Dielectric dissipation factor 25°C	**10**	**0,9**	**< 10**	**30**
Permitivity ε 23 °C, 50 Hz	**3.3**	**2.7**	**2.2**	**4.4**
Breakdown voltage IEC 60156 (kV)	**55**	**50**	**60**	**50**
Combustion point (°C) (ASTM D 92)	**310**	**>335**	**150-175**	**-**
Flash point (°C) (ASTM D 92)	**257**	**>300**	**135-145**	**200**
Combustion heat (kJ/kg 10^3)	**36.8**	**32.2**		**12.6**

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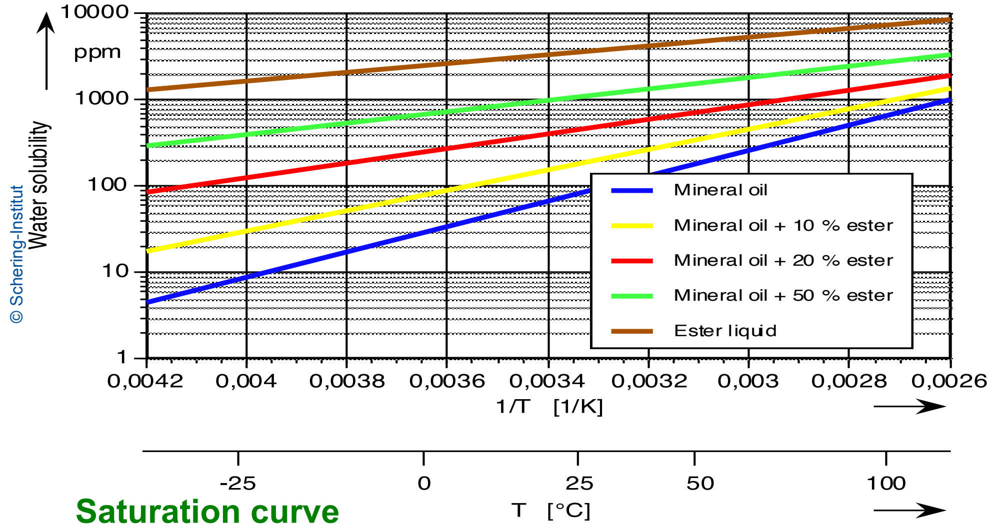
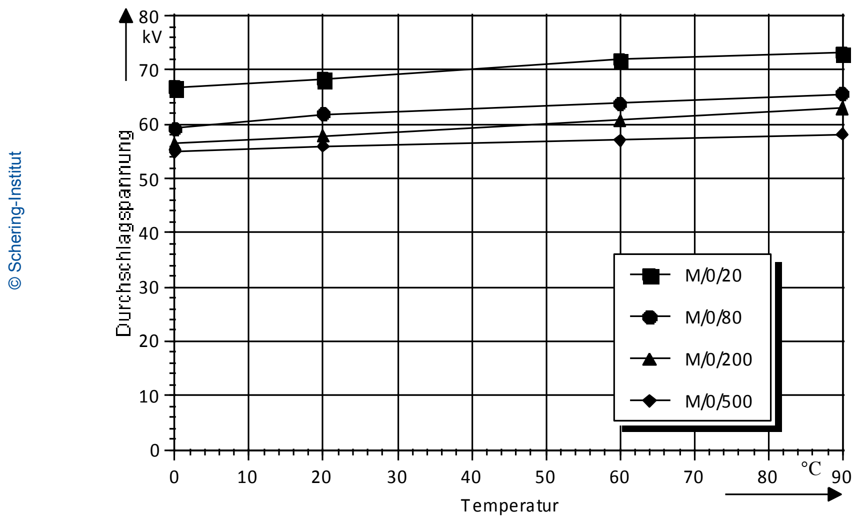
water in Midel 7131, in Mineral oil and mixture Midel/Mineral oil



Saturation curve

Breakdown voltage of new Midel 7131 versus the temperature at different water contents



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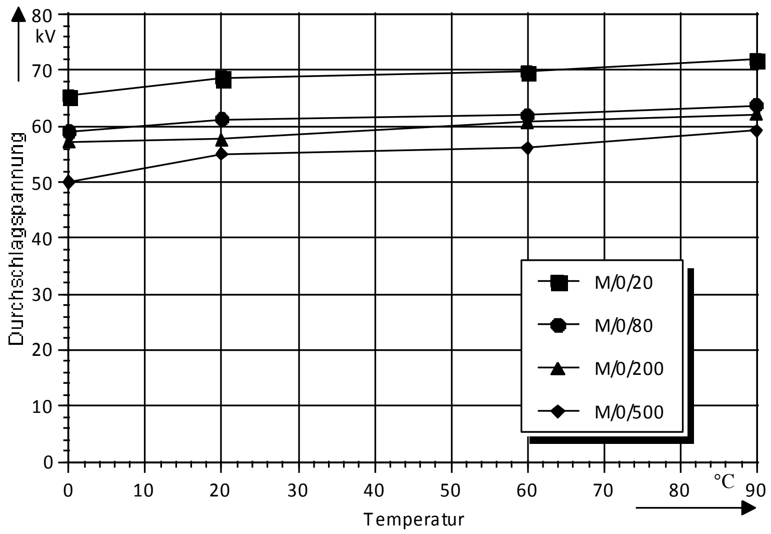
Breakdown voltage of aged Midel 7131 versus the temperature at different water contents



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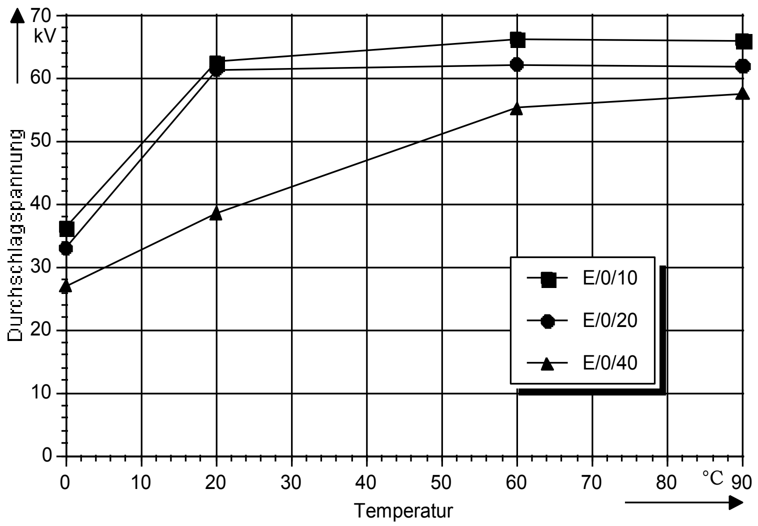
Breakdown voltage of new mineral oil versus the temperature at different water contents



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IfES Breakdown voltage of aged mineral oil versus the temperature at different water contents

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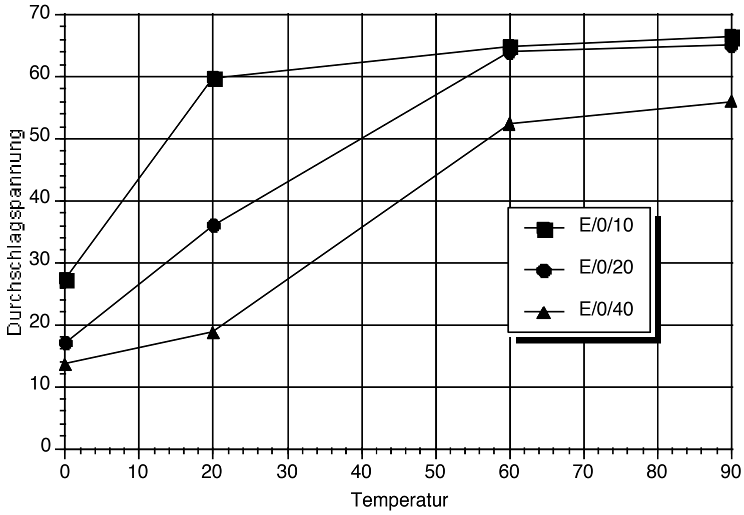

IfES Advantages of Esterfluid

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takes the heat aging water from the cellulose

keeps the cellulose dry and improves the cold start conditions

is extending the lifetime of the transformer

Fire point *Midel 7131* = 322°C, max. operating temperature 130°C

flash point mineral oil 160°C, max. operating temperature 105°C

Midel 7131 is selfextinguishing Not fire propagating

classified for less flammable liquid insulated transformers

according to NEC 450-23, 1996

less costs for safety equipment, fire walls, etc

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