Study Committee A2

Power Transformers and Reactors

Paper ID 11066

QUALIFICATION OF INSULATING LIQUIDS FOR POWER TRANSFORMERS AND TAP-CHANGERS

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Motivation

- Insulating liquids (for transformers, tap-changers, bushings, etc.) fulfil multifaceted requirements.
- Current standards for insulating liquids do not sufficiently define liquid performance parameters.
- Equipment manufacturers use individual test procedures and processes to approve an unknown liquid – which is inefficient.
- Many new liquids are launched as an alternative to conventional mineral insulating oils.
- Common understanding is needed how to make liquid performance comparable.
- Objectives:
  - Approval of a new unknown liquid with as less effort as possible.
  - Agreement on a comprehensive set of standardized test procedures.

Important Liquid Parameters and their Relevance for Transformers and Tap-Changers

Parameter	Transformer	De-Energized Tap-Changer (DETC)	On-Load Tap-Changer (OLTC) Tap selector	On-Load Tap-Changer (OLTC) Diverter switch non-vacuum type	On-Load Tap-Changer (OLTC) Diverter switch vacuum type
Electrical Insulation	■■	■■	■■	■■	■■
Cooling	■■	■■	■■	■■	■■
Material Compatibility	■■	■■	■■	■■	■■
Oxidation Stability	■				■
HOT	■				■
Gassing Behaviour	■	■	■		■
Arc-quenching Capability			■	■■	■
Viscosity	■			■■	■■
Lubricating Capability		■	■■	■■	■■

■ important ■■ very important

Liquids & Standards

- Mineral oil from petroleum products (IEC60296)
- GTL oils (IEC 60296)
- Other hydrocarbons (IEC 60296)
- Natural esters (IEC 62770)
- Synthetic organic esters (IEC 61099)
- Synthetic aromatic hydrocarbons (IEC 60867)
- Modified or blended esters (IEC 63012)
- Silicone oils (IEC 60836)

Method/Approach

- Analyze current standards
- Harmonize test strategies by developing generally accepted methods;
  - easy to apply
  - with potential to be standardized
- Develop expedient test arrangements
- Agree on a reasonable test program
- Install an efficient process how to evaluate new liquids.

Discussion on Standards

- **What is covered by current standards ?**

Status Quo

Parameter	Value defined in Standard	Impact on / Evaluation of
Viscosity [mm²/s]	Max	• Cooling Efficiency
Pour Point [°C]	Max	
Density [kg/m³]	Max	
Water Content [mg/kg]	Max	• Dielectric Strength and Losses • Purity and Ageing Condition of Liquid
Breakdown Voltage [kV]	Min	
Dissipation Factor []	Max	

Status Quo ist not sufficient for designing transformers with higher demands, or when using ester or silicone liquids.

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Discussion on Standards (cont'd)

1. **Which parameters are missing ?**
   - **for Transformers**
   - **for Tap-Changers**
2. **How can these parameters be tested ?**

1

Parameters missing – Transformers

Parameter	Value to be defined	Impact on / Evaluation of
Acceleration Voltage [kV]	Min	Streamer Breakdown Behaviour
Material Compatibility Index [%]	Max	Aggressivity of Liquid

With aid of new IEC 63177, a Material Compatibility Index can be developed.

Parameters missing – Tap-Changers

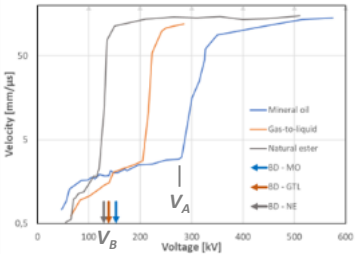
Parameter	Value to be defined	Impact on / Evaluation of
Viscosity [mm²/s]	Max **& Min**	Lubricating Capability of Liquid
Friction Force / Mechanical Wear	Max	
„Cold-and-Hold" Behaviour [%]	Max	Cold Start Capability
Arc-Breaking Capability	Min	Switching Capacity
Density [kg/m³]	Max **& Min**	Accuracy/Function of • Buchholz relay • Oil level indicator

For the time being, no acknowledged method exists to determine Arc-Breaking Capability.

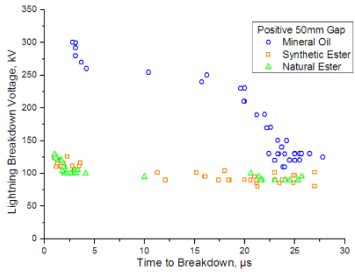
2

Acceleration Voltage V_A vs. LI Breakdown Voltage V_B

V_A: the voltages at which streamers start to propagate faster



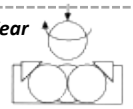
2 (cont'd)

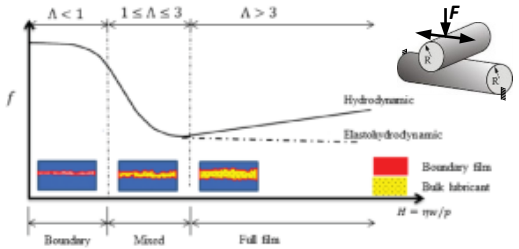


V-t curves are helpful to evaluate the LI breakdown behaviour of new liquids.

Viscosity AND Friction Force / Mechanical Wear

- ***Low contact resistance and good fluid film lubrication are conflictive requirements***
- ***"4-Ball-Wear Test" represents long-time contact wear***

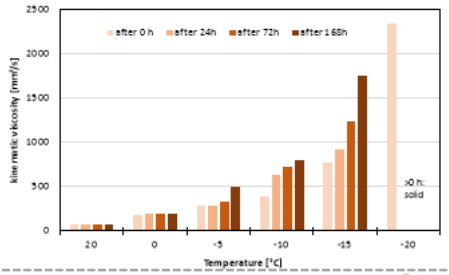




If viscosity is too low, sliding behaviour of contacts is impaired. Switching sequence may be disturbed.

Cold-and Hold Behaviour

Viscosity of natural esters increases after longer standing times



Density

- ***Max & Min limits are necessary to ensure proper function of floats (buoyancy).***
- ***Low liquid density increases sensitivity of oil-flow relay.***

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Test Method for the Evaluation of Dielectric Behaviour of new Liquids

Proposed tests

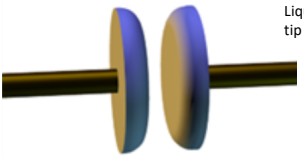
- Lightning impulse withstand voltage test, full wave (LI FW): 1.2 µs / 50 µs
- Lightning impulse withstand voltage test with solid insulation, full wave: 1.2 µs / 50 µs
- Lightning impulse withstand voltage test, chopped wave (LI CW): 1.2 µs / (2 – 6) µs
- Switching impulse withstand voltage test, full wave (SI FW): 250 µs / 2500 µs
- Switching impulse withstand voltage test with solid insulation, full wave: 250 µs / 2500 µs
- AC withstand voltage test, procedure according to IEC 60060-1 1 Min / 45-65Hz

Proposed liquid conditions during tests

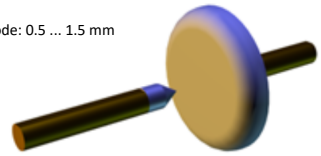
- Moisture content: ≤5 % r.H. (<10 ppm) for mineral oil,
  ≥5 to ≤15 % r.H. for alternative liquids
- Permissible particle contamination as given in IEC 60422 for factory acceptance test and transformer commissioning
- Liquid temperature: 20 … 25 °C), ± 5 K

Proposed test arrangements

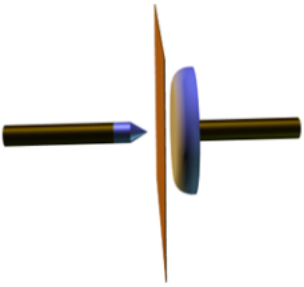
Liquid gap: 5 … 30 mm,
tip radius of point electrode: 0.5 ... 1.5 mm



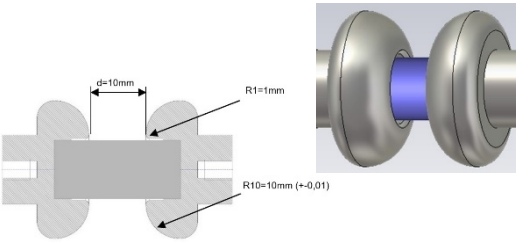
a) homogeneous test arrangement with coplanar electrodes



b) inhomogeneous test arrangement with point-plate electrodes

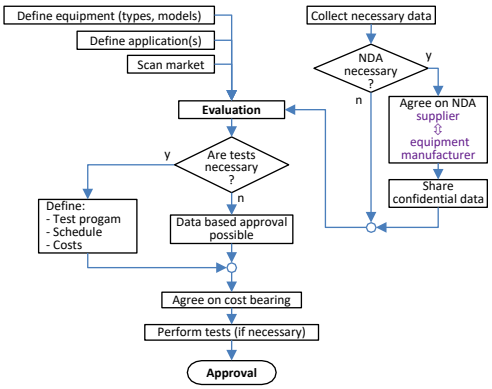


c) point-plate arrangement with barrier, 2x d/2



d) arrangement with longitudinal solid/liquid interface and oil wedges (overall field factor $\eta = 0.56$)

Approval Process for new Liquids



Conclusion

- Electrical equipment has been designed and optimized for mineral oil.
- Today's standards only define quality parameters of the liquid, but not its performance.
- Individual test procedures of equipment manufacturers lead to ambiguous evaluations.
- New liquids show deviant behaviour (compared to mineral oil) – which calls for thorough testing.
- Common understanding between liquid manufacturers, equipment manufacturers and users/operators is necessary to achieve common judgement on new liquids and to simplify the approval process.
- Discussion in Cigre should take place and the respective standards should be revised to cover all relevant properties, so that liquid manufacturers can develop liquids which allow an unrestricted and reliable operation of the equipment.