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Alternative Insulating Liquid Prospects

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What prospects are there for development of new insulation liquids with improved properties compared with existing liquids?

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Alternative Insulating Liquid Opportunities

- **Transformer design trade-off**
  - Optimised to a certain liquid's properties, *or*
  - Benefits of mass standardisation and forward compatibility of transformer and component designs.
- **Dielectric Design Suitability a major aspect**
  - A recent CIGRE TB 856 concerning the dielectric performance of insulating liquids
  - Immense design data which is based on (aromatic containing) mineral insulating oils
  - As outlined in there is a great need for more standardised dielectric screening and liquid "approval" processes IEC TR 60076-26 .
  - Possible approach: screen and categorize new insulating liquid types by their chemistry
  - Dielectric screening tests only if certain key aspects differ.
- **Component and OLTC approval** also a major challenge for new insulating liquid types.

Liquid Type	Main Advantages	Main Disadvantages
Traditional naphthenic mineral insulating oils	• Track Record • Component and Design approvals • Dielectric Properties • Cost-to-Performance ratio	• Crude oil based • Not usually readily Biodegradable • Standard flash point
Re-refined naphthenic mineral insulating oils	• Same Dielectric properties to the original oil • Sustainable (Circularity) • Re refining processes lead to improved quality compared to clay treatment (reclaimed oils)	• Not usually readily Biodegradable • Standard flash point
Gas-to-liquid (and similar highly refined or synthetic oils)	• IEC 60296 compatible • Sulphur Free	• Absence of aromatics leads to some dielectric differences • Component and design approvals generally required • Not usually readily Biodegradable • Standard flash point
Bio-Based Hydrocarbon (Low Viscosity)	• IEC 60296 compatible • Sustainable (Fully Bio-Based, residues) • Readily Biodegradable • Low viscosity, thermal design optimisation potential • Closer Dielectric behaviour to mineral oil than esters	• Absence of aromatics leads to some dielectric differences • Component and design approvals generally required • Standard flash point
Natural Esters	• Sustainable (Bio-based, but food crop competition should be considered) • Readily Biodegradable • High flash point • High temperature design option (*Disputed*) [1]	• Major dielectric and thermal design changes generally needed • Many variations between seed crops • Oxidation Stability and stray gassing draw backs • Component and design approvals generally required
Synthetic Esters	• Readily Biodegradable • High flash point • Better oxidation stability than natural esters • High temperature design option (*Disputed*) [1]	• Major dielectric and thermal design changes generally needed • Not fully bio-based • Component and design approvals generally required

[1] The direct transformer design relevance of reported paper ageing benefit aspects of esters at high temperature are somewhat under dispute. To be of use in transformer designs depends on trade-offs between liquid lifetime, stray gassing, short circuit design and no-load and load-loss capitalization considerations.

Thermal Optimization opportunity of low viscosity liquid

- Low viscosity liquids offer a great potential for thermal design optimisation of transformers, but they require either a dedicated transformer design or a dual name plate approach so the end user can take advantage of the improved cooling.

Rating	Ref. Liquid	Top Oil Temp. With BIO	Hot Spot with BIO	Ref.
40 MVA 145/11.1 kV K/O FAF	Syn. Ester	≈ -12 K	≈ -8 K	[1]
80 MVA 115/21 kV ONAF	“GTL”	≈ -4 K	≈ -6 K	[2]

[1] C. Wolmarans, T. Feischl, I. Radic, and V. Maljkovic, "Factory Acceptance Test of a 40 MVA power transformer filled with a bio-based & biodegradable hydrocarbon insulating liquid," presented at the Accepted in 41st CIGRE International Symposium Ljubljana, 1-4 June 2021, 2021.

[2] C. Wolmarans, A. Gamil, A. Al-Abadi, M. Milone, J. Jordaan, and R. Hellberg, "Type Testing of 80 MVA Power Transformer with a new Bio-based, Biodegradable and Low Viscosity Insulating Liquid," presented at the CIGRE Session 2022, Paris, 2022.