SC A2 POWER TRANSFORMERS AND REACTORS

PS2 - Beyond the Mineral Oil-Immersed Transformer and Reactors

Paper A2 10772_2022

SUPPORTING DEVELOPMENT OF TRANSFORMERS WITH NATURAL ESTERS BY COMPREHENSIVE EVALUATION OF INSULATION SYSTEMS

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Motivation

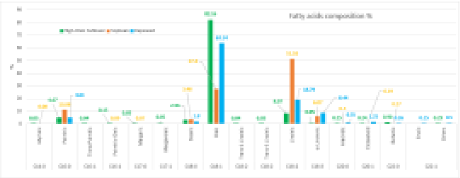
The use of high-oleic sunflower natural esters coupled with solid insulating materials of higher performance (like aramid insulation) provides the best solution for more flexible and resilient transformers. The continuous improvements in formulations of new esters and careful evaluations of new liquids in new transformer applications result in a wider acceptance of ester liquids in power transformers. After successful pilot projects for transformers up to 300 MV and 400 kV, transmission system operators or other users of power transformers have considered specifications with broader use of natural esters.

Approach

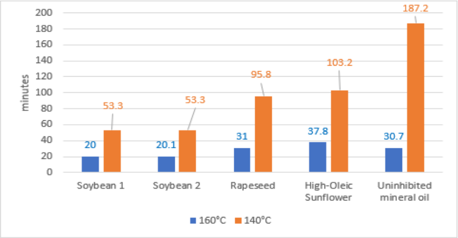
1. This publication provides selected physical-chemical characteristics of a high-oleic sunflower natural ester available for power transformers. Proper material characterization is critical for reliable long-term performance of transformers with higher power and voltage ratings.
2. An important part of insulation material characterization is its thermal performance evaluation when used together with different materials, which supports developing adequate design rules for the specific insulation system. This publication presents thorough evaluation of insulation system thermal properties following the established and standardized test method as per IEEE Std. C57.100-2011. Additionally, the results have been validated and certified by a 3rd party certification company to ensure the highest quality of the generated test data.

Detailed physical-chemical characteristics

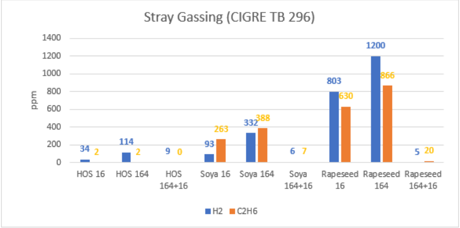
Fatty acid composition (%) of new high-oleic sunflower natural ester:



Oxidation stability by Rapid-Oxy 100 tests at 140°C and 160°C:



Hydrogen (H_2) and ethane (C_2H_6) generated during the stray gassing tests at 120°C:



3rd party certified insulation system

- Insulation system consisting of selected paper and natural ester evaluated following industry standard IEEE C57.100-2011.
- The testing was conducted at the solid insulation manufacturer's laboratory. Around 2 years' worth of equipment preparation and test setup, aging, and evaluation involving a span of aging times and temperatures to ensure generation of quality data.
- All equipment, procedures, and personnel followed the 3rd party witness testing program with three witness testing sessions completed over the course of this test program.
- Multiple curve fitting techniques and analysis models were applied to the generated data with the result of a 130°C thermal class as per IEEE C57.100-2011.
- The 3rd party analyzed the test data and post process calculations and provided certification. This system is now listed in the 3rd party on-line database as "Nomex® + Ester 130".
- This system is the first certified Electrical Insulation System (EIS) for liquid filled transformers.

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Thermal evaluation of insulation system

Thermal evaluation method

This test program was based on IEEE Std. C57.100-2011 "IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Liquid Immersed Power and Distribution Transformers"; Annex B "Materials testing – standard test procedure for sealed tube aging of liquid-immersed transformer insulation".

The intent was to define the thermal rating of an insulation system consisting of thermally upgraded cellulose paper enhanced with aramid with the new high-oleic sunflower natural ester.

Reference insulation system

- Insulating liquid – mineral naphthenic oil Univolt N 61B by Mobil – 2000 ml
- Layer insulation – 0.127 mm thick TUK paper by Weidmann – 112 cm^3
- Low density pressboard – representative pressboard by Weidmann – 12 cm^3
- Copper foil – 1 032 cm^2
- Core steel – 516 cm^2

Aging time for refence insulation system for establishing end-of-life aging criteria:

- 150°C for 4434 hours
- 165°C for 1316 hours
- 180°C for 424 hours

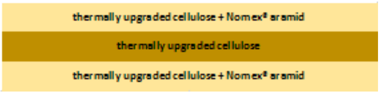
The tested end-of-life criteria for representative commercially available paper resulted in an average of 29.6% of remaining tensile strength of the paper (reference condition for 180 000 h, i.e. approx. 20 years). This end-of-life criterion was then used as the target end-of-life for the new candidate insulation system.

Example of materials loaded into the aging cells

Candidate insulation system

For evaluation of the candidate system, the list of materials loaded to the aging cells was the same as in the reference system except the fluid and insulating paper:

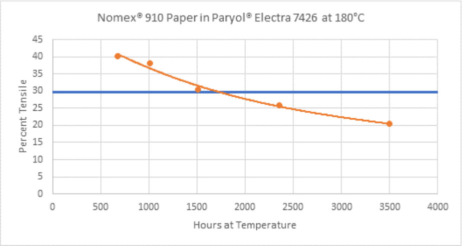
- Natural ester based on high-oleic sunflower – Paryol Electra 7426 by A. A. Fratelli Parodi – 2000 ml
- Layer insulation – 0.127 mm thick aramid enhanced cellulose paper DuPont™ Nomex® 910 – 112 cm^3



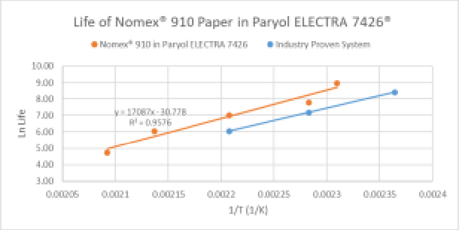
Simplified structure (cross-section) of aramid enhanced thermally upgraded cellulose paper

Results – temperature index analysis

Tensile retention curve of the tested insulation system at 180°C:



Thermal performance life curve of the tested insulation system compared with the industry proven reference system:



The life curve of candidate system was projected to reference lifetime of 180 000 hours to arrive at the temperature index of the evaluated candidate insulation system. The curve projected to a temperature index of **125.5°C**, resulting in a **thermal class of 130**.

$$LIFE = EXP^{\left[\frac{17087}{T+273} - 30.778\right]}$$

where:

- LIFE is the life in hours,
- T is the aging temperature in °C.

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Discussion on thermal evaluation results

- The obtained temperature index for the evaluated insulation system shows improvement of the thermal performance of the tested paper as compared to the historical aging test data with mineral oil.
- The natural ester enhanced the insulation thermal performance by reducing the degradation effects of the paper, consequently increasing the temperature index by about 5°C.
- The improvement in thermal performance may be different for different insulation types, e.g., for Kraft papers or thermally upgraded Kraft papers, as well as for other natural ester liquids derived from other seeds than high-oleic sunflower.
- In order to better understand the performance of other insulation systems, more thermal evaluations are planned for alternative systems with different solid materials and ester liquids combinations.
- One expanded test program is currently in progress: dual-temperature sealed tube testing per IEEE C57.100-2011. This test procedure allows for independent control of the hottest spot temperature of conductor insulation from the top oil temperature of the insulation system.

Example of dual temperature test cell that allows for independent control of conductor temperature and oil temperature. In the bottom, laboratory setup with dual temperature aging cells running.

Conclusion

- Providing properly developed material characterization is critical for reliable long-term performance of power transformers.
- Selected detailed characteristics of a new natural ester liquid available for power transformers have been provided.
- Thorough evaluation of insulation system thermal performance have been done and presented. It may support developing adequate design rules for transformers using that specific insulation system.
- The 3rd party analyzed the test data and post process calculations and provided certification. This system is the first certified Electrical Insulation System (EIS) for liquid filled transformers.