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Q2.5 There seem to be conflicting opinions concerning the use of some alternative transformer technologies at higher temperatures, especially ester-immersed transformers. What is the experience of using alternative transformer technologies at higher temperatures? What further work is needed on this subject?

# Bubble generation temperature evaluation of ester-immersed transformer windings

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Summary

- Transformers using vegetable oils (esters) are applied for renewable energy such as solar power and wind power to achieve carbon neutrality, and the oil deterioration prevention structure may be a nitrogen-sealed type, not a conservator type.
- If the oil deterioration prevention structure is a nitrogen-sealed type then caution might be necessary because the bubble generation temperature is lower than in the case of a conservator type, in using esters in high temperature designs, as in the case of a mineral oil.

## 1. Introduction

Synthetic esters, natural esters (vegetable oils), and more recently modified esters derived from vegetable oils have all been developed as alternatives to mineral oil. In particular, vegetable oils have contributed to reducing carbon dioxide emissions.
Transformers using vegetable oils (esters) are applied for renewable energy such as solar power and wind power to achieve carbon neutrality, and the oil deterioration prevention structure may be a nitrogen-sealed type, not a conservator type.
Some caution might be necessary in using esters in high temperature designs, as in the case of mineral oil.
The risks of a transformer due to overloading can be classified into two categories: (a) reduced mechanical strength of the insulation paper in the transformer winding due to accelerated thermal aging and (b) reduced insulation property due to bubble generation caused by heat produced in the transformer winding.
In general, the bubble generation temperature in ester-immersed transformer windings is higher than that in mineral oil-immersed transformer windings.

## 2. Bubble generation temperature

The bubble generation characteristics of two esters (FR3 and Pastell NEO, see Table 1) with almost the same saturated water content and different kinematic viscosities were investigated using a winding model simulating the steep overload of a transformer.
Figures 1–4 illustrate the experimental system, procedure, and winding model. Fig. 5 and 6 shows the bubble generation in winding model and experimental results, respectively.
As a result, experiments using both conservator and nitrogen-sealed type winding models to simulate the oil deterioration prevention structure showed that with similar water content in the insulation paper, the bubble generation temperature was higher with conservator than with nitrogen-sealed type.

## 3. Couclusion

If the oil deterioration prevention structure is a nitrogen-sealed type then caution might be necessary because the bubble generation temperature is lower than in the case of a conservator type, in using esters in high temperature designs, as in the case of a mineral oil.

Table 1. Principal properties of insulating oils.

| Property | Mineral oil | FR3 | Pastell NEO |
|---|---|---|---|
| Density at 20 °C (kg/m$^3$) | 880 | 920 | 860 |
| Viscosity at 40 °C (mm$^2$/s) | 8.8 | 32 | 5.1 |
| Water solubility at 25 °C (ppm) | 70 | 1100 | 1000 |
| Solubility of $N_2$ at 90 °C (vol %) | 10.3 | 9.3 | --- |
| Surface tension (N/m) | 0.030 | 0.024 | --- |

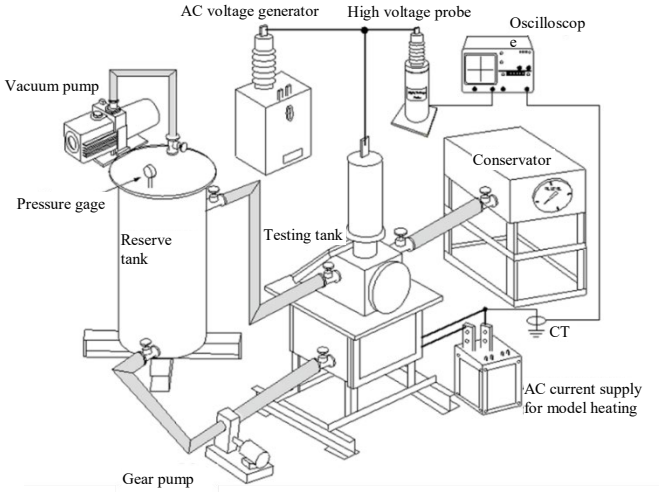


Figure 2. Outline of experimental system.

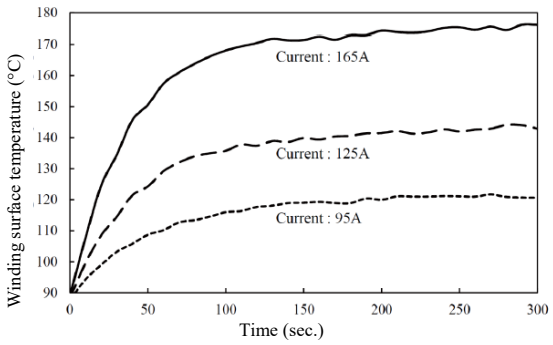


Figure 4. Time characteristics of winding surface temperature in FR3.

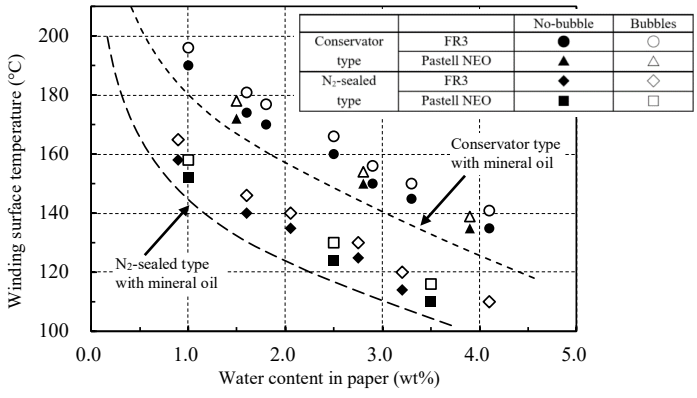


Figure 6. Comparison of esters to mineral oil results.

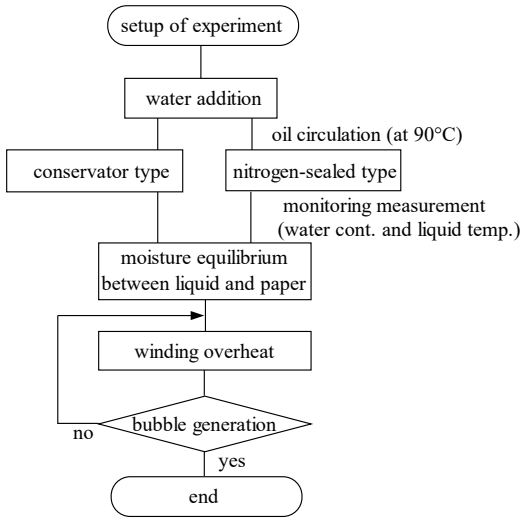


Figure 1. Overview flowchart of experimental procedure.

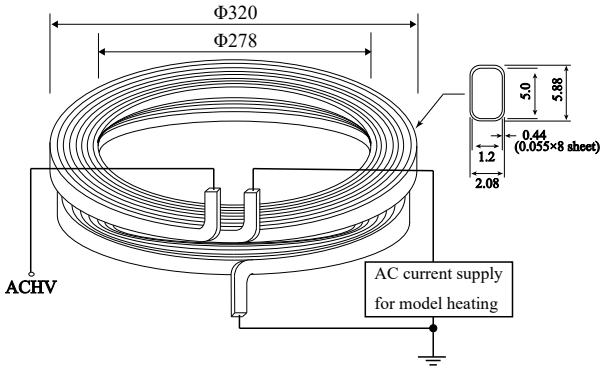


Figure 3. Winding model for bubble generation.

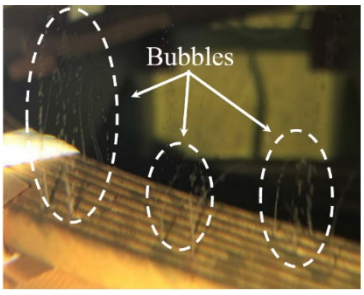


Figure 5. Bubble generation in winding model

FR3 is a registered trademark of Cargill, Incorporated.
Pastell NEO is a registered trademark of Lion Specialty Chemicals Co., Ltd.