Establishment of the Reference Value of Methanol for Diagnosing Transformer Insulating Paper Ageing

Oil And Coal Testing Section：Lee, Li-Chi; Lee, An-Ping; Tung, Yao-Tsung

1. Background

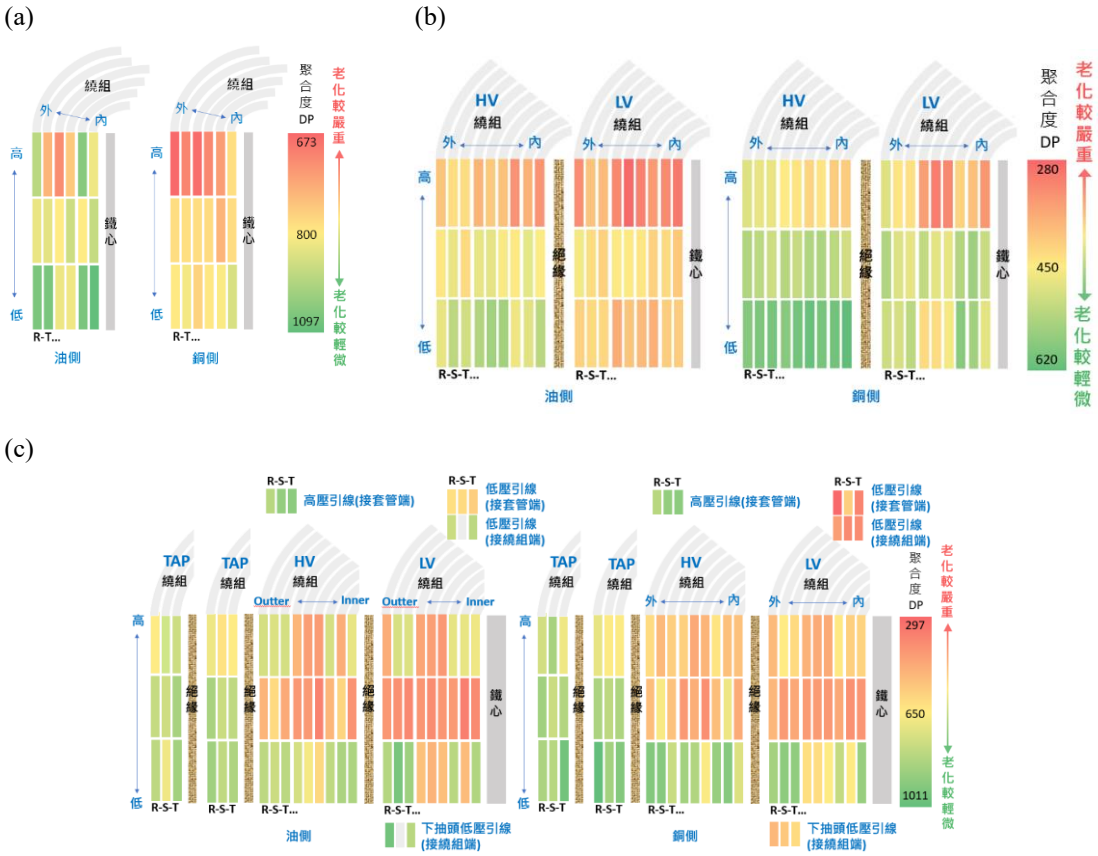
For many years, Taipower Company has used "furfural" in transformer oil as an ageing indicator for insulating paper. International research reports show that using furfural as an ageing indicator for traditional Kraft paper (suitable for transformers with a temperature rise limit of 55°C) is more reliable. Still, the chemical stabilizers added to the material affect the test results for thermally upgraded Kraft paper (TUK, suitable for transformers with a temperature rise limit of 65°C). The new indicator "methanol" (or “MeOH”) has good and consistent test results for different types of insulating paper. The testing standard was announced in 2020 by The American Society for Testing and Materials [1], and International Council on Large Electric Systems (CIGRE) has also included the methanol diagnostic insulating paper ageing formula into the transformer ageing diagnosis technical brochure [2]. Taipower Company’s newly purchased power transformers are tested with thermally upgraded insulating papers. To improve diagnostic technology, TPRI joins the “Investigation of the application of methanol as a new marker for cellulose degradation in oil-impregnated power transformers” international cooperative research and development team of the Japanese Electric Power Information Exchange Organization (IERE) and continues to develop, validate and introduce methanol in oil testing and diagnostic technology.

2. Research Contents

Carbon dioxide, furfural, and methanol concentrations in insulating oil are indirect indicators for evaluating the ageing degree of insulating paper. The correlation between these indirect indicators and the ageing degree of insulating paper is a mathematical model established by simulation tests. However, in the ageing process of a real transformer, the ageing degree of insulating paper in different parts will be significantly different due to exposure to different operating conditions. Therefore, whether the ageing index can accurately reflect the ageing degree of the actual insulating paper needs to be verified by disassembling the transformer to obtain insulating paper.

To achieve the above purpose, TPRI dismantled several repaired or decommissioned transformers and obtained insulating paper samples from different parts according to the plan to conduct polymerization tests. After data analysis, three typical ageing patterns can be summarized for Taipower Company's transformers: “high lead temperature-dominated thermal ageing,” “acid-catalyzed hydrolysis-dominated ageing,” and “local area oil temperature-dominated thermal ageing.” “High lead temperature dominated thermal ageing” equipment has higher oil and lead temperatures than ordinary transformers during operation. The ageing of insulating paper is most serious on the “copper side” of the upper conductors of the transformer (Figure 1(a)). During the ageing process, excessive carbon dioxide in the oil will usually occur first. The growth of furfural and methanol will begin, and moisture management problems will occur in the later stages of ageing. “Acid-catalyzed hydrolysis-dominated ageing” equipment insulating oil usually has problems with

moisture, acid value and interfacial tension, as well as high furfural and methanol. The ageing condition of the insulating paper is the most serious on the "oil side" of the upper conductor on the "low voltage side" of the transformer (Figure 1(b)). In the "local area oil temperature dominant type thermal ageing" equipment, the insulating paper at the "middle height" of the transformer winding has the most serious ageing condition, which reflects that it cannot efficiently guide the insulating oil through the oil channel to the upper part of the winding for heat dissipation, causing heat stored inside the winding in the middle section (Figure 1(c)).



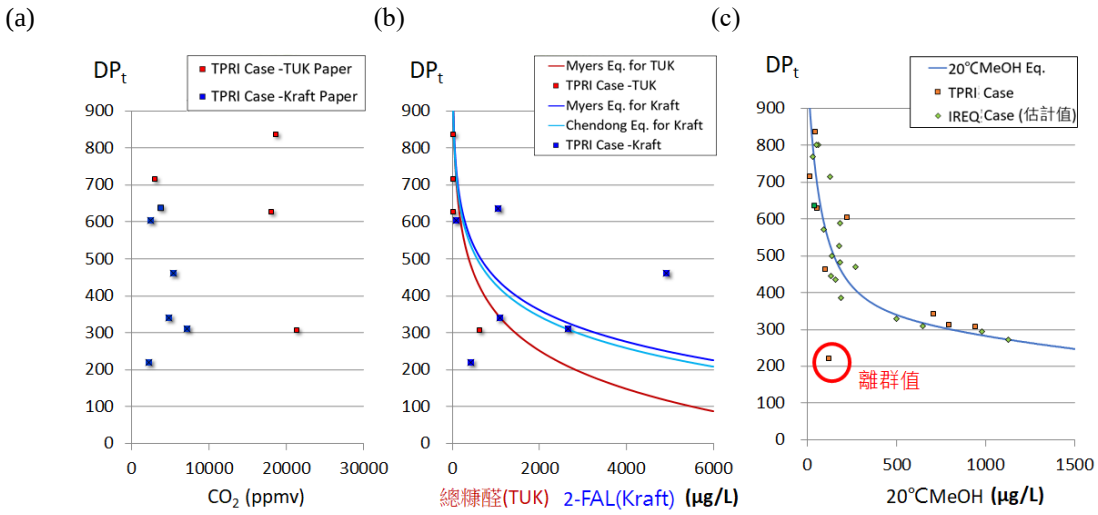
Data source: Drawn by TPRI

Figure 1 Disassemble the transformer to verify the aggregation degree distribution

(a) high lead temperature-dominated thermal ageing; (b) acid-catalyzed hydrolysis-dominated ageing; (c) local area oil temperature-dominated thermal ageing

After dismantling ten transformers, the average value of the insulating paper ageing test results was plotted against the ageing chemical indicator concentration and compared with the international mathematical model. It can be found that although carbon dioxide is an ageing index, its concentration cannot directly reflect the ageing degree of insulating paper (Figure 2(a)). Although mathematical models corresponding to Kraft paper and TUK paper have been established internationally for furfural, the relationship between furfural concentration and DP was found to be underestimation or overestimation in many cases (Figure 2(b)). The formula for calculating the degree of polymerization of insulating paper with methanol, whether in the dismantling transformer verification activities of Quebec Electric Company or

Taipower Company, shows that it is good for evaluating the ageing degree of insulating paper (Figure 2(c)). Among the three insulating paper ageing indicators used by Taipower, the methanol indicator shows the best accuracy and has nothing to do with the type of insulating paper. It can avoid the burden of identifying the type of insulating paper when using it. Currently, TPRI has introduced methanol as a normal test item for Taipower's transformers and has established relevant diagnostic standards, as shown in Table 1.



Data source: Drawn by TPRI (Myers, Chendong Eq IREQ Case reference: [3][4][5])

Figure 2 Verification of mathematical model of disassembled transformer [3][4][5]

Table 1 Insulating paper condition evaluation reference index concentration table [6]

Paper Condition	DP Value	Furfural (μg/L Oil)		20°C Methanol (μg/kgOil)
		Kraft Paper	TUK Paper	
		2-FAL	Total furan	
Healthy	≧600	≦300	≦200	≦100
Moderate Deterioration	<600，≧350	＞300，≦2000	＞200，≦1000	>100，≦400
Extensive Deterioration	<350	＞2000	＞1000	>400

3. References

[1] "Standard Test Method for Determination of Methanol and Ethanol in Electrical Insulating Liquids of Petroleum Origin by Headspace (HS)-Gas Chromatography (GC) Using Mass Spectrometry (MS) or Flame Ionization Detection (FID)1," ASTM D8086, 2020

[2] "Field Experience with Transformer Solid Insulation Ageing Markers," CIGRE Technical Brochure 779, 2019.

[3] R. D. Stebbins, D. S. Myers, and A. B. Shkolnik, "Furanic Compounds in Dielectric Liquid Samples: Review and Update of Diagnostic Interpretation and Estimation of Insulation Ageing," Proceedings of the 7th International Conference on Properties and Applications of Dielectric Materials, Nagoya, Japan, 2003.

[4] C. D. Xue, “Monitoring paper insulation ageing by measuring furfural contents in oil,” in 7th International Symposium on High Voltage Engineering, 1991, pp.139–142.

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[6] Taipower Research Institute, “Power Transformer/Reactor Fault: Furfural and Methanol Diagnostic Indicator,” Edition 2, 2023.