Detection of Inhibitor Content in Transformer Oil at Wavelengths below 1000 nm

Vimal Angela Thiviyanathan, Pin Jern Ker*, Yang Sing Leong, Nur Afini Fauzi, M. Z. Jamaludin,
Institute of Power Engineering
Universiti Tenaga Nasional
Jalan IKRAM-UNITEN
43000 Kajang, Selangor
*pinjern@uniten.edu.my

H. M. Looe, C. K. Lo
TNB Research Sdn. Bhd.
Jalan Ayer Itam
43000 Kajang, Selangor

***Abstract*—Power transformers are significant in the power transmission and distribution network. A continuous monitoring of the transformer is crucial in ensuring a longer life spend service of the transformer. This paper focuses on the characterization of transformer oil using optical detection method at wavelengths below 1000 nm, which can be detected using Silicon photodetector. Transformer oil samples with 5 different concentrations of inhibitor content were prepared for the optical characterization from 950 nm to 970 nm. The results of the experiment show an excellent correlation between the concentration of inhibitor content in the oil and the magnitude of the peak absorbance at the 959 nm wavelength. This approach can potentially lead to the development of low cost and portable device that can measure the concentration of inhibitor of the transformer oil.**

Keywords—main transformer tank, inhibitor content, spectrophotometer, transformer oil aging

I. Introduction

Power transformers are very important in the transmission and distribution network. The main function of a transformer is to transfer power from one magnitude of voltage to another before exporting the power to end users [1]. A transformer failure can be catastrophic. Thus, maintaining the conditions of the transformer to ensure a prolonged life spend is crucial.

One of the most important sections of the transformer is the insulation system. The insulation system consists of two major parts, namely, solid and liquid. Solid insulation is made up of kraft papers while the liquid insulation, also known as transformer oil, is made up of processed crude oil. Apart from regulating the temperature of the transformer by transferring heat away from the coils, transformer oil also maintains the electrical properties of the electrical coil [2].

Being a mixture of aromatic, naphthenic and paraffinic compounds, transformer oil is very susceptible to oxidation which progresses through a free radical reaction whereby copper and oxygen act as a catalyst in the reaction [3]. This reaction results in the generation of polar compounds such as ketones, aldehydes and hydroperoxides which affects the properties of the transformer oil [4]. Apart from that, the acidic compounds also deteriorates the tensile strength of the kraft paper [5].

To slow down the process of oxidation, transformer oil is added with antioxidants. These antioxidants trap the free radicals and stops the action of copper [3]. The most commonly used antioxidant is 2,6-ditertiarybutyl-para-cresol (DBPC) [2]. DBPC is widely accepted due to its advanced properties in inhibiting oxidation as compared to other inhibitors such as 1,2,3-Benzotriazol (BTA), 2,6-ditertiarybutyl phenol (DBP) and 2-tert-butyl-p-cresol (2-t-BPC) [6]. DBPC specifically inhibits the radical propagation mechanism during initiation step in the oxidation of oil. The inhibition of DBPC can be seen in Fig. 1.

Initiation

RH $\rightarrow$ R* + H

Propagation

R* + O_2 $\rightarrow$ ROO*

ROO* + RH $\rightarrow$ ROOH + R*

ROOH $\rightarrow$ RO* + OH*

RO* + RH $\rightarrow$ ROH + ROO*

OH* + RH $\rightarrow$ H_2O + ROO*

Termination

ROO* + ROO* $\rightarrow$ (Oxidation by-products)

Inhibition of DBPC

ROO* + DBPC $\rightarrow$ ROOH + DBPC*

DBPC* $\rightarrow$ (stable by product)

Fig. 1. Inhibition of DBPC.

Apart from inhibiting the oxidation of oil, antioxidant also provides information of the condition of the transformer oil. A decreasing concentration of inhibitor content indicates an increasing trend of oxidation reaction in the oil. Therefore, monitoring the concentration of inhibitor content in the oil can ensure a prolonged lifespan of the transformer.

The conventional method of detecting inhibitor content in transformer oil is by using the Fourier-transform infrared (FTIR) spectroscopy method based on the ASTM D 2668 and IEC 60666 standards [7, 8]. Although accurate, but this technique is very tedious and expensive. The procedures include, sampling the oil from site, transporting the samples to the laboratory and running the samples. Apart from the additional cost are also incurred for the regular maintenance of the transformer.

Across the years, many researchers have studied many methods of detecting the inhibitor content in the transformer oil as an effort to overcome the limitation of the conventional method. These methods includes electrochemical techniques [9], liquid chromatography, and gas chromatography-mass spectrometry [10, 11]. However, these methods have some disadvantages. Electrochemical techniques are confined to detecting DBPC. Gas chromatography and liquid chromatography, on the other hand, requires a complex system of

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operation and experts to analyze the results. Thus, human error is prone to happen.

Ammawath et al. [12] detected the presence of DBPC in palm oil using FTIR. The result of the experiment demonstrated a dominant peak at 2757.10 nm which reflected the hydroxyl (OH) groups in the compound Similar results were obtained by Percherancier et al. who reported that the phenolic OH stretch of DBPC can be observed at the 2739.73 nm [7]. This method was then adopted by the ASTM D2668 and IEC60666 standards. Recently, using optical spectroscopy method, Leong et.al [2, 13], reported that DBPC in transformer oil can be observed in the 1403 nm region. The spectroscopy technique used can overcome the limitation of the currently available methods. This is because this method is simple, cheaper as well as eliminates the occurrence of error. However, although being in the telecommunication waveband, the light source may be slightly expensive. Thus, the research gap focused in this experiment is to detect the presence of inhibitor content at the IR region (960 nm).

II. EXPERIMENTAL DETAILS & RESULTS

Transformer oil samples were prepared with five different concentrations of inhibitor (DBPC). These samples include transformer oil with no inhibitor, 0.5%, 1%, 3% and 5% of inhibitor. The concentration of DBPC dissolved is calculated based on equation (1).

$$\text{Concentration of DBPC} = M_{DBPC} / (M_{DBPC} + M_{Tranformer\ Oil}) \quad (1)$$

Where, M_{DBPC} is the mass of DBPC inhibitor and $M_{Transformer\ Oil}$ is the mass of transformer oil.

The oil was slightly heated to speed up the rate of dissolving. The samples were then stored in an amber bottle for optical spectroscopy measurements.

The prepared transformer oil samples were measured for their optical absorbance using the Agilent Cary5000 double beam spectrophotometer. The spectrophotometer produces light in the ultraviolet-visible-near infrared (UV-Vis-NIR) region which passes through a 1-cm pathlength cuvette with the sample and another 1-cm pathlength of cuvette with the reference oil. New uninhibited transformer oil was used as the reference oil for this measurement. The measurement was done in the range of 200 nm to 3300 nm. The resulting light was collected by a detector to obtain an optical spectrum. The working principal of the spectrophotometer can be seen in Fig. 2.

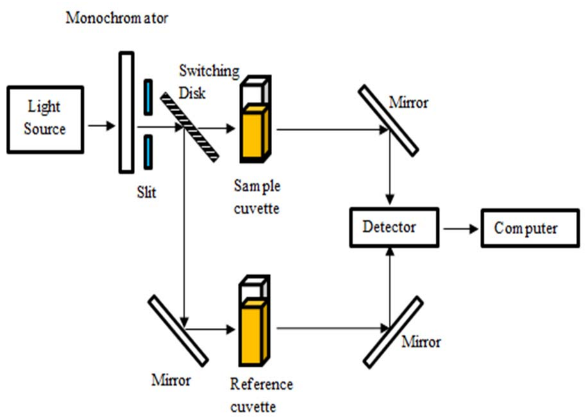

Fig. 2. Working principal of Agilent Cary5000 double beam spectrophotometer.

The samples were analyzed in the range of 950 nm to 970 nm waveband. The summary of the experimental details is depicted in Fig. 3.

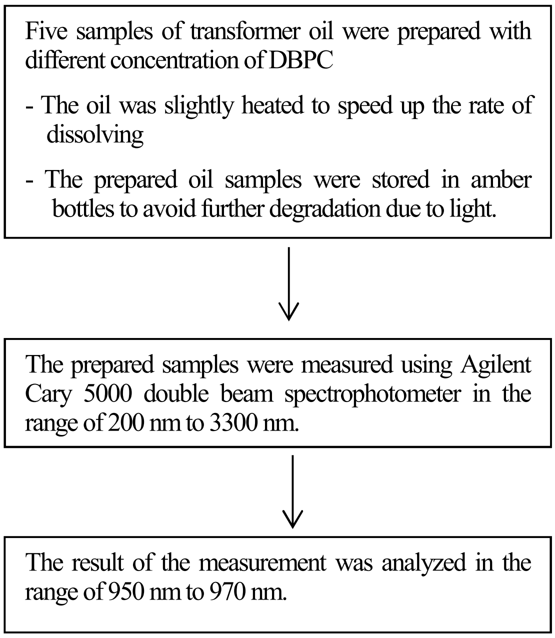

Fig. 3. Flowchart of details of the experiment.

The results of the experiment are depicted in Fig. 4 and Table I. It can be observed that as the inhibitor content concentrations of the transformer oil increases, the optical absorbance near 959 nm increases, while the transformer oil with no inhibitor shows almost zero optical absorbance.

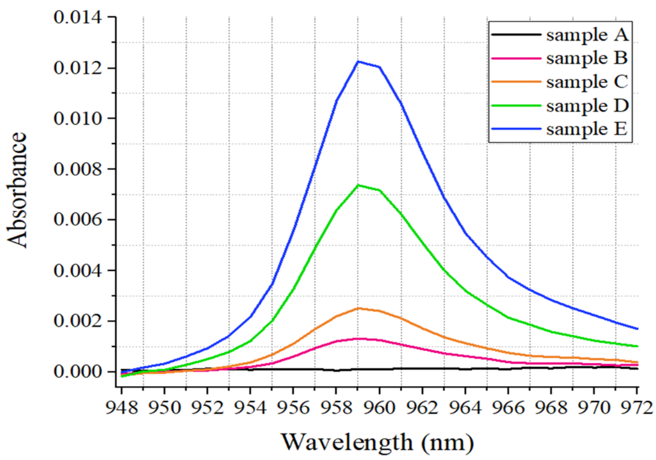

Fig. 4. Peak absorbance of different concentration of DBPC

TABLE I. SUMMARY OF PEAK ABSORBANCE AND AREA UNDER THE GRAPH FOR DIFFERENT CONCENTRATION OF DBPC.

Sample name	Concentration of DBPC	Peak absorbance	Area under graph
A	Nil	-	-
B	0.5 %	0.00135	0.00868
C	1 %	0.00265	0.0162
D	3 %	0.00745	0.06016
E	5 %	0.01225	0.07323

III. DISCUSSION

The relationship between the different concentration of DBPC and the area under the graph can be seen in Fig. 5. The graph shows a linear relationship between the various concentration of DBPC and area under the graph.

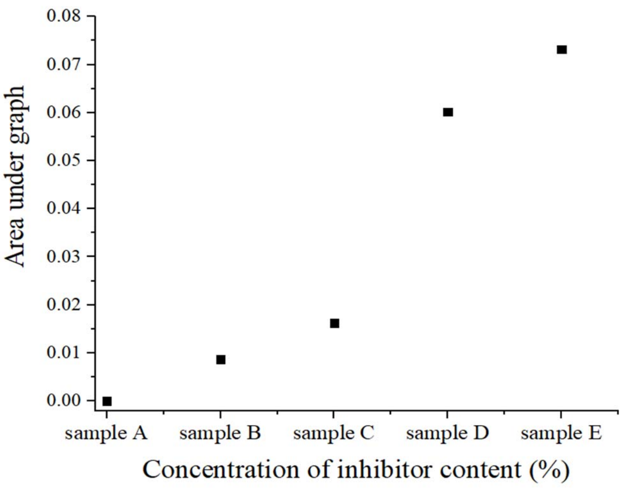

Fig. 5. Area under graph of different concentration of DBPC.

Based on Fig. 4 and Fig. 5, a clear relationship can be observed between the concentration of DBPC and the intensity of the peak absorbance at a wavelength of 959 nm. The highest peak absorbance is for 5% of DBPC where the absorbance is at 0.01225 and the lowest peak absorbance is for 0.5% DBPC where the peak is about 0.0035. Apart from that, it can also be observed that the area under the graph increases as the concentration of DBPC in the oil increases.

The experimental results reports a slightly shifted wavelength as compared to the wavelength reported by Wheeler et al. [14] who stated that a second overtone of OH groups appears at a wavelength of 971 nm, and Wulf et al. [15] who reported a shifted peak at 970.87 nm. This difference could be because of the detection of these compounds in different mediums. This experiment detects the OH group of DBPC in oil while Wheeler et al. detects it in a carbon tetrachloride solution and Wulf et al. conducted the investigation in tetrachloromethane. Apart from that, the type of OH group detected is also different. Wheeler et al. detects the OH group in methanol. Wulf et al. detects the OH group in a phenol and in this experiment, the OH is detected in a phenol group with methyl groups at the ortho and para position. Therefore, the difference in the medium of detection and the difference in the electronegativity of the surrounding atoms may have influenced the shifting of the peak absorption wavelength. It is also important to note that although the OH groups are detected in different hydrocarbons, the peaks that correspond to the OH groups are similar. This could indicate that the peak near the 960 nm waveband generally corresponds to the O-H bond itself but does show a distinct difference between OH group from phenols and alcohols. Therefore, a more comprehensive study can be conducted to study the characteristic of an alcoholic OH group and a phenolic OH group in oil.

Based on the results of the experiment, it is acceptable that optical spectroscopy characterization is an easier way to detect the concentration of DBPC in the transformer oil. It can overcome the limitation of the conventional method which is time consuming and can incur a lot of cost. However, the accuracy and the repeatability of this experiment can be further analyzed with real operating transformer oil samples.

IV. CONCLUSION

This study emphasizes on the optical characterization of transformer oil with different concentrations of inhibitor. The results obtained show that optical absorbance peak was observed at a wavelength of 959 nm. The peaks with a higher absorbance correspond to a higher concentration of inhibitor in the oil and vice versa. It can also be observed that the area under the graph increases with the increase of in the concentration of inhibitor content. Therefore, the inhibitor content in transformer oil can be detected at a waveband lower than 1000 nm where it can be detected using Silicon photodetector.

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