A COMPARATIVE STUDY OF PARTIAL DISCHARGE BEHAVIOUR IN OIL IMPREGNATED INSULATION SYSTEMS

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Abstract: This paper presents a preliminary result of experimental investigation that is aimed to look at the possible differences in PD behaviour in biodegradable and mineral oil impregnated systems at elevated temperature. To simulate a condition of transformer insulating system, 2 pieces of electrical pressboard and 2 layers of insulating paper were used as a test sample. The sample was fully immersed in the oil and placed in a glass compartment. The temperature was increased and decreased at a constant test voltage level. The initiated PDs were detected and analysed using a wide band PD detector. The experimental results indicated that the PD properties in oil-impregnated systems are significantly affected by the temperature change. It was also observed that the PD behaviour in biodegradable oil system has some differences from that in mineral oil.

1 INTRODUCTION

Oil-impregnated insulating systems were used for the first time more than a century ago. Transformers, including power and instrument transformers, are the main power equipment that utilise oil-impregnated systems as an electrical insulating material. Cellulose based materials such as insulation paper and electrical pressboard are immersed fully in transformer oil to isolate the windings from one another and from earth potential. The pressboard and wood are used to construct gaps between the turns of the copper conductors, hence allowing the transformer oil to circulate adjacent to the conductors and to dissipate heat produced during service of the transformer to the surrounding ambient.

At present time, mineral oil has been used widely as a transformer insulating system. Besides being an insulating material, transformer oil also functions as a cooling media. Characteristics of the mineral oil insulating systems and their performances during service have been well-documented.

Recently, vegetable oils have been proposed as a substitute for mineral oils. The most attractive features of the vegetable oils are that it is highly biodegradable and environmentally friendly. It has been found that the physical and chemical properties of the refined vegetable oils are comparably similar to those of mineral oil. They also have good thermal properties and satisfy most situations during operation of a transformer [1-6].

Although a number of investigations of properties and applications of biodegradable oils as insulation liquid have been carried out, however, long time properties and ageing characteristics of these oils have not been fully investigated. Therefore, further studies in particular for biodegradable oil impregnated systems are still required.

This paper presents a preliminary result of experimental investigations that is aimed to look at the properties of PDs in biodegradable oil impregnated system at elevated temperature. This study is also aimed to look at whether PDs behave differently with those in mineral oil. Results of this study will provide contributions in analyzing PD data during condition monitoring of high voltage equipment, particularly that using oil insulating system, such as power and instrument transformers.

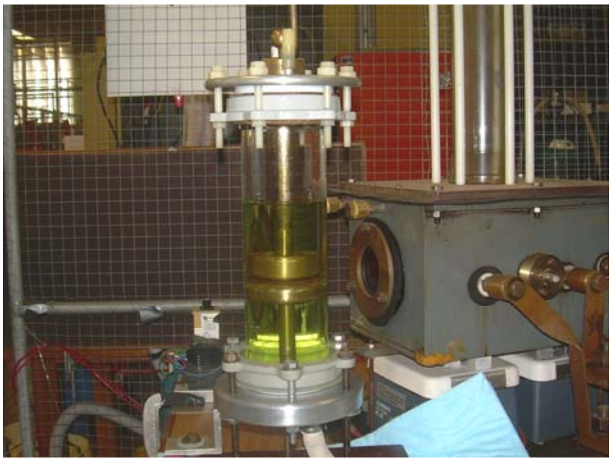

Figure 1: The experimental setup. The specimen is fully immersed in oil within a glass compartment.

2 EXPERIMENTAL SETUP

2.1 Test sample

The test configuration simulated a common fault condition on transformer insulating system. 2 pieces of 1.5mm thick electrical pressboard and 2 layers of 0.05 mm thick insulating paper were used as the specimen. A cylindrical void with a diameter of 8 mm was created in the middle of the top pressboard layer and covered by the paper layers.

The test specimen was placed between two plane electrodes and fully immersed in insulating oil within a glass cell, as shown in Figure 1. No particular treatment was given to the pressboard, paper and the oil prior to the test. The moisture content of the pressboard and paper was approximately 5%, while that of the biodegradable and mineral oils was about 40ppm.

2.2 Testing procedure

The ambient temperature during PD tests was in the range of ~20-25°C. Temperature of the specimen was increased by using a heating device located at the lower part of the test cell. The temperature was increased and decreased at a constant test voltage level and at a frequency of 50Hz. The increase rate of the temperature was adjusted gradually to prevent sudden expansion of the glass compartment. The maximum test temperature for PD tests using biodegradable oil was about 70°C, while that for PD tests using mineral oil was about 55°C.

The circuit for PD measurement and calibration procedure followed the IEC-60270 Standard [7]. The PD measuring system presents the PD quantities such as maximum and average PDs, PD number and PD current. The measurement bandwidth of the PD detector was ~350-650kHz. An alternate bandwidth of 500kHz-1500kHz was applied to investigate possible differences in PD patterns and quantities [8].

3 RESULT AND DISCUSSION

3.1 PD Test Using Biodegradable Oil

PD inception voltage for the test using biodegradable oil was ~3kV and the extinction voltage was ~2.5kV. The PD test was carried out at a voltage level of 4kV (30% above inception) to attain a stable discharge pattern [8,9].

Figure 2 to 5 illustrate the average PD magnitude and PD number at different test temperature, for the test using biodegradable oil. Note that BW1 and BW2 denote PD data measured with a bandwidth of 350-650kHz and of 500kHz-1.5MHz, respectively. It can be seen that as the test temperature increases, the average PD magnitude increases sharply and then fairly constant at a temperature above 45°C (Figure 2). The average PD magnitude tends to decrease gradually and back to the initial value as the test temperature decreases. A significant decrease in average magnitude occurs at a temperature below 35°C (Figure 3).

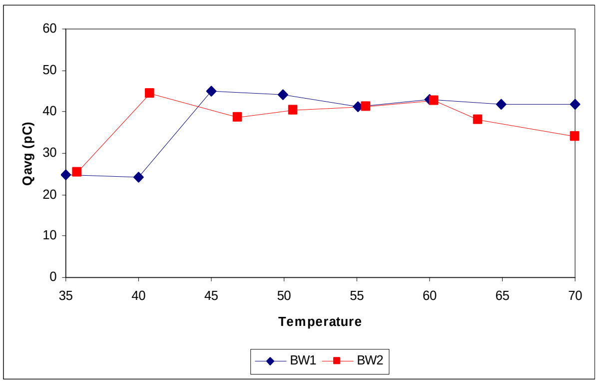

Figure 2: PD average magnitude (pC) vs. test temperature for biodegradable oil (increasing) [8].

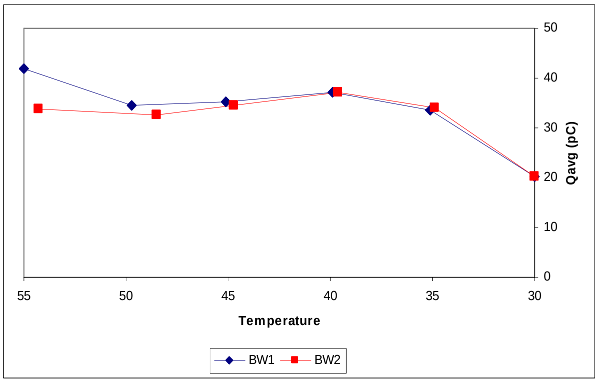

Figure 3: PD average magnitude (pC) vs. test temperature for biodegradable oil (decreasing) [8].

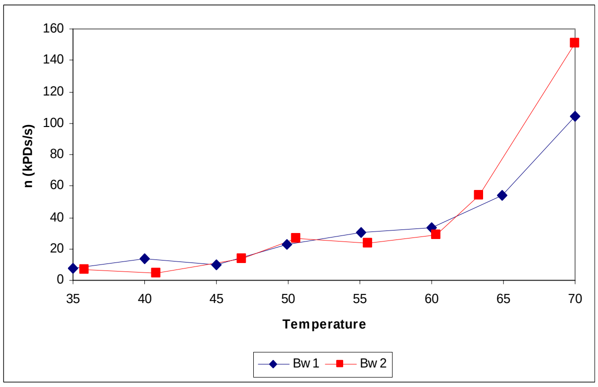

Figure 4: PD number vs. test temperature for biodegradable oil (increasing) [8].

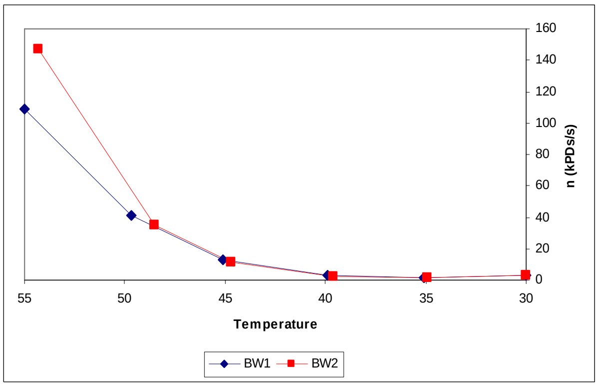

Figure 5: PD number vs. test temperature for biodegradable oil (decreasing) [8].

Figure 4 and 5 illustrate the correlation between PD number and the test temperature for the two measurement bandwidths. It is clear that the PD number increases significantly as the test temperature increases, and then decreases back as the temperature decreases.

A significant increase in PD number occurs at a temperature above 60°C (Figure 4). At these points small bubbles appear and release from the test sample to the oil surface. As the temperature continue to increase, the number of bubbles increases considerably. Note that at a temperature above 60°C, there is a large difference in the PD number measured from the two different bandwidths. The gas bubbles disappeared and the PD number decreases sharply as the test temperature decreased back to ambient (Figure 5).

Figure 6 to 9 show the PRPD patterns at a test temperature of 35°C and 70°C, for detection bandwidth of 350-650kHz and 500kHz-1.5MHz. These patterns indicate gas discharges within the void bounded by dielectric materials. The rabbit ear like pattern may indicate the development of tracking paths on the sample interface, due to trapped small bubbles between the sample layers.

It is clear that as the test temperature increases, the PD number increases and the PD pattern changes. The increase in PD number causing a wider spread of PD distributions at a higher test temperature. Note that the increase in discharge number is mostly contributed by an increase in small discharges (below 50pC). This is most probably due to the appearance of small bubbles.

Figure 6 to 9 also show that there are some differences between the PD patterns detected with a bandwidth of 350-650kHz and that detected with a bandwidth of 500kHz-1500kHz. Generally, the PD distribution measured using a wider bandwidth has a lower peak than that of narrower bandwidth. However, at a high test temperature, the system with a wider bandwidth (500-1500kHz) detected a higher number of PDs than the system with a narrower bandwidth (350-650kHz).

3.2 PD Test Using Mineral Oil

The PD inception voltage for PD test using mineral oil was ~2.3kV and the extinction voltage was ~2kV. In order to keep a stable discharge pattern, the PD test was carried out at a voltage level of 3kV.

The average PD magnitude and PD number at different test temperature for PD test using mineral oil are illustrated in Figure 10 to 13. It is clear that as the test temperature increases, the average PD magnitude increases gradually and keeps increasing even when the test temperature was decreased back to ambient (Figure 11).

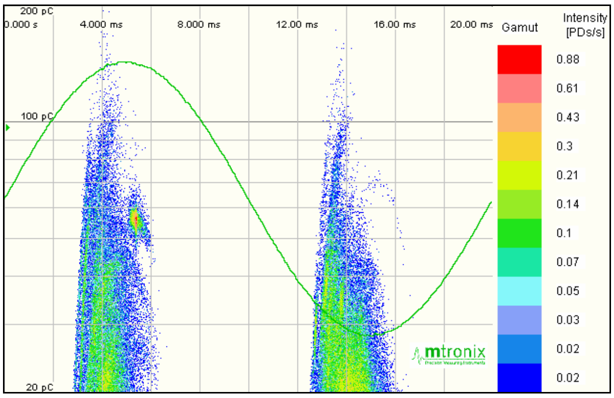

Figure 6: PD pattern at 35°C for biodegradable oil (Measuring bandwidth: 350-650kHz).

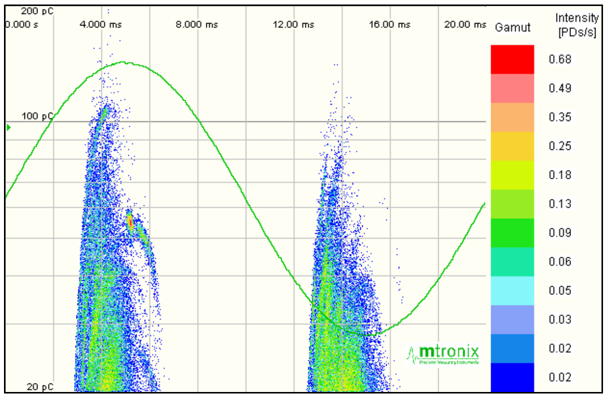

Figure 7: PD pattern at 35°C for biodegradable oil (Measuring bandwidth: 500-1500kHz).

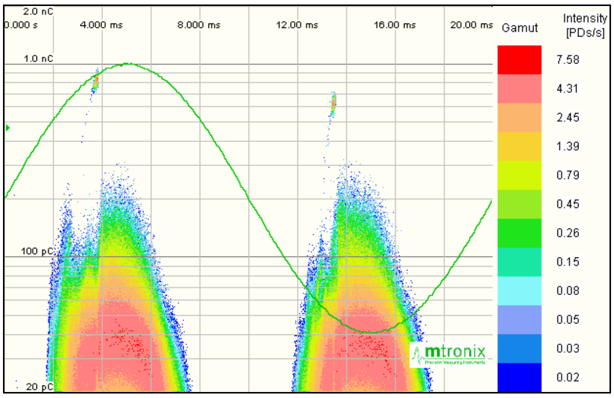

Figure 8: PD pattern at 70°C for biodegradable oil (Measuring bandwidth: 350-650kHz).

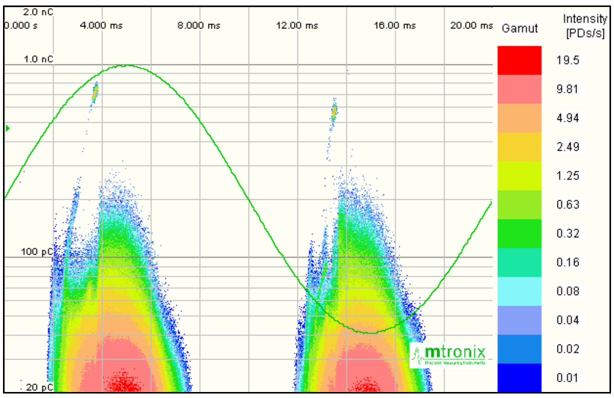

Figure 9: PD pattern at 70°C for biodegradable oil (Measuring bandwidth: 500-1500kHz).

Correlation between PD number and the associated test temperature for the two measurement bandwidths are depicted in Figure 12 and 13. The PD number increases sharply as the test temperature increases, and then decreases as the temperature decreases. Significant reduction in PD number is notable at a temperature below 45°C.

During PD tests using mineral oil, small bubbles start to appear at a lower temperature, which is approximately 45°C. Consequently, a significant increase in PD number occurs at a temperature above 45°C (see Figure 12). At this stage, the two different measuring bandwidths detected a large difference in PD number.

Figure 14 to 17 show the PRPD patterns at a test temperature of 35°C and 55°C, for a detection bandwidth of 350-650kHz and 500kHz-1500kHz. Again the patterns indicate gas discharges within the void bounded by dielectric materials. Note that the maximum PD in this test is lower than that in biodegradable oil.

Similar to that in the PD test using biodegradable oil, as the temperature increases, the PD number also increases and the PD pattern changes. The increase in PD number causing a wider spread of PD distributions at a higher test temperature.

Figure 14 to 17 again show that the PD distribution measured using a bandwidth of 500-1500kHz has a lower peak compared to that measured using a bandwidth of 350-650kHz. At high temperature, however, the system with a bandwidth of 500kHz-1500kHz detected much more PDs than the one with a 350-650kHz bandwidth.

4 CONCLUSIONS

The analysis results show that PD level and number varies as the test temperature varied. This evidence indicated that the temperature variation becomes an important factor in using PD diagnostics to assess insulation condition in transformers.

Detailed analysis of the PD data showed some significant differences in distribution of discharges. These differences are significant in terms of the frequency response of the PD detection systems. This fact suggests that the analysis of PD data must be performed carefully with particular attention being given to the frequency response of the sensor.

Results of this preliminary study indicated that there are differences in the characteristics of PDs in biodegradable oil from that in mineral oil. Further investigations in ageing characteristics of bio-degradable oil insulation system are still required.

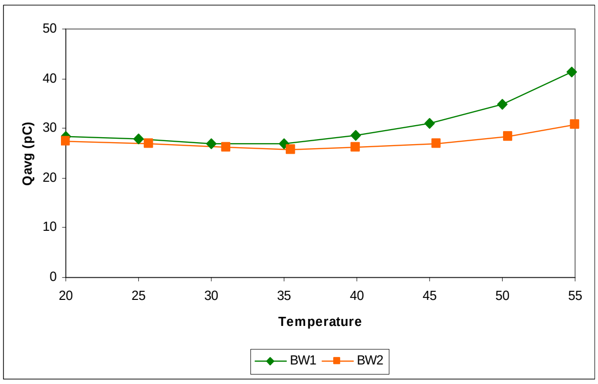

Figure 10: PD average magnitude (pC) vs. test temperature for mineral oil (increasing).

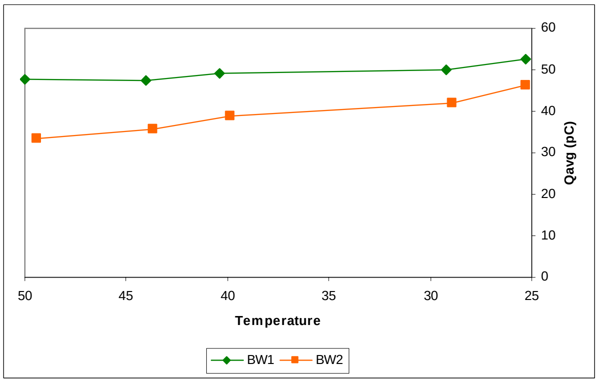

Figure 11: PD average magnitude (pC) vs. test temperature for mineral oil (decreasing).

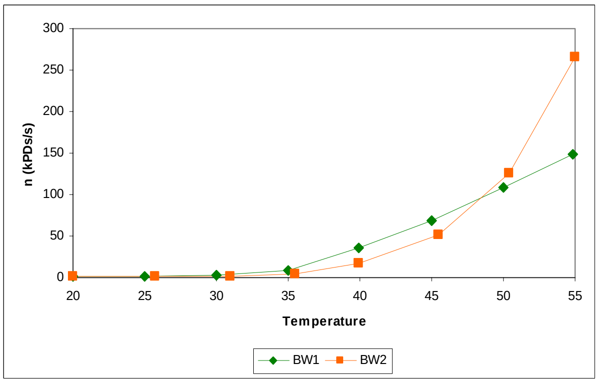

Figure 12: PD number vs. test temperature for mineral oil (increasing).

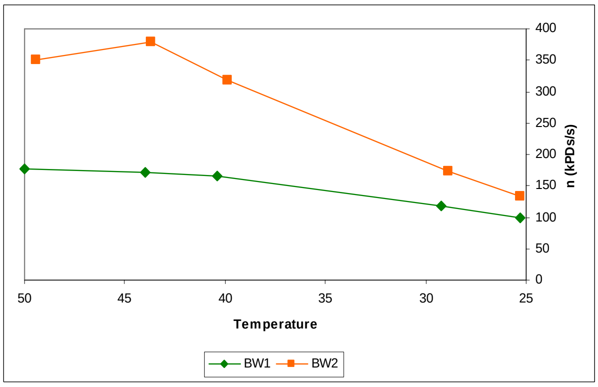

Figure 13: PD number vs. test temperature for mineral oil (decreasing).

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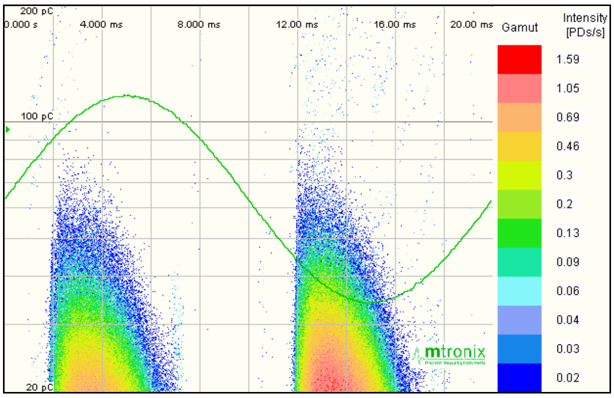

Figure 14: PD pattern at 35°C for mineral oil (Measuring bandwidth: 350-650kHz).

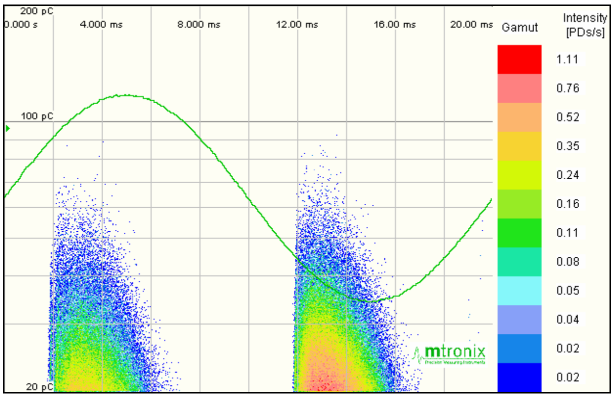

Figure 15: PD pattern at 35°C for mineral oil (Measuring bandwidth: 500-1500kHz).

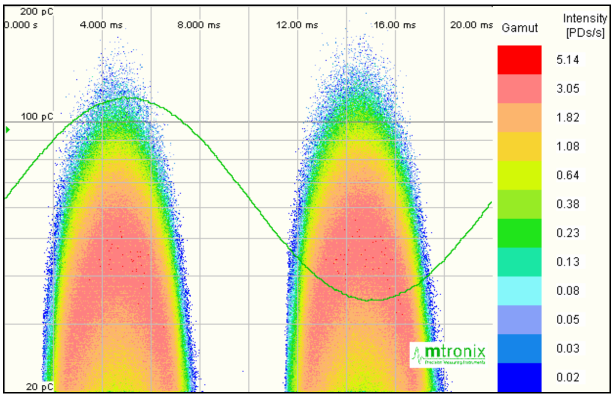

Figure 16: PD pattern at 55°C for mineral oil (Measuring bandwidth: 350-650kHz).

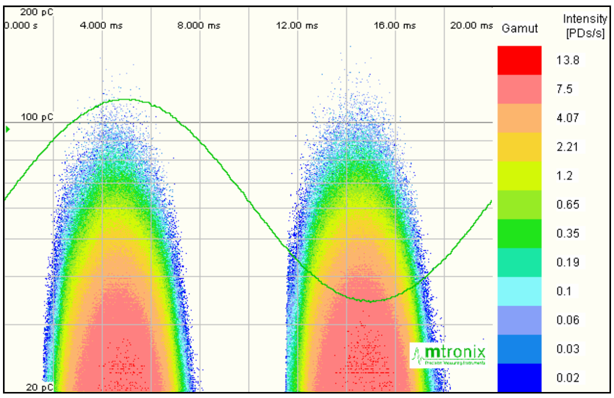

Figure 17: PD pattern at 55°C for mineral oil (Measuring bandwidth: 500-1500kHz).