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Thermal effects on acoustic emission based PD in transformer oil: A study

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Abstract: Transformers operate at different service conditions in the field resulting in operating temperatures of oil and winding, much above ambient temperature. Acoustic emissions due to partial discharge activity in transformer insulation system, including transformer oil, have been investigated by a few researchers at temperatures ranging from 25°C to 40°C. It is more realistic to consider the study at service temperature which could be around 50°C to 70°C; depending on the service conditions and type of insulation employed. The paper deals with acoustic partial discharge behaviour in transformer oil at temperatures ranging from 30°C to 75°C along with some of the properties of transformer oil.

Key words: Partial Discharge (PD), acoustic emission, acoustic energy, frequency content, specific resistivity, tan δ, total gas content (TGC)

INTRODUCTION

Acoustic emissions (AE) are transient elastic waves generated by the rapid release of energy from localized sources within the material [1]. Acoustic emissions can occur inside the transformer due to small-scale breakdowns called as partial discharge (PD), heating and core vibrations [2,3,4,5,6,7]. Acoustic emissions propagate through the oil and other insulating media which can be captured with the help of suitable acoustic sensors. The acoustic method for PD measurement is based on detection, acquisition and analysis of acoustic emission signals generated during PD activity. High frequency piezoelectric sensors, mounted on the transformer tank surface, are generally used to detect these acoustic emissions. Advancement in software and hardware technology including data acquisition, data analysis, and computational techniques has resulted in application of AE technique as one of the important tools in identifying the defects like PD in transformer insulation.

A few publications have appeared dealing with acoustic emissions due to PD in transformer oil at ambient temperature ranging up to 40°C [8]. However, it is more realistic to study the behaviour of insulation system at service conditions which will be around 50°C to 75°C; depending on the service conditions and type of insulation employed. In order to generate this type of data and to assess PD behaviour of transformer oil, certain laboratory studies have been carried out. Influence of temperature on some of the important acoustic based PD properties has been investigated.

Several acoustic signal parameters are generally employed for acoustic PD measurement [9]. Acoustic PD signal parameters considered for the present study are discharge amplitude (dBae), acoustic energy (µVs), attenuation, velocity and peak frequency. These parameters have been measured under controlled experimental conditions for temperatures ranging from 30°C to 75°C. Dissipation factor (tanδ), dielectric constant, specific resistivity and viscosity of the transformer oil have also been measured as a function of temperature to study the thermal effects on acoustic PD signal propagation in transformer oil.

EXPERIMENTAL WORK

Experimental studies have been performed in the laboratory employing a prototype transformer model of size, one cubic meter, made of mild steel material and filled with transformer oil [10]. For Acoustic PD investigation, the transformer oil was heated to the required temperature with the help of heaters and oil circulation arrangement to maintain uniform oil temperature. Partial discharges in oil were generated in a point plane electrode geometry placed within the oil medium. The tip diameter of the point electrode was 0.03mm.The electrode gap considered for the study was in the range of 0.25 m to 0.66 m. A multichannel acoustic emission system with piezo electric sensors (DT15I) of M/s PAC, USA, was used for acquiring acoustic signals due to PD in oil [11]. PD measurement has been carried out at temperatures ranging from 30°C to 75°C and voltages ranging from 15 kV to 25 kV. Influence of temperature on acoustic properties of PD in oil has been studied by maintaining the oil temperature for a period of 8 hours at each temperature.

EXPERIMENTAL RESULTS

Properties of transformer oil considered for the study are listed in Table 1. Fig.1 (a) shows the measured values of tanδ and dielectric constant and Fig. 1(b) shows viscosity and specific resistivity of the oil as a function of temperature from 30°C to 75°C.

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The experimental results reported in the paper are for oil temperatures from 30°C to 75°C. Acoustic PD parameters namely discharge amplitude and acoustic energy measured as a function of temperature and voltage are depicted in Fig. 2 and Fig. 3, respectively. Distance between the PD source and the acoustic sensor was 0.60 m. Attenuation and propagation velocity of acoustic PD signals in transformer oil as a function of temperature is shown in Fig. 4 and Fig. 5.

Table 1: Measured properties of transformer oil.

Transformer oil property	Measured value
Dielectric Dissipation Factor (tanδ) @90°C & RH 48%	0.034
Specific Resistivity(Ω-cm) @90°C& RH 48%	$7.4x10^{+12}$
Specific Resistivity(Ω-cm) @27°C& RH 48%	$138x10^{+12}$
Dielectric Constant @90°C& RH 48%	2.14
Viscosity(cSt) @27°C	14.11
Total Gas Content (μL/L)	107933
BDV(kV rms)@ 27°C& RH 48%	20

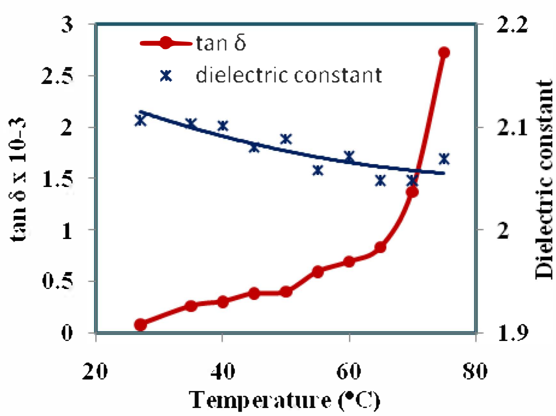

Figure 1(a). Values of tan δ & dielectric constant of transformer oil measured at different temperatures,

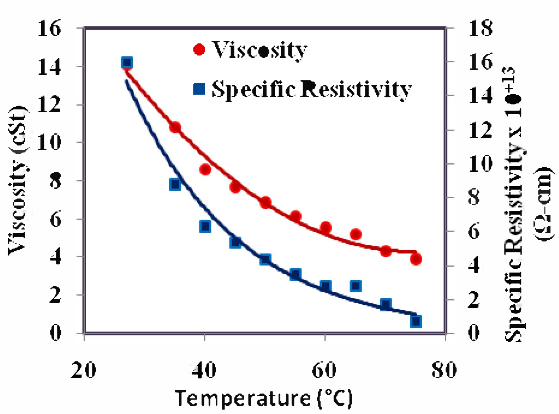

Figure 1(b). Values of viscocity& specific resistivity of transformer oil measured at different temperatures.

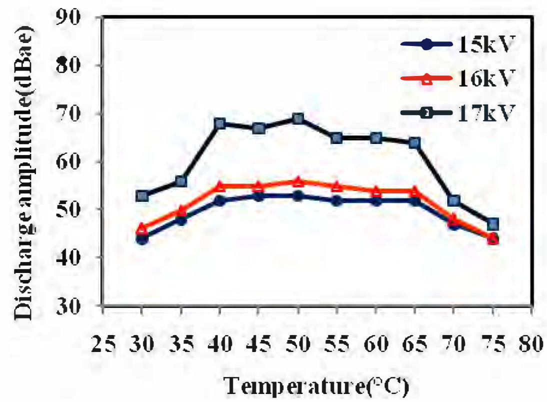

Figure 2. Discharge amplitude(dBae) measured at different temperatures

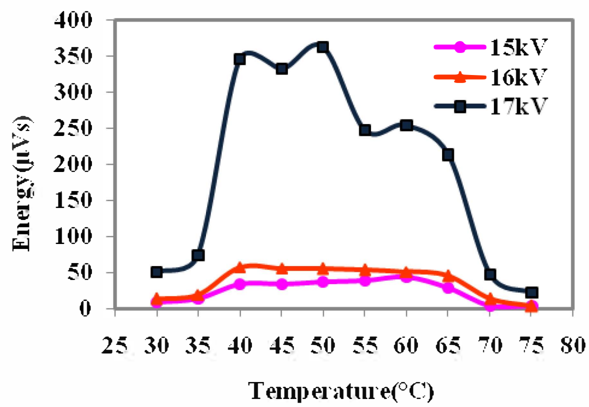

Figure 3. Acoustic energy measured at different temperatures

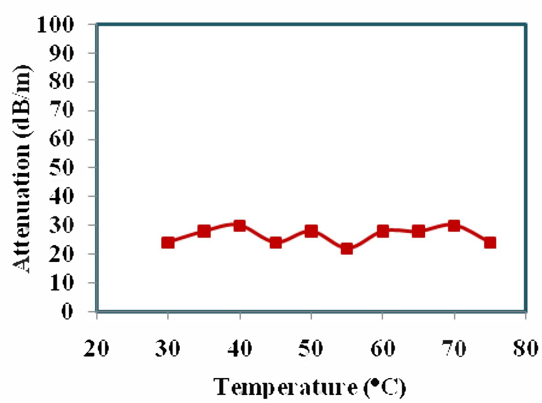

Figure 4. Attenuation of acoustic PD signals in transformer oil with temperature.

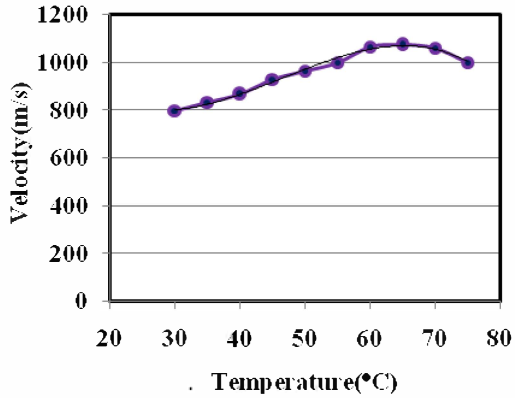

Figure 5. Velocity of acoustic PD signals in transformer oil with temperature.

DISCUSSION

The measured properties of transformer oil (refer Table 1 and Figs. 1 (a) and (b)) considered for the study indicate the satisfactory condition of the oil.

Discharge amplitude of PD signals has shown (Fig. 2) an increased activity in the temperature range from 30°C to 40°C and has further remained almost unchanged (within 5 dB) up to 65°C. Beyond 65°C, a reduction in discharge amplitude has been observed. This behaviour has been consistently seen at all the three voltages 15 kV, 16 kV & 17 kV. Applied voltage has shown a minimal influence on discharge amplitude of acoustic signals up to 16 kV. A substantial increased PD activity has been observed at 17 kV

Applied voltage has shown a minimal influence on acoustic energy of PD signals in oil up to 16 kV (Fig. 3). At 17kV, a contrast behaviour has been observed. A sudden burst of energy has occurred beyond 35°C with a peak at 50°C after which the energy has dropped drastically.

Temperature of oil appears to have a little influence on the attenuation of acoustic PD signals (Fig. 4). Variation observed is within 6 dB/m for temperatures from 30°C to 75°C for propagation distances up to 1m.

Propagation velocity of acoustic signals due to PD in transformer oil depends on temperature and pressure of the oil. Velocity in transformer oil has been estimated from experimental data at different temperatures and at atmospheric pressure of 685mm of Hg (Fig. 5). An empirical relation between velocity and temperature has been derived based on the experimental results over temperatures ranging from 30°C to 75°C as shown in equation (1).

$$v=1480-56.64t+1.447t^2-0.01t^3 \quad \ldots\ldots(1)$$

where, t is the temperature of oil in °C and ν is the velocity in metres/sec. The equation will be of practical help for estimating the velocity at the required temperature for transformer oil.

Frequency analysis of acoustic PD signal has been carried out employing FFT [8]. Peak frequency (f_{pk}) in the FFT spectrum is the point at which peak amplitude occurs.

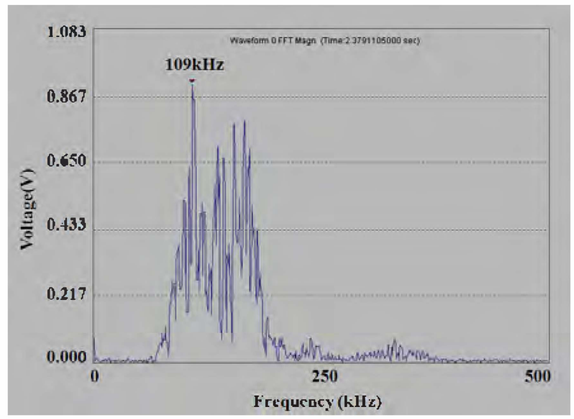

Figure 6(a). FFT spectra of acoustic signals due to PD in oil at 30°C

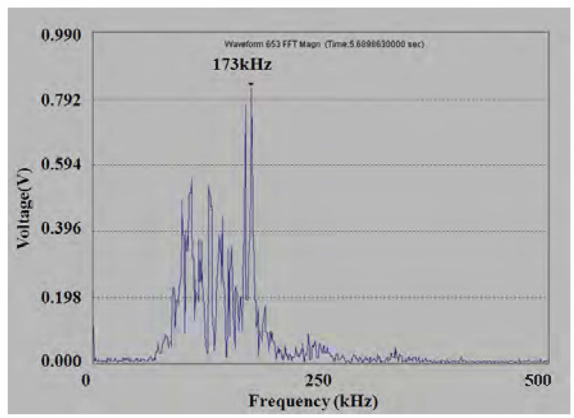

Figure 6 (b). FFT spectra of acoustic signals due to PD in oil at 45°C

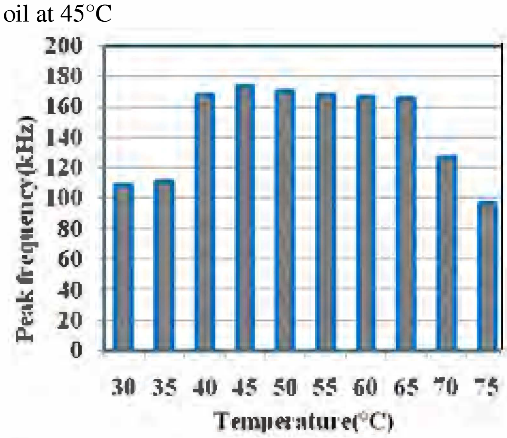

Figure 7. Peak frequency versus temperature

A real time FFT spectrum of acoustic PD signals at 17 kV has been analysed to examine the influence of temperature on peak frequency. FFT spectra at 30°C and 45°C, as shown in Figs. 6 (a) and 6(b), indicate a shift in f_{pk} from 109 kHz to 173 kHz. Fig. 7 illustrates the distribution of peak frequency over the temperatures from 30°C and 75°C at 17 kV. Peak frequency of PD signals has shifted from 109 kHz to 168 kHz, in the temperature range from 30°C to 40°C and has further remained almost unchanged at 168 kHz ± 3 kHz up to 65°C. Beyond 65°C, a reduction in f_{pk} has been observed to a value of 97 kHz.

Explanation for the behaviour of acoustic PD activity in transformer oil beyond 65°C needs further study. However, the findings of the experimental study would be of practical importance while analysing the acoustic PD signals from transformers in service operating at temperatures up to 75°C.

CONCLUSION

Based on the study performed, the following important conclusions are drawn.

- Discharge amplitude of PD signals has increased with temperature in the range from 30°C to 40°C and has further remained almost unchanged (within 5 dB) up to 65°C. Beyond 65°C, a reduction in discharge amplitude has been observed for voltages up to 17 kV.
- Applied voltage has shown a minimal influence on acoustic energy of PD signals in oil up to 16 kV. At 17 kV, a steep increase in acoustic energy of PD signals has been observed with temperature in the range from 30°C to 50°C beyond which it has dropped drastically.
- Oil temperature has a minor influence on the attenuation of acoustic PD signals (within 6 dB/m) in the temperature range of 30°C to 75°C.
- Empirical relationship between velocity and oil temperature suggested in the paper based on the experimental data can be used for estimating the velocity of acoustic PD signals at required temperatures.
- Experimental results reported could be of practical importance while analysing the acoustic PD signals from transformers in service operating at temperatures up to 75°C.

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