Pak. j. sci. ind. res., vol 32, no.9, September, 1989

IMPACT OF DESERT ENVIRONMENT ON THE PROPERTIES OF TRANSFORMER OIL UNDER SERVICE LOAD IN SAUDI ARABIA

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(Received April 21, 1989; revised September 21, 1989)

This paper presents and discusses the experimental results of the effect of temperature variation on transformer oil aged under service load and installed in the arid region of Saudi Arabia. The oil properties investigated are the i-V characteristics under non-uniform fields and High Performance Liquid Chromatography (HPLC) spectroscopy. An important consequence of desert environment is the strong dependence of the i-V characteristics on temperature. The current changes by several orders of magnitude with a relative change of temperature $\Delta T/T$ of the order of less than 15%. Moreover the i-V characteristics show a departure from Nikuradse behaviour at higher temperature. The variation of the i-V characteristics with temperature are modelled. It is believed that the conduction mechanism is complicated at higher voltage and temperature, and the model is not a simple exponential. HPLC spectroscopic analysis indicates change in the molecular structure of oil due to aging under service conditions.

Key words: Conduction, Transformer oil, Spectroscopy.

Introduction

Although there are several characteristics of insulating oils that have been explored, the most important one is the strong dependence of current on voltage as soon as the electric field exceeds 50 kV/cm [6]. Extensive explanations have been put forward in the literature for conduction in hydrocarbon oils [7], but little investigation has been made, as far as the author's knowledge is concerned, in service aged transformer oil at elevated temperatures. The role played by the chemical structure of oil under electrical stress at higher temperature also needs to be investigated. This paper studies the factors that control the i-V behaviour of transformer oil at elevated temperatures and also characterizes its chemical constituents using HPLC technique.

Experimental

The oil sample used in this study is acquired from an EHV breathing transformer and conforms to BS.148:1972. This unit is installed in a coastal desert area where ambient temperature varies from 0-50°. This unit has been operating without any fault for the last 9 years. Non-uniform field is obtained using an electrode assembly which consists of a steel sewing needle of 25 μm radius and a brass plane electrode of 25 mm diameter with its edges rounded. The positive voltage is applied to the needle electrode. The two electrodes are spaced 0.75 mm apart. The applied voltage is raised from +5.0 to +14.0 kV, and the temperature of the sample regulated from 33° to 80°± 1° in an environmental chamber. The experimental set up is described in detail elsewhere [El-Sulaiman *et al*. [4].

Results and Discussion

1. *i-V Characteristics.* Figure 1 shows the voltage dependence of quasi-steady conduction current i at a time lapse of 100s, after the application of voltage (V) for temperatures variation from 33°-80°. The i-V characteristics at 33° shows that the current increases as the voltage is increased. Earlier reports on transformer oil [1] show that as

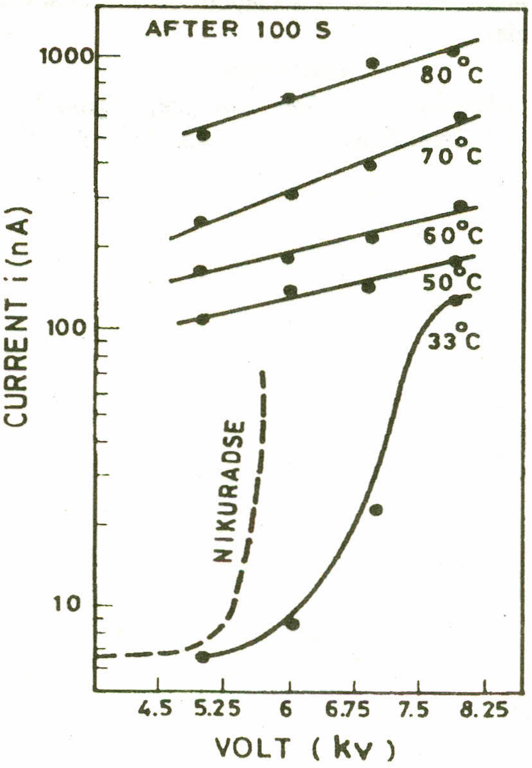

Fig. 1. Current voltage characteristics after 100s for various temperatures.

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the voltage is increased, the current increases and thereafter starts declining upon further voltage increase. Such declining continues to a certain voltage after which the current starts to increase rapidly till it approaches a breakdown. Similar behaviour has also been reported to occur in *n*-hexane [8]. A close study of the curve shows that if a factor of correction is introduced, the characteristic at 33° can be fitted to the Nikuradse ideal characteristic [5]. As the temperature is further increased, the i-V characteristic will almost remain unchanged upto around 60° [2] where after the characteristic departs considerabiy from Nikuradse ideal characteristics. It can be seen that the current changes by several orders of magnitude with relative change of temperature ($\Delta T/T$) of the order of less than 15%. Also the rate of the current increase with voltage is almost constant upto a temperature of 60° after which the rate increases relatively. This may be due to the fact that the charge carriers are influenced by two mechanisms. The first is the metal/liquid interface which consists of an insulating film and space charge [3]. The insulating film acts as an effective blocking layer for conduction resulting inflection in the i-V curve at the lower temperature regime, Fig 1., where the mobility of the charge carriers is low. The second is the thermal excitation which enhances the energy level and carriers suddenly jump from low energy site to higher one. In addition to this there is also electrohydrodynamic (EHD) motion under the influence of which charge carriers move much faster than their true mobility. And it has been reported [6] that ion's mobility under high fields is enhanced by a factor which depends on $\sqrt{\varepsilon/\rho}$, where ε and ρ are the oil permitivity and specific mass respectively, may increase many-fold at higher temperature, and therefore, enhance the velocity of the carriers appreciably. Therefore, with the elevation of temperature, the carriers mobility increases appreciably following Arrhenins equation [2] while the effect of the blocking layer diminishes beyond the transition temperature the condition is dominated by the high mobility charge carriers.

The variation of the i-V characteristics at different temperatures from 33° to 80° has been fitted, using least square method, to three possible models, namely as shown in Table 1. Comparing the co-relation coefficient, F-value and t-test of these models, it is found that model (II) results in the minimum degree of scatter of data points about the regression line as shown in Fig 2. For this model the constants are given in Table 2 at different temperatures.

Above 50° the i-V characteristic satisfies adequately the equation:

$$\ell n\, i = 7.3 \exp.\ (-\ 1.53/V).$$
$$= [1-(1.53/V)]$$

While the model at 33° can be represented by:

$$\ell n\, i = 32.8\ [1-(15.5/V)]$$

It is to be noted that model (I) is similar to the field ionization current while model (III) is similar to field emmission current [9]. It is evident from these results that the

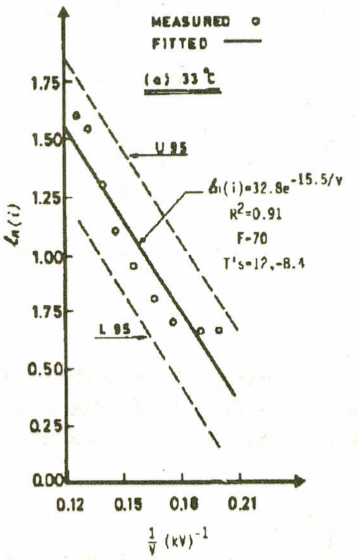

Fig. 2a. Fitting the measured data to model in $i=B\ e^{-a/V}$ showing test result of correlation coefficient R2, F-value, student t-test T, U95 and 95 the upper and lower confidence limits respectively for (a) 33°C.

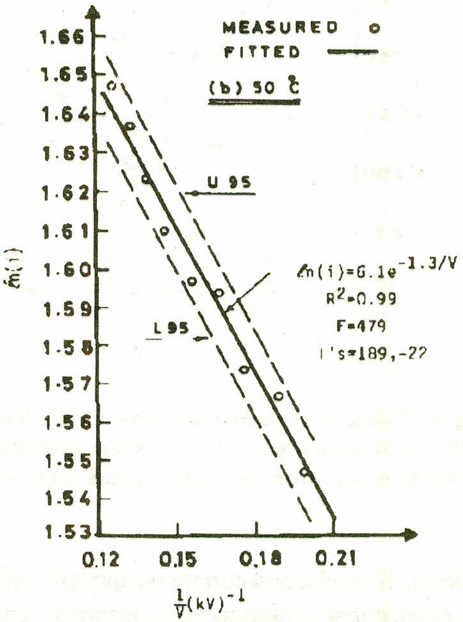

Fig. 2b. Fitting the measured data to model in $i=B\ e^{-a/V}$ showing test result of correlation coefficient R2, F-value, student t-test T, U95 and 95 the upper and lower confidence limits respectively for (b) 50°C.

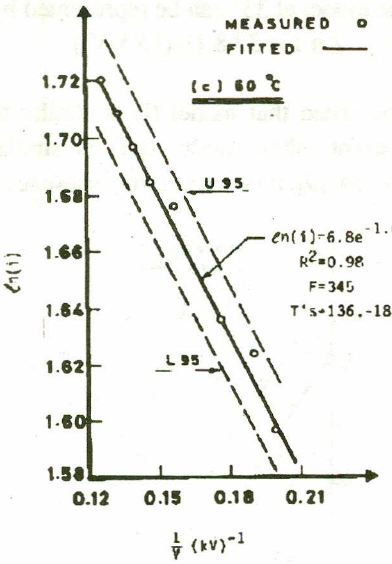

Fig. 2c. Fitting the measured data to model in $i=B\,e^{-n/V}$ showing test result of correlation coefficient R2, F-value, student t-test T, U95 and 95 the upper and lower confidence limits respectively for (c) 60°C.

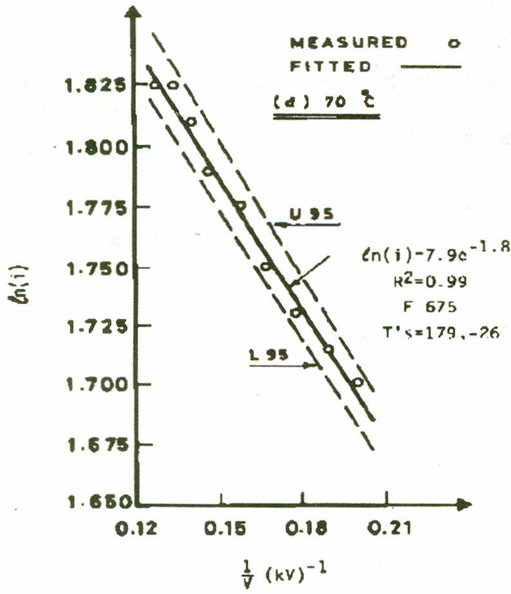

Fig. 2d. Fitting the measured data to model in $i=B\,e^{-n/V}$ showing test result of correlation coefficient R2, F-value, student t-test T, U95 and 95 the upper and lower confidence limits respectively for (d) 70°C.

dependence of conduction current on applied voltage is not a simple exponential. Consequently, injection current cannot be interpreted as being due to electronic collisional ionization only. It is more likely that electrohydrodynamic (EHD) motion plays an important role in this case. At relatively low temperature, the conduction mechanism is controlled by

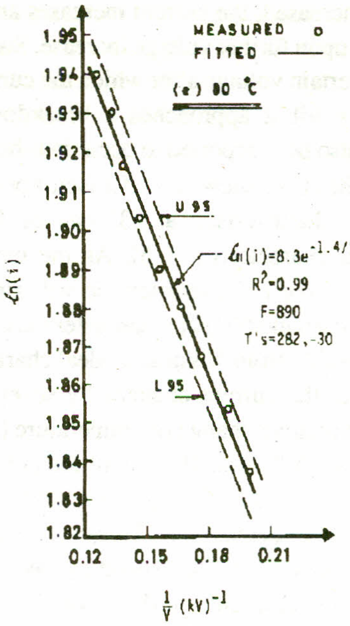

Fig. 2e. Fitting the measured data to model in $i=B\,e^{-n/V}$ showing test result of correlation coefficient R2, F-value, student t-test T, U95 and 95 the upper and lower confidence limits respectively for (e) 80°C.

Table 1. Three tested models

Model	Linear from	Current mechanism
(I) $i=Ae^{-(m/V)}$	$\ln i=A_0-m(1/V)$	Field ionization
(II) $\ln i=Be^{-n/V}$	$\ln(\ln i)=B_0-n(1/V)$	ThermalandEHD Enhanced Fieid Ionization
(III) $i/V^2=Ce^{-(q/V)}$	$\ln(1/V^2)=C_0-q(1/V)$	Field emission

Where i is the conduction current, V is the applied voltage, A,B and C are the intercepts, m,n,q are the slopes of the linear form of the model

Table 2. Constants of the Model II ($\ln i=B\exp(-n/V)$) at different temperatures

Temperature °C	n	B
33	15.5	32.8
50	1.3	6.1
60	1.6	6.8
70	1.8	7.9

dissociation of molecules under the influence of the applied voltage.

2. *High performance liquid chromatograms.* Figure 3 shows the results of high performance liquid chromatograms of the chemical standards (Traidencane, Toluene, Nephatalen and Anthracen), fresh and aged oil samples. It reveals the

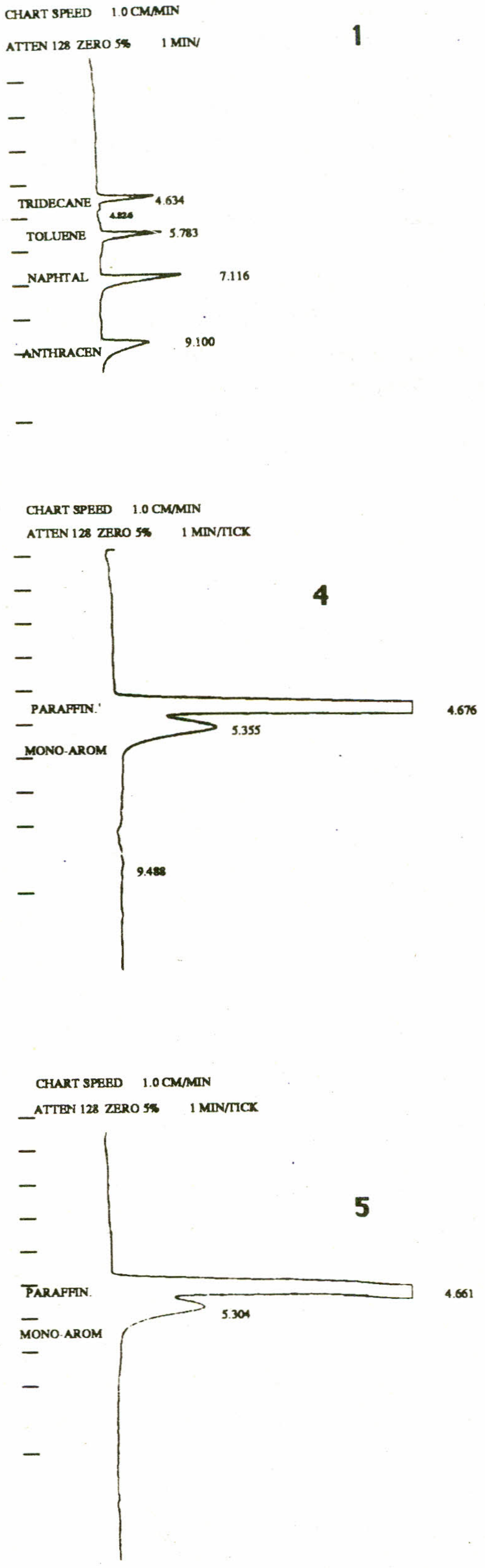

Fig. 3. HPLC spectra of standard oil (#1), fresh oil (#4) and aged oil (#5).

presence of different components of oil and particularly a good resolution with retention time of 4.6 min. (Paraffinic part) and 5.3 min. for monoaromatics in both fresh and aged oil samples. The components with retention time 9.48 min. which is aromatic addditive are shown in the fresh oil sample spectra. This indicates that additive have been decomposed during the service, whereas the rest of the structure remained unchanged. Any change in the general structure especially in olefin part will be seen using this technique. This means that the processes that take place under the electric stress and thermal energy are more complicated. HPLC technique, under these experimental conditions, could not show the structural changes in oil components which support the previous findings [4] using GC and C^{13} -NMR. Modified techniques of HPLC, GC and C^{13}-NMR are under investigation.

Conclusion

From the above studies the following conclusion can be drawn:

1. The i-V characteristics are strongly dependent on temperature. The current changes by several orders of magnitude with a change of temperature of the order of less than 15%.

2. Beyond 60° the rate of increase of current with voltage increases considerably.

3. The dependence of conduction current at different temperature with voltage is not a simple exponential. However, it is found that it can be represented by a model of the form ln i = B exp (-n/V).

4. HPLC technique is useful in detecting only the additive decomposition during the transformer operating. Therefore modified spectral techniques need to be investigated in order to understand the structure changes in the oil components.

Acknowledgement The authors wish to thank the Board of Research Centre, College of Engineering for financial support and the Research Centre of College of Pharmacy for providing spectroscopy test equipment facility. We are also indebted to SCECO of Central Region for providing the oil samples.

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