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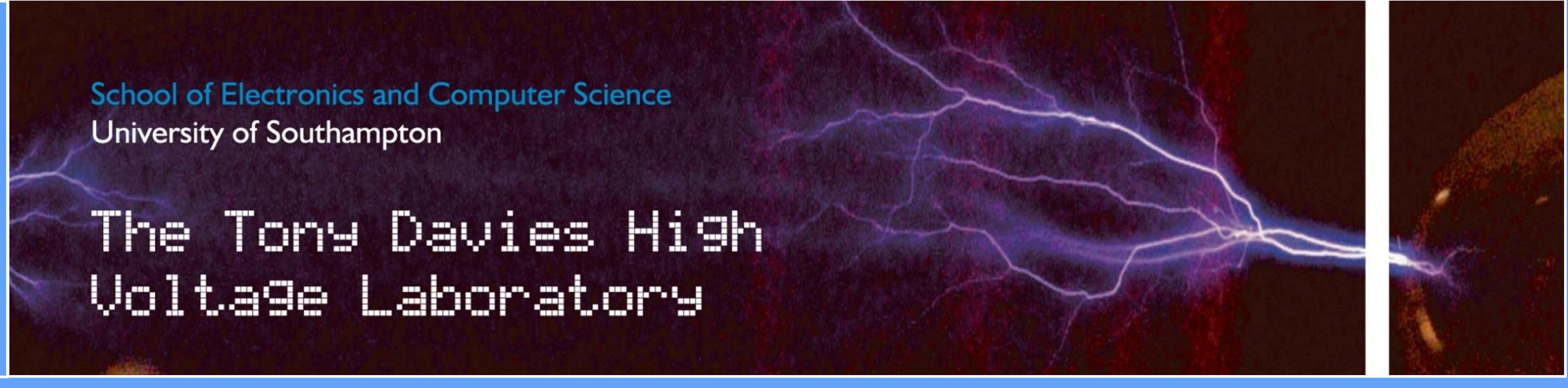
School of Electronics and Computer Science
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Electrode effect in new mineral oil studied by dielectric spectroscopy

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Introduction

Dielectric spectroscopy, as a non-destructive measurement, has been employed for analysing dielectric properties of material for many years, including mineral oil that has been widely used in power transformers. Understanding the mechanism of the conduction of mineral oil will benefit the research of oil condition which is important for reliable operation of power transformers.

In this paper, the dielectrics spectroscopy tests have been performed under different temperatures and two electrode gap spacing, and the oil model established from DC current simulation has been used to model the conductivity derived from dielectric test, whilst new factors have be added to improve the quality of the curve fit.

From the test, the conductivity of the oil calculated from dielectric response in the low frequency range (100Hz~0.001Hz) comprises three stages: two steady states joined by a transient process. It has been found that both the spacing between two electrodes of the testing cell and the temperature influence the starting frequency of the transient process.

Experiment details

The mineral oil ZX-IG, provided by Shell Company, has be vacuumed for half an hour to remove the air bubbles before test.

The dielectric spectroscopy tests were performed at four different temperatures, 25°C, 50°C, 75°C, 90°C, and two different electrode gaps, 0.6mm and 0.12mm.

The frequency range for the test was 0.001Hz - 100Hz, and dielectric spectroscopy was carried out using Solartron 1296 dielectric interface and Model 1260A Impedance/ Gain-Phase analyser.

The test procedure proposed by CIGRE JWG A2/D1.41 was followed.

Experimental results

The dielectric test results are shown below (Figure 1 – Figure 4).

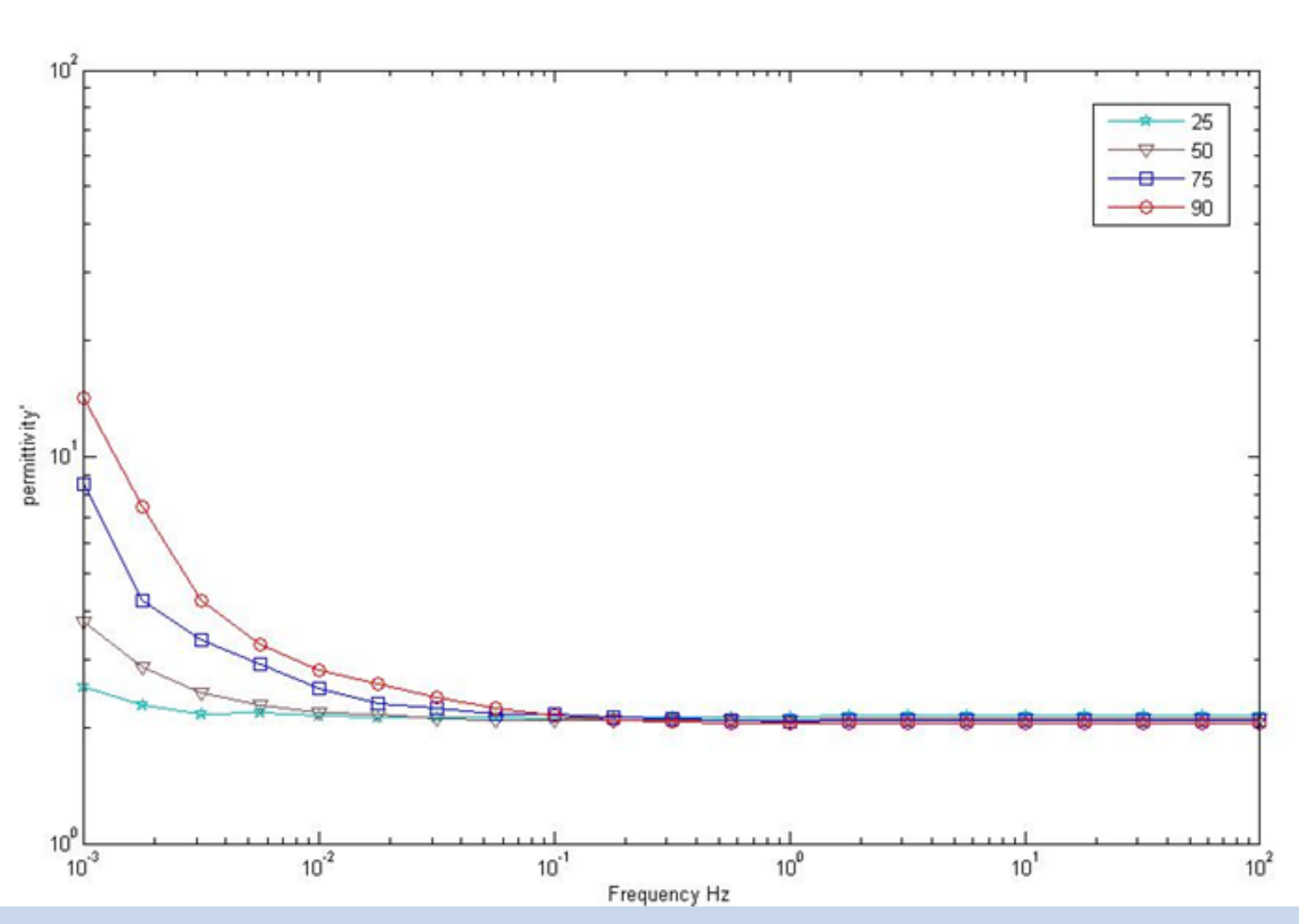

Fig. 1 Real part of oil permittivity with 0.6mm gap

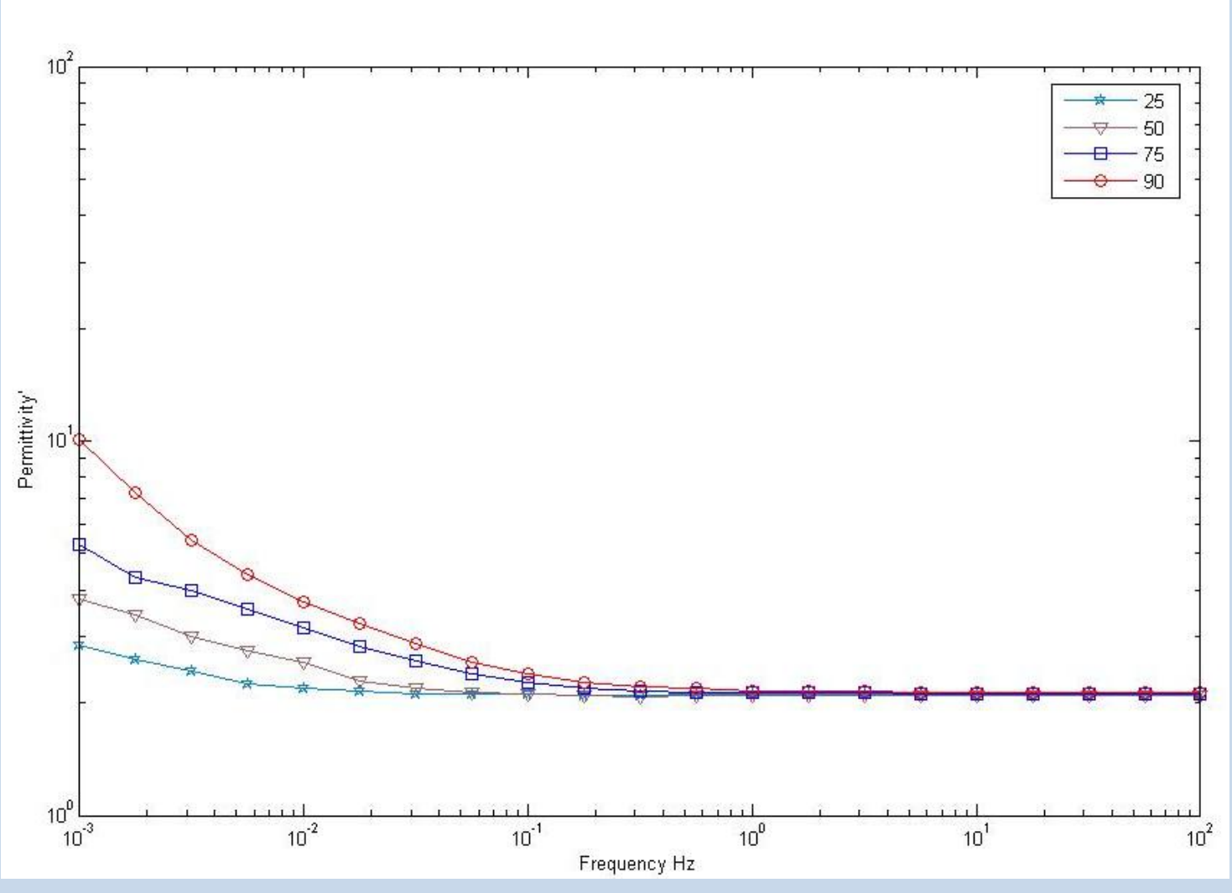

Fig. 2 Real part of oil permittivity with 0.12mm gap

The oil permittivity with two different gap distances is almost the same. These curves are constant at high frequency and increase significantly at low frequency. It seems the frequency at which the permittivity starts to increase is higher for smaller gap. At higher temperature, the permittivity increases faster and the starting frequency is also higher.

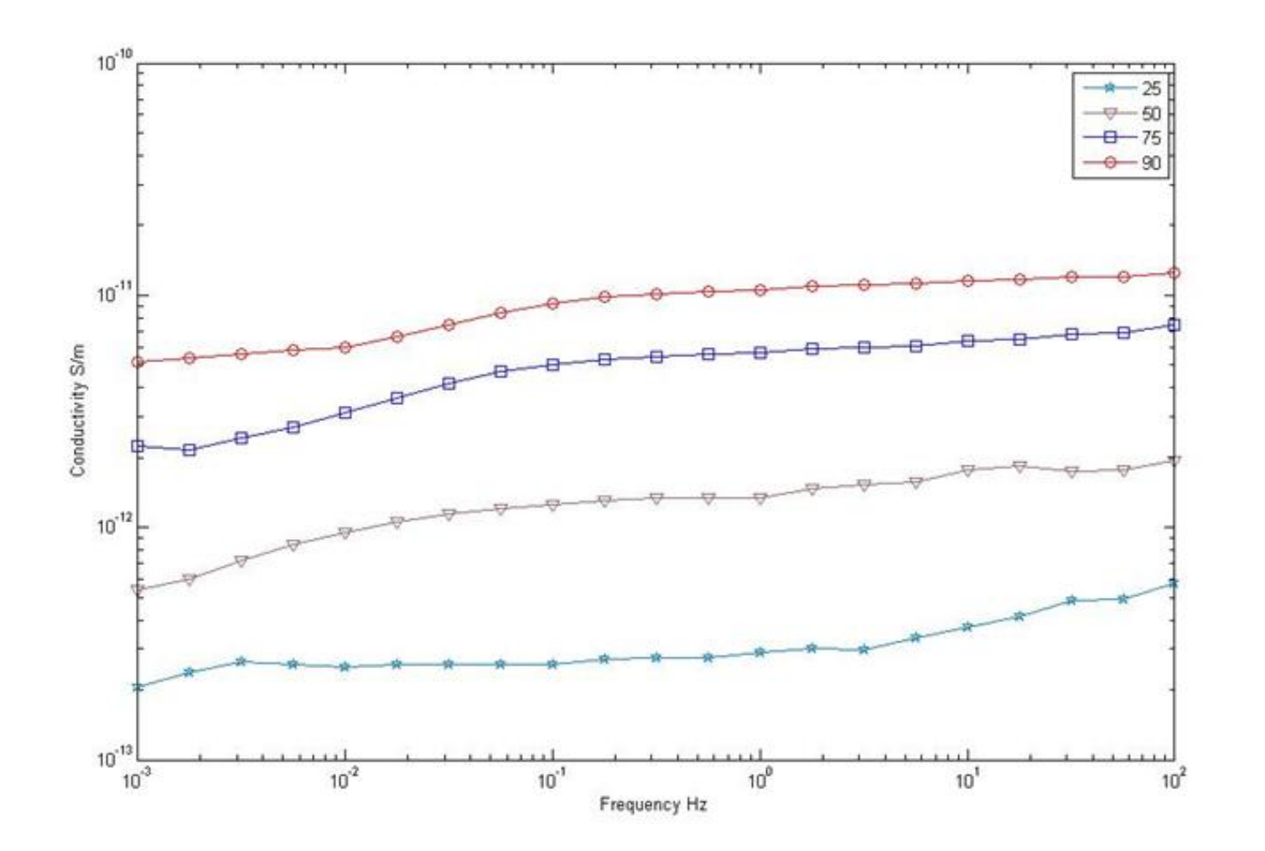

Fig. 3 Frequency dependence of conductivity of 0.6mm sample

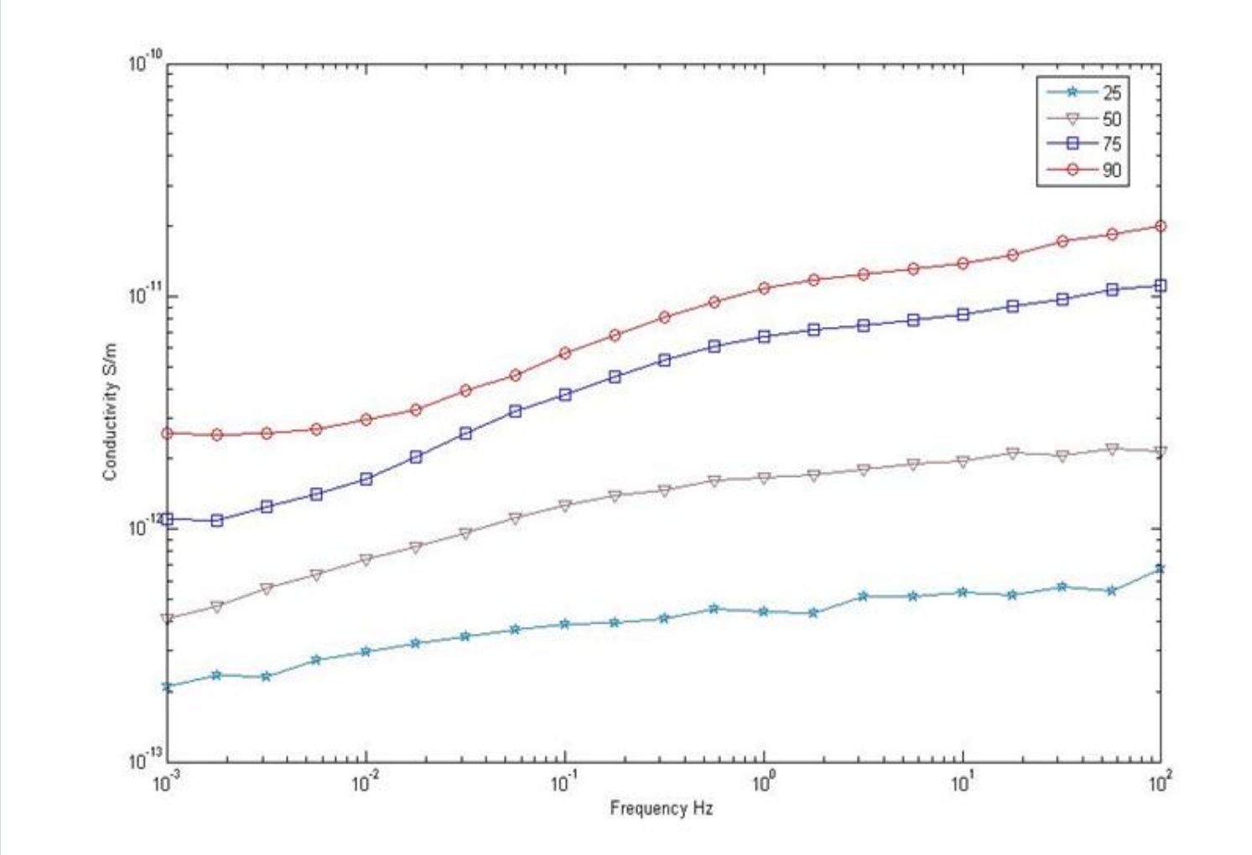

Fig. 4 Frequency dependence of conductivity of 0.12mm sample

The conductivity curves reveal a slightly decrease at higher frequency, then decrease notably prior to reaching a constant value. It is apparent that all those curves have a transient stage, and this might be due to the electrode effect and diminishing of charge carriers. The frequency at which this transient process starts or ends would be higher at smaller gap distance and higher temperature. For the easy analysis, three stage processes have been defined. The first stage is the quasi-steady state at higher frequency, the second stage is the transient process around 0.01-10Hz, the third stage is the quasi-steady state at lower frequency where a much lower conductivity is obtained comparing with the first stage.

For further analysis and simplicity, we define the slope of conductivity as this:

$$s = \frac{\sigma(f_n) - \sigma(f_{n-1})}{\sigma(f_n)}$$

and the critical frequencies are defined using the following equation:

$$s(f_{crit}) = \frac{s_{\max} - s(f_0)}{5}$$

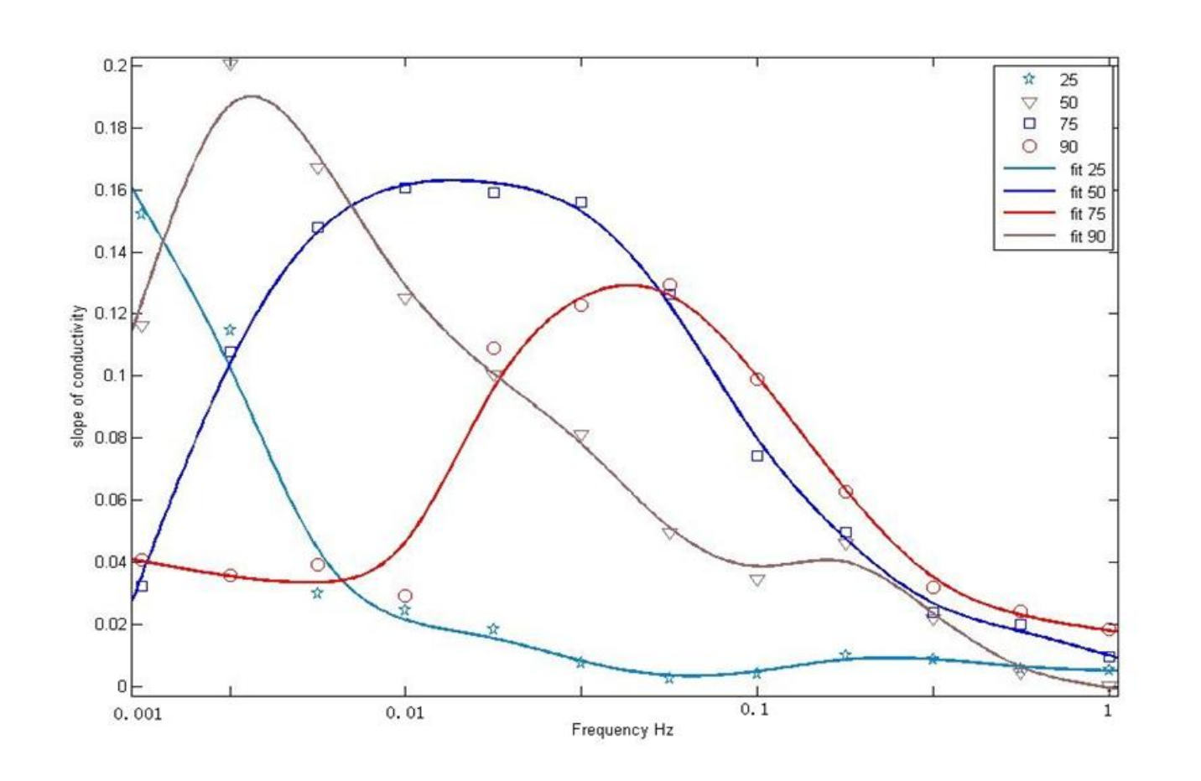

Fig 5 Change in conductivity slope with 0.6 mm gap

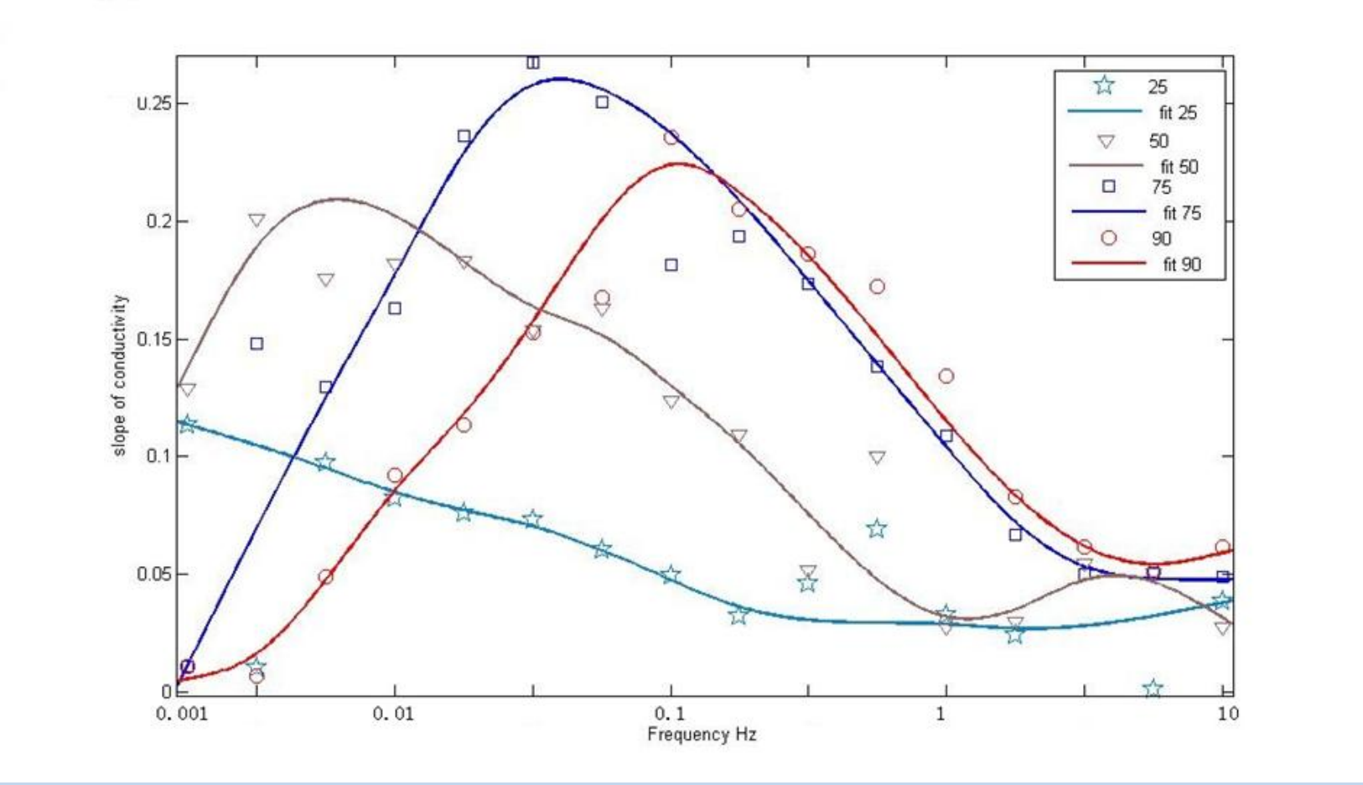

Fig 6 Change in conductivity slope with 0.12 mm gap

where S_{max} is the maximum value of the curve, while $S(f_0)$ means a quasi-constant value in the curve at higher or lower frequency. The change in conductivity slope for two electrode gaps is shown in Fig. 5 and Fig. 6. The mountain-shaped curves moves from higher frequency to lower frequency as the temperature decreases. Shorter distance between electrodes will move these curves towards higher frequency.

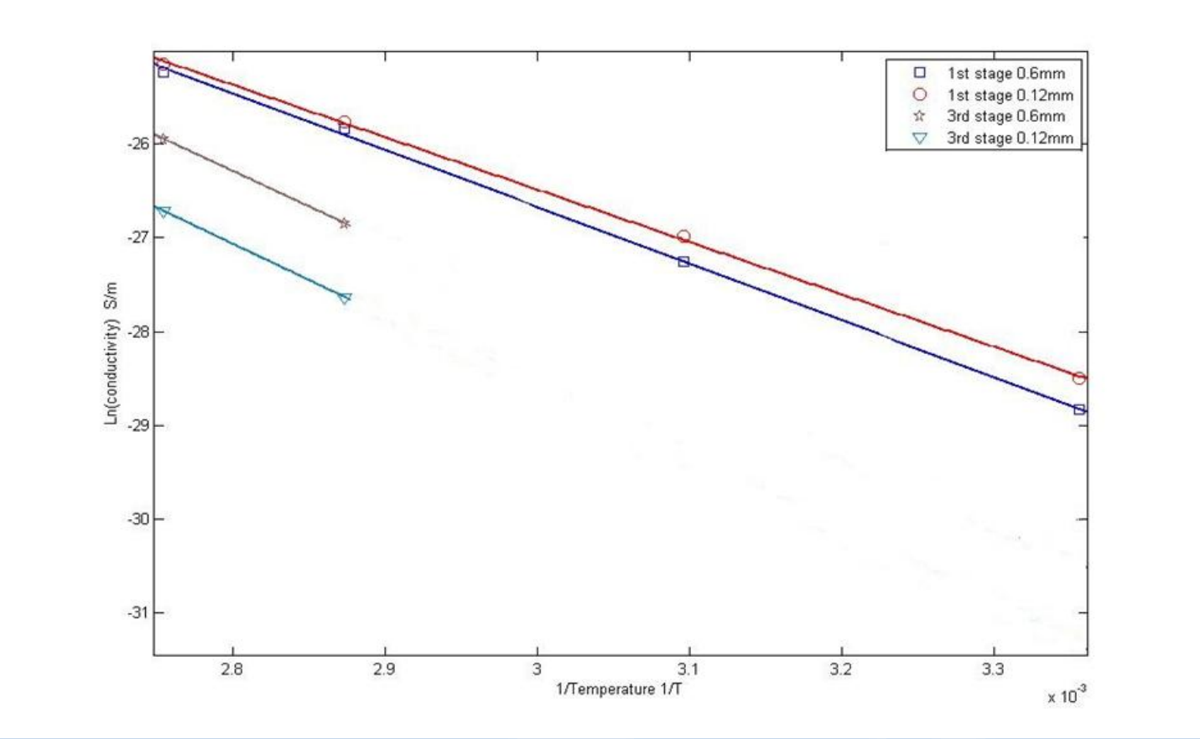

Fig 7 Temperature dependence of conductivity

Fig. 7 shows that, although conductivity at the first stage is almost the same, the difference between the conductivity at the third stage is not negligible, and the conductivity with smaller dap distance is much lower than the other one, which might be caused by the charge carriers accumulated around the electrode and the reduction of total charge carriers in the system.

Simulation based on the oil model under dc condition

In the model used for oil dc conductivity, the initial amount of charge carrier remians constant, and the charge at time t is reduced due to the flowing current.

$$Q(t) = Q(0) - \int i(t)dt$$

The current can be denoted as the following equation

$$i(t) = Q(t) \times \mu \times E(t) / L + I_{end}$$

However, since during the test process, new charge carriers can also be generated though injection, electron transfer, dissociation etc, it would be reasonable to introduce a new factor K, the generating rate to the existing model. Thus, the above equation can be modified as,

$$\frac{dQ}{dt} = -i + K(Q^2(0) - Q^2(t))$$

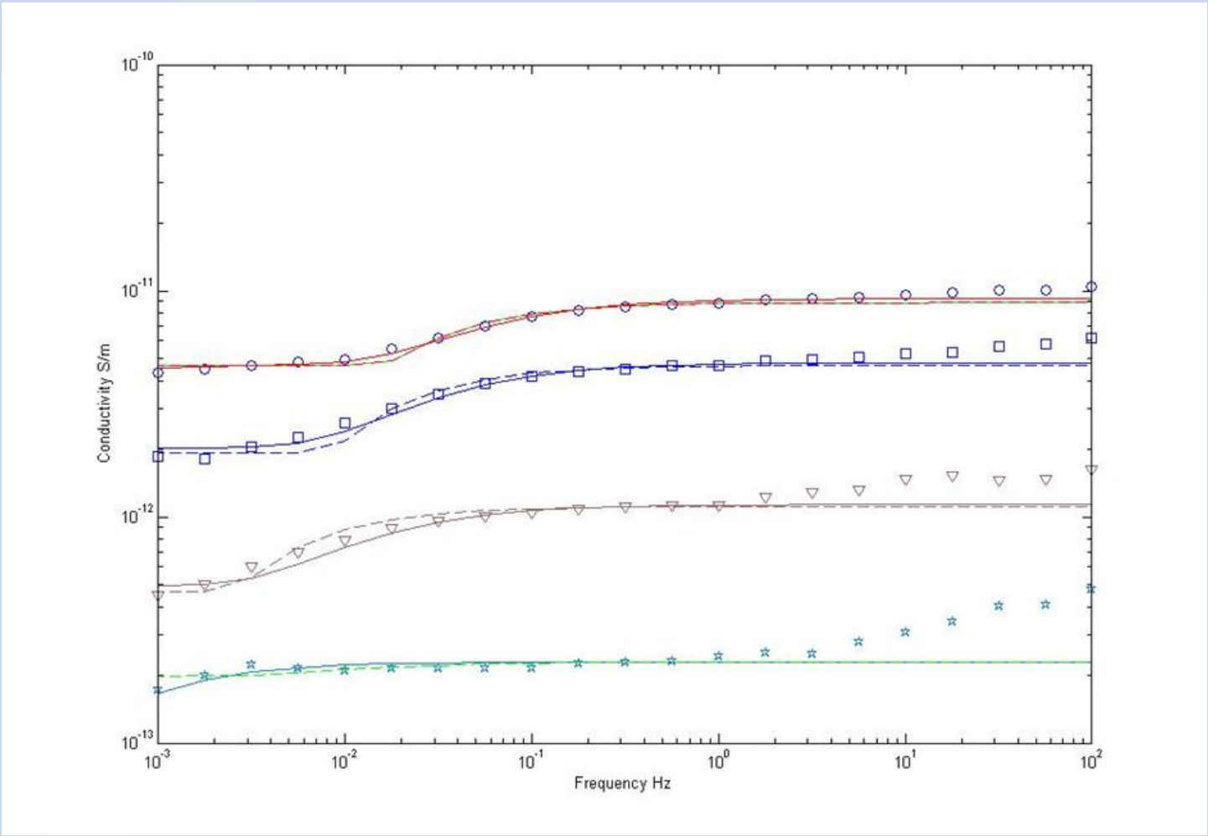

Fig 8 Compare of old and new models on sample with thickness of 0.6mm

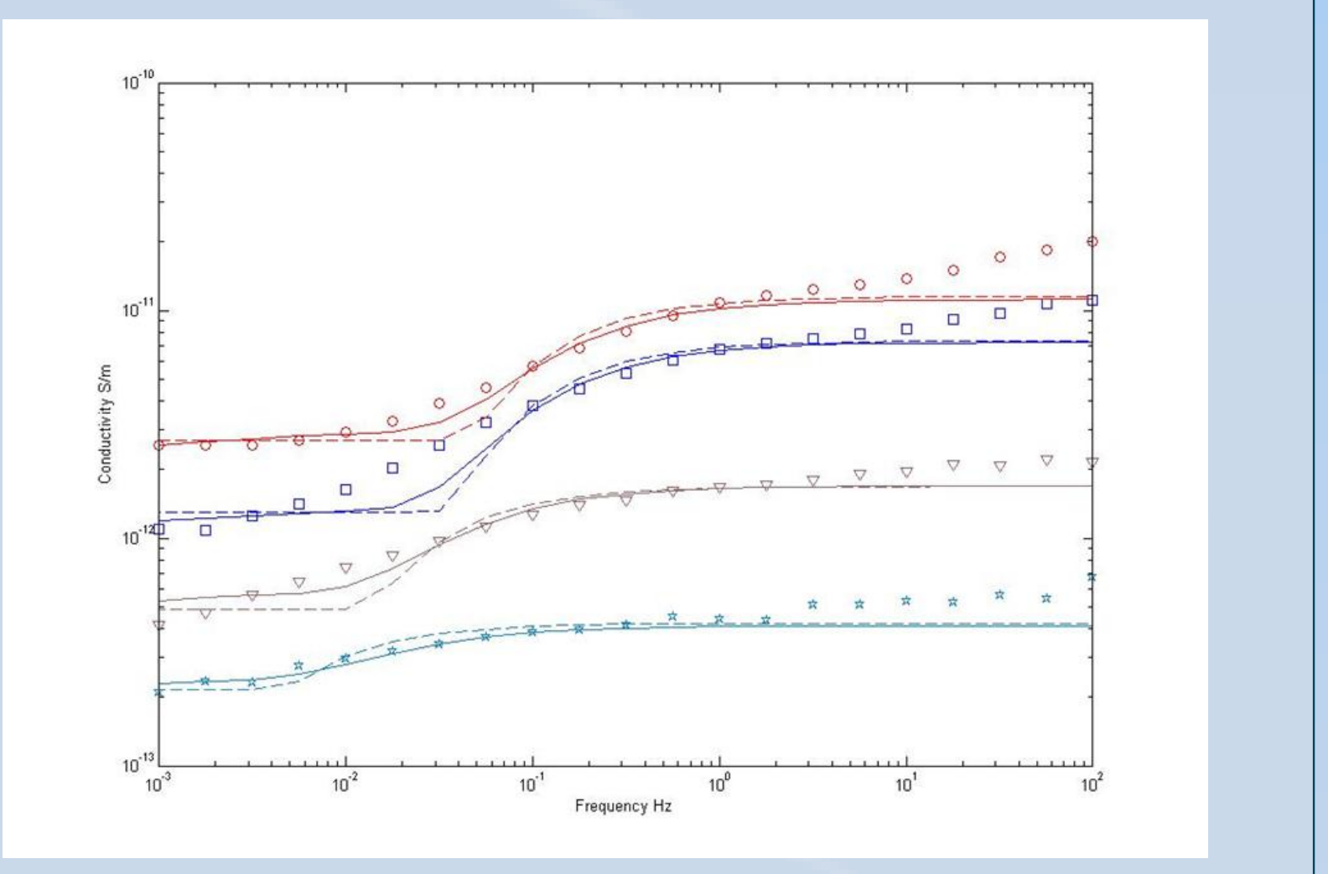

Fig 9 Compare of old and new models on sample with thickness of 0.12mm

The simulation results based on the new charge dynamics are shown in Fig. 8 and Fig. 9 for two gap distances. From the simulation results, we can clearly see that the improved model can fit the result much better than the old one due to less relative error. There are still some factors not involved in this model, it does not fit the experimental data perfectly. Thus, more improvement is required.

Conclusions

From the experimental results and analysis, it has clearly demonstrates the following features:

1) Oil conductivity decreases in the mid frequency range and becomes constant again at lower frequency, thus 3 stages analysis can be used.

2) Prominent change in the permittivity in the lower frequency range

3) Oil conductivity increases with temperature

4) Shifting of the responses towards higher frequency with temperature and the distance between electrodes.

5) Oil conductivity at the third stage decreases with electrode gap distance.

From the simulation result, it seems the improved oil model can fit the curve a little better, however, further improved can be made by including other factors such as charge accumulation and ionic drift and diffusion, etc.

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