Dielectric Proprieties Determination of High Density Polyethylene (HDPE) by Dielectric Spectroscopy

T. Seghier and F. Benabed

***Abstract*—Dielectric methods are now widely used to study and characterization of organic or inorganic insulators, because of the wide range of frequency that can be studied with excellent resolution. In this article, we present and analyze the dielectric properties of high-density polyethylene (HDPE) by dielectric spectroscopy, we present permittivity, loss factor and conductivity data at frequency range of 10-2 Hz to 1 MHz over temperature range of -60 ℃ to 60 ℃.**

***Index Terms*—Dielectric proprieties, high density polyethylene, spectroscopy, temperature.**

I. Introduction

The isolation function is critical because it is one of the basic operating conditions of electrical energy (production, transmission and distribution). Given the importance of insulation systems in the life of high and medium voltage equipment, we must study and understand the mechanisms that are responsible for the degradation of these systems.

Polyethylene is the most widely used insulation materials because of its electrical and mechanical properties which have made it a preferred material for cable insulation in high voltage [1]. There are several types of polyethylene, which are distinguished by their chemical structure.

In this paper, we present the dielectric proprieties of high density polyethylene HDPE which is obtained at low pressure, and is a linear, crystalline and rigid polymer.

These proprieties such as permittivity ε', conductivity σ and loss factor tanδ are measured by dielectric relaxation spectroscopy (DRS) in the frequency range (10^{-2} - 10^{6}) Hz at temperature between -60 and 60 ℃.

II. Dielectric Spectroscopy

Dielectric spectroscopy, which is based on the measurement of current and voltage (amplitude and phase AC system) is widely used to study the dielectric properties of polymers such as (ε', tanδ …) [2], [3].

Its scope very high frequencies (~ THz) which are used to characterize all atomic phenomena and electronic polarization, and down to very low frequencies range (~ MHz) to characterize the state of different interfaces which may exist between insulation components [4].

Under an alternative (ac) sinusoidal supplied voltage, the real part of permittivity and loss factor is computed using the following equations:

$$\varepsilon' = \frac{C_p\, d}{\varepsilon_0 A} \tag{1}$$

$$tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{1}{R_p C_p \omega} \tag{2}$$

where ε_0 is the vacuum permittivity, d the thickness of the sample polymer, A the electrode area and ω the angular frequency, C_p and R_p are the capacitance and the resistance measurements.

The static (dc) conductivity has been derived from the (ac) conductivity measurements at low frequency:

$$\sigma_{ac}(\omega) = \omega\varepsilon_0\varepsilon''(\omega) = \sigma_{dc} + K\omega^n \tag{3}$$

where K is an empiric parameter and n represents the high frequency slope of the (ac) conductivity from 0 to 1 [5].

III. Experimental Method

The material used in this study is a High density Polyethylene (HDPE). As shown in Fig. 1, the specimens used in measurements are gold coated on each face to obtain circular electrodes of 16 mm in diameter and the thickness of the sample is 1 mm. Samples are prepared in laboratory to analyze partial discharge phenomena [6], [7].

Measurements of the real part of the permittivity, the loss factor and the conductivity for polymer samples were performed under AC voltage 1V in the frequency range 10^{-2} Hz to 1 MHz using a Broad Band Dielectric Controller (Novocontrol), Alpha, Beta Analyzer.

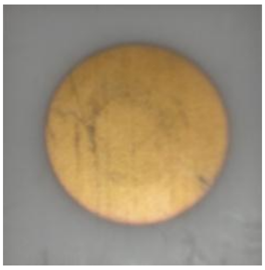

Fig. 1. Picture of the solid insulation sample HDPE.

IV. Results and Discussion

The experimental results of the loss factor and real part of the permittivity versus frequency and temperature for the samples of HDPE are illustrated in Fig. 2 and Fig. 3.

From Fig. 2, it is clear that the dielectric constant ε' is a slight function of frequency with a slight decrease as frequency increases. Dielectric constant is higher at low

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frequencies; the decrease with temperature is attributed at the temperature-dependent of the specific volume of HDPE [8].

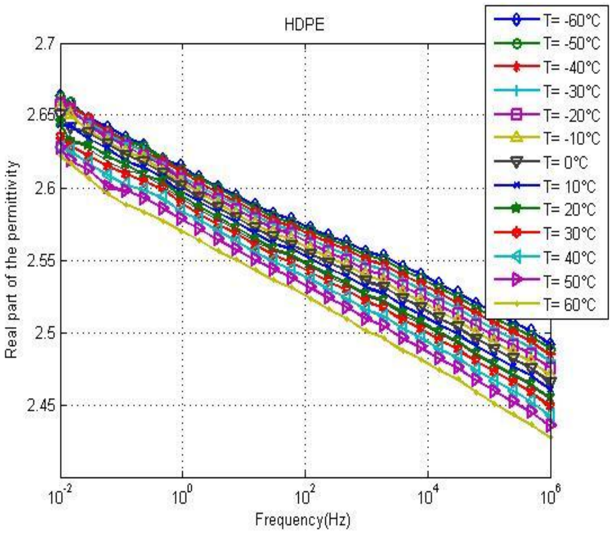
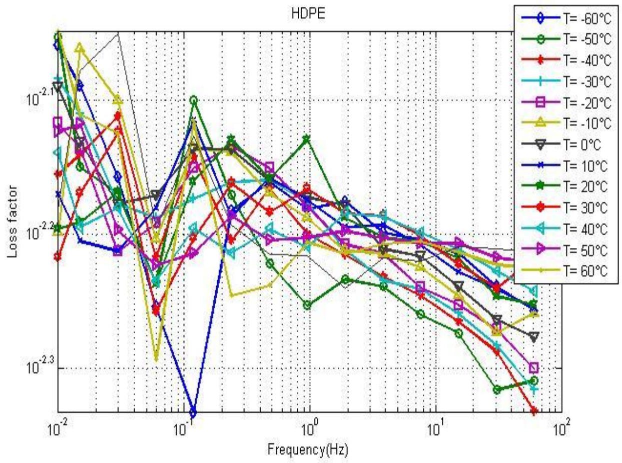
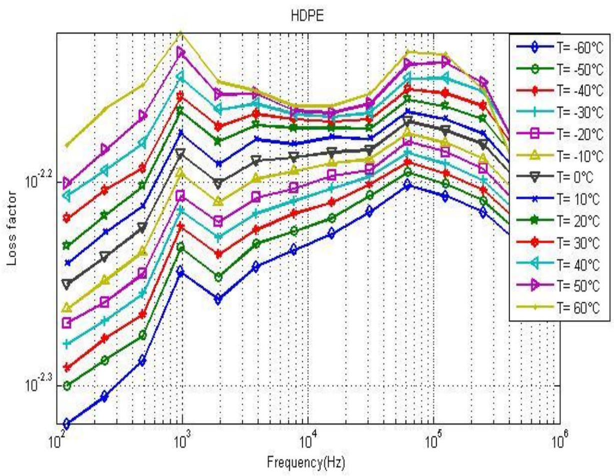


Fig. 2. The real part of the permittivity ε' of HDPE as function of frequency for different temperature.



(a) Frequency range 10^{-2} to 10^{2}Hz



(b) Frequency range 10^{2} to 10^{6}Hz

Fig. 3. Loss factor of HDPE as function of frequency for different temperature.

In contrast from Fig. 3, the loss factor varies with temperature more vigorously at lower temperature due to change in structure. We know that the polyethylene has a very low glass transition temperature, which lies in the region where the fluctuations are observed [9].

The variation of ε' and $\tan\delta$ with ω, including the effect of DC conductivity, is shown in Fig. 4.

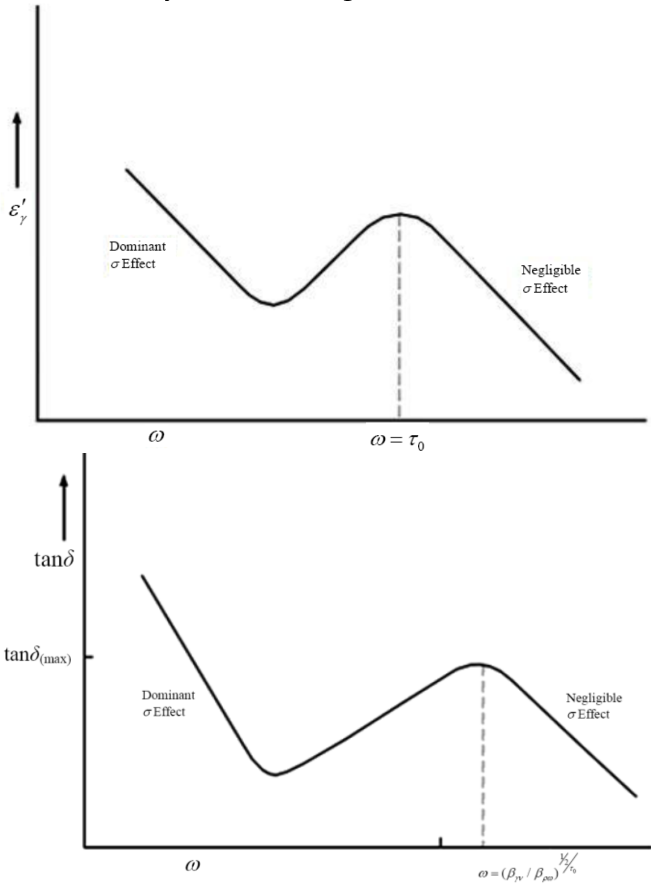


Fig. 4. Permittivity ε' and loss factor as functions of pulsation taking into account the effect of dc conductivity [10].

An important increase in values of ε' and $\tan\delta$ at low frequencies and high temperature is observed. This reflects conductivity effects due to free charge motion within the material [11].

For very low frequencies there is enough time for these ions to build up at the interface between the material and the electrodes giving rise to space charge polarization.

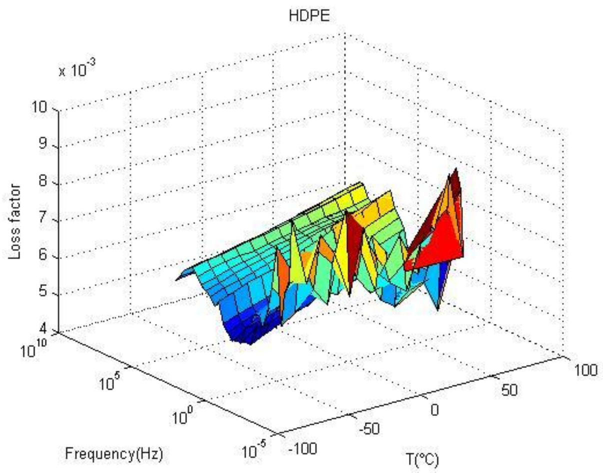


Fig. 5. Loss factor of HDPE as function of frequency and temperature.

For more details, we present the variations of the real part of the permittivity ε', the Loss factor and the real part of the conductivity σ' as a function of frequency and temperature in 3D curves, on Fig. 5 and Fig. 6 respectively.

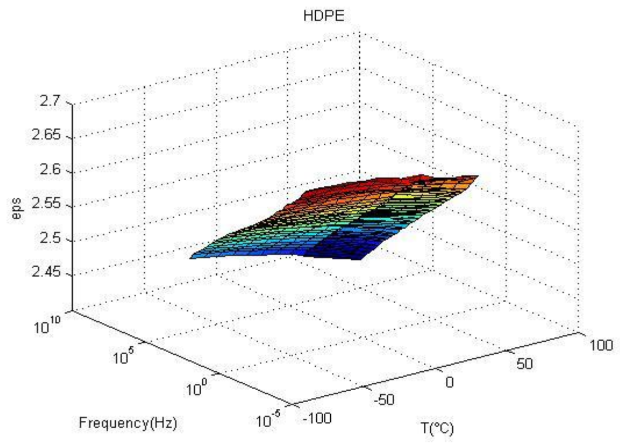


Fig. 6. The real part of the permittivity ε' of HDPE as of frequency and temperature.

Theatrically a non-polar polymer such as HDPE should show only α- dispersion since the only motion that can occur is due to the main chain at the glass transition temperature, but from Fig. 5, two loss regions are observed in HDPE: the exact temperature and frequency can be determined by recognizing the morphology and impurity for the samples [9].

The loss peaks may due to the presence of polar additives or other impurity.

The dielectric loss of HDPE at different temperature is almost constant because HDPE is thermally stable than other polymers [6]. But the peaks observed in Fig. 3 and Fig. 6 are related to the orientation-induced modifications of the structural and morphological parameters [12].

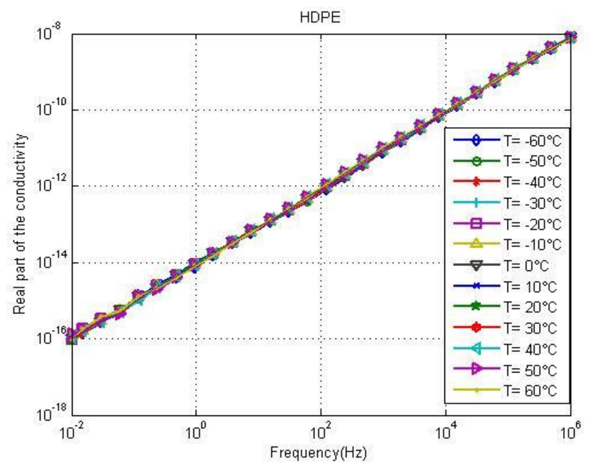


Fig. 7. The real part conductivity σ' as function of frequency for different temperature.

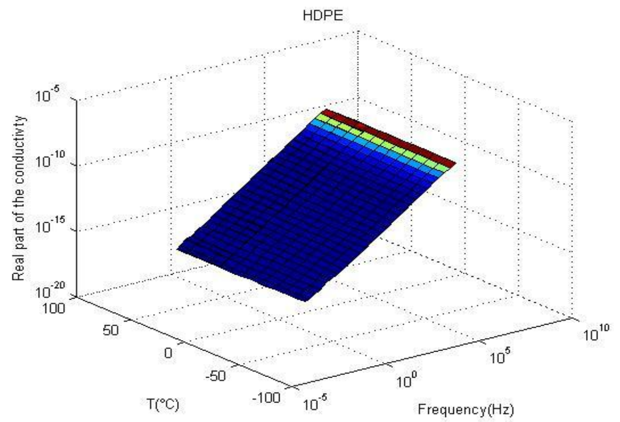


Fig. 8. the real part Conductivity σ' as function of frequency and temperature

From Fig. 7 and Fig. 8, it is clear that conductivity increases with frequency, while the temperature has no effect.

It is generally believed that conductivity and the relaxation process contribute to the increase in both real part of permittivity and the loss factor on decreasing frequencies [13].

V. Conclusion

In this work we have presented results of electrical and dielectric studies in polyethylene high density by using of dielectric relaxation spectroscopy (DRS in frequency range 10^{-2} - 106 Hz and temperature between -60 ℃ and 60 ℃. The use of dielectric spectroscopy technique allowed observing the dielectric behavior of HDPE samples in the low frequency region and the results of DRS were analyzed within the permittivity formalism.

The experimental results indicate that the decrease in dielectric constant with frequency and temperature for HDPE which is a non-polar polymer, is described to the weak polar nature of this polymer, some loss peak are observed as a result of the presence of additive and other impurities.

The results also show that the decreasing in the dielectric constant with increasing frequency is due to the DC conductivity contribution.

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