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Determination of the Dielectric Constants of Carbonated High Density Polyethylene (HDPE)

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INTRODUCTION

In this research work we studied dielectric constant of carbonated polymers. Polymers have been with us since the formation of the earth. Some of the synthetic polymers were discovered during the nine-teen century and at late 1930s.

Some polymers like tar, shellac, tortoise shell and horn, tree sap that produces amber and latex exist naturally. These natural polymers can be processed to get useful product for commercial consumption. We have plastic polymer classified into thermoplastics and thermosetting. Thermoplastics include elastomers (unvulcanised), polyvinyl chloride (PVC), polyethylene (PE), Polystyrene (PS), polyurethane (PU) and resins. Thermosetting include elastomers (vulcanized), polyethylene, polyesters. Polymers have found uses in all spheres of life with demand for better materials. The average per capital global consumption of polymers is estimated to be about 17kg. Presently the consumption /demand are estimated at around 5.5 million tones.

POLYETHEYLENE:

Polyethylene is the simplest polymer, composed of chain of repeating $-CH_2-$ units, Piringer et-al. (2008). It is produced by addition polymerization of ethylene $CH_2 = CH_2$ (ethene). The properties of polyethylene depend on the manner in which ethylene is polymerized, Kenneth (2005). When it is catalyzed by organ metallic compounds at moderate pressure (15 atm), the product is high density polyethylene HDPE. HDPE is hard, tough resilient and are mostly used in manufacturing of containers like milk bottles and laundry detergent jugs, Baedeker (2012).

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Molecular arrangement of Polymers can be either Crystalline or amorphous.

DIELECTRICS AND DIELECTRIC CONSTANTS K

A dielectric material is an electrical insulator that can be polarized by an applied electrical field (Encyclopaedia Bricannica). Dielectrics are placed across the plate of a compaction like a little non – conducting bridge and are also used in reference to non-conducting layer of a compactor. When a dielectric field, electric charger do not flow through the material as they do in a conductor. They serve three purposes in compactor these are to keep the conducting plates from coming in contact, allowing for small plate separation and higher capacitance. They increase the effective capacitance by reducing the electric field strength, Daintith (1994). Most dielectric material are solids examples include mica, glass, plastics, oxides of various metals, dry air and are used in variable capacitors. Dielectric constant K is the relative permittivity of a dielectric material. It is the measure of the ability of a material to be polarized by an electric field or store electric energy in the presence of an electric field.

CARBON / CARBONATION OF POLYMER

Carbonation of polymer means addition of extra carbon substance to polymer. There are different isotopes of carbon; graphite, diamond and amorphous carbon. They come in different forms like lamp black and charcoal, Michael smith (1999).

Lamb black is a form of carbon also known as carbon black or furnace black. It is fine soot collected from incompletely burned carbonaceous material. It is used in matches, lubricants, fertilizers and as pigments.

Charcoal is a light black residue consisting of carbon, and residual ash obtained by removing water and other constituents from animal and vegetation substances. Charcoal is produced by pyrolysis through the heating of wood and other substances in the absence of oxygen, Michael smith (1999). It is an impure form of carbon because it contains ash.

CAPACITORS AND CAPACITANCE

A capacitor is a passive two terminal electrical component used to store energy in an electrical field, Donf etal. (2001). Capacitors are widely used as part of electrical circuits in many common electrical devices. According to Cletus J Kaiser, capacitor consists of two parallel conductive plates usually of metal which are prevented from touching each other by an insulating material called dielectric material. The application of voltage to these plates causes electric current to flow and charge up these plates, one plate is charge with positive charge and other plate with equal and opposite charge with respect to the voltage supply.

There are different types of capacitor which include electrolytic capacitors, solid dielectric capacitors and air dielectric capacitor. Electrolytic capacitors use an aluminum or tantalum plate with an oxide dielectric layer. The second electrode is a liquid electrolyte connected to the circuit by another foil plate. Electrolyte capacitors are often very high capacitance but suffer from poor tolerances, high instability, gradual loss of capacitance especially when subjected to heat and high leakage current, keithley et. al (1999).

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METHODOLOGY / SAMPLE PREPARATION

Here, many samples of High Density Polyethylene (HDPE) were purified by washing them in cold distilled water and allowed to dry under the sun. Each sample was measured with digital weighing balance to obtain three to five specimens of different weights.

Charcoal which is a form of carbon obtained from the burning of star apple wood was crushed into powder and sieved to remove rough and ungrounded ones. The grounded charcoal was measured to get different weighed samples for the polymer samples used. 30g of HDPE was measured for five different times and were poured in five beakers (100ml) labeled samples A1, A2, A3, A4 and A5, respectively. It was observed that this HDPE has bright white colour, very strong and tough when felt with both hand and teeth. Sample A (pure and uncarbonated) was heated with the help of heating mantle for 5 minutes. The bright white colour of the polymer sample started changing from white to water colour. Some smokes with choking smell were also seen and perceived during the heating process. The melting sample of HDPE was stirred at every four minutes interval to hasten the melting of the sample. The sample started changing from the solid form to liquid form, around ten minutes and the water colour was also changing, at temperature around 160^o-180^o, the sample was seen to have melted and had a brownish yellow colour. It was allowed to cool and solidify in the beaker.

The four other remaining samples, A2, A3, A4 and A5 were measured 30g each and heated differently. Four different weighed samples of carbon 5g, 10g, 15g and 20g were added to the above polymer sample A2, A3, A4 and A5 respectively. They were all stirred vigorously to ensure homogeneity of mixture of the sample. All these samples were allowed to solidify and cool in the beakers. The result of the experiment is as shown on table 1.1 below.

Sample	Weight of Polymer (g)	Weight of Carbon (g)	% Weight of Carbon	Ratio of Polymer to Carbon

A1	30	0	0	30:0
A2	30	5	16.7	6:1
A3	30	10	33.33	3:1
A4	30	15	50	2:1
A5	30	20	66.7	3:2

Table 1.1: High Density Polyethylene (HDPE)

EXPERIMENTAL CONSTRUCTION OF A CAPACITOR PLATE

Two circular plates of diameter 118mm (0.118m) were cut out from a thin copper plate bought from bridge head market Onitsha. The edges of the cut out circular plates were smoothened with a filing machine (bench grinder). The surface of the plates were also washed with sandpaper and clean water to remove trapped dirt and oxide, they were allowed to dry. Two thin wires were soldered at the back of the plates respectively. A wooden guard ring was constructed to support the two circular plates when they were placed parallel to each other. The plates were also glued on the ring to enable a firm grip, a rectangular base was provided for the guard rings. The wooden guard rings reduced and eliminated edge effect (they protect the two copper plates from being touched with hand).

EXPERIMENTAL MEASUREMENT OF THE DIELECTRIC CONSTANT OF BOTH CARBONATED AND UNCARBONATED POLYMER SAMPLES

The dielectric constant of a material can be measured with different methods. Some of these methods are alternating current bridge method, time domain method, transmission method, direct current (D/C) method, sub millimeter method, ballistic method, impedance method and resonance method. In this work we used resonance method which involves the application of voltage or current into an LC (inductance-capacitance) resonance circuit. It is a useful method used especially when the frequencies are greater than 1MHZ. Measurement over a range of frequencies may be made by using coils with different inductive values, but ultimately the inductance required becomes impractically small in the range

10^8-10^9 H, reentrant cavity are often used. These are hybrid devices in which the plate holding the specimen still forms a lumped capacitor, but the inductance and capacitance are distributed along a coaxial line. In this method the resonance frequency f_o (the frequency at which the response amplitude is a relative maximum) is noted and also the amplitude where the resonance frequency occurred.

Figure 1.1: Experimental Set up for the Measurement of Diaelectric Constant of Polymers by Resonance Frequency Method.

The cathode ray oscilloscope used is a single beam type (instek oscilloscope Gos 620 20MHZ). It provided accurate time and amplitude measurement of voltage signals over a wide range of frequencies. The oscilloscope was plugged to the main supply and the power was switched on, a green light was shown indicating the presence of power supply. The oscilloscope warmed up within a short period of one minute after which a trace of beam appeared. The vertical and the horizontal controls were used to place the line on the center of the graticule. The signal generator was connected between red inputs. An A/C knob was pressed since an A/C main was used. Volt /cm knob was adjusted to obtain a display of convenient amplitude. The time /cm switch was adjusted to display as much details as required.

The different samples of both carbonated and noncarbonated polymer with different thicknesses ranging from 0.5cm-2.0cm were inserted one at a time between the capacitor plates, the plates were made to fit closely on both sides of the dielectric material. Firstly, the two plates of capacitors are placed at a very small distance of about (2cm), the resonance frequencies f_o and

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amplitudes A were obtained with air as the dielectric. The spacing between the two copper plates should be small for a good result to be obtained. The electric materials were introduced between the plates which raised the capacitance of the capacitor. The resonance frequency when air was the dielectric is denoted by f_o and that of the polymer material was f_p, the peak to peak values of the wave form were recorded.

At resonance, the tuned signal generator frequency is in phase with the natural oscillation of the LC system. The energy (amplitude) superimposition was observed on the CRO under this condition

$F=1/2\Pi\sqrt{LC}$ ....(1)

Were L=inductance of the inductors, C=capacitance of the capacitor, F= frequency.

$C=1/4\Pi^2LF$ .... (2)

$C_O=1/4\Pi^2LF_0{}^2$ ....(3)

$C_P=1/4\Pi^2LF_P{}^2$ ....(4)

Where F_o is the resonance frequency with air as the dielectric,

F_p = the resonance frequency with polymer as the dielectric, L= the inductor of the circuit then

$$C_p/C_O = 1/4\Pi^2 L F_0^{\,2} \times 4\Pi^2 L F_0^{\,2}/1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

$$C_p/C_O = F_0^{\,2} / F_p^{\,2} = k \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where C_O and $C_{P,}$ are capacitances of the capacitor with air and polymer as dielectric materials. Equation 6 was used in calculating the dielectric constant of both carbonated and pure polymer samples. The tabulated result is as shown below;

With Air		With Polymer	
Frequency (Hz)x10^4	Amplitude (Cm)	Frequency (Hz)x10^4	Amplitude (Cm)
1.0	0.50	0.5	0.2
1.5	0.60	0.7	0.4

2.0	0.80	1.1	0.5
2.5	1.10	1.3	0.65
3.0	1.45	1.75	1.0
3.7	3.0	2.21	2.11
3.9	2.7	2.45	1.7
4.3	1.0	3.2	0.9
4.5	0.8	3.5	0.3

Table 1.2: 30g High Density Polyethylene with 0% Carbon

With Air		With Polymer	
Frequency (Hz)x10^4	Amplitude (Cm)	Frequency (Hz)x10^4	Amplitude (Cm)

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1.0	0.3	1.0	0.5
1.5	0.6	1.1	0.7
2.0	0.7	1.2	0.75
2.5	0.8	1.3	0.9
3.0	1.1	1.5	1.9
3.5	2.2	1.7	2.4
3.7	3.0	2.3	2.85
3.8	2.8	2.35	2.0
4.0	2.0	2.6	1.90
4.5	0.7	4.5	0.65

Table 1.3: 30g High Density Polyethylene with 16.67% Carbon (5g carbon) with Thickness 1.8cm.

With Air		With Polymer	
Frequency (Hz)x10^4	Amplitude (Cm)	Frequency (Hz)x10^4	Amplitude (Cm)
1.0	0.5	1.0	0.2
1.5	0.6	1.5	0.5
2.5	0.8	1.7	0.8
3.0	1.2	2.1	2.47
3.5	2.3	2.5	2.11
3.7	3.1	2.7	0.59
3.8	2.8	3.7	0.4
4.0	2.0	3.5	0.35

4.5	0.7	4.0	0.15

Table 1.4: 30g High Density Polyethylene with 10g Carbon (33.33% carbon) with Thickness 0.8Cm.

With Air		With Polymer	
Frequency (Hz)x10^4	Amplitude (Cm)	Frequency (Hz)x10^4	Amplitude (Cm)
1.0	0.3	1.0	0.4
1.5	0.6	1.2	0.8
2.5	1.1	1.4	1.5
3.0	2.2	1.6	2.9
3.5	2.8	1.7	3.2

3.7	3.0	1.8	4.0
3.8	4.2	3.5	3.0
4.0	2.4	4.0	1.9
4.5	0.9	4.5	0.9

Table 1.5: 30g High Density Polyethylene with 15g Carbon (50%) Thickness 0.8cm

With Air		With Polymer	
Frequency (Hz)x10^4	Amplitude (Cm)	Frequency (Hz)x10^4	Amplitude (Cm)
1.0	0.5	0.5	0.6
1.5	0.6	0.8	0.7
2.0	1.2	1.0	1.2

2.5	2.3	1.1	1.25
3.0	2.7	1.2	2.0
3.5	2.9	1.3	2.7
3.6	3.0	1.5	3.9
3.7	3.8	2.0	3.0
3.8	2.5	3.0	2.7
4.0	0.8	4.0	1.1
4.5	0.4	4.5	0.9

Table 1.6: 30g High Density Polyethylene with 20g Carbon (66.67% carbon) with Thickness 2.0cm.

Tables 1.1-1.6, show that there is increase in frequency when air and polymer were used as dielectrics. The amplitude also increases until it gets to a maximum value after which it starts decreasing. The frequency that gives the maximum value of amplitude is known as resonance frequency. This occurred in both pure and carbonated polymer samples.

Calculation of Dielectric Constant

The table below shows the resonance frequencies of different carbon composition of high density polyethylene including their dielectric constants.

Weight of Carbon (%)	Resonance frequency with air F_o (Hz)	Resonance frequency with polymer F_p	F_o^2 (Hz)	F_p^2	$K=F_o^2/F_p^2$
0	3.7×10^4	2.45×10^4	1.37×10^9	6.00×10^8	2.28
16.67	3.6×10^4	2.3×10^4	1.30×10^9	5.2×10^8	2.24
33.33	3.7×10^4	2.1×10^4	1.37×10^9	4.41×10^8	3.10
50.0	3.8×10^4	1.8×10^4	1.44×10^9	3.24×10^8	4.46
66.6	3.7×10^4	1.5×10^4	1.37×10^9	2.25×10^8	6.08

Table 1.7: Calculated Dielectric Constants of HDPE

CONCLUSIONS AND RECOMMENDATIONS

The dielectric constant of pure and carbonated samples of high density polyethylene thickness was studied. The dielectric constants of polymers increased with increase in the weight of carbon (charcoal). For the pure samples, the dielectric constant of HDPE was found to be 2.28. As different weights of carbon were added, the dielectric constants of the samples increased with the increase in the carbon weight.

The above effect is in line with the assumed effect of fillers on the polymers. The fillers tend to increase the conductivity of the polymer samples. The introduced carbon black acted as filler improved the physical properties of the polymer. This filler to a great extent controlled the mechanical properties (dielectric constant) and strength of polymer; it has lesser effect on the electrical properties. For high density polyethylene (HDPE), the dielectric constant obtained for various carbon compositions ranged from 2.28-9.51. When there is excessive potential difference across the dielectric separating a pair of charged conductor, the dielectric will break down and become conductor.

This effect was taken care of in the resonance frequency method used as the current was passed through the generator and the inductors to the plates. To obtain maximum value of capacitance, the thickness of the plates must be so very small and also the surfaces of the heated polymer samples must be very flat so that the capacitor plate will fit closely and tightly.

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