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# Determination of the Dielectric Constant of Pure and Bamboo Carbonated Polymers using the Impedance Method

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## ABSTRACT

*In this research work, we investigated the dielectric constant of pure and carbonated polymers using the impedance method. In carrying out the research, low density polyethylene (LDPE) and metallocene polyethylene (MPE) were used as the polymers. The main difference between LDPE and MPE is that low density polyethylene is produced by high pressure free-radical polymerization of ethylene while MPE is produced by low pressure polymerization technology using metallocene as catalyst to copolymerize ethylene and another monomer such as butane-1. Bamboo charcoal which serves as the carbon was added to each samples. The dielectric constant of the polymers increased with increased weight of carbon. For LDPE, the dielectric constant increased from 2.34 to 7.16 as the percentage of carbon was increased from 0% to 20%. For MPE, the dielectric constant increased from 2.27 to 7.26 as the percentage of carbon was increased from 0% to 20%. This showed that bamboo which is known for its high tensile strength when carbonated with polymers enhanced electrical properties of the polymers. Our result showed that bamboo carbon will also protect the polymer from ultra-violet degradation, being that polyethylene is particularly sensitive to ultra-violet radiation. This showed that bamboo charcoal is good for carbonation of polymer.*

**Key words:** Dielectric Constant, Bamboo, Carbonated Polymers and Impedance Method

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## INTRODUCTION

In this research work we studied dielectric constant of carbonated polymers. Polymer implies large molecule or macromolecule composed of many repeated subunits [1]. We have natural and synthetic polymer. They play essential and ubiquitous role in everyday life [2]. Polymer ranged from synthetic plastics such as polystyrene to natural biopolymer such as DNA and proteins [3]. Polymers both natural and synthetic are created through polymerization of many small molecules known as monomers [4].

Two different samples of crystalline polymers were collected from different plastic companies. These polymers are Low Density Polyethylene (LDPE), and Metallocene polyethylene (MPE).

### DIELECTRICS AND DIELECTRIC CONSTANT K

A dielectric material is an electrical insulator that can be polarized by an applied electrical field [5]. 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 in a dielectric field, electric charge 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 [6]. 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. The study of dielectric properties concerns storage and dissipation of electric and magnetic energy in materials [7].

**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 [8]. 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 [8]. 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 filed [9]. Capacitors are widely used as part of electrical circuits in many common electrical devices. The different types of capacitor are electrolytic capacitors, solid dielectric capacitors and air dielectric capacitor. Electrolytic capacitors are devices in which a thin layer of an oxide is deposited on one of the electrodes to function as the dielectric as used in an aluminum or tantalum plate with an oxide dielectric layer [10].

**BAMBOO**

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. Bamboo is the most marvelous plant in nature. Bamboo is stronger than wood or timber in tension and compression. Chemical analysis reveals that bamboo has about 1.3% ash, 4.6% ethanol-toluene, 26.1% lignin, 49.7% cellulose, 27.7% pentosan [17]. In Hiroshima, Japan the only plant which survived the radiation of the atomic bomb in 1945 was a bamboo plant. In Costa Rica, a building made with bamboo withstood earthquake. It is used in many applications viz; in building it can be used as roof, floor, walls, scaffolds and supports in road construction as bridges. In power generation bamboo is used as check dams in rivers and in agriculture as organic fertilizer and preservative medium. Its charcoal absorbs radiation like nuclear reactor etc [18].

## METHODOLOGY/ SAMPLE PREPARATION

Two different samples of crystalline polymers were collected from different plastic companies. These polymers are Low Density Polyethylene (LDPE), and Metallocene polyethylene (MPE). These samples were washed in distilled water in order to remove some particles or dirt's that may be trapped in the samples. The samples were dried under sun to ensure that the samples are free from moisture of any kind. After thorough drying of the samples, each sample was measured with a digital weighing balance to obtain five specimens with different masses with respect to the polymers use. The masses of the different samples of polymers used were kept constant while the mass of grounded bamboo charcoal was increased. The different samples of polymers was heated with a heating mantle (a type of electric heater), about 10 minutes of heating, the bright white color of the different polymer sample started changing from white color to water color. Some smokes where seen and perceived during the heating process (choking smell). At every interval of 5 minutes, the melting samples of polymers were stirred to hasten the melting of the samples. At about 20 minutes the samples started changing from solid to liquid. The different samples melted at various temperature interval and some colors was observed during the melting of the various polymers. The samples were allowed to cool and solidify in a beaker.

**LOW DENSITY POLYETHYLENE (LDPE)**

50g of LDPE was measured out six times and pour into six different beakers (100ml) label $A_1$, $A_2$, $A_{3,}$ $A_{4,}$ $A_5$ and $A_6$ respectively. LDPE has a very bright white color, hard when feel with hand and teeth. Sample $A_1$ is pure and no carbon was added while $A_2$ $A_3$ $A_4$, $A_5$ and $A_6$ respectively were carbonated with 2g, 4g, 6g, 8g and 10g weighed samples of bamboo carbon. Sample $A_1$ was heated and it melted at temperature interval of $170^0$C-$185^0$C. The melting sample was very elastic in semi liquid melting stage. LDPE gives a choking odor of paraffin while heating. Sample $A_1$ was not carbonated and was allowed to cool in a beaker. LDPE has higher melting point than MPE. The five other samples were heated, a choking smell was also perceived. The samples were allowed to cool and solidify in their beakers. They had darkish color due to the addition of carbon. The cooled samples were broken out from the beakers and a cylindrical shape was obtained in the process. After which the samples was smoothened with a filling machine in order to get a circular shape.

**Table 1.1 Low Density Polyethylene (LDPE)**

| Samples | Weight of polymer (g) | Weight of carbon (g) | Percentage weight of carbon (%) | Ratio of polymer to carbon |
|---|---|---|---|---|
| A1 | 50 | 0 | 0 | 50:0 |
| A2 | 50 | 2 | 4 | 25:1 |
| A3 | 50 | 4 | 8 | 25:2 |
| A4 | 50 | 6 | 12 | 25:3 |
| A5 | 50 | 8 | 16 | 25:4 |
| A6 | 50 | 10 | 20 | 5:1 |

## METALLOCENE POLYETHYLENE (MPE)

50g of MPE was weighed out six times and transfer to different beakers (100ml) label B1, B2, B3, B4, B5 and B6 respectively. MPE has a white color, lighter and softer than LDPE when feel with hand. B1 was heated with a heating mantle and it melted at temperature interval of $107^0$C-$115^0$C .The melting sample is more elastic than LDPE when in semi liquid melting stage. While heating the sample, a choking smell was perceived and the color changes from white to brown, sample of MPE is thicker than LDPE while in liquid form due to elastic properties of MPE. Sample B1 was not carbonated and was allowed to cool. The cooled sample of MPE was cylindrical in shape. Samples B2, B3, B4, B5 and B6 were also melted differently through heating in their beakers and carbon was added to each sample of MPE in the proportion of 2g, 4g, 6g, 8g and 10g respectively. The mixtures were stirred vigorously to obtain evenly distributed mixtures. All the five samples were allowed to cool and solidify and a darkish cylindrical finished sample was obtained.

**Table 1.2 Metallocene polyethylene (MPE)**

| Samples | Weight of polymer (g) | Weight of carbon added (g) | Percentage of carbon (%) | Ratio of polymer to carbon |
|---|---|---|---|---|
| B1 | 50 | 0 | 0 | 50:0 |
| B2 | 50 | 2 | 4 | 25:1 |
| B3 | 50 | 4 | 8 | 25:2 |
| B4 | 50 | 6 | 12 | 25:3 |
| B5 | 50 | 8 | 16 | 25:4 |
| B6 | 50 | 10 | 20 | 5:1 |

## EXPERIMENTAL CONSTRUCTION OF A CAPACITOR PLATE

Two circular plates of diameter 118mm (0.118m) were cut out from a thin copper plate bought from head bridge market Onitsha. The edges of the cut out circular plates were smoothened with a filing machine (bench grinder). The surfaces of the plates were also washed with sandpaper and clean with water to remove trapped dirt and oxide and they were allowed to dry. Two thin wires were soldered at the back of the plate 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 have a very significant role to play on the two copper plate, they reduced and eliminated edge effect (they protect the two copper plates from being touched with hand).

## METHODS OF CHARACTERIZATION/RESULTS AND DISCUSSION

There are different methods use for characterizing and measuring the dielectric constant of carbonated polymers. They are alternating current bridge method, time domain method, transmission method, direct current (DC) method, sub millimeter method, ballistic method, impedance method and resonance method. In this research work, the method used for characterizing or determining the dielectric constant of pure and carbonated polymers is the impedance method. Impedance is the total amount of opposition to the flow of current in an A.C. circuit through a capacitor, resistor or an inductor. It is denoted by Z and measured in Ohm (Ω). In this research work, it contains only an opposition through a capacitor and this opposition is termed capacitive reactance. It is denoted by Xc and measured in Ohm (Ω). This method involves an AC voltage supplier which supplies a variable voltage between 1V to 30V. The AC voltage supplier uses 220V for its operation. A voltmeter was connected in parallel to the AC voltage supplier to read the values of potential difference across the terminals of the device. An ammeter was connected in series with the voltmeter to read the current that flows through the circuit. The constructed parallel plates were connected in series with the ammeter as shown in the figure below.

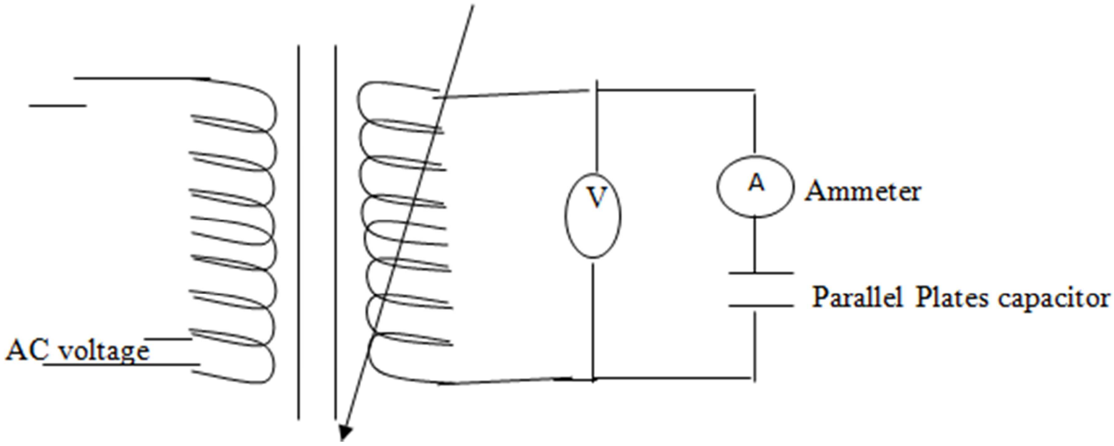


**Fig. 1.1 Circuit diagram for measuring the dielectric constants of the polymer material using the impedance method**

The parallel plates were constructed as disc of diameter and area $0.12m^2$. The circuit diagram for measuring the dielectric constants of the polymeric material using the impedance method is shown on figure 1 above. By definition, the capacitive reactance of a capacitor $\mathbf{X_C}$ is given as

$$x_C = \frac{1}{2\pi fc} \qquad 1$$

According to Ohms law, the capacitive reactance in Ohms can be defined in terms of current and voltage

$$V = I X_C$$

$$X_C = \frac{V}{I} \qquad 2$$

Combining equation (1) and (2), we have

$$\frac{1}{2\pi fc} = \frac{V}{I} \qquad 3$$

By definition, the capacitance of a device that can store energy is given by

$$C_o = \frac{\varepsilon_O A}{d} \qquad 4$$

Equation (4) is the capacitance of a device which air as the dielectric material. $\varepsilon_o$ is the permittivity of free space given as $8.85x10^{-12}$F/m.

For a device which the dielectric material is not air, the capacitance of such device is given as

$$C = \frac{\varepsilon A}{d} \qquad 5$$

Where $\varepsilon$ is the permittivity of the material used as dielectric, A is the area of plates, d is the distance of separation between the plates.

Substituting equation (5) into (3)

$$\frac{1}{2\pi F(\varepsilon A/d)} = \frac{V}{I}$$

$$\frac{d}{2\pi f\varepsilon A} = \frac{V}{I} \qquad 6$$

Where f is the frequency of the AC voltage given as 50Hz. Rearranging equation (6), we have

$$\varepsilon = \frac{I\,d}{2\pi f A V} \quad (7)$$

Equation (7) gives the permittivity of polymers used as dielectric material which is directly proportional to current (I) and distance (d) of separation and inversely proportional to the frequency, area of the plates and voltages in the current.

In this experiment, we want to determine the dielectric constants of pure and carbonated MPE and LDPE using the method discussed above. The distance of separation of the plates, voltage and area of the plates were kept constant throughout the experiment. We noticed that the current varies as different carbonated polymers were inserted between the plates.

**Table 1.3 Metallocene Polyethylene (MPE)**

| Mass of Carbon in the Polymer (g) | Permittivity of Carbonated Polymer $\varepsilon \times 10^{-11}$ (F/m) | Current I (μA) | Thickness of the Carbonated Polymer d(m) | Voltage (Volts) | Area of the Plates ($m^2$) | Dielectric Constant of Carbonated Polymer $K = \frac{\varepsilon}{\varepsilon_0}$ |
|---|---|---|---|---|---|---|
| 0 | 2.01 | 0.20 | 0.07 | 18.5 | 0.12 | 2.27 |
| 2 | 3.42 | 0.34 | 0.07 | 18.5 | 0.12 | 3.87 |
| 4 | 3.91 | 0.39 | 0.07 | 18.5 | 0.12 | 4.42 |
| 6 | 4.82 | 0.48 | 0.07 | 18.5 | 0.12 | 5.44 |
| 8 | 5.62 | 0.56 | 0.07 | 18.5 | 0.12 | 6.35 |
| 10 | 6.42 | 0.64 | 0.07 | 18.5 | 0.12 | 7.26 |

Table 1.3 is the table for Metallocene Polyethylene (MPE). The mass of carbon (g) in the polymer increased from 0 to 10g and this has resultant effect on the dielectric constant of carbonated polymer which increased from 2.27 to 7.26. The area of the plates, voltage and thickness of the carbonated polymer were kept constant at 0.12, 18.5 and 0.07 respectively; throughout the experiment. The current (μA) increased from 0.20 to 0.64.

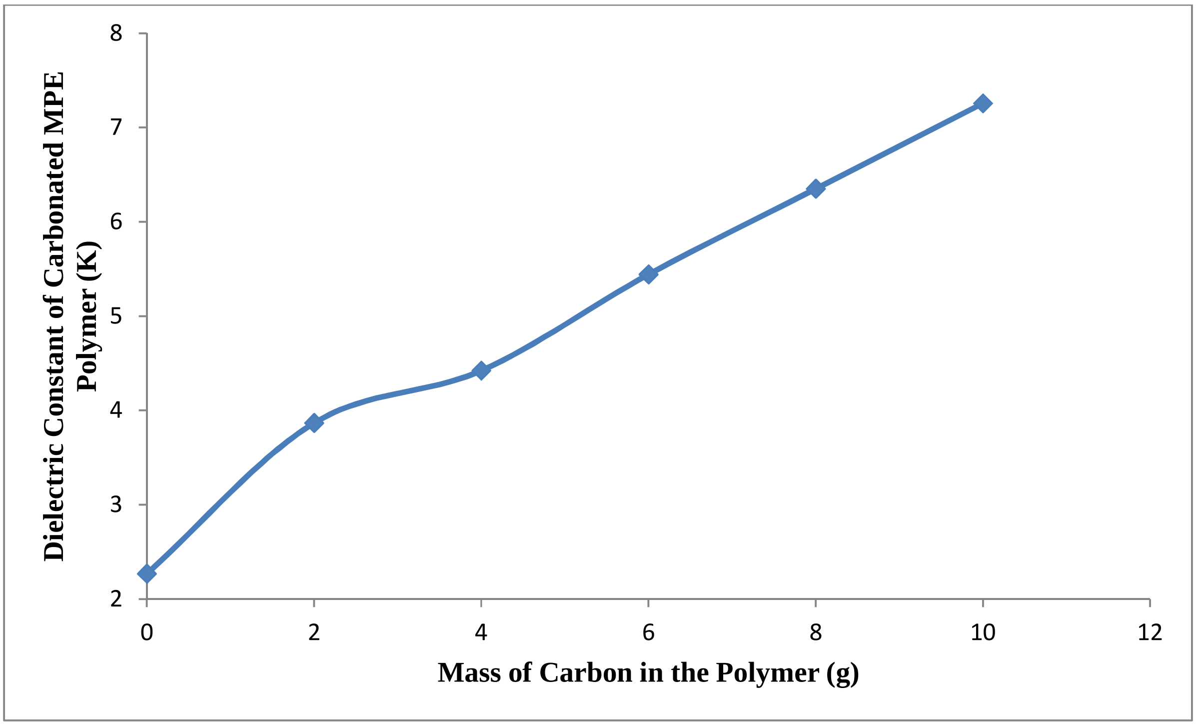


**Fig. 1.2 Mass of Carbon in the Polymer**

In figure 1.2, the dielectric constant of carbon of carbonated MPE polymer is proportional to the mass of carbon in the polymer. This implies that as the mass of carbon increases, the dielectric constant increases.

**Table 1.4 Low Density Polyethylene (LDPE)**

| Mass of Carbon in the Polymer (g) | Permittivity of Carbonated Polymer $\varepsilon \times 10^{-11}$ (F/m) | Current I (μA) | Thickness of the Carbonated Polymer d(m) | Voltage (Volts) | Area of the Plates ($m^2$) | Dielectric Constant of Carbonated Polymer $K = \frac{\varepsilon}{\varepsilon_0}$ |
|---|---|---|---|---|---|---|
| 0 | 2.07 | 0.25 | 0.06 | 16.5 | 0.14 | 2.34 |
| 2 | 3.22 | 0.39 | 0.06 | 16.5 | 0.14 | 3.64 |
| 4 | 3.72 | 0.45 | 0.06 | 16.5 | 0.14 | 4.20 |
| 6 | 4.71 | 0.57 | 0.06 | 16.5 | 0.14 | 5.32 |
| 8 | 5.37 | 0.65 | 0.06 | 16.5 | 0.14 | 6.07 |
| 10 | 6.28 | 0.76 | 0.06 | 16.5 | 0.14 | 7.10 |

Table 1.4 is the table for low density polyethylene (LDPE). The mass of carbon (g) in the polymer increased from 0 to 10g and this has resultant effect on the dielectric constant of carbonated polymer which increased from 2.34 to 7.10. The area of the plates, voltage and thickness of the carbonated polymer were kept constant at 0.14, 16.5 and 0.06 respectively; throughout the experiment. The current (μA) increased from 0.25 to 0.76.

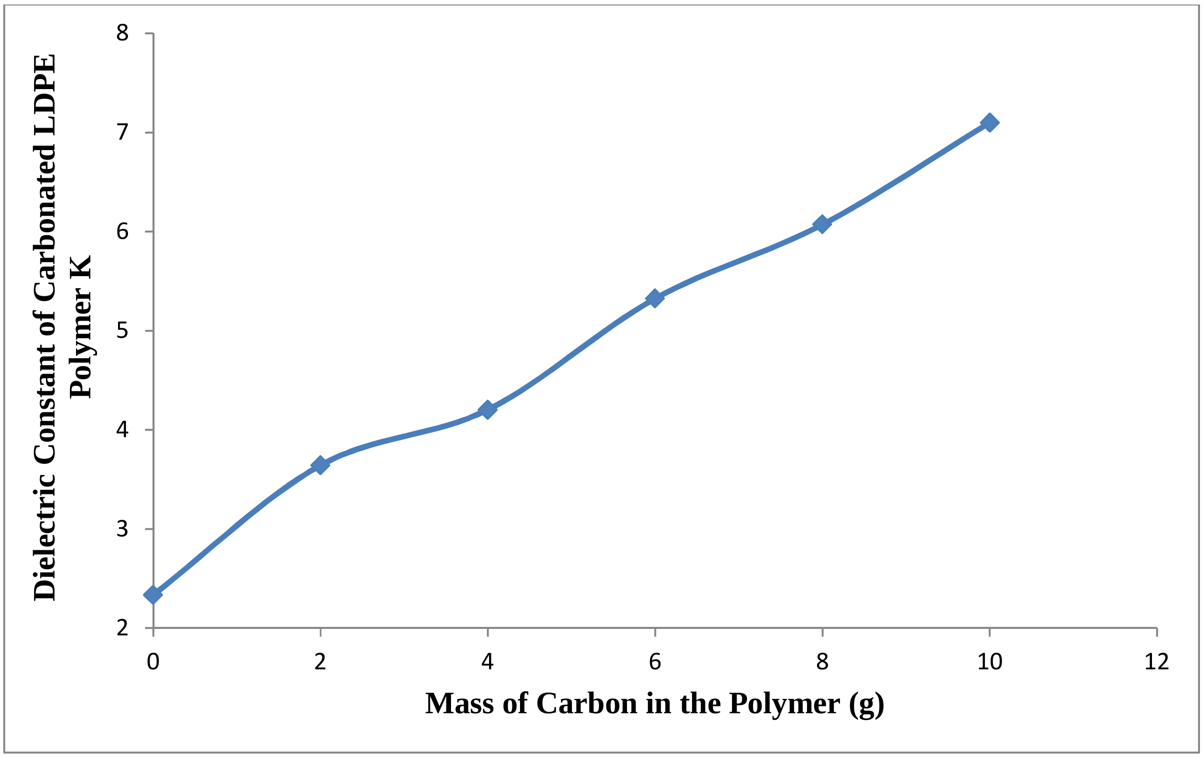


**Fig. 1.3 Dielectric Constant of Carbonated LDPE against Mass of Carbon in the Polymer**

Figure 1.3 is the graph of dielectric constant of carbonated LDPE polymer against mass of carbon in the polymer. The graph shows that the dielectric constant of the polymer increased with increase in the mass of carbon.

## CONCLUSIONS AND RECOMMENDATIONS

We investigated the dielectric constant of pure and carbonated polymers using the impedance method. In carrying out the research, low density polyethylene (LDPE) and metallocene polyethylene (MPE) were used as the polymers. The main difference between LDPE and MPE is that low density polyethylene is produced by high pressure free-radical polymerization of ethylene while MPE is produced by low pressure polymerization technology using metallocene as catalyst to copolymerize ethylene and another monomer such as butane-1. Bamboo charcoal which serves as the carbon was added to each samples. The dielectric constant of the polymers increased with increased weight of carbon. For LDPE, the dielectric constant increased from 2.34 to 7.16 as the percentage of carbon was increased from 0% to 20%. For MPE, the dielectric constant increased from 2.27 to 7.26 as the percentage of carbon was increased from 0% to 20%. This showed that bamboo which is known for its high tensile strength when carbonated with polymers enhanced electrical properties of the polymers. Our result showed that bamboo carbon will also protect the polymer from ultra-violet degradation, being that polyethylene is particularly sensitive to ultra-violet radiation. This showed that bamboo charcoal is good for carbonation of polymer.

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 acting as filler improves the physical properties of the polymer. This filler to a great extent controls the mechanical properties (dielectric constant) and strength of polymer; it has lesser effect on the electrical properties. When there is excessive potential difference across the dielectric separating a pair of charged conductor, the dielectric will break down and become conductor. 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. In the further study on this topic, we suggest that; the carbon should be characterized to know if other elements and materials are contained.

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