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New Materials for Capacitors

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Abstract

A capacitor is a device designed to store and release charge quickly. In basic design a capacitor is two aluminum plates with an insulator in between to keep the positive and negative charges apart, allowing one to store a charge through the basic attraction of opposite charges and not have the charge dissipate. By alternating the insulator or as it is known in this system, the dielectric, one may increase the capacitance of the capacitor, therefore increasing the amount of charge the capacitor may hold. Capacitors are used in all kinds of devices that need electricity quickly, such as an amplifier which has large capacitors to hit large base notes. This experiment is testing alternative dielectrics that could be used to build capacitors with a higher capacitance. By loading different dielectrics into a testing capacitor, the dielectric constant may be found and therefore determining how effective the dielectric would be in capacitors.

Introduction

Capacitors are used in almost all electronics, from cars to iPhones, capacitors have been in use longer than electronic devices have been around. The type of material used as a dielectric in capacitors is incredibly important from a financial standpoint, as the use of unstable dielectrics can cause the premature failure of electronics and possibly cost companies large amounts of revenue (Zogbi 2002). The First Capacitor, the Leyden Jar was invented in 1746, at the University of Leyden in Holland. It was a glass jar wrapped inside and out with a metal foil. The outer foil was connected to the ground, and the inner foil was connected to a source of charge (Capacitors 2015). This Capacitor was very inefficient, but it worked in storing charge. While storing charge is generally the description of a battery, a capacitor does this same task, but through a different function. A capacitor's capacitance is measured in Nano-farads, equal to about what it would take for one coulomb of charge to cause a potential difference of one volt (source).

A capacitor is, in modern day use, two pieces of metal sandwiching an insulator or the dielectric. If electricity is applied to the plates then the plates will become charged, one being positive and the other negative, like battery terminals. If the electric charge is removed, then the plates will remain charged, this phenomenon is called electrostatic induction. The capacity of the device to store an electric charge is called its capacitance, which can be increased by decreasing the distance between the plates, increasing the surface area of the plates, or changing the dielectric (Jayalakshmi and Balasubramanian 2008.).

This project focuses on testing alternative dielectrics for building capacitors that could possibly work better than dielectrics currently in use today's capacitors. The dielectric is the most important piece of the capacitor, without this, the capacitor would be limited in its capabilities. Each Dielectric has its own dielectric constant, a specific number that helps determine the capacitance of a capacitor. The most common use of capacitors is for AC to DC conversions with a rectifier, a device that converts alternating current to direct current (Webster 1976). In alternating current, the voltage changes direction periodically, opposed to a direct current which has a constant voltage flow from positive to negative. Most homes use DC power, while mobile vehicles use AC current. Due to the fluctuation in AC current a rectifier corrects this by using diodes to cut out the negative charge and allow only the positive charge to flow through (Walker, J. S. 2016).

By building bigger and better capacitors, a computer can run better graphics and have more power to its system, allow it to run higher functions, giving us the ability to have better and better systems for computers. Better capacitor technology could allow us to even create new devices that can run faster, clearer processes. Another way that new dielectrics can be used is to build supercapacitors. The idea behind a supercapacitor is that it holds the electrical charge of a battery while charging in the amount of time of a capacitor, a couple of seconds (Jayalakshmi and Balasubramanian 2008). If this could be made and mass produced, a person could put a phone on the charger and have it fully charged before they walk away. Beyond the use of smartphones, a supercapacitor could be used in electric cars, replacing that extra-long charge time with a short minute, possibly faster than pumping gas into a car (Jayalakshmi and Balasubramanian 2008).

Recently supercapacitors have been turning to a substance known as graphene to use as a dielectric. Graphene is a type of polymer made of bonded carbon atoms that form in sheets one atom thick (source). This remarkable substance can have remarkable effects throughout science if an effective way to mass produce it can be found. Graphene would make a great dielectric for super capacitors if a way to mass produce it could be found (Woltornist 2013). Today Graphene looks to be a positive source for supercapacitors, furthering the idea of smaller flatter devices, rather than having a battery in a device there might be a capacitor a couple sheets of paper thick. (Wang et al. 2009)

Dielectrics in capacitors today are generally composed of glass, oil paper, and ceramic. These dielectrics are generally used for their durability and reliability in machinery over certain other dielectrics such as an unstable electrolyte. While it is important to use dielectrics that have been proven to work, it must also be important to continue research in improving capacitors to make machinery and computers that run and process even more efficiently over the course of years to come.

Hypothesis:

Null Hypothesis

$$K_{\text{New Materials}} = K_{\text{Manufactured}}$$

The null hypothesis states that the new materials (Black Walnut Leaves, Magnolia Leaves, Sugar, Seashells, Cedar Bark, Dirt, Used Motor Oil, Grass, Quartz, Sand, and Peat moss) will have a similar dielectric constant to the manufactured materials (Glass, Ceramic, Oil, Oil Paper, and Plastic Film) in use.

Alternate Hypothesis

$$K_{\text{New Materials}} > K_{\text{Manufactured}}$$

The alternate hypothesis states that the new materials (Black Walnut Leaves, Magnolia Leaves, Sugar, Seashells, Cedar Bark, Dirt, Used Motor Oil, Grass, Quartz, Sand, and Peat-moss) will have a higher dielectric constant than the manufactured materials currently in use (Glass, Ceramic, Oil, Oil Paper, and Plastic Film).

K = Dielectric Constant

Materials and Methods

By using the equation for capacitance, $C = \frac{\varepsilon_0 \kappa A}{d}$ the surface area (A) of the capacitor, and the distance between the plates (d) became a constant. The $\in_0$ (8.5 x 10^{-12} farad meter) will also be known as a constant. The materials tested included both organic and inorganic substances: first are black walnut leaves and magnolia leaves; using a specific type of leaf in case there is a variable between different types of leaves. Following that are fertile potting soil, cedar bark, dry soil, seashells, sand, used motor oil, and fresh cut grass. The final substance tested is quartz, this being the most difficult to test as it is a solid that is not very malleable, as such, quartz powder was used rather than a hard slab. To test each material, samples were loaded one at a time between the two aluminum plates of a testing capacitor. The surface area of the plates was 0.95 cm^2. The aluminum plates were held 0.5 cm apart and a multi-meter was used to test the capacitance, giving a single variable, the dielectric constant (K) (Grove 2004). This was repeated 3 times for each material tested with the resulting dielectric constants being averaged for each material tested. Materials already in use as dielectrics such as oil paper, glass, ceramic, and plastic film were tested in addition to the new materials (Black Walnut Leaves, Magnolia Leaves, Sugar, Seashells, Cedar Bark, Dirt, Used Motor Oil, Grass, Quartz, Sand, and Peat-moss) to see if there is any unexpected difference in the dielectric constant in the materials. Air was used as a baseline constant. Once the data was collected, it was placed in a chart to make a visual representation of the dielectric constants.

Results

A table of averaged results and raw data can be found in the appendix. The results of testing indicate that the new materials work better as dielectrics in the test capacitor than the manufactured materials (See Table 1). The results shown in Table 1 allow us to conclude that the best dielectric for capacitors is sand, while the dielectric with the highest dielectric constant is grass. However, grass is unreliable as a dielectric in the long run due to its water content, same being said of magnolia leaves (Figure 1). Due to the data present in Table 1, one can reject the null hypothesis of both dielectrics being equal.

Table 1

Substance		**Dielectric Constant**		**Dielectric Constant**		**Dielectric Constant**		***Average Data***		**Accepted Range**
Air		1.0		1.0		1.0		1.0		1
Sand		3.2		2.6		2.6		2.8		4
Quartz		1.2		1.2		1.1		1.2		4.5
Glass		0.9		0.8		0.8		0.8		7.5
Black Walnut Leaves		0.8		0.7		0.7		0.7		-----
Cedar Bark		1.0		0.9		0.8		0.9		-----
Sugar		1.2		1.1		1.0		1.1		1.85
Dry Dirt		2.5		2.0		1.8		2.1		.....
Peat moss		1.5		1.4		1.3		1.4		.....
Plastic Film		0.8		0.8		0.8		0.8		2.15
Paper		1.9		1.7		1.6		1.7		2
Magnolia Leaves		3.1		2.9		2.8		2.9		.....
Seashells		1.2		1.1		1.0		1.1		7.6
fresh Oil		1.1		1.0		0.9		1.0		2.1
Oil Paper		1.4		1.3		1.2		1.3		.....
Grass		20.3		18.7		17.3		18.8		-----

Table 1

This table displays the dielectric constant (K) for each material tested and averaged data across the three trials as well as the calculated percent error for each trial are included.

As shown in Figure 1, magnolia leaves have the highest dielectric constant (2.9 nF), with sand having a very similar dielectric constant (2.8 nF). However, due to the water content in the magnolia leaves, the sand would serve as a more reliable dielectric. Black walnut leaves, glass, and plastic had the lowest dielectric constants at 0.7 nF, 0.8 nF, and 0.8 nF respectively. The low dielectric constants indicated that none of these three substances would make reliable, efficient dielectrics.

Table 2

	Air	Sand	Quartz	Glass	Black Walnut Leaves	Cedar Bark	Sugar	Dry Dirt	Peat moss	Plastic Film	Paper	Magnolia Leaves	Seashells	fresh Oil	Oil Paper	Grass
Air								Significant								Significant
Sand	Significant	Significant	Significant	Significant	Significant	Significant	Significant		Significant	Significant	Significant		Significant	Significant	Significant	Significant
Quartz		Significant						Significant				Significant				Significant
Glass		Significant						Significant				Significant				Significant
Black Walnut Leaves		Significant						Significant			Significant	Significant				Significant
Cedar Bark		Significant						Significant				Significant				Significant
Sugar		Significant						Significant				Significant				Significant
Dry Dirt	Significant		Significant	Significant	Significant	Significant	Significant			Significant		Significant	Significant	Significant		Significant
Peat moss		Significant										Significant				Significant
Plastic Film		Significant						Significant				Significant				Significant
Paper		Significant		Significant	Significant					Significant	Significant	Significant				Significant
Magnolia Leaves			Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant		Significant	Significant	Significant	Significant
Seashells		Significant						Significant				Significant				Significant
fresh Oil		Significant						Significant				Significant				Significant
Oil Paper		Significant										Significant				Significant
Grass	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	

Table 2: Displays any significant relationships between the dielectric materials tested.

Figure: 1

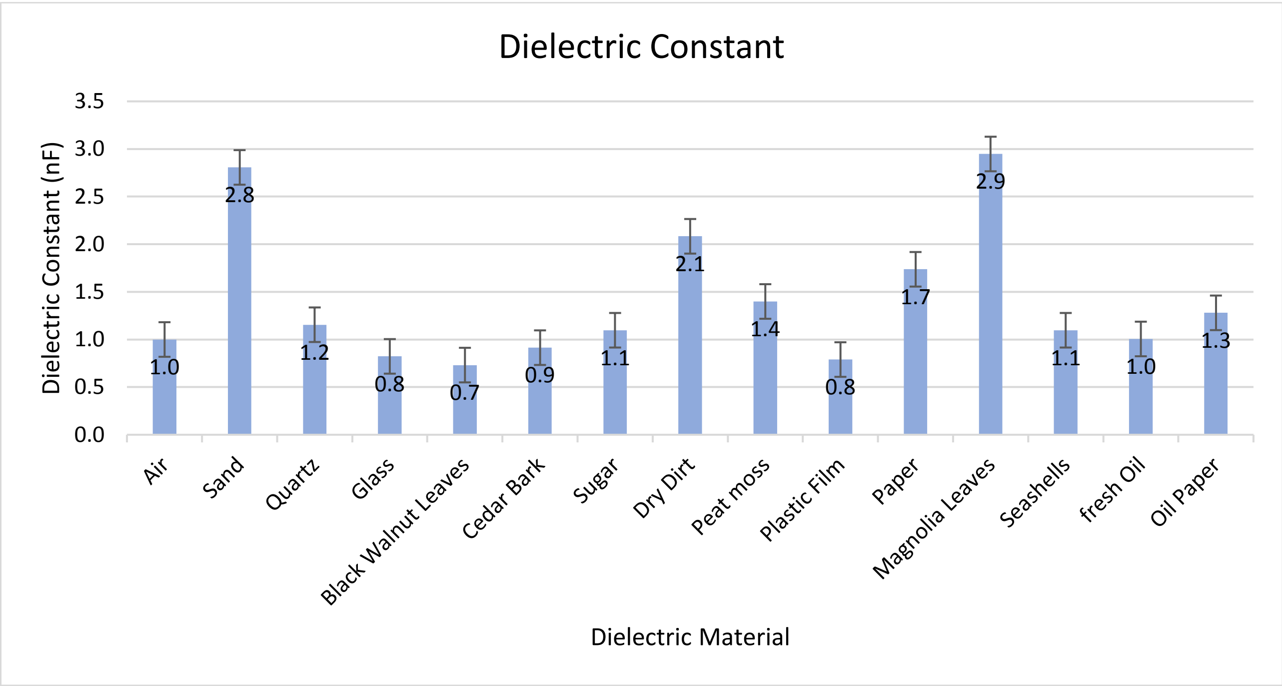

Figure 1:

A comparison of the dielectric constant determined for each sample material tested in the test capacitor, error bars are in one common standard error between data results.

Analysis & Conclusion

While several of the new materials show promise as better dielectrics than those currently used, the downside is that the new materials will have some additional expenses in gathering. The quartz would need to be ground up into a powder, and the leaves would eventually dry up and biodegrade over time rendering the capacitor useless. Other materials such as dirt would continue to work, even wet dirt which would have to be dirt soaked in oil would maintain its dielectric constant as time goes by. The manufactured dielectrics are known for longer use, holding their dielectric constant for long periods of time, and are unlikely to have errors or malfunctions within the device the capacitor is used for. The wet dirt and grass have a high dielectric constant due to the same reason as the magnolia leaves, high water content. The wet materials had an increased constant due to the amount of water giving a huge increase compared to the dry materials. The magnolia leaves do a better job retaining their water due to their waxy film while black walnut leaves dry out faster, thus the change in dielectric constant between the two leaves that had been cut from their respective branches in the same time frame. Superficially, adding water to any substance would create a superior capacitor; however, the water would either perform electrolysis or evaporate in the capacitor causing the capacitor to burst, rendering the electronic device useless.

In conclusion, the best dielectric for capacitors would most likely be sand, though it would be best to conduct a study to determine what makeup of sand would make the best dielectric, since sand is a combination of materials such as silica (silicon dioxide), aragonite (calcium carbonate), or broken up grains of coral or shellfish. Possible errors in this experiment may include the testing capacitor's data being off by random percentages depending on the material in comparison to the already accepted dielectric constants for those substances (do you have a reference here that lists them?) Other possible errors may include the difficulty in breaking the quartz up into a fine enough powder to fit completely into the capacitor without gaps, the distance between the plates being too large, or the surface area not being large enough. In the future, the experiment could be altered in numerous ways, perhaps considering the cost efficiency versus the efficiency of the capacitors, such as would it be more cost effective to use one quartz capacitor or two glass capacitors. In the future, it may warrant future research into the use of quartz, sand, and possibly magnolia leaves in capacitors using better methods to study the dielectric constant of the materials.

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Appendix

Table 1

Substance		*Test 1* Readings	Dielectric constant		*Test 2* Readings	Data		*Test 3* Readings	Data		*Average Data*		Range Studied
Air		0.010	1.0		0.011	1.0		0.012	1.0		1.0		1
Sand		0.032	3.2		0.029	2.6		0.031	2.6		2.8		4
Quartz		0.012	1.2		0.013	1.2		0.013	1.1		1.2		4.5
Glass		0.009	0.9		0.009	0.8		0.009	0.8		0.8		7.5
Black Walnut		0.008	0.8		0.008	0.7		0.008	0.7		0.7		-----
Cedar Bark		0.01	1.0		0.01	0.9		0.01	0.8		0.9		-----
Sugar		0.012	1.2		0.012	1.1		0.012	1.0		1.1		1.85
Dry Dirt		0.025	2.5		0.022	2.0		0.021	1.8		2.1		.....
Peat moss		0.015	1.5		0.015	1.4		0.016	1.3		1.4		.....
Plastic Film		0.008	0.8		0.009	0.8		0.009	0.8		0.8		2.15
Paper		0.019	1.9		0.019	1.7		0.019	1.6		1.7		2
Magnolia		0.031	3.1		0.032	2.9		0.034	2.8		2.9		.....
Seashells		0.012	1.2		0.012	1.1		0.012	1.0		1.1		7.6
fresh Oil		0.011	1.1		0.011	1.0		0.011	0.9		1.0		2.1
Oil Paper		0.014	1.4		0.014	1.3		0.014	1.2		1.3		.....
Grass		0.203	20.3		0.206	18.7		0.207	17.3		18.8		-----

Table 1: List of data and readings from the multimeter.

Table 2

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Air	3.0	3.0	1.0	0.0		
Sand	3.0	8.4	2.8	0.1		
Quartz	3.0	3.5	1.2	0.0		
Glass	3.0	2.5	0.8	0.0		
Black Walnut	3.0	2.2	0.7	0.0		
Cedar Bark	3.0	2.7	0.9	0.0		
Sugar	3.0	3.3	1.1	0.0		
Dry Dirt	3.0	6.3	2.1	0.1		
Peat moss	3.0	4.2	1.4	0.0		
Plastic Film	3.0	2.4	0.8	0.0		
Paper	3.0	5.2	1.7	0.0		
Magnolia Lea	3.0	8.8	2.9	0.0		
Seashells	3.0	3.3	1.1	0.0		
fresh Oil	3.0	3.0	1.0	0.0		
Oil Paper	3.0	3.8	1.3	0.0		
Grass	3.0	56.3	18.8	2.3		
ANOVA						
urce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Gro	869.1	15.0	57.9	342.7	6.0731E-31	2.0
Within Grou	5.4	32.0	0.2			
Total	874.5	47				

Table 2: One way Anova of data.

Table 3

DryDirt-Air	0.1446202
Grass-Air	0.0000000
MagnoliaLeaves-Air	0.0001886
Paper-Air	0.6947928
Sand-Air	0.0006078
DryDirt-BlackWalnutLeaves	0.0234180
Grass-BlackWalnutLeaves	0.0000000
MagnoliaLeaves-BlackWalnutLeaves	0.0000202
Paper-BlackWalnutLeaves	0.2293522
Sand-BlackWalnutLeaves	0.0000652
DryDirt-CedarBark	0.0834443
Grass-CedarBark	0.0000000
MagnoliaLeaves-CedarBark	0.0000912
Sand-CedarBark	0.0002948
FreshOil-DryDirt	0.1505600
Glass-DryDirt	0.0450386
Grass-DryDirt	0.0000000
MagnoliaLeaves-DryDirt	0.4501205
PlasticFilm-DryDirt	0.0354883
Quartz-DryDirt	0.3341481
Seashells-DryDirt	0.2508703
Sugar-DryDirt	0.2508703
Grass-FreshOil	0.0000000
MagnoliaLeaves-FreshOil	0.0001995
Sand-FreshOil	0.0006425
Grass-Glass	0.0000000
MagnoliaLeaves-Glass	0.0000429
Paper-Glass	0.3614836
Sand-Glass	0.0001387
MagnoliaLeaves-Grass	0.0000000
OilPaper-Grass	0.0000000
Paper-Grass	0.0000000
Peatmoss-Grass	0.0000000
PlasticFilm-Grass	0.0000000
Quartz-Grass	0.0000000
Sand-Grass	0.0000000
Seashells-Grass	0.0000000
Sugar-Grass	0.0000000
OilPaper-MagnoliaLeaves	0.0019330
Paper-MagnoliaLeaves	0.0637696
Peatmoss-MagnoliaLeaves	0.0049728
PlasticFilm-MagnoliaLeaves	0.0000325
Quartz-MagnoliaLeaves	0.0006791
Seashells-MagnoliaLeaves	0.0004235
Sugar-MagnoliaLeaves	0.0004235
Sand-OilPaper	0.0059896
PlasticFilm-Paper	0.3080648
Sand-Paper	0.1566943
Sand-Peatmoss	0.0148897
Sand-PlasticFilm	0.0001049
Sand-Quartz	0.0021557
Seashells-Sand	0.0013540
Sugar-Sand	0.0013540

Table 3: Values for which values are statistically different between the dielectrics.