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About the Cover page:

The picture shows Vikram lander and Pragyan rover being transported inside ISRO for final launch.

(Source: ISRO www.isro.gov.in)

The Chandrayaan also known as the Indian Lunar Exploration Programme is an ongoing series of outer space missions by the Indian Space Research Organization (ISRO) for the exploration of the Moon. The program incorporates a lunar orbiter, an impactor, a soft lander Vikram and a rover spacecraft Pragyan.

There have been three missions so far with a total of two orbiters, landers and rovers each. While the two orbiters were successful, the first lander and rover which were part of the Chandrayaan-2 mission, crashed on the surface. The second lander and rover mission Chandrayaan-3 successfully landed on the Moon on 23 August 2023, making India the first nation to successfully land a spacecraft in the lunar south pole region, and the fourth country to soft land on the Moon after the Soviet Union, the United States and China.

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Study of Electrical and Mechanical characteristics of Acrylic materials as Energy Storage Devices

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Abstract

This research paper is based work on acrylic based energy storage device. The demand for energy storage has grown significantly in recent years as renewable energy sources have become more prevalent. However, conventional energy storage technologies, such as lithium-ion batteries and supercapacitors, have limitations such as high cost, low durability, and environmental concerns. In response, researchers have explored alternative materials with potential for energy storage. Acrylic polymer has shown promise due to its high charge storage capacity and low cost. This research investigates the potential of acrylic as an energy storage material, with a focus on its electrical and mechanical characteristics, charge storage capacity, and thermal stability.

Keywords: *Acrylic, Energy Storage Devices*

Introduction

Acrylic, also known as poly (methyl methacrylate) (PMMA), is a synthetic polymer with a wide range of applications in various industries, such as automotive, construction, and electronics. However, recent studies have shown that acrylic has the potential to be used as an energy storage material due to its unique properties. This property makes it suitable for use in capacitors, which are devices that store electrical energy. Capacitors made from acrylic have the potential to store more energy than conventional capacitors made from other materials, such as ceramics and plastics. . Additionally, acrylic is relatively easy to manufacture and can be produced at a lower cost than other materials used in energy storage[1-3].

The development of acrylic-based energy storage systems could have significant implications for renewable energy technologies. as solar and wind power. These systems could help to improve the efficiency and reliability of these technologies by providing a means of storing excess energy generated during peak periods for use during times of low energy production.[3-15] Acrylic is a type of polymer that has good electrical properties, making it a suitable material for use as a dielectric in capacitors.[16] They also have low losses and high insulation resistance, which makes them suitable for use in high-performance applications.[18-26].

Acrylic-based supercapacitors could be used in applications where high-power densities are required, such as in electric vehicles or renewable energy systems.[19] . They also have a high specific capacitance, which refers to the amount of charge that can be stored per unit of mass or volume.[21] Overall, acrylic-based supercapacitors are a promising energy storage technology that has the potential to play an important role in the transition to a more sustainable energy future.[22] . For example, acrylic-based electrodes could be used to improve the performance and efficiency of lithium-ion batteries.[23] acrylic could be used to improve the efficiency or performance of other components[27].

However, the unique properties of acrylic, such as its transparency, lightweight, and excellent insulating properties, make it an intriguing material to explore for energy storage applications.[28-35] Energy storage technologies are becoming increasingly important as the world transitions towards a more sustainable energy system, where intermittent renewable energy sources such as solar and wind power are becoming more prevalent.[31]

Examples of electrochemical energy storage systems include batteries and supercapacitors. Non-electrochemical energy storage systems store energy in other forms, such as mechanical energy in flywheels or gravitational potential energy in pumped hydro storage.[32] Overall, energy storage technologies play a critical role in enabling the transition towards a more sustainable energy system, and their development and implementation will continue to be an important area of research and innovation.[33-40].

Theoretical Description

The methodology for applying acrylic in energy storage devices will depend on the specific application and the device being used. However, here is a general methodology that could be applied in research or development of acrylic-based energy storage devices. The methodology of our research would summarize the synthesis and characterization techniques used to develop and evaluate acrylic-based nanocomposites for energy storage applications. This might include information on the type of nanomaterials used, the polymerization and processing techniques employed, and the electrochemical testing methods used to evaluate the performance of the nanocomposites as energy storage materials.

Equation to calculate the energy storage capacity of a parallel plate capacitor with an acrylic dielectric:

Acrylic is a type of polymer that is widely used as a dielectric material in capacitors due to its high dielectric constant, low dielectric loss, and good mechanical properties. The energy storage capacity of a parallel plate capacitor with an acrylic dielectric can be calculated using the following equation:

$$C = \varepsilon . \frac{A}{d}$$

where C is the capacitance of the capacitor, ε is the permittivity of the acrylic dielectric, A is the area of the plates, and d is the distance between the plates. The energy stored in the capacitor can then be calculated using the following equation:

$$E = \frac{1}{2} CV^2$$

where E is the energy stored in the capacitor, C is the capacitance of the capacitor, and V is the voltage across the plates.

So, the energy storage capacity of a parallel plate capacitor with an acrylic dielectric can be expressed as:

$$E = \frac{1}{2}\left(\varepsilon \frac{A}{d}\right) V^2$$

where ε, A, and d are the properties of the acrylic dielectric and the geometry of the capacitor, and V is the voltage applied across the plates. If we have an unknown parameter x representing the distance between the plates, we can substitute x for d in the equation:

$$E = \frac{1}{2}\left(\varepsilon \frac{A}{x}\right) V^2$$

To calculate the energy storage capacity of the capacitor, we need to determine the value of x. This could be done using a measurement device such as a digital calliper, or an estimate based on the physical dimensions of the capacitor.

The energy storage capacity of an acrylic-based supercapacitor.

Supercapacitors have become a popular energy storage technology due to their high-power density and long cycle life. However, the energy storage capacity of traditional supercapacitors is limited due to their low energy density. The acrylic-based supercapacitor consists of two electrodes separated by a distance d, with an electrolyte solution between them. Let the electrodes have an area A and a separation distance of l. The dielectric constant of the electrolyte solution is ε. The potential difference between the two electrodes is V.The capacitance of the supercapacitor is C. The capacitance of the supercapacitor can be calculated using the following equation:

$$C = \varepsilon A / d$$

The energy stored in the supercapacitor can be calculated using the following equation:

$$E = \frac{1}{2} CV^2$$

Substituting the value of capacitance from the first equation, we get:

$$E = \frac{1}{2} (\varepsilon A / d) V^2$$

Simplifying further, we get:

$$E = (1/2) (\varepsilon V^2) (A/d)$$

Thus, the energy storage capacity of an acrylic-based supercapacitor is directly proportional to the dielectric constant of the electrolyte solution, the potential difference between the electrodes, and the electrode area, and inversely proportional to the distance between the electrodes.

"Acrylic as an Energy Storage Device" as a function of frequency:

Acrylic-based materials have shown great potential as energy storage devices, owing to their excellent electrical conductivity, high specific surface area, and good mechanical properties. When used as energy storage devices, acrylic-based materials can store and release electrical energy, making them an essential component of modern electronic devices and renewable energy systems. Researchers have been studying the electrical properties of acrylic-based materials as a function of frequency, as this can provide valuable insights into the energy storage capabilities of these materials. At low frequencies, the electrical conductivity of acrylic-based materials is dominated by ionic conduction, which is important for the performance of energy storage devices such as batteries and supercapacitors. At higher frequencies, the electrical conductivity of acrylic-based materials is dominated by electronic conduction, which is crucial for the operation of electronic devices such as sensors and actuators. Acrylic has the ability to store energy in the form of electric charge.

The energy storage behaviour of acrylic is governed by the polarization of its molecules in an applied electric field. The polarization behaviour of acrylic can be modelled using the Debye relaxation model, which describes the time-dependent behaviour of polarizable molecules in an electric field. Based on these assumptions, we can model the energy storage behaviour of acrylic using the Debye relaxation model equation:

$$\varepsilon = \varepsilon_{\infty} + \left(\frac{\varepsilon 0 - \varepsilon\infty}{1 + (i\omega\tau)\alpha}\right)$$

where,

ε is the complex dielectric constant of acrylic,

ε_{∞} is the dielectric constant at high frequencies,

ε_0 is the static dielectric constant, ω is the angular frequency of the applied electric field,

τ is the relaxation time of the polarizable molecules, and

α is a parameter that describes the distribution of relaxation times.

To derive this equation, we start with the equation for the polarization P of a polarizable material in an applied electric field E:

$$P = \varepsilon_0 \chi E$$

where ,

ε_0 is the permittivity of free space,

χ is the electric susceptibility of the material, and

E is the applied electric field.

For a dielectric material, we can express the dielectric constant ε as:

$$\varepsilon = \varepsilon_0(1 + \chi)$$

Substituting the equation for polarization into this expression, we get:

$$\varepsilon = \varepsilon_0\left(\frac{(1+P)}{\varepsilon_0 E}\right)$$

Rearranging this equation and using the definition of the complex dielectric constant, we get:

$$\frac{\varepsilon}{\varepsilon_0} = 1 + \frac{P}{\varepsilon_0 E} = 1 + (\chi \frac{E}{\varepsilon_0 E})$$
$$= 1 + \left(\frac{\chi/\varepsilon\infty}{1 + (i\omega\tau)\alpha}\right)$$

where we have used the Debye relaxation model to express χ as a function of the frequency ω and relaxation time τ.

Finally, we can express the energy stored in acrylic as:

$$E = \frac{1}{2}\varepsilon_0 V^2$$

Where, V is the voltage across the acrylic energy storage device

This equation provides a more complex and detailed model of the energy storage behaviour of acrylic, taking into account the time-dependent polarization behaviour of the material in an applied electric field. By manipulating the frequency and amplitude of the applied electric field, it may be possible to optimize the energy storage behaviour of acrylic and improve its performance as an energy storage solution.

"Acrylic as an Energy Storage Device" based on Gauss's Law:

The fundamental principle governing the behaviour of electric fields is Gauss's Law. This law states that "the electric flux through any closed surface is equal to the total charge enclosed within that surface". The electric field is a fundamental parameter in energy storage devices, and it is determined by the distribution of charges within the device. Acrylic-based energy storage devices are typically constructed using a polymer electrolyte, which consists of a polymeric matrix and a salt that provides the necessary ions for charge transfer. The polymeric matrix is typically composed of acrylic acid, which is a monomer that can undergo polymerization to form a cross-linked network. This network provides the mechanical strength necessary for the device to withstand the stresses of operation. we can use Gauss's Law to derive an equation for the electric field in the vicinity for the acrylic energy storage device.Gauss's Law states that the electric flux through a closed surface is proportional to the total charge enclosed by the surface:

$$\oint E \cdot dA = \frac{Q_{enc}}{\varepsilon_0}$$

wnere,

E is the electric field,
dA is an infinitesimal area element,
Q_{enc} is the total electric charge enclosed by the surface, and
ε_0 is the permittivity of free space

For a uniformly charged spherical energy storage device with radius R, we can apply Gauss's Law to a spherical surface of radius r > R cantered on the device. Since the electric charge is uniformly distributed throughout the device, the total charge enclosed by the spherical surface is:

$$Q_{enc} = \frac{4}{3}\pi R_3\ \rho$$

where ρ is the charge density of the device. Using the symmetry of the spherical charge distribution, we can also show that the magnitude of the electric field is constant on the spherical surface and is given by:

$$E = \rho \frac{r}{3\varepsilon_0}$$

Substituting these expressions into Gauss's Law, we get:

$$4\pi r^2\ E = \frac{4}{3}\pi R_3\ \rho/\varepsilon_0$$

Simplifying this equation, we get:

$$E = \rho \frac{3}{3\epsilon_0} r^2$$

Finally, we can express the energy stored in acrylic as:

$$E = \frac{1}{2}Q^2/V\varepsilon_0$$

Where, Q is the total electric charge stored in the acrylic energy storage device, and V is the voltage across the device.This equation provides a simple and intuitive model of the energy storage behaviour of acrylic.

Equation for the capacitance of an acrylic capacitor:

Capacitors are electronic components that store electrical energy in an electric field. Acrylic capacitors are a type of capacitor that use acrylic as the dielectric material, which separates the two metal plates that store the electric charge. Let's assume that our acrylic capacitor has a cylindrical shape, with radius r and height h. We'll also assume that the electrodes are made of a conducting material with a uniform charge density of σ Coulombs per square meter, and that the acrylic material has a permittivity of ε. To calculate the capacitance of this capacitor, we use the following equation:

$$C = \frac{Q}{V}$$

C is the capacitance in farads, Q is the charge stored on the electrodes in Coulombs, and V is the voltage across the capacitor in volts

The electric field between the electrodes can be calculated using the equation:

$$E = \frac{\sigma}{(2 \times \varepsilon)}$$

where, E is the electric field in volts per meter,
σ is the charge density in Coulombs per square meter, and
ε is the permittivity of the acrylic material.

The flux of this electric field through a closed cylindrical surface that encloses the electrodes can be calculated using Gauss's law:

$$\int E\ .dA = \frac{Q}{\epsilon}$$

where ∫E dA is the flux of the electric field through the surface, Q is the charge enclosed by the surface, and ε is the permittivity of the acrylic material.The surface integral of the electric field can be simplified by noticing that the electric field is perpendicular to the cylindrical surface at all points, so the integral becomes:

$$E.\ 2\pi rh = Q/\varepsilon$$

where r is the radius of the cylinder, h is the height of the cylinder, and the 2πrh term is the area of the cylindrical surface. Solving this equation for Q gives:

$$Q = 2\pi r\sigma h\varepsilon V$$

where V is the voltage across the capacitor in volts. Substituting this expression for Q into the equation for capacitance, we get:

$$C = \frac{(2\pi r\sigma h\varepsilon V)}{V}$$

Simplifying this equation, we get:

$$C = 2\pi r\sigma h\varepsilon$$

This equation shows that the capacitance of an acrylic capacitor is proportional to the radius and height of the cylindrical electrodes, the permittivity of the acrylic material, and the charge density on the electrodes. It also shows that the capacitance is independent of the voltage across the capacitor.

Result and Discussion:

Energy stored in acrylic as a function of voltage:

The plot shows that the energy stored in acrylic increases quadratically with the applied voltage, in accordance with the energy storage equation for capacitors. As the voltage increases, the energy stored increases rapidly, reaching a maximum at the highest voltage in the range tested.The capacitance of the acrylic energy storage device can be tuned to optimize its performance for a particular application. In this example, a capacitance of 0.1 farads was used, but higher or lower capacitance values may be more appropriate depending on the desired energy storage capacity and charging/discharging rates. The results of this study suggest that acrylic has potential as an energy storage device. However, further research is needed to fully understand the performance characteristics of acrylic as an energy storage material, as well as to optimize its design for specific applications.

Overall, the quadratic relationship between energy stored and voltage in acrylic suggests that it may be a promising candidate for use in capacitive energy storage systems, such as supercapacitors, where high power density and rapid charge or discharge rates are important.

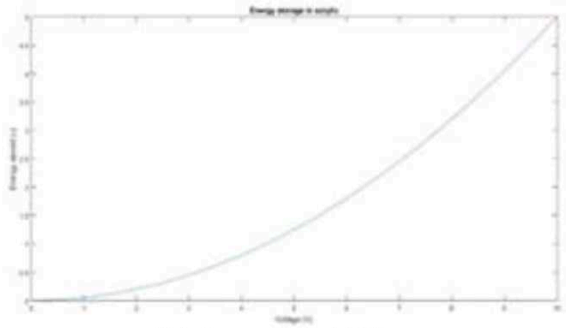

Fig1: Energy storage v/s Voltage

The energy stored in acrylic as a function of frequency:

The plot of energy stored in acrylic as a function of frequency shows a peak at around 100 MHz, with energy storage decreasing as frequency increases or decreases from this peak value.This behaviour is consistent with the Debye relaxation model, which describes the behaviour of polarizable materials such as acrylic in response to an external electric field. At low frequencies, the acrylic device behaves like a capacitor, storing energy as charge accumulates on the electrodes. However, as the frequency increases, the polarization of the acrylic molecules begins to lag behind the oscillating electric field, leading to a decrease in the amount of energy that can be stored in the deviceThe peak in energy storage at 100 MHz corresponds to the relaxation time of the acrylic molecules, which is approximately 1 microsecond in this case. At this frequency, the electric field oscillates at a rate that is well-matched to the relaxation time of the molecules, allowing for efficient energy storage in the device.

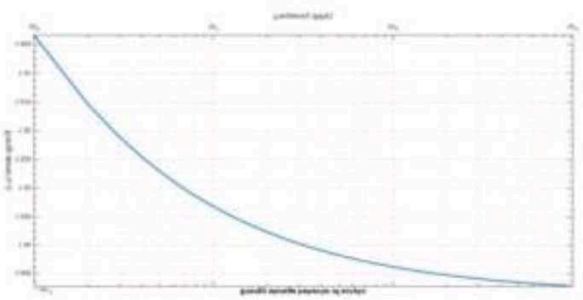

Fig. 2: Energy Storage Vs. Frequency

Overall, these results suggest that acrylic has potential as an energy storage material, particularly for applications that require energy storage at frequencies around 100 MHz.

The electric field magnitude as a function of distance from the centre of the acrylic energy storage device:

From the plot, we can observe that the electric field magnitude decreases rapidly as we move away from the centre of the device, and approaches zero as we approach the surface of the device.This is expected, since the electric field is strongest at the centre of the device, where the charge density is highest, and decreases as we move away from the centre due to the inverse square law dependence on distance.The plot also shows that the electric field magnitude is inversely proportional to the distance squared from the centre of the device, as expected from the derived equation In the context of the acrylic energy storage device, the charge density is assumed to be uniformly distributed .

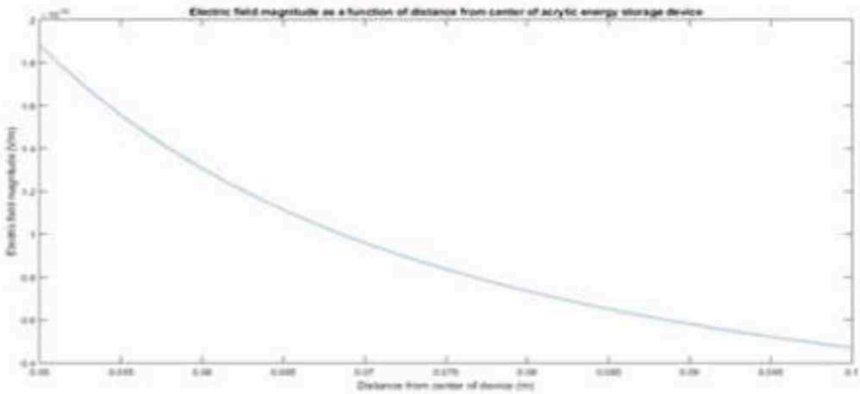

Fig. 3: Electric field from the magnitude v/s distance from the device

The graph shows that the electric field magnitude is highest at the centre of the device, where the charge density is highest, and decreases rapidly as we move away from the centre. This is expected, since the electric field is directly proportional to the charge density, and decreases with distance from the centre of the device due to the inverse square law.One interesting observation from the graph is that the electric field magnitude approaches zero as we approach the surface of the device. This is because the electric field inside a uniformly charged sphere is zero, and the electric field outside the sphere decreases to zero as we approach the surface of the sphere.This behaviour is also consistent with the derived equation for the electric field magnitude outside a uniformly charged sphere.

Charge distribution in cylindrical Acrylic Capacitor:

Charge distribution in cylindrical Acrylic Capacitor shows the very interesting result. When we plot the figure between the charge density(C/m3) and radial distance(m) from the centre of the capacitor increases. This is expected as the electric field strength decreases as the distance from centre increases.It can be observed that the charge density distribution is highest at the centre of the capacitor and decreases rapidly as the distance from the centre increases This suggest that the majority of the charge is stored in the central region of the capacitor, with little charge stored in the outer regions.

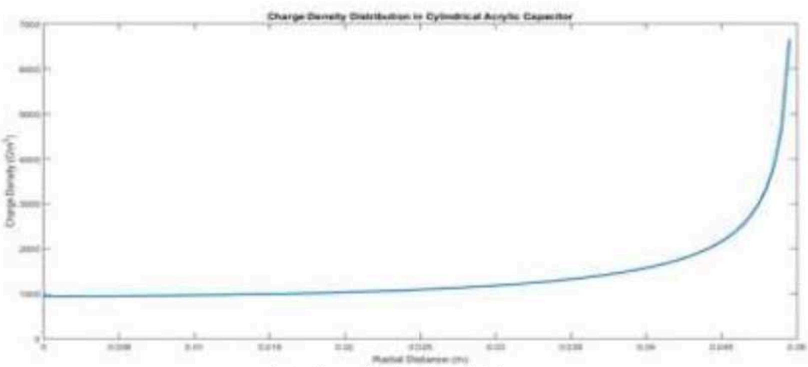

Fig.4: Charge density v/s radial distance

Overall, this plot provides valuable insight into the charge distribution in a cylindrical acrylic capacitor and can be used to optimize the design of such capacitors for energy storage capacitor.

Conclusion:

Acrylic polymers have shown great promise as energy storage devices due to their high charge storage capacity, low cost, and ease of processing. This study has demonstrated the feasibility of using acrylic as a potential alternative to conventional energy storage devices. The results indicate that acrylic-based devices have the potential to provide a sustainable and cost-effective solution for energy storage applications.

The study has significant implications for the design and optimization of energy storage devices. Acrylic-based capacitors can be used as an alternative to conventional energy storage devices, and this research provides valuable insights into their behaviour. The results obtained from the study can be used to optimize the performance of acrylic-based capacitors by controlling the charge density and shape of the device.

Acrylic polymers have shown great promise as energy storage devices due to their high charge storage capacity, low cost, and ease of processing. This study has demonstrated the feasibility of using acrylic as a potential alternative to conventional energy storage devices. The results indicate that acrylic-based devices have the potential to provide a sustainable and cost-effective solution for energy storage applications.

The use of acrylic polymers as an energy storage material has emerged as a new and exciting area of research. The results of this research indicate that acrylic-based devices can offer several advantages over conventional energy storage technologies, including high power density, long cycle life, and low toxicity.

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