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A Comprehensive Review On Natural Fiber Based Super Capacitors

Nagaraja N[1], Deepa Pathar[2], Gavisiddayya Mathad[2], Kavya[2], Sharanagouda[2], Pooja[2]

[1]Associate Professor, Department Of Physics, Sahyadri Science College, Kuvempu University, Shivamogga, Karnataka, India
E-mail: nnkadur@gmail.com
[2]Research Scholar, Department Of Physics, Sahyadri Science College, Kuvempu University, Shivamogga, Karnataka, India

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ABSTRACT

The demand for renewable energy sources worldwide has gained tremendous research attention over the past decades. Energy storage and delivery technologies such as supercapacitors can store and deliver energy at a very fast rate, offering high current in a short duration. The past decade has witnessed a rapid growth in research and development in super capacitor technology. Super capacitor (SC) is proposed to be one of the most effective and reliable electrochemical energy storage devices, because it can provide reasonably high power density and specific energy density, including the high stability and long cycle lifetime of fast charge/discharge process. This paper aims to provide a comprehensive review of SC applications and their developments. Accordingly, a detailed literature review was carried out. The structure, working principle, and materials of SC are given in detail to be analyzed more effectively in this paper.

Key Words: Super capacitor, power density, specific energy density, Energy storage, Pseudo-capacitors, Hybrid capacitors.

1. INTRODUCTION

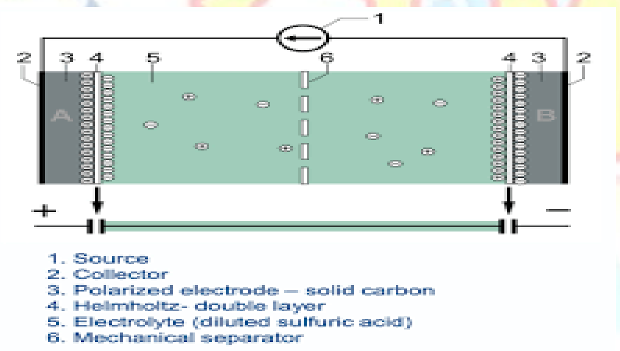
Rising global population and the global energy crisis has led to concerns regarding electrical energy generation and consumption. There is therefore a need for an alternative energy storage device that has a higher capacity than the current technologies. The storage of electrical energy has been exclusively based on batteries and capacitors. Batteries have been the most utilized and preferred candidate, owing to high energy capacity coupled with insubstantial power evolved.

However, when substantial energy is required at high power, capacitors remain the suitable device to date. Despite their benefits, both batteries and capacitors are inadequate for storing high energy and power density required for effective consumption and performance of renewable energy systems. (M.I.A.Abdel Maksoud et.al 2020). Energy storage and delivery technologies such as supercapacitors can store and deliver energy at a very fast rate, offering high current in a short duration. Supercapacitors are categorized as an electrochemical storage device, sometimes called an ultra-capacitor. They can store and deliver energy at a very fast rate offering high current in a burst. Hence, they have found applications in electric vehicles, uninterruptible power supplies (UPS), and memory backups in IT systems. They also have virtually unlimited cycle life, accompanied by high specific power. They also work better than batteries in extreme temperatures, offering excellent low-temperature charge and discharge performance (Kwadwo Mensah-Darkwa et.al 2019).

1. **Super-capacitor:**

A super-capacitor (SC), also called an ultra-capacitor, is a high-capacity capacitor, with a capacitance value much higher than other capacitors but with lower voltage limits. It bridges the gap between electrolytic capacitors and rechargeable batteries. It typically stores 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerates many more charge and discharge cycles than rechargeable batteries. Electrical energy is stored in supercapacitors via two storage principles, static double-layer capacitance and electrochemical pseudo-capacitance.

Structure of Super-capacitor



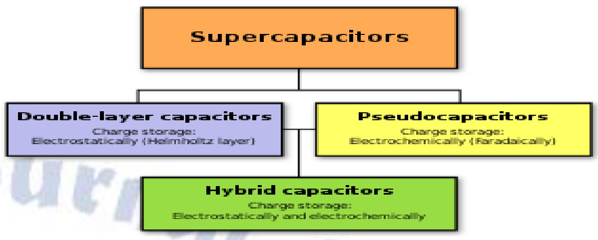
- **Principle of Super-capacitor:**

The basic principle of super-capacitor energy storage is to store electrical energy through the electric double-layer capacitance formed by the charge separation on the interface between the electrolyte and the bath solution. The two electrodes form a series circuit of two individual capacitors C_1 and C_2. The total capacitance C_{total} is given by the formula

$C_{total} = c1.c2 / c1+c2$

Supercapacitors may have either symmetric or asymmetric electrodes. Symmetry implies that both electrodes have the same capacitance value, yielding a total capacitance of half the value of each single electrode (if $C_1 = C_2$, then $C_{total} = ½ C_1$). For asymmetric capacitors, the total capacitance can be taken as that of the electrode with the smaller capacitance (if $C_1 >> C_2$, then $C_{total} \approx C_2$).

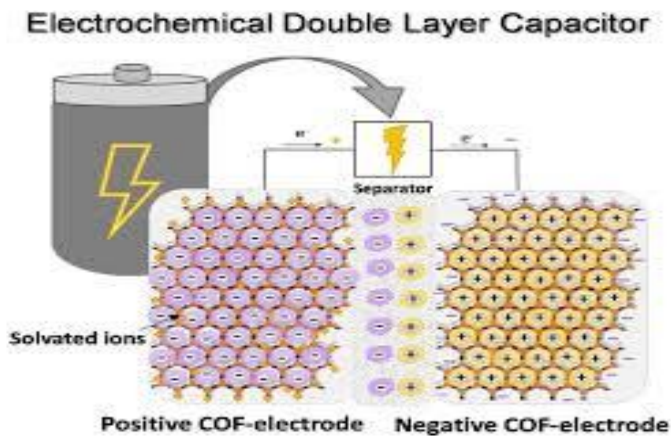
Classification of Supercapacitor



<u>**Supercapacitors are classified into three types**</u>

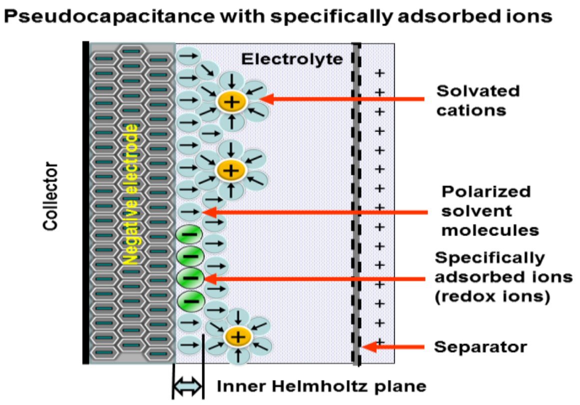
- **Electrostatic double-layer capacitors:**

Two electrodes, a separator, and an electrolyte are components of these kinds of capacitors. The mixture of positive and negative ions dissolved in water is known as an electrolyte. A separator separates the two electrodes. The electrostatic double-layer capacitance of the carbon electrodes or their derivatives used in these supercapacitors is significantly higher. Electrostatic double-layer capacitors have a smaller charge separation than normal capacitors; it is between 0.3 and 0.8 nm.



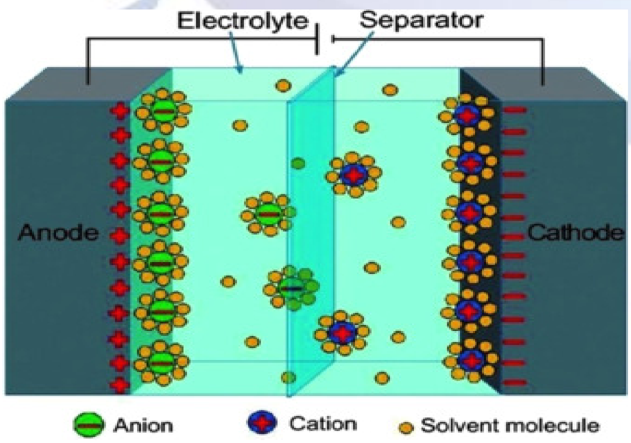
- **Pseudo-capacitors:**

Electrochemical pseudo-capacitors are another name for pseudo-capacitors. These capacitors use conducting polymer electrodes or metal oxide electrodes with substantial electrochemical pseudo-capacitance. By transferring electron charges between an electrode and an electrolyte, these components store electrical energy. A reduction-oxidation reaction, or redox reaction, can accomplish this.



- **Hybrid capacitors:**

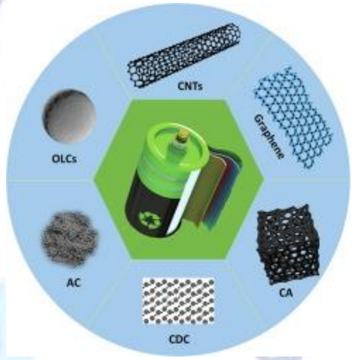
The double-layer capacitor and pseudo-capacitor techniques are used to create the hybrid capacitors. Different electrodes with various properties are utilized in these components. The ability of one electrode to display electrostatic capacitance and the ability of the other electrode to display electrochemical capacitance. A few instances of hybrid capacitors are lithium-ion battery capacitors.In recent years, there has been an increasing interest in biomass-derived activated carbons as an electrode material for super-capacitor applications. The development of an alternative super-capacitor electrode material from bio-waste serves two main purposes: (1) it helps with waste disposal; converting waste to a useful product, and (2) it provides an economic argument for the substantiality of super-capacitor technology (Kwadwo Mensah-Darkwa et.al 2019).



2. Super capacitor Electrode Materials (Noor I. Jalal et.al. 2015**)**

Electrode materials are of high importance in the performance of SCs. To get excellent SC performance results, the material must have high capacitance. The capacitance of SC is on the basis of effective surface area related to its electrode materials. The following are the some electrode materials;

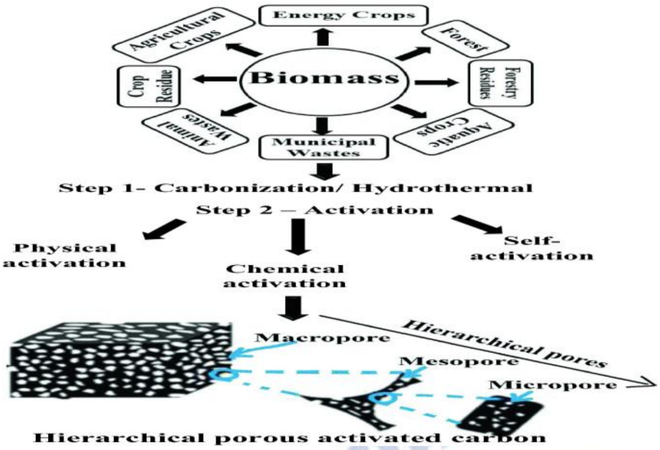
2. EDLCs ELECTRODE MATERIALS:



General electric engineers discovered EDLCs in series of experiments in the year 1957 with devices on the basis of porous carbon electrodes. After that, it has been indicated that energy is contained inside the carbon pores.

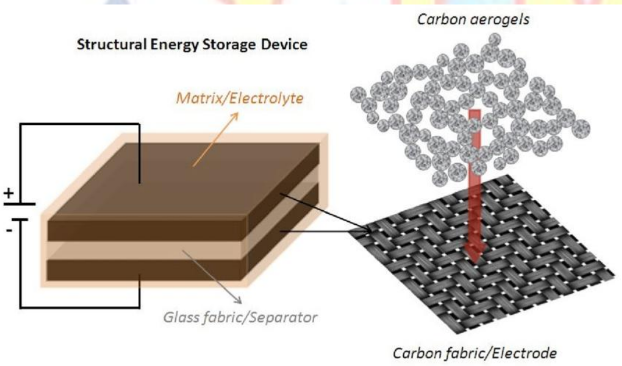
2.1Activated Carbon:

This is considered as one of the treated carbon forms that is produced through a series of relatively simple and inexpensive activation processes. It is obtained by burning carbon materials without oxygen and then the burned material is chemically and physically treated. It is treated to obtain small, finite pores that increases the surface area provided for chemical reactions or absorption. Due to the fact that they are less costly and have high surface area compared with the other carbon based materials, the activated carbon was the major utilized electrode material in SCs. Activated carbon has the ability for storing specific capacitance in range of (50-150) Fg-1 for organic electrolytes and (100-200) Fg-1 for aqueous electrolytes and achieving capacitances of 225 and 160 Fg-1, respectively, with KOH treated activated carbon in the aqueous electrolytes.



2.2 Carbon Aero Gels:

Carbon aerogels have been formed with interspersed meso-pores from continuous network related to the conductive carbon nano-particles. External adhesive binding agent doesn't need to be applied via carbon aero-gels, due to such continuous structures as well as their capability for chemically bonding to current collector.

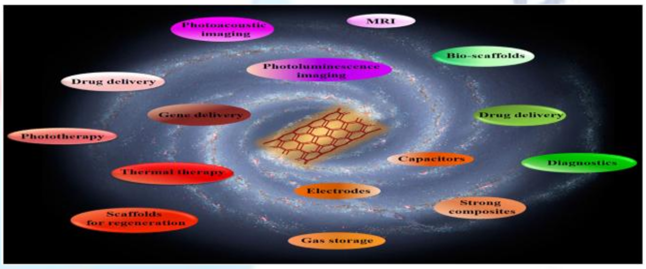


2.3 Graphene:

It was recently suggested that graphene might be utilized as one of the substrates for the applications of SC, due to the fact when utilizing graphene as SC electrode materials, in contrary to the other carbon materials including carbon nanotube, activated carbon and so on; it isn't based on the pores' distribution at solid state.Another advantage of utilizing graphene as one of the electrode materials was that graphene's main surfaces were external and electrolyte-friendly. Researchers are conducted on developing many forms of graphene, which include micro-mechanical exfoliation, arc discharge, chemical vapor deposition, electrochemical and chemical methods, and graphite intercalation methods.

2.4 Carbon nano-tubes (CNT):

Because of its distinctive pore structures, strong thermal and mechanical stability as well as the excellent electrical characteristics, a lot of focus was steered towards CNTs as SC electrode materials. In order to increase its basic capacitance, the carbon nano-tube might be activated (chemically) by means of KOH.

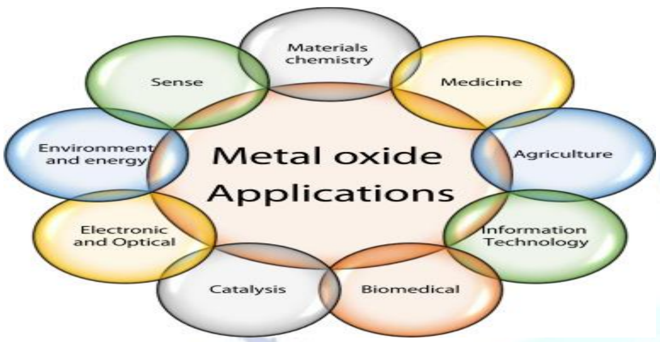


3. PSEUDO CAPACITOR ELECTRODE MATERIALS:

The electrically conductive polymers and transition metal oxides are chosen as pseudo-capacitor electrode materials. Also, the pseudo-capacitor electrodes are using redox reactions on the electro active materials' surfaces. While the redox reactions were dependent on the electrode potential and changing according to the discharging and charging. This process is providing excellent energy density and capacitance in comparison to the purely carbon based EDLCs.

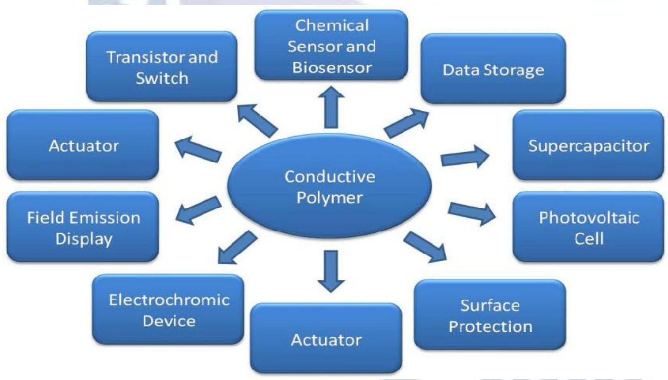
3.1 Metal oxides:

Co3O4, NiO, RuO2, MnO2 and V2O5 are the major transition metal oxides presently studied for pseudo-capacitors electrodes. An increase in capacitance is caused when such metal oxides are undergoing multiple oxidation states at specific potentials. From the various metal oxides utilized as electrode materials, RuO2 was widely effective due to its benefits of long-life cycle, extremely reversible reduction oxidation reaction, wide potential window regarding the highly specific capacitance, along with their metallic type conductivity. With regard to SC applications, the RuO2 has been produced (electrochemically) by means of electro deposition approach.



3.2 Conducting Polymer (CPs):

CPs has been majorly examined as pseudo-capacitor materials, in which the charges were stored within reversible and fast redox reactions at the surface as well as the bulk related to electrode. In addition, the CP electrode materials, like the polypyrrole (PPy), polyaniline (PANi) and polyethylene dioxy thiophene (PEDOT), are showing maximal theoretical specific capacitance of 1000F/g (100µF/cm2-400µF/cm2), that has been approximately two-times high compared to that related to EDLCs. The good conductivity of CP is due to the electrons' delocalization along the backbone of the conjugated polymer, which allows the electron transport in doped state.



- **Natural Fiber reinforced Polymer Composites for super capacitor:**

Many of the research work have done on natural fiber reinforced polymer composite which exhibits significant application in super capacitors. Environmentally friendly energy devices and systems are of increasing interest for the circular economy and sustainable information and communications technology.

An eco-friendly energy autonomous system comprising of natural jute fiber-based temperature and humidity sensors which are powered by a SC–also based on jute-fiber. Most of the fiber- or textile-based SCs use metal coated cloth, which suffers from issues such as chemical instability due to reaction with electrolytes .PEDOT: PSS coated jute fiber is used for the fabrication of SC due to better stability, uniform film property, excellent conductivity, and higher electro activity in comparison with other conducting polymers (Libu Manjakkal, et.al. 2021).

The cellulose paper/RGO composite electrode,which gave high specific capacitance of 177 F/g. It was successfully applied for an all-paper based flexible super capacitor that provided a capacitance of 212 F/g. The extraction of cellulose fibers from waste paper and subsequent application in super capacitor electrodes is proposed as a cost effective route for developing energy storage devices with improved performance (Jasmine Jose et.al.2019).

The push toward more environmentally sustainable is also
driving the development of sensors on cellulose-based materials with biocompatible or biodegradable electrodes. This is also needed to overcome the traditional issues with standard electrodes such as the hazardous nature of the employed materials. The PEDOT: PSS coated jute-fiber based humidity sensor shows an almost linear relationship between the relative humidity (RH) and resistance up to nearly 50% RH, with resistance decreasing with increasing humidity. The temperature sensor was powered using the fabricated SC after the latter was charged with solar cells. The charging–discharging performance shows the potential use of the complete system in applications such as wearable's, food quality, and environmental monitoring.(Libu Manjakkal 2021).

Researchers have recently been involved in the production of
super capacitor electrodes from agricultural waste because of their cost-effectiveness, high surface area, and

exceptionally high electronic conductivity (Akhil Pradiprao Khedulka 2022).

The electrode material of commercial supercapacitors use a porous carbon made from natural materials, namely coconut shell. The porous carbon can be prepared by carbonization of natural materials such as coal, coconut shells, corn stalks, wood, bamboo, paper waste. Porous carbon potential to be used as supercapacitors electrode material because it has the potential for high energy density, pore good accessibility and relatively low manufacturing costs. To increase the capacitance of supercapacitor energy can be done by preparing porous carbon material which has mesoporous fraction and high surface area. The material used for the manufacture of a supercapacitors electrode including graphene, carbon nanotubes, carbon aerogel, a porous carbon and minerals-carbon composites. It was found that the capacitive behavior was improved as the meso porous ratio increased.(Maryati Doloksaribu 2017).

Flexible supercapacitor electrode from a hybrid composite material, Ag–PANI–NC, made of nanocellulose derived from locally available areca nut husks, PANI and silver nanoparticles via a simple solution processing method Electrochemical studies of the electrode made of the composite showed excellent capacitance properties, such as a specific capacitance of 780 F g1 , an energy density of 15.64 W h kg1 and a power density of 244.8 W kg1 (Soorya Sasi, 2021).

natural hollow fiber of CGFs for significant enhancement of flexible supercapacitor performance, which gave a specific capacitance of 785.78 ±6.01 mF cm-2 (341.64±2.61 F g-1 or 19.64±0.15 F cm-3) at a current density of 4 mA cm -2, a 21.2 ± 4.5% increase over that of the SCs with pristine PPy. The area specific capacitance of these SCs remained almost unchanged after over 100 bending cycles and could power optoelectronic devices like LEDs (Qi-Qi Yang, 2017).

A modified jute-fiber based PEDOT: PSS/SWCNT electrode and cellulose as a major component and their use for development of energy- autonomous system having temperature and humidity sensors and SC.(Libu Manjakkal,2021)

A high performance binder-free electrode was prepared based on nickel hydroxide and zinc oxide, through a simple and rapid electrochemical modification and it confirming the effectiveness of the electro-deposition method for super capacitor electrode elaboration with improved specific capacitance and good control (Salah Eddine Berrabah,2023).

The rapid development in wearable electronics has spurred a great deal of interest in flexible energy storage devices, particularly fiber-shaped energy storage devices (FSESDs), such as fiber-shaped supercapacitors (FSSCs) and fiber-shaped batteries (FSBs). Depending on their electrode configurations, FSESDs can contain five differently structured electrodes, including parallel fiber electrodes (PFEs), twisted fiber electrodes (TFDs), wrapped fiber electrodes (WFEs), coaxial fiber devices (CFEs), and rolled electrodes (REs). Various rational methods have been devised to incorporate these fiber-shaped electrodes into multifunctional FSESDs, including fiber-shaped supercapacitors, lithium-ion batteries, lithium–sulfur batteries, lithium–air batteries, zinc–air batteries, and aluminum–air batteries. Although significant progress has been made in FSESDs, it remains a major challenge to make high-performance fiber-shaped devices at low cost.(Yang Zhou, 2019).

4. CONCLUSION:

The main contributions in the different areas, summarized from the literature review are given and the main classification and sub-classification with classification details are provided. The general studies mainly included the history, review, and developments of SCs, electrode materials, natural fiber based composites used for SCs, and the other components explained in this paper. It helps upcoming researchers to know more about SCs.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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