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REVIEW

Review on Activated Carbon for Supercapacitors

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ABSTRACT

Carbon is a lavish element that has a large number of composite elements. Activated carbon is the main source for storing the charge in the Supercapacitor. The management of waste is a big issue in Kathmandu Valley, and by converting the waste into activated carbon the waste management is somehow solved. The wet blue leather waste is found to be more reliable for making supercapacitors than the other waste material. The lowest value of capacitance is found in the eggshell material.

Keyword: Carbon; Capacitance; Composite element; Supercapacitor; Waste

1. Introduction

Carbon is one of the most lavish elements in our earth also called the king of the elements [1]. It produces a large no of composite elements more than others. Carbon dioxide and limestone are abundant sources of inorganic carbon where whereas oil and coal are the sources of organic deposits of carbon [2]. Activated carbon is the carbon used to eliminate water, air, and other impurity from it which is used to increase surface area by reducing the pore's volume [3]. More than 15 different models were found in the structure of activated carbon. It is suggested that some structures are fullerenes along with carbon rings of pentagonal and heptagonal. Solid waste materials such as coconut husks, wood, and paper mills are the main source of activated carbon. The activated carbon from such solid waste materials can be used as the activated carbon electrodes for supercapacitors. The hybrid composite electrodes were designed from activated carbon [4]. The pore structure of the activated carbon also affects the performance

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of the supercapacitor [5]. Such a carbon-activated supercapacitor has the capacity to store large electrical energy between the carbonaceous electrode and the adsorbed layer of electrolyte [6].

Management of waste is a big issue in this Kathmandu valley. Every day about 523.8 metric tons of waste is produced in this valley. The composting and the recycling of waste material are most needed in Kathmandu Valley [7]. Nowadays the fuel consumption ratio of the world increasing day by day which produces the emission of CO_2 rapidly in an uncontrolled way. Focusing on such issues the CO_2 capture and utilization technique will be used for balancing the carbon emission in the atmosphere. The CO_2 can be used with solid wastes in three different ways such as CO_2 utilization, transformation, and mineralization [8].

The energy crises in Nepal induced investment in alternative energy resources such as solar energy, hydro-power generators, biogas, and biofuel from solid waste materials. Nepal imported 2634301-kilo liters and 536028 MT of petroleum products and liquefied petroleum gas this year. In addition, 100 rupees in a cylinder makes five billion Nepalis rupees which is equal to the money the government spent on the small renewable energy technology installed last time [9].

Carbon capture and storage techniques are widely used for absorbing the CO_2 from industries and power plants which induce global warming and climate change by emission of greenhouse gasses. This is a very expensive technique for capturing CO_2, some low-cost technique is also used for capturing CO_2 i.e., pre-combustion, post-combustion, and oxy-combustion capture [10]. CO_2 can be used as a novel source of carbon for the synthesis of inorganic and organic materials which helps to produce methane or methanol by using the hydrogen reduction technique. After producing hydrogen from renewable energy it can be stored as electrical energy like chemical energy [11].

Buffalo has been an essential source of milk, meat, and draft power in Nepal for centuries. The leather industry in Nepal is primarily supplied by the buffalo meat industries. The people of the rural area don't know the value of skinning and selling to the market. They treated it as a solid waste material. Birgunj has installed an industrial wastewater treatment facility. Efforts are being made to centralize the leather industry in Nepal in order to minimize and share the cost of environmental protection systems such as those in place in Birgunj. Due to such industries in Nepal, the income for these rural communities will assist in sending children to school and providing food which also induces rural transportation infrastructure [12].

Activated carbon as an energy storage device, specifically in the context of energy storage systems (ESS) or Supercapacitors, is an area of ongoing research and development. It possesses properties that make it suitable for certain energy storage applications. Here's how activated carbon can be utilized in energy storage:

Supercapacitors or electrochemical capacitors

1) High surface area

Activated carbon has an incredibly high surface area, providing a large interface for charge storage. This property is crucial for enhancing the capacitor's energy storage capacity.

2) Pore structure

The porous structure of activated carbon allows for rapid ion diffusion and promotes efficient charge/discharge cycling.

3) Capacitance

The electrochemical capacitance of activated carbon is utilized for storing electrical energy. This capacitance is often higher than that of traditional capacitors and can compete with or complement batteries in certain applications.

4) Rapid charge/discharge

Supercapacitors based on activated carbon can deliver high power density and exhibit fast charge/discharge characteristics, making them suitable for applications where rapid energy release is essential.

5) Long cycle life

Activated carbon-based supercapacitors can have a longer cycle life compared to some battery technologies, making them attractive for applications requiring frequent charge and discharge cycles.

6) Applications

Supercapacitors with activated carbon are used in various applications, including regenerative braking systems in vehicles, backup power systems, and smoothing out intermittent renewable energy sources.

7) Environmental considerations

Activated carbon is considered environmentally friendly and can be sourced from sustainable materials, aligning with the growing emphasis on green and sustainable energy technologies.

8) Research and development

Ongoing research aims to improve the energy density, capacitance, and overall performance of supercapacitors based on activated carbon. This includes exploring advanced materials and manufacturing techniques. It's important to note that while activated carbon-based supercapacitors excel in certain aspects, they typically have lower energy density compared to traditional batteries. As a result, they are often used in conjunction with batteries to provide a combination of high power density and energy density in hybrid energy storage systems. The field of energy storage is dynamic, and advancements in materials science continue to shape the landscape of energy storage technologies.

2. Literature review

The first time the supercapacitor was made from the waste newspaper by preparing the KOH activation process which consists of carbon to carbon composite electrode material. In this supercapacitor, the surface morphology and the nature of the amorphous were determined by using the X-ray diffraction method (XRD), and electron scanning microscopy technique. The cyclic voltammetry (CV) result gives the capacitance of this supercapacitor 180 Fg^{-1} at 2 mV s^{-1} [12]. The Cassava peel (solid waste material) is used for making activated carbon-based electrodes using chemical and physical activation processes which result in the capacitance of the supercapacitor increased to 264.08 F/g in the previous study. This result shows that cassava peel (solid waste) is used for the production of high-performance and low-cost activated carbon electrode substances for designing electric double-layer capacitors [13].

The multiwalled carbon nanotube with pyrolysis of seaweed used for supercapacitor gives excellent results for electrical conductivity by reducing the cell resistance and enhancing the specific power of the supercapacitor than that of carbon nanotubes (CNT) free carbons [14]. The solid waste material birch wood is used for designing the supercapacitor by using NaOH solution activated at 800 °C temperature. The capacitance of the supercapacitor using this technique is found to be 302 F/g in the sulfuric acid aqueous electrolyte which has a high current density relative to the commercial carbons [15].

The solid waste material cotton stalk is used for designing low-cost and high-specific capacitance by using the phosphoric acid chemical activation method at the temperature of 800 °C. The capacitance of the supercapacitor is found to be 114 F/g which is less in comparison to the previous research. It is used for making electrode material for double-layer capacitors with low cost and high performance [16]. The waste tires are used for making supercapacitors by using pyrolysis and the chemical activation method. From the study, it is found that the specific capacitance of the capacitor depends on the micropore volume and not depends in the mesopore volume [17]. The waste material sugar cane waste is used for making the electrodes of supercapacitors by using polymer gel electrolytes. The capacitance of the supercapacitor is found to be 248 F/g which is quite a better result than the cotton stalk.

The solid leather waste is used for making supercapacitor applications. Here solid leather waste is used for designing hierarchical porous carbon (HPC) by using KOH solution at high temperature. The maximum capacitance of a capacitor is found to be 1960 F/g which is very high relative to the previous research for energy storage devices [18]. A similar solid leather waste material was used for designing the electrodes of the supercapacitor using Sulfuric acid as an electrolyte at the temperature of 900 °C. The maximum capacitance of the capacitor was recorded as 1833 F/g which is slightly less than the previous research on similar solid waste material [19]. The wet blue leather solid waste (WBW) is for making the electrode of the supercapacitor. In this research, WBW is used for making activated carbon using 1 M Na_2SO_4 solution at the temperature of 900 °C. This results in the capacitance of the supercapacitor being increased to 2203 F/g which is very high in comparison to the previous work [20].

The bio waste eggshell is used for the electrode of the supercapacitor. Here calcium carbonate is used as an activated carbon for making the electrode i.e. anode and cathode of the capacitor. The capacitance of the capacitor is found to be 47.5 F/g. As the capacitance is quite small, it is used for designing the cathode/anode of the batteries or capacitors [21]. The waste SIM cards are used for recovery of the copper oxide and reused for the electrode of the supercapacitor. The capacitance of the capacitor using this material is found to be 542 F/g which is used for the high-performance supercapacitor [22].

The coffee-derived biowaste is used as a supercapacitor. The highly porous microstructure activated carbon is designed with 1 M Na_2SO_4 solution which gives a capacitance of 84 F/g. It is used as an electrochemical energy storage material [23]. The waste wood dust of Sisau is used for the production of porous activated carbon used for hybrid composite electrodes of supercapacitors by using manganese IV oxide. The specific capacitance of these materials was found to be 300.2 F/g which is greater than bio waste eggshell, sugarcane waste, solid waste material cotton stalk, and waste newspaper [24].

Scanning Electron Microscopy (SEM) is a powerful technique used to examine the surface morphology and structure of materials at the micro- to nanoscale. When analyzing activated carbon using SEM, it provides detailed insights into the surface characteristics and porous structure of the material. Here's what you might observe in an SEM image of activated carbon.

2.1 Porous structure

Macro/Meso/Micropores: Activated carbon is known for its well-developed porosity, which includes macro, meso, and micropores. In SEM images, you'll see a network of pores of various sizes, contributing to the high surface area.

2.2 Surface texture

Irregular Surface: Activated carbon surfaces are typically irregular and may appear rough or textured under SEM. The irregularities contribute to the enhanced surface area available for adsorption.

2.3 Pore distribution

Uniform or Varied Distribution: SEM can reveal the distribution of pores across the surface.

Uniformly distributed pores are often desirable for efficient adsorption.

2.4 Particle agglomeration

Particle Clusters: SEM images may show individual activated carbon particles or clusters of particles. The degree of particle agglomeration can influence the material's performance in applications like adsorption or energy storage.

2.5 Activation effect

Surface Modification: The activation process may result in changes to the surface morphology. SEM images can help in assessing the effectiveness of the activation process in creating a porous structure.

2.6 Contaminant adsorption

Presence of Adsorbates: In some cases, SEM might reveal the presence of contaminants or ascorbate on the surface of activated carbon particles, providing insights into their adsorption capabilities.

2.7 Surface defects

Surface Irregularities or Defects: SEM can highlight any surface defects or irregularities, which may impact the material's mechanical or adsorption properties.

Residual Carbonization Products: If the SEM analysis is conducted on activated carbon derived from a specific source or precursor material, remnants of the carbonization process may be observable. SEM, when coupled with energy-dispersive X-ray spectroscopy (EDS), can also provide information about the elemental composition of the activated carbon. It's important to note that the specific features observed in an SEM image will depend on factors such as the activation method, precursor material, and the intended application of the activated carbon. SEM analysis is a valuable tool for researchers and engineers working on optimizing the properties of activated carbon for various industrial applications [25].

The rising demand for energy storage systems (ESS) alongside the emergence of renewable energy technologies necessitates a thorough examination of their environmental impacts. Addressing disposal and after-use treatment aspects of diverse ESS is paramount, as they can adversely affect the environment and ecological systems. Scientists, governmental bodies, and non-governmental organizations are actively engaged in studying and evaluating the environmental implications of ESS, with a particular focus on waste disposal. The various ESS types and delineates their associated environmental impacts. Additionally, it underscores the disposal and recycling challenges related to batteries, delving into the regulatory frameworks governing their disposal in different regions. Notable statutes include the European Union's Directive 2006/66/EC, the United States' Resource Conservation and Recovery Act, and Australia's Hazardous Waste (Regulation of Exports and Imports) Act, which classify and manage ESS waste. While the EU and the US rigorously enforce these regulations, Australia faces challenges in implementation. Jordan, part of the Basel Convention, confronts ESS waste management issues, with the Ministry of Environment claiming adherence to EU rules, albeit lacking effective implementation. The scarcity of specialized landfills compounds the problem, emphasizing the urgent need for increased social awareness in Jordan to ensure proper disposal of ESS waste and encourage safe collection, treatment, and recycling practices [26].

The surge in interest in electrical energy storage primarily stems from the rapid growth of intermittent renewable sources like wind and solar, coupled with the global push for decarbonizing the energy sector. Despite this momentum, existing global electrical grid systems are ill-equipped to seamlessly integrate large-scale intermittent energy sources, risking significant disruptions. It's widely acknowledged that surpassing a 20% penetration from intermittent renewables could destabilize the grid. To address these challenges, large-scale electrical energy storage systems emerge as potential solutions. They have the capacity to rectify inefficiencies in the grid, enhance reliability, enable full integration of intermittent renewables, and effectively manage power generation. Additionally, electrical energy storage offers the advantages of decoupling electricity generation from the load, facilitating supply and demand regulation, and providing distributed storage opportunities for local grids or micro grids, thereby improving grid and energy security. Despite the growing need, the current global installed storage capacity is limited to 170 GW, with over 96% provided by site-constrained pumped-hydro technology. To comprehensively address diverse large-scale electrical storage requirements, a varied portfolio of technologies is essential. Covering mechanical, thermal, electrochemical, and chemical storage, the article not only delves into the current status and options but also provides tutorial-level background information on fundamental principles. This inclusive approach caters to both the uninitiated audience and active scientists and engineers involved in energy storage technologies, with a specific focus on large-scale electrical energy storage [27].

In developing countries like India, the escalating industrialization, urbanization, and population growth contribute to a steady increase in waste generation. The mismanagement of municipal solid waste (MSW) not only adversely impacts the environment but also poses risks to public health, giving rise to socio-economic challenges that warrant attention. Urgent improvements in waste collection, segregation, and safe disposal are imperative. Waste-to-energy (WtE) technologies, encompassing pyrolysis, gasification, incineration, and biomethanation, offer viable solutions to convert MSW into renewable energy (electricity and heat) in environmentally sound ways. The review addresses the challenges of MSW management, underscores the health implications, explores opportunities for energy recovery through WtE technologies, provides detailed insights into various WtE processes, and assesses the current status of WtE technologies in India. Additionally, it delves into the challenges faced by WtE projects in the Indian context and offers recommendations to enhance the existing solid waste management practices. Aimed at assisting scholars, researchers, authorities, and stakeholders involved in MSW management, however, the review seeks to inform and guide effective decision-making in this critical domain [28].

3. Conclusions

The key points from the review include:

3.1 High surface area and porosity

Activated carbon's exceptional surface area and porous structure play a pivotal role in enhancing the electrochemical capacitance of supercapacitors. The extensive surface area provides ample sites for charge storage, contributing to high energy density.

3.2 Rapid charge/discharge

Supercapacitors based on activated carbon exhibit fast charge and discharge characteristics. The porous structure facilitates rapid ion diffusion, enabling quick energy release and uptake, making them suitable for applications requiring high power density.

3.3 Long cycle life

Activated carbon-based supercapacitors often demonstrate a longer cycle life compared to certain battery technologies. This longevity is advantageous for applications involving frequent charge and discharge cycles, contributing to the durability of the energy storage system.

3.4 Environmental considerations

Activated carbon is considered environmentally friendly and can be sourced from sustainable materials, aligning with the growing emphasis on green and sustainable energy technologies. The eco-friendly nature of activated carbon enhances its attractiveness for use in energy storage systems.

3.5 Integration with battery technologies

While activated carbon-based supercapacitors offer high power density, they typically have lower energy density compared to traditional batteries. As a result, research and development efforts are exploring hybrid energy storage systems that combine the strengths of both supercapacitors and batteries to achieve a balance between power and energy density.

3.6 Advancements in materials science

Ongoing research is focused on advancing materials science to further improve the energy density, capacitance, and overall performance of activated carbon-based supercapacitors. Researchers are exploring novel materials and fabrication techniques to push the boundaries of energy storage capabilities.

3.7 Applications in various sectors

Activated carbon-based supercapacitors find applications in diverse sectors, including regenerative braking systems in vehicles, backup power systems, and integration with renewable energy sources. The versatility of these energy storage devices makes them suitable for a wide range of industrial and technological applications.

This review shows that the wet blue leather solid waste is very good for supercapacitors as its capacitance is almost higher than all other materials that have been researched in the past time. The minimum capacitance is found in the bio-waste eggshell. This shows that the wet blue leather solid waste is more reliable for designing supercapacitors than the other materials.

Author Contributions

Authors R.Shrestha and N. Phulara contributed equally to the conceptualization, design, and execution of the study. Both authors actively participated in the literature review, data analysis, and manuscript writing. Author R.Shrestha took the lead in drafting the manuscript, while Author N. Phulara played a significant role in critical revisions and review. Both authors approved the final version of the manuscript.

Conflict of Interest

There is no conflict of interest.

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