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ARTICLE

Activated Carbon Precursors Derived from Jute Fiber: Social, Economic and Environmental Development

Md. Touhidul Islam*

Department of Textile Engineering, Mawlana Bhashani Science and Technology University, Tangail, Dhaka, 1902, Bangladesh

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ABSTRACT

Activated carbon fiber (ACF) is undoubtedly one of the most significant carbon nanocomposite materials to consider from the perspective of application in adsorption. Compared to other commercial porous storage materials, it offers many benefits. With a fiber-like shape and a clearly defined porosity structure, activated carbon fiber (ACF) is a potential microporous material. In general, synthetic carbon fiber (CF) can be used to commercially make ACF with the inclusion of an activation procedure. High packing density, outstanding volumetric capacity, rapid adsorption/desorption, and ease of handling are some of the unique properties of ACF. The production expenses of ACF are made up of fiber processing costs and activation costs, both of which are comparatively more expensive than those of other activated carbons. Recently, researchers have indicated that the manufacturing of ACF from less expensive precursors might be accomplished by preparing activated carbon (AC) from agricultural wastes. In comparison to synthetic ACF, there were fewer details and publicly accessible sources of information about these natural fiber derived ACF. The cost of processing fiber is higher and shaping fiber into the correct shape is challenging. In this study, social and environmental compliance, economic development, advantages of carbon fiber,and applications of carbon fiber are discussed.

1. Introduction

ACFs (activated carbon fibers) are porous carbon fibers having a fiber form and a well-defined porous structure that can be manufactured with a high adsorption capacity [1]. Activated carbons (ACs), which are carbon-based structures, are versatile and effective materials that have been widely used in a variety of applications, including catalysts and catalyst supports, adsorbents in chemical recovery operations, industrial purification, air purification, removal of organic and inorganic pollutants from water, anti-corrosion coatings, and enhanced oil recovery [2]. Carbonaceous materials are in high demand around the world

*Corresponding Author:
Md. Touhidul Islam,
Department of Textile Engineering, Mawlana Bhashani Science and Technology University, Tangail, Dhaka, 1902, Bangladesh;
Email: te17035@mbstu.ac.bd

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due to their unique features and wide range of applications. However, the high cost of commercial carbonaceous materials prevents them from being used on a broad basis. As a result, novel precursors for producing carbonaceous materials that are less expensive and more efficient must be investigated. As a result, researchers from all over the world are interested in carbonaceous materials made from renewable and low-cost agricultural resources, such as agricultural byproducts and waste as precursors, that contain enough carbon in their structure [3]. Activated carbon fibers have a large specific surface area, superior adsorption performance, and electrical conductivity, which distinguishes them from other porous carbon materials. Activated carbon fiber has the following benefits: (1) The activated carbon fibers' micropores are directly exposed to the fibers' surface, allowing for molecular and ion adsorption and desorption. (2) Activated carbon fiber (ACF) electrode materials can be developed without a binder during the assembly process, lowering internal resistance. (3) Because they have a lower density than activated carbon powder, they can produce higher gravimetric specific capacitance. (4) ACF possesses adaptable properties that can be used to create adaptable devices [4]. Biomass-based products made from natural resources have recently gotten a lot of interest in academia and industry. This is owing to benefits such as sustainability, recyclability, cost-effectiveness, and environmental friendliness [5]. Although the fibers are not discontinuous, limited in fiber length, and have relatively low mechanical properties in comparison to conventional rayon-based and PAN-based carbon fibers, it would be desirable and useful if carbon fibers or activated carbon fibers could be made from biomass-based natural fibers, which are abundant in nature and less expansive [6]. Jute fiber, on the other hand, is a natural fiber made from jute plants. Jute is commonly referred to as the "golden fiber" and is sold under two names: white jute (Corchorus capsularis) and tossa jute (Corchorus olitorius) [7]. Jute fiber (Corchorus capsularis) is commonly used because it is one of the most affordable cellulose-based natural fibers and has a high Young's modulus compared to many other natural fibers. It also contains a significant amount of cellulose and lignin. The chemical composition of jute fiber includes cellulose (64.4%), hemicellulose (12%), pectin (0.2%), lignin (11.8%), water soluble (1.1%), wax (0.5%), and water (10%), cellulose (64.4 percent) [8]. Jute fiber is made up of many cells. These cells are made up of cellulose-based crystalline microfibrils that are joined to a full layer by amorphous lignin and hemicellulose. A multiple-layered composite is formed when numerous cellulose and lignin/hemicellulose layers in one primary and three secondary cell walls bind together. The composition (ratio of cellulose to lignin/hemicellulose) and orientation of the cellulose microfibrils differ in these cell walls. Carbonization of natural fibers can result in significant weight loss and thermal shrinkage. The physical, chemical, and morphological properties of cellulose-based carbon fibers are influenced by the chemical pre-treatment as well as the heat-treatment condition. Jute fiber is one of the most widely available, longest, and strongest natural fibers, as well as a low-cost (0.5 USD/kg) lignocellulosic fiber. Jute is the second most significant fiber in the world. Jute fiber is the most widely used natural fiber on the planet. Its popularity has grown dramatically as a result of its unusual combination of physical, chemical, and structural qualities, as well as mounting environmental concerns [9]. Jute fibers provide high thermal and acoustic insulating characteristics, with mild moisture resorption and no skin irritations. Jute fiber is currently produced at 3.2 million tons per year around the world and is utilized in a variety of applications. The bag cloth industry consumes most of the jute fibers available on the market. Jute bags have gained popularity as an environmentally beneficial alternative to both nonbiodegradable poly bags derived from petroleum and paper bags that use a lot of wood. Every year, a large volume of jute fibers is wasted and dumped in landfills, either as slivers from jute cloth manufacture or as old clothes following the end-of-life of the product [10]. As a result, jute is regarded as a low-cost, widely available, renewable, and environmentally benign carbon source. As a result, a lot of work is being done to figure out how to convert jute stick and fiber as precursors into various sorts of innovative carbon compounds using diverse methods [11]. Water treatment, electrochemical energy storage, hydrogen storage, and electrochemical sensors are just a few of the possibilities for jute-derived carbon. However, no study has yet focused on summarizing the various procedures used to manufacture carbon from jute, as well as the usage of the carbon obtained for various applications. As a result, we've compiled the study on the preparation and application of activated carbon produced from jute in this review. Figure 1 indicates activated carbon fiber composites.

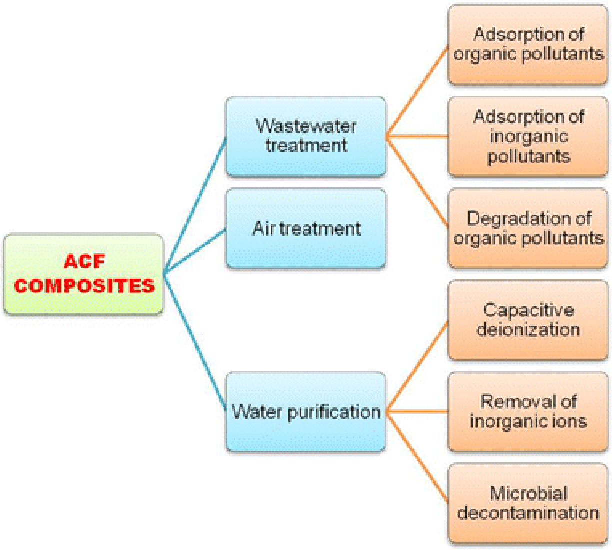

Figure 1. Activated carbon fiber composites [12]

2. Objectives

The objective of this research is to investigate at the advanced possibilities and implications of using jute to form activated carbon. It is also designed to look for innovative jute applications and their prospects. The use of accessible natural resources and the quest for cost-effective options for activated carbon extraction are the objectives of this research. The focus of this research was to analyse the jute fibre as well as to create and characterize the activated carbon that resulted.

3. Social and Environmental Compliances

Jute is good for both people and the environment. It contributes to environmental cleanliness by using fewer fertilizers. It has numerous advantages, but its significance has not yet been fully appreciated. Jute provides underprivileged people with work options. Jute is a time-consuming crop to grow. Every 0.4 hectare (1 acre), the labor cost of raw jute cultivation is roughly 60-70 percent of the total cost. Dried jute leaves and plants are edible and supply disadvantaged people with free or low-cost meals. Jute is gathered in flooded fields where fish can develop, and these fish provide a good source of nutrition. Jute stalks, which are obtained by remining jute plants after the fibres have been removed, are used as cooking fuel and building materials, contributing to deforestation. The widespread usage of already-banned plastic bags has harmed Jute's popularity. The cost of production is the primary reason for polythene's increased popularity. Jute is a little more expensive than cotton. Polythene, on the other hand, is harmful to the environment because it is not biodegradable [13]. Polythene production releases a large amount of carbon dioxide into the atmosphere, which contributes to global warming. It's also bad for the soil because it depletes the soil's fertility. In terms of environmental benefits, it points out that jute takes CO_2 from the environment as it grows and returns it when it decays. The researchers found that throughout the jute growing season, one hectare of jute plants consumes 15 tons of CO_2 and releases 11 tons of oxygen. In comparison to carbon dioxide produced during polypropylene manufacturing, carbon dioxide emissions from transporting and milling jute fibres are one-sixth. CO_2 in the atmosphere is a significant greenhouse gas that contributes to global warming. As a result, jute can play an important role in environmental protection while also lowering CO_2 levels in the atmosphere. Synthetic goods obstruct water movement, resulting in flooding and water logging. It also produces a large amount of non-biodegradable waste, which is a major issue. Because of its physical and chemical qualities, such as strong tensile strength, low extensibility, and superior breathability, jute has a wide range of applications [14]. It also has significant environmental benefits. Figure 2 indicates the flow diagram showing the steps in the production of Activated carbon.

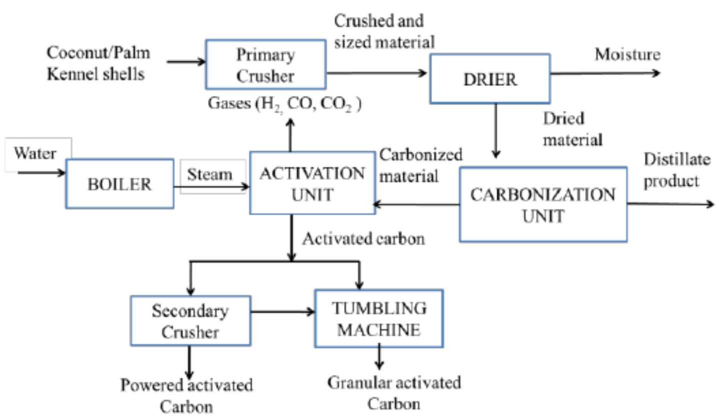

Figure 2. Flow diagram showing the steps in the production of Activated carbon [15]

3.1 Biodegradability

The most essential characteristic of jute is that it is biodegradable and non-polluting. It produces no trash and helps to keep the environment clean.

3.2 Cleaning the Environment

According to studies and research, throughout a season of around 100 days, one hectare of jute plant may absorb up to 15 tons of carbon dioxide and release 11 tons of oxygen. This is great news for the environment, which is already poisoned.

3.3 Contributes to Decreasing Environmental Pollution

Jute goods aid in the reduction of environmental pollution by reducing the demand for non-biodegradable plastic bags that contaminate the environment. Jute bags are more handy than plastic bags since they may be reused multiple times.

3.4 Eases the Pressure on Natural Oil Stock

Petrol is a renewable natural resource with a finite supply. Petroleum products are used to make plastic and poly bags. This places a lot of strain on our finite petroleum supply. As a result, jute might help to lighten the load.

3.5 Requires Less Land for Cultivation

It necessitates less land to cultivate. When compared to other goods, jute requires less land. This could be beneficial in the production of other crops, such as food crops. This will assist in the reduction of food demand.

3.6 Less Requirement of Fertilizers & Pesticides

When compared to a crop like cotton, jute uses fewer fertilizers and insecticides. As a result, the environment will be cleaner since soil pressure will be reduced. The leftovers from the jute crop, including as leaves and roots, contribute to improve soil condition and fertility.

3.7 Improves the Soil

Jute improves the condition of the soil while also increasing its fertility.

3.8 Environment Friendly Practices

Jute and its by-products are produced using environmentally friendly methods that have a minimal impact on our environment.

3.9 Helps in Maintaining Eco Balance

In our environment, trees play a critical function. By promoting jute and its products, we can maintain a perfect eco-balance. This will aid in the growth of trees, which will aid in the resolution of issues such as loss of fertile soil, rain shortages, and reduced forest cover.

4. Economic Development

The jute plant is a cousin of the hemp plant. Jute, on the other hand, is free of narcotic components and odor. Jute can be mixed and matched with both synthetic and natural fibers [16]. Jute may absorb a wide range of cellulosic dyes, including natural, vat, sulfur, pigment, and reactive dyes. The need for blended jute and cotton fibre will rise day by day as the desire for natural comfort fibres rises. Fabrics made of jute and cotton yarns can help save money on wet processing processes. Jute and wool can be mixed. For blending with wool, caustic soda is used to improve the pliability, softness, and appearance. To add the characteristics of flame resistance in jute, liquid ammonia is used to treat with flame proofing agents. Along blending with wool, new concept, technology, and techniques are attempted to blend jute with polyester and acrylic for manufacturing diversified yarns. These diversified jute blended yarns are used to produce value added products such as home textiles, decorative fabrics, geo-textiles, carpet backing cloth and so on. These end fabrics from diversified jute blended yarns poses different qualities, comfort, and cost benefits. Bangladesh currently earns roughly $600 every ton of raw jute exported. Exporting these value-added diverse jute products can boost the export value by tenfold. Bangladesh can earn $3,000-$10,000 by exporting one ton of these various items, depending on quality and kind. He expressed optimism about increased jute usage, stating that the obligatory packaging act for utilizing jute bags contributed to a rise in manufacturing of more than 1 billion jute sacks. Local enterprises increased the export base of jute items from 135 in 2016-2017 to 240 in 2017-2018. By 2021, the market for jute bags is expected to reach $2.6 billion, while the market for home textiles including garments and fabrics will reach $130 billion. Jute has the potential and prospect of being the next important driver in the economy with value addition and new applications, whereas garments are currently the main key driver in Bangladesh. The country requires a new growth motor, which jute and jute products may provide. However, emphasize the importance of collaboration between the jute and textile industries. In Bangladesh, around 0.5 million people are directly employed in the jute industry.

However, there is a scarcity of skilled workers. Bangladesh is currently undergoing the fourth Industrial Revolution [7]. As a result, the fourth Industrial Revolution's technology should be applied to the development of the jute industry. As a result, market analysis, international branding of jute products, implementation of investment-friendly policies, worker skill development, and the establishment of specialist jute mills are all key variables to consider while exploring jute's economic potential.

5. Advantages of Activated Carbon Fiber

Activated carbon fibers are promising solid materials that, when compared to granular activated carbon and powdered activated carbon (PAC), offer remarkable characteristics (GAC). Numerous researchers have expressed interest in continuing their research on ACF [17]. The followings are the primary traits and benefits of ACFs: Exceptionally high adsorption capacity and surface area: According to T.J. Mays, ACF has high adsorption capabilities because it lacks minimum mesopore gaps and non-adsorbing macropores [18]. For instance, T.-H. Ko and colleagues thoroughly investigated and found that new tiny pores were created in fibers because of etching of the ACF surface during the activation process. These pores, which were between 10 nm and 30 nm in size, vanished throughout the activation phase. After the activation procedure, the surface area increased by several hundred times. Activation can encourage the growth of new pores as well as the expansion of existing pores. Compared to unactivated carbon fiber, these ACF show a greater porous structure and capacity for basic dye adsorption [19]. While in GAC, the adsorbate gas molecules must first travel via macropores and mesopores before reaching micropores, in ACF, the majority of micropores are exposed to the fiber surface and the adsorbate gas directly [20]. According to Manocha (2003), in this instance, the rates of toluene adsorption and desorption on ACF are significantly higher than those on GAC. Of course, increasing the temperature on ACF can speed up this desorption of toluene gas more [21]. ACFs are a lightweight, highly flexible material. They can simply proceed with the product in various sorbent shapes and forms, such as woven clothing, non-woven mats, papers, and felts. These materials' flexibility also directly improves the handling and packing efficiency for specific specialized applications [22]. For instance, ACFs can be utilized as capacitors, deodorants in refrigerators, and filtration candles for minor purification systems. According to research by Tanahashi and colleagues, ACF electrodes may be tailored more precisely than GAC electrodes when used as capacitor electrodes [23]. ACF is combined with wood pulp utilizing paper-making technology to increase material toughness, and it is afterwards produced as polarizable electrodes for electric double layer capacitors. Using this method will prevent issues that have occurred during the packing of the grains or power- ders of conventional ACs [24]. Narrow and homogeneous distribution of pore sizes: The pore size of ACFs is primarily composed of micropores, which are smaller than the 2 nm limit set by IUPAC. Pore diameters typically vary from 0.8 nm to 1 nm (ultra-micropore area). Figure 3 indicates Activated carbon market global forecast.

Figure 3. Activated carbon market global forecast [20]

6. Application of Activated Carbon Fiber

Activated carbon is employed in a variety of industrial processes nowadays, such as gas and air cleaning with conventional reusable substance recovery methods. New applications have developed as a result of increased environmental consciousness and the implementation of tight emissions regulations, most notably in the field of air pollution removal. Additionally, the treatment of water, including drinking water, groundwater, service water, and wastewater, is using activated carbon more and more. Its main function in this situation is to adsorb dissolved organic impurities and to remove flavors, colors, and odor-causing agents from halogenated hydrocarbons and other organic contaminants.

6.1 Storage of Natural Gas

Due to its relative safety and lower pressure (3 MPa ~ 4 MPa) at room temperature for the application of methane adsorption, adsorbed natural gas (ANG) is a more preferred technology than compressed natural gas (CNG). Without reducing deliverable capacity, ANG may be able to achieve gas storage pressure with a single-stage compressor. In ANG technology, natural gas is frequently stored in a thin cylinder that is packed with very porous adsorbents [25]. Numerous studies on methane storage have been conducted with an emphasis on the development and characterization of carbon-based porous materials that can achieve the best methane adsorption capabilities and delivery. According to the results of these studies, activated carbon fiber (ACF) is the best adsorbent for use in methane storage applications and has a significant advantage over AC [26]. Figure 4 indicates the activated carbon fiber for energy storage.

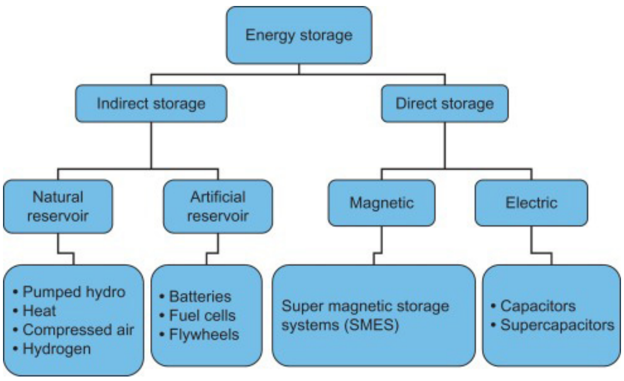

Figure 4. Activated carbon fiber for energy storage [27]

6.2 Removal of SO_2 and NOx

ACF's use in the removal of SO_2, and NOx has been widely documented elsewhere following AC as a primary material. The effectiveness of activated carbon fibers based on pitch for the removal of SO_2 and NOx has been examined by the team led by Mochida et al. The results showed that the maximum SO_2 reduction activity in the presence of water at 25 °C was obtained in pitch based ACF that had undergone heat treatment in nitrogen at temperatures ranging from 600 to 900 [28]. Through the combination of the TiO_2 photocatalyst and urea, reduction of air NOx to safe N_2 was successfully accomplished utilizing pitch based ACF. Utilizing natural wind, the ACF for NOx removal system in the atmosphere could function well in urban areas. The unusual porous nature of ACF, which allows the adsorption process to proceed more quickly, gives it an edge over traditional AC in gas-phase adsorption. In essence, the structures of ACFs consist of readily accessible microporosity for the adsorbate and a lack of diffusion within meso- and microporosity that limits transfer [29]. The most urgent issue currently facing fashion companies is sustainability, which should come as no surprise given that the sector is responsible for 10% of global CO_2 emissions (more than international aircraft and shipping combined) [30]. Figure 5 indicates Activated carbon fiber SO_2 and NOx removal process.

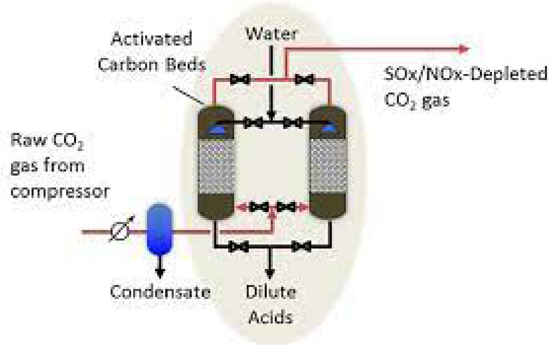

Figure 5. Activated carbon fiber SO_2 and NOx removal process [31]

6.3 Water Purification

One of the most vital elements on earth is water. To guarantee that the water supply is pure and fit for use, it must be purified, toxins from wastewater must be removed, and bacterial development must be inhibited. Granular activated carbon was formerly a widely used material for water filtration. Recent research, however, suggests that ACF may be a superior choice than GAC as a media for water purification [32]. ACF can perform superior adsorption capacities and rates for low molecular weight pollutants, and it may be inferred from those investigations. ACFs also have the added benefit of being simpler to regenerate. However, due to the fiber structure of ACF, bacteria are easily recognized and propagated. Water pollution and water quality issues may result from the presence of bacteria. Oya and his team created antibacterial activated carbon fiber with the inclusion of silver for water purification in 1993 to address this issue. Applications of these antibacterial ACF revealed antibacterial Escherichia coli and Staphylococcus aureus [29]. By combining natural materials, technology, and information into effective technologically, designers can produce new forms of eco-friendly materials without using dangerous chemical production methods [33]. Figure 6 indicates the activated carbon fiber water purification process.

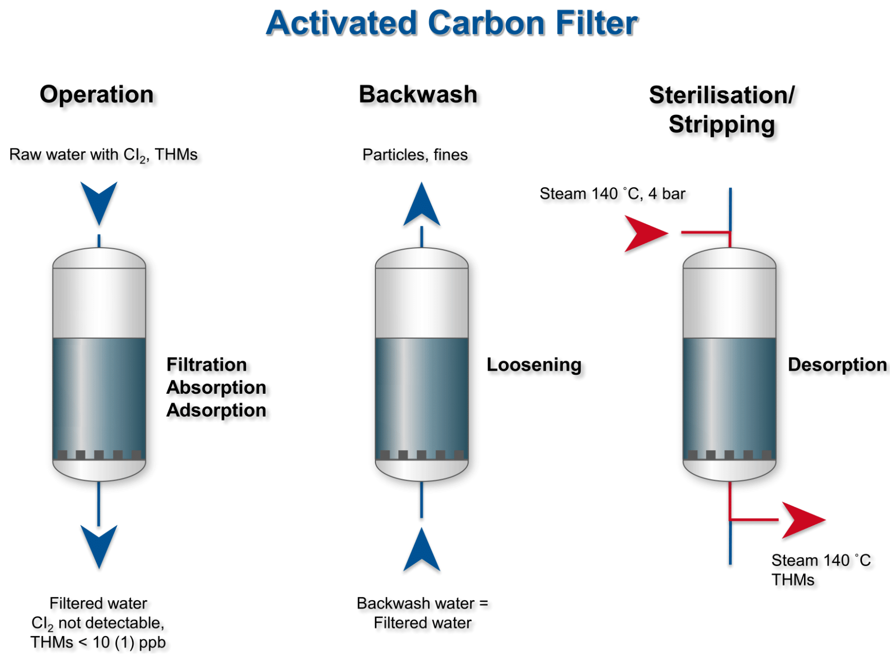

Figure 6. Activated carbon fiber water purification process [34]

7. Conclusions

According to the more typical powder or granular forms of porous carbon, ACFs provide several important advantages. High rates of adsorption from the gas or liquid phase are among them, as well as surfaces with high surface areas and adsorption capacities. As a result, activated carbon fiber combines the greatest attributes of both carbon fiber and activated carbon. The advantages of ACFs over conventional active carbon are their increased adsorption capacity, bigger surface areas, faster adsorption rates, and simplicity of production. ACFs can be created by synthesizing them from a variety of basic materials, including phenolic resins, mesophase pitch, pitch fiber, polyacrylonitrile, and biomass**.** The process used to activate carbon fibers has a significant impact on how porous they are. Increased pore production and continued pore size growth may be facilitated by activation added to the process. The process of activation can be carried out chemically or physically. The activated carbon fiber is cleaned during this procedure of the disordered carbons that obstruct the pores. Pore size distribution and porous structures in the manufacture could be customized through proper precursor carbon fiber selection, activation technique, and experimental circumstances. Materials for synthesizing activated carbon fibers (ACFs) for required applications. The raw material, activation procedure, pore structure, surface roughness, and surface functionalities are only a few of the variables that affect the adsorption capacity of ACFs.

Conflict of Interest

There is no conflict of interest.

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