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Review Paper

Research progress in Synthesis and Characterization of Carbon based Nanomaterials

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Abstract

The enormous amount of plastic waste obstructs resource recovery and effective environmental management. Although plastic is a revolutionary material with thousands of applications, it constitutes a large portion of the waste generated worldwide. Experts have long worked to address this issue. Research in this area is still in its early stages, but it offers a feasible pathway for both waste reduction and the production of high-value carbon materials such as fullerenes, nanorods, graphene oxide nanosheets, quantum dots, carbon dots, and multi-walled carbon nanotubes. This review thoroughly discusses the synthesis, characterization, and remediation methods that use carbon-based products to remove harmful chemicals from wastewater, including heavy metals, dyes, pesticides, and polycyclic aromatic hydrocarbons. Researchers employ synthesis techniques such as chemical vapor deposition, fuel-assisted combustion, sol-gel processing, pulsed wire discharge, hydroxide-assisted co-precipitation, and spray pyrolysis to prepare carbon nanomaterials. They characterize carbon nanoparticles using Fourier transform infrared spectroscopy, UV–visible spectroscopy, TEM, thermogravimetric analysis, XRD, Raman spectroscopy, and vibrating sample magnetometry. The review also describes waste water remediation processes, including adsorption, filtration, ultrasonic techniques, photocatalysis, phytoremediation, sedimentation, bioretention, and other nanotechnology-based approaches. Furthermore, it examines the synthesis of carbon nanoparticlesfromwasteplasticsusinglowenergyandenvironmentally benign methods to achieve the zero-waste hypothesis. Finally, it briefly discusses the environmental and energy-related applications of these materials.

Keywords: Carbon nanomaterial; Plastic; wastewater; Synthesis; Characterization.

Introduction

Plastic trash poses a serious threat to the ecosystem. Even while it is impossible to totally avoid using plastic, its careless use has resulted in an excessive buildup in both land and water environments. Toxic substances are progressively released by plastic, harming all biotic and abiotic elements of our earth. Plastics are used the most around the world because it is lightweight, chemical resistance, and cheap among other materials. The accumulation of plastic waste in water and on land, is referred to "white pollution[1]. Plastic, which is primarily non-biodegradable, is produced in massive quantities and dis-carded into the environment. Around 370 metric tons of plastic was produced globally in 2020, and by 2050, that amount is Estimated to rise to over 33 billion tones. Plastic pollution is the biggest threat to the ecosystem. It is non-biodegradable, releases harmful chemicals into the environment, and can lead to endangerment of aquatic life, causing cancer and other serious diseases[2]. According to recent reports, over 8 metric tons of waste plastic invade the ocean annually, disturbing marine ecosystems, entering into the food chain and having an adverse effect on human health[3]. Plastic is a synthetic polymeric material that is widely utilized in many industries. It comes from the Greek word "plastikos", which means "to be formed in different shapes". It has a high molecular weight and a polymeric structure. These polymers are made using a variety of organic substances and reagents, including vinyl chloride, ethylene, vinyl alcohol, vinyl acetate, and so forth. Because of its exceptional qualities such as being lightweight, inexpensive, strong, resilient, resistant to corrosion, and possessing insulating qualities for thermal and electrical applications plastic has become extremely important. Plastics are widely utilized worldwide because they can easily be molded into a variety of products. Packaging, building, electronics, electrical items, furniture, cars, homes, agriculture, and other industrial uses are among the most common uses for plastic[4].

Although polymers are not biodegradable, unused plastic can be properly recycled. High levels of carbon are present in polymers including PE, PP, PET, and PVC. These could be used as inexpensive raw materials to create activated carbon materials (ACM). The majority of plastics are not biodegradable; therefore, they remain in the ecosystem for a very long period, endangering it[5]. Serious environmental problems related to the disposal of plastic waste are currently being addressed by chemists. Recycling of plastics is considered a valuable and

time-consuming operation due to the numerous processes involved, such as the collection, sorting, and processing of waste plastics. The widespread use of recycled plastics is also limited by the low characteristics of the recovered materials. The reduction of plastic usage to a minimum is regarded as the most effective approach to combat this plastic threat. Thus, significant attention has been gained in recent decades by the upcycling of plastic waste into useful products[6]. Waste management is necessary to reduce plastic waste and minimize environmental impacts. Common options include waste reduction, recycling (mechanical, chemical, and thermal), and land filling[7]. Water pollution has become a serious environmental issue as a result of increased industrialization, as different chemical additives are released into water bodies. A large number of heavy metals are hazardous. Industrial waste contains zinc, mercury, cadmium, and chromium, all of which are dangerous to all living things in large concentrations. In order for wastewater to be recycled and used again, it is imperative that pollutants be removed. Numerous innovative ways for treating wastewater have been developed recently, including membrane separation, adsorption, chemical treatments, biological procedures, and electrochemical processes[8]. From an environmental safety perspective, wastewater treatment and the appropriate disposal of the sludge generated are essential due to the dangerous effects of industrial, municipal, and hospital wastewater on air, water, soil and agricultural products. Large-scale development of economical and effective waste water treatment methods is necessary in a nation like India. Water conservation and avoiding needless water loss will be greatly enhanced by this.Wastewater treatment employing straightforward, affordable, and user-friendly techniques has been the subject of extensive research in the latest years all around the world. Activated carbon has long been utilized for the adsorption of colors and heavy metal ions from wastewater[9].

The review's primary goal is to turn waste plastic into activated carbon, which can be used to purify water. Microporous and mesoporous structures with medium to high interior surface areas are found in activated carbons. They can be used to remove certain dyes and metal ions from water because of various functional groups and their large surface area.

Methodology

The size, composition, and form of carbon nanomaterials are determined by the preparation method utilized in their synthesis, and their unique and useful characteristics are consequently dictated. As a result, greater focus has recently been placed by scientists on the production of carbon nanoparticles with appropriate concentration, size, and form. Plastic waste is converted into carbon nanoparticles through various physical and chemical processes, including chemical vapor deposition, co-precipitation, spray pyrolysis, laser ablation, electrolysis, arc discharge, catalytic methods, sol–gel processing, pyrolysis, spray drying, the citrate precursor method, solvothermal and hydrothermal refluxing methods, combustion, and pulsed wire discharge. A brief summary of research that used different plastics for the synthesis of carbon nanomaterials under various conditions are discussed in Table.1. Refer at the end.

Oxidative Pyrolysis: This process, which involves oxidative pyrolysis, is done in the presence of air. Here, waste plastic was utilized as the carbon source and heated at a lower temperature while catalysts such as nickel carbonate, ferrocene, cobalt chloride, etc. were present. To obtain the porous carbon nanoparticles, the pyrolysis temperature and catalyst variations will be investigated. The heat breakdown of plastic garbage will produce carbon nanoparticles. Carbon nanoparticles and nanotubes are created when plastics are first pyrolyzed to produce non-condensable and condensable gases, which subsequently decompose in the presence of catalysts[18].

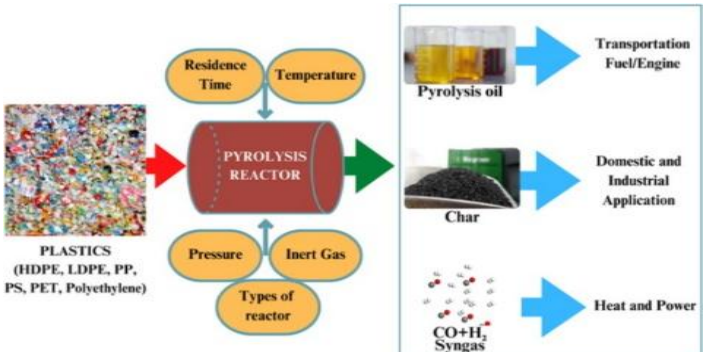


Figure-1: Solid, liquid, and gaseous fuels are produced through the pyrolysis process[19].

Sol gel method: Sol–gel synthesis is regarded as one of the simplest, most economical and fastest technologies and several advantages are offered, such as low processing temperature, uniformity of the produced products, and the development of complex structures or composite materials[20]. In the sol–gel technique, metal oxide nanoparticles are produced by dissolving a molecular precursor (often a metal alkoxide) in alcohol or water, after which the mixture is stirred and heated to initiate hydrolysis or alcoholysis. The sol–gel process is carried out in a liquid medium at a low temperature, usually below 100°C. As a result of the polymerization process, a solid powder is obtained as the final product[21].

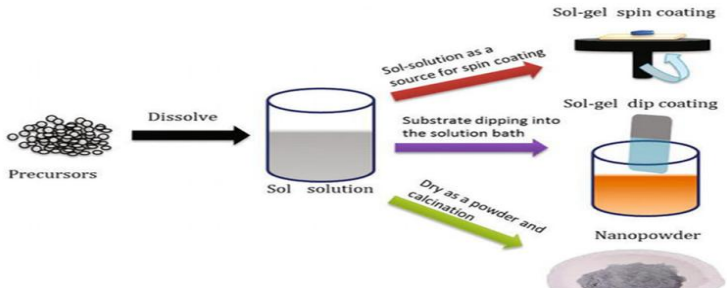


Figure-2: The sol–gel processing is schematically represented[22].

Results and Discussion

Carbon nanomaterials were synthesized through various methods such as oxidative pyrolysis and the sol–gel method, and they were characterized using a variety of analytical techniques, including scanning electron microscopy, X-ray diffraction, Fourier transform infrared spectroscopy, and ultraviolet–visible spectroscopy. In these Review-Waste plastic was used to create activated charcoal. The ability of activated charcoal to adsorb dyes was carefully examined.Analyses of actual water samples showed improved dye removal efficacy.Better adsorption capacity is achieved by new techniques for synthesizing activated carbon from waste plastic. Acquired Surface area and porosity development are highly developed in activated carbon.

FTIR Spectroscopy: The IR spectrum is acquired by FTIR spectrometers using the optical transform of the IR signal, which is generated by the Fourier transformation of the signal obtained from an interferometer with a moving mirror. Functional groups or individual atomic components that exhibit resonance in the IR at specific frequencies can therefore be detected, and the structure and constituents of molecules can be identified. This technique is also used for purposes beyond chemical analysis. Additionally, tacticity, molecular strain, and crystallinity can be measured[23]. Distinct light interference patterns are produced depending on the position of the moving mirror, and the light intensity for each wavenumber is quickly calculated by a computer using a Fourier transform.

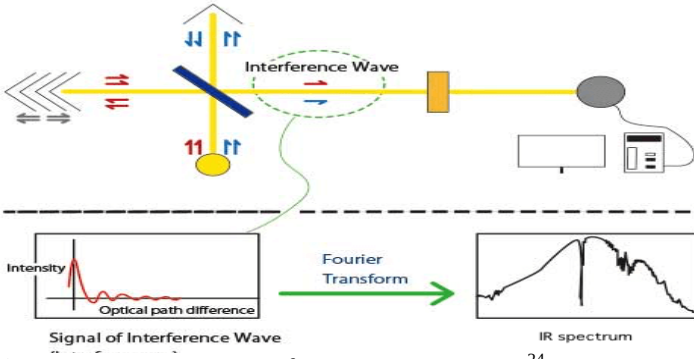


Figure-3: Instrument setup for FTIR spectroscopy[24].

UV-Visible Spectroscopy: This method is often applied for the identification, strength, quality, and purity of distinct samples. The basic principle of UV–Visible spectroscopy is based on the absorption of specific wavelengths of light by samples, and important information about how substances respond to this absorption is provided. It is also used as a useful technique for identifying, describing, evaluating, and studying nanomaterials. According to UV–Visible spectroscopy measurements, the maximum wavelength is shifted from 300 nm to 370 nm when $Zn(NO_3)_2$ is transformed into zinc oxide nanoparticles[25].

Scanning electron Microscopy: A focused beam of electrons is employed in SEM, and it is directed onto a specific area of the sample's surface using an electron optical system. When the material is interacted with by these primary electrons, various types of particles, including X-rays, transmitted electrons, secondary electrons, and backscattered electrons, are emitted. In the imaging process of SEM, secondary and backscattered electrons are considered especially significant, as signals are generated from the interaction between the incoming electron beam and the sample surface. A depth of focus approximately three hundred times greater than that of a light microscope is offered by SEM, along with excellent resolution. As a result, a useful depth of field of more than 1000 µm at a magnification of 1000 and about 10 µm at a magnification of 10,000 is obtained. The sample can also be tilted up to 60 degrees in both directions[26].

X-Ray Diffraction: XRD is also considered a powerful characterization technique in electrocatalytic applications where Pd/Ni nanoparticles are utilized to modify graphene oxide, and the validity of the effective assembly of heterostructures is required. This is accomplished by comparing the XRD patterns of graphene oxide, the Pt/Ni alloy, and the final graphene composite material, after which all peaks of the composite are attributed to the original components. By comparing the peaks of the composite material with those of the corresponding starting components, graphene modifications are successfully verified[27]. High-resolution atomic-scale images are also produced using X-ray diffraction as a well-known technique. However, certain limitations have been identified, including low intensity compared to electron diffraction and the requirement of a specific validation condition in which the substance is available[28].

Conclusion

One of the current concerns is the environmentally sustainable treatment of waste plastics. Carbon nanoparticles are thought to be an excellent adsorbent for removing different heavy metals and colors from waste water, and they have several industrial uses. Carbon nanoparticles are considered high-value products since they have been demonstrated to possess special and beneficial qualities in a variety of applications. Using waste plastics as a source to produce carbon nanoparticles presents a favorable approach for waste management. Various studies have explored different reactor configurations and methods for producing carbon nanoparticles from plastic waste. Carbon-based materials find wide use in water treatment, separation processes, electrical systems, and medical applications. Although they are considered highly versatile and effective in these areas, there are certain difficulties in the production of carbon nanoparticles that need to be addressed in order to better explore their potential uses. Activated carbon made from waste plastic is capable of removing multiple types of pollutants from wastewater, supporting sustainable waste management and improving water purification methods.

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