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Characteristics of Plastic Waste-Based Activated Carbon: A Preliminary Review

Muhammad Adam Akmal Azuan[1], Siti Amira Othman[1,*]

[1] Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, 84600, Pagoh, Johor.

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ABSTRACT

This review encompasses an overview of the existing literature related to the transformation of solid plastic waste into activated carbon for wastewater treatment and explores its diverse applications. The transformation of plastic waste into activated carbon has gained significant attention in recent years due to its potential to address two critical environmental issues, which are plastic waste management and wastewater treatment. The literature reveals various techniques employed to transform solid plastic waste into activated carbon. Studies emphasize the favourable properties of plastic waste-based activated carbon, including high surface area and porosity, enabling effective adsorption of pollutants in wastewater. The material has demonstrated promising results in removing contaminants such as dyes, pharmaceuticals and heavy metals. Additionally, its diverse applications extend beyond wastewater treatment to include air purification, energy storage and catalyst support.

1. Introduction

1.1 Adsorption Mechanism for Wastewater Treatment

Adsorption is a commonly used mechanism in wastewater treatment to remove pollutants and contaminants [1]. It involves the adherence of dissolved or suspended substances onto the surface of a solid material, known as an adsorbent [2]. The adsorbent material can be activated carbon, zeolites, silica gel or other porous materials with a high surface area. The adsorption process occurs due to various forces and interactions between the adsorbate (the substance being adsorbed) and the adsorbent [3].

Eq. (1) is used to determine the adsorption energy (E_{ads}) and is given by the difference between the energy of a complex comprising the adsorbent and contaminant (E_1) and the energies of the isolated adsorbent (E_2) and contaminant (E_3),

$$E_{ads} = E_1 - E_2 - E_3 \quad (1)$$

* *Corresponding author.*
E-mail address: sitiamira@uthm.edu.my

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In Eq. (2), the interaction energy (V_{ij}) is calculated. V_{ij} represents the overall interaction energy between the adsorbent and contaminant. It is composed of two components: V_{LJ} and V_C. V_{LJ} represents the energy-dependent on the distance between atoms, often referred to as the van der Waals interaction energy. V_C is the energy obtained from theelectrostatic conversion factor, which accounts for the electrostatic interactions between the adsorbent and contaminant. Therefore, Eq. (2) can be written as:

$$V_{ij} = V_{LJ} + V_c \quad (2)$$

These equations are used in the field of adsorption studies to evaluate the energy contributions and interactions between adsorbents and contaminants in a system. Adsorption mechanisms play a vital role in wastewater treatment for the removal of pollutants and contaminants [4]. These mechanisms include Van der Waals forces, electrostatic forces, chemical bonding and pore diffusion.

Van der Waals forces are weak attractive forces between molecules. They facilitate the adsorption process by allowing adsorbate molecules to adhere to the surface of the adsorbent. These forces are particularly significant for non-polar adsorbates and non-polar adsorbents [3]. Electrostatic forces arise from the attraction or repulsion of charged particles. Many pollutants in wastewater, such as heavy metals and dyes, carry a net charge.The adsorbent surface may also have charged sites. Electrostatic forces between the charged adsorbent surface and the oppositely charged adsorbate promote adsorption.

Chemical bonding can occur between the adsorbate and the adsorbent surface [5]. This bonding can take the form of covalent bonds, hydrogen bonding or other types of chemical interactions. Chemical bonding provides a strong adsorption mechanism and can result in a high degree of pollutant removal [6]. Pore diffusion is a process that takes place in porous materials with interconnected pores. Pollutants present in wastewater diffuse into the pores of the adsorbent, where adsorption occurs. Pore diffusion influences the rate at which adsorption takes place.

These adsorption mechanisms collectively contribute to the effective removal of pollutants in wastewater treatment. Each mechanism operates based on different forces and interactions, offering advantages in targeting specific contaminants. Understanding and optimizing these mechanisms is crucial for enhancing the efficiency of wastewater treatment processes [7].

1.2 Properties and Characteristics of Plastic Waste-Based Activated Carbon
1.2.1 Porosity

Activated carbon derived from plastic waste exhibits high porosity, a key property resulting from the carbonization process [8]. This process involves subjecting the plastic waste to high temperatures without oxygen, causing decomposition and leaving a carbon-rich residue. During carbonization, a highly porous structure forms within thematerial, creating a network of interconnected carbon atoms and a wide range of poresand channels. This porosity enables the activated carbon to effectively adsorb pollutants, including organic compounds, heavy metals, odors and volatile organic compounds (VOCs).

Contaminants are attracted to the surface and held within the porous structure through physical and chemical interactions, effectively removing them from the environment [7].The design of next-generation plastic waste-derived carbon materials (PWCMs)-based functional materials will require several factors to be considered. First, it is essential to engineer the porosity of PWCMs, and activators are required to tailor the nanostructures of PWCMs-based functional materials [9]. This statement emphasizes the significance of controlling the porosity of PWCMs to develop advanced functional materials. The porosity of PWCMs plays a crucial role in determining their performance and applications. By engineering porosity, it becomes possible to create materials with specific characteristics and functionalities that are suitable for various desired applications [10].

1.3 Adsorption Capacity

Plastic waste-based activated carbon (PWAC) has excellent adsorption capacity due to its high surface area and porous structure [11]. The carbonization process converts plastic waste into activated carbon with interconnected pores, providing a large surface area for adsorption. The activated carbon's high surface area enables efficient adsorption of various pollutants, including organic compounds, heavy metals and VOCs. Its micropores and mesopores attract and hold contaminants through different interactions, such as van der Waals forces [12].

Due to its porous structure and tailored surface chemistry for selective adsorption, heavy metals in industrial wastewater can be effectively removed by PWACs. Additionally, it can efficiently capture and retain VOCs, reducing their release into the air and improving air quality. The adsorption capacity of PWACs depends on factors like the plastic waste used, the carbonization process and surface modifications. Optimization of these parameters enhances its performance for water and air purification applications [13].

1.4 Surface Chemistry

The surface chemistry of PWACs can be modified to enhance its adsorption properties for specific contaminants. This is done through the activation process, which involves subjecting the carbonized material to high temperatures and then treating it with chemical agents or gases to create pores and increase surface area. Impregnation, grafting and chemical treatments are additional techniques used to customize surface chemistry. These methods involve soaking the activated carbon in solutions containing specific compounds, attaching functional groups through chemical reactions or treating it with acids, bases or oxidizing agents. By tailoring the surface chemistry, PWACs becomes more effective in removing targeted pollutants from water or air [9].

1.5 Effectiveness of PWACs in Removing Contaminants from Wastewater

1.5.1 Dye absorption

Dyes in industrial wastewater pose a challenge for treatment, but PWACs shows promise for effective removal [14]. Industrial processes like textile manufacturing generate wastewater with colored dyes that can be toxic and harmful tothe environment. Activated carbon, traditionally made from coal or coconut shells, is a commonly used adsorbent to trap pollutants [15]. Researchers have been exploring the use of plastic waste for activated carbon production, which offers a sustainable and eco-friendly approach. PWAC is produced through carbonization and activation processes, resulting in a material with a unique porous structure that effectively captures and retains dye molecules. The attractive forces between the carbon surface and the dye molecules cause them to bind, removing them from the water even at low concentrations [16]. This approach addresses plastic waste management and contributes to a more sustainable and circular economy by transforming plastic waste into a valuable resource for water treatment [17].

2. Conclusions

This preliminary review is extremely important to address the effects of water pollution on the ecosystem resulting from the release of different poisons, such as organic dyes into water resources. Using discarded plastic materials as starting points to produce activated carbon fibers not only contributes to the reduction of solid plastic waste but also offers a more affordable and environmentally friendly option than activated carbon that is sold in stores. By addressing the issues of high energy and manufacturing costs and generating inexpensive activated carbon with a large adsorption capacity, this approach method advances the general objectives of waste management and environmental preservation.

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