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Wastewater Treatment Using Economical Adsorbents

Hashirudeen, Muhammed Mokolade
Environmental Chemistry Unit
Department of Chemistry, University of Ibadan, Ibadan, Nigeria
E-mail: hashirudeenmuhammad@gmail.com
Phone: +2347010137732, +234701265104

ABSTRACT

Water is crucial for public health, because it is utilized for drinking, cooking, or recreation purposes. Improved water supply and sanitation, as well as better water resource management, can assist countries in growing economically and reducing poverty. Despite many technological advances, wastewater treatment remains a critical issue internationally. Adsorption is frequently used in wastewater treatment because of its cost-effectiveness, design, and flexibility. Activated carbon is the most commonly utilized adsorbent for its ability to absorb organic materials. Due to its high cost, this adsorbent is challenging to regenerate. New adsorbents, on the other hand, have evolved to complement conventional materials. These materials have a large of surface area, a strong mechanical strength, and chemical inertness. This paper provides an overview of various classical and emerging adsorbents used in wastewater treatment.

Keywords: Adsorption, Conventional, Novel, Isotherms, Adsorption, Wastewater

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1. BACKGROUND TO THE STUDY

Water pollution has always been a source of public concern. Wide range of chemicals and substances are now used to improve the quality of human life and consumer goods, due to scientific and technological breakthroughs. On the other hand, misuse and unregulated discharge of such compounds into water bodies frequently have long-term negative effects on aquatic life and human health.

The fact that much of industrial pollutants are metal ions or refractory organic compounds that stay in water bodies adds to the problem. These pollutants make river water unsafe for drinking and recreation (Schweiter and Noblet, 2018).

Irrigation and food production account for 70% of current global freshwater consumption, according to reports and statistics from several international organizations, and this consumption is expected to rise by 19% (including rain-fed and irrigated agriculture) over the next 40 years as the world's population grows (UNWater, 2017). Water stress, in which available freshwater sources fail to satisfy demand due to low quality (a result of water pollution), is expected to affect two-thirds of the world's population by 2025 if no efforts to reduce water pollution are taken (UNESCO, 2017). Urbanization is the primary source of water contamination in developed countries. In poor countries, on the other hand, 70% of garbage is dumped into rivers, lakes, and coastal zones without being treated, and 90% of wastewater is released into rivers, lakes, and coastal zones (UN Water, 2017; UNESCO, 2017). Wastewater industrial effluent and agricultural operations is a major source of concern due to its toxicity, bioaccumulation, biomagnifications, global range, and persistence in the environment.

According to additional research, roughly 12% of synthetic dyes are wasted during production and processing operations, with approximately 20% of these dyes ending up in industrial wastewaters (Demirbas, 2009). The United Nations has stated that 80% of the global wastewater are released to the ecosystem sometimes without or with some treatment (UN WWDR, 2017). As a result, if left untreated, these contaminates can cause irreversible harm to the natural environment and human health, and these toxic effluents pose a severe threat to the surrounding ecosystem (Afonze and Sen, 2018). Several methods have been investigated in treatment of different contaminants in wastewater i.e. dyes and heavy metals such as solvent extraction, ion exchange, chemical precipitation, adsorption and electrochemical technologies. Selection of the approaches used generally rely on: e.g. costs, efficiency, reliability, feasibility, environmental impact, practicality and operation difficulties (Crini and Lichtfouse, 2019). However, these technologies have certain disadvantages, such as inefficiency, insufficient removal, delicate operating conditions, large energy demands, and costly disposal procedures.

2. ADSORPTION

Adsorption techniques have proven to be effective among all wastewater treatment technologies, due to its flexibility in operation, design processes, and considerable impact on toxicity, biological availability, and transport of contaminants in wastewater. Transit of contaminant from aqueous solution to sorbent surface, adsorption onto solid surface, and transport within sorbent particle are the three processes involved in adsorption. Activated carbon is the most widely used adsorbent due to its capacity for the adsorption of organic materials. This adsorbent is difficult to regenerate due to its high cost. Langmuir maximum adsorption capacity (qmax) and Freundlich adsorption isotherm are the two most widely utilized isotherm parameters (KF).

2.1 Types of Adsorption

Physical and chemisorption (activated adsorption) are the two main types of adsorption. Physical adsorption is the binding between adsorbent and adsorbate surface due to non- specific van der Waals force whereas the latter forms ionic or covalent bonds by chemical reactions. Physical adsorption is reversible, but less specific, on the other hand, chemisorption is more specific and irreversible (Tripathi and Rawat Ranjan, 2015). There are several factors which influence the adsorbent's efficiency including temperature, pH, stirring duration and initial concentration. The rate of heavy metal adsorption typically rises with the surge of the above-mentioned factors (Burakov et al., 2018).

2.2 Adsorbents Activated Carbons

Activated carbons (ACs) are frequently used as adsorbents at water treatment plants for adsorbing heavy metals owing to the microporous structure, large surface area and chemical complexity. Their external surface possesses variable functional groups for example phenol, carbonyl, lactone, carboxyl, quinone and others. It is proven that the adsorption performance of ACs is dependent on surface functional groups and pore size distribution. However, activated carbon may react with oxygen under moderate temperature (300oC). Commercial ACs are present in granular, powder, clothe and fibrous form (Ahmad and Azam, 2019).

Activated carbon is a low-cost material with distinct characteristics such as a large specific surface area, high porosity, and appropriate surface functionalization. Coal is used but it is expensive and production is not eco-friendly. This has piqued researchers interest onto development of ACs from abundant and inexpensive agricultural waste materials. Generally, adsorption relied on adsorbent concentration, temperature, time and pH of the solution (optimum pH: 12.0) (Khan et al., 2004). ACs are mostly used to remove undesirable odors, color, taste and organic impurities from water in the treatment of domestic and industrial wastewater, but the adsorption by ACs have some restrictions such as loss of adsorption efficiency after regeneration, the need for regeneration after exhausting and may cause secondary pollution as the contaminants are separated from the ACs but not destroyed (Chai et al., 2021).

2.3 Biomaterials

Biosorption or bioremediation is a process that uses mainly microorganisms, plants, or microbial or plant enzymes to detoxify contaminants in the soil and other environments. It high efficiency and low operating cost, has made it to be used in adsorbing contaminates in wastewater treatment process. The production of biomass such as fungi, bacterial is cheaper than other conventional materials.

The adsorption process on biosorbents cell walls especially bacteria can be dependent or independent of metabolism. Metabolism dependent biosorption occurs on the surface via formation of van der Waals forces, electrostatic attraction, covalent bond and precipitation. Such adsorption mechanism involves generation of energy from ATP (Adenosinetriphosphate) in which the ligands on the biological material cell wall immobilizes heavy metal and allow adsorption to take place. Cell wall composition, medium conditions and nature of heavy metals are among the factors that affect metal uptake by living biomass. On the other hand, metabolism independent biosorption happens in biomass comprising of dead cells. Ionic bonding or physiochemical adsorption involves in this process (Chai et al., 2021). Some biosorbents commonly use are algae, bacteria, fungi and biochar.

Fungi are eukaryotic living organism and can be used as biosorbents in living or biomass forms. The cell wall structure of fungi that is made up of 90% polysaccharides, offers good metal binding properties with various functional groups such as proteins, carboxyl, phosphate and uranic acids. They grow easily, yield large amount of biomass that can be handled morphologically and genetically.

Fungal biosorption provides an environmentally sound and economically feasible solution for the removal of heavy metals from aqueous solutions (Dhankhar and Hooda, 2011). Biochar is a material that is rich in carbon, manufactured in the absence of oxygen by heating the biomass through pyrolysis process. As a result of its graphene-like carbon matrix, high porosity, enhanced surface area, high cation and anion exchange capacity, biochar is able to hinder contaminants and pollutants from water or soil to organisms and further reduce the bioavailability of pollutants by adsorption. Biochar have been extensively used during anaerobic digestion and to eliminate the trace metals, pathogens and suspended matter in wastewater treatment process (Tan et al., 2020).

Bacteria is an environmental and economical adsorbent. Bacteria have been used as biosorbents because of their ability to grow under controlled conditions and resilience to a wide range of environmental conditions. Fungi are eukaryotic living organism and can be used as biosorbents in living or biomass forms. The cell wall structure of fungi that is made up of 90% polysaccharides, which offers good metal binding properties with various functional groups such as proteins, carboxyl, phosphate and uranic acids. Desirable biosorption process for fungi takes place at room temperature. Fungal biosorption provides an environmentally sound and economically feasible solution for the removal of heavy metals from aqueous solutions (Dhankhar and Hooda, 2011).Biomaterials have been shown to be successful at removing heavy metals from wastewater due to their low cost of production.

2.4 Graphene

Graphene is a two-dimensional (2D), single atomic thick layer of sp2 hybridized carbon atoms arranged in hexagonal lattice through sigma and pi bonds. It is accessible in numerous forms including original graphene, graphene oxide (GO) and reduced GO (rGO) (Low et al, 2016 and 2020). Graphene exhibits unique mechanical, chemical and physical properties that makes it applicable in heavy metal adsorption from water. Its outstanding properties include large specific surface area, great chemical stability, enhanced functional sites and active sites found on its surface. The largely delocalized p electrons and adjustable chemical properties of graphene make it a more promising adsorbent in wastewater treatment than activated carbon. GO is the oxidized form of graphene derived from the chemical oxidation of graphite. It has high negative charge density and hydrophilicity contributed by the oxygen functional groups present (Ramesha et al., 2011).

The production of graphene is relatively cheaper since there are various methods to synthesize it chemically (chemical vapor deposition, chemical exfoliation, mechanical cleavage, etc.). Among the graphene-based materials, graphene oxide with pore size of about 0.9 nm emerges to be highly cost effective. GO is non-conductive making it highly durable. The prospect of producing large amount of graphene nanomaterials have been performed via an economical approach in water purification (Sreeprasad et al., 2013)

2.5 Metal organic framework (MOF)

Metal organic frameworks (MOFs) are crystalline porous solids comprise of three-dimensional (3D) network of positively charged metal ions (metal nodes) held in place by multidentate organic molecules via coordination bonds forming a cage-like structure (Wang et al., 2019). MOFs have a remarkably large internal surface area ranging from 1000 to 10000 m2 /g exceeding activated carbons due to their hollow and highly ordered structure. Most of the MOFs exhibit superb chemical stability under harsh conditions (Wang et al., 2016). They can also be synthesized using low coast and simple methods on a large scale.

3. CONCLUSIONS

Adsorption is effective technique in treatment of wastewater due to its variability and availability. Cost production and regeneration of activated carbon has led researchers into finding economical and eco-friendly alternatives. Conventional adsorbent such as rice husk, coconut shell, wood, fungi, bacterial, biochar cannot offer preferred removal efficacy for some contaminants in wastewater due to low adsorption capacity. Novel adsorbent such as graphene, nanotubes, MXenes has been use effectively in wastewater treatment. These materials have a high specific surface areas, exceptional mechanical strength and large pore volumes combined with various intermolecular interactions allowing adsorption to occur.

Functionality and durability has been the challenges that confront researcher which are important in environmental applications. Although most of the novel materials show excellent adsorption performance through theoretical simulations, the number of experimentally synthesized novel materials, for example MXenes are still limited. Therefore, the synthesis of large scale of MXenes becomes a significant research direction. Moreover, there are often large inconsistencies between the experimental and theoretical uptake capacities leading to non-ideal surface conditions which appear to be a challenge for the wide scale usage of novel materials in wastewater treatment.

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