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NANOTECHNOLOGY METHODS USING FRUIT PEEL WASTE (FPW) IN WASTEWATER MANAGEMENT

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Abstract

Due to its adsorption properties, fruit peel waste (FPW) is readily available from agriculture and the food processing industry. This article reviewed the function of FPW in the management of wastewater. Additionally, this article provides information on the use of absorbent materials and modelling in wastewater treatment using nanotechnology. The investigation shows that there is little literature on the properties and behavior of commercial plants' adsorbents. The results for FPW as adsorbents are also not readily available. However, due to its affordability, FPW is regarded as an efficient method of wastewater treatment. The available research verified that FPW is a highly effective adsorbent for removing heavy metals and dyes. More research is needed to understand how FPW adsorbents behave while removing organic and gaseous contaminants.

***Keywords**: Fruit Peel Waste (FPW), Wastewater, Pollutants, Absorbent, Adsorption*

INTRODUCTION

Water is a pure natural resource that is accessible on earth and serves as a vital resource for both humans and other living things. In addition, water is regarded as a universal solvent because of its important qualities, including power, electrolyte, solubility, and others. Water contamination is a problem that the entire world is currently facing. Several factors contribute to the water contamination, including waste from industry, a lack of agricultural opportunities, inadequate sewage treatment, waste from radioactive materials, marine dumping, and others. [1]. Water pollution has a negative effect on the ecosystem, and it also contributes to air pollution, which has a risky effect on people's health. The economic and social development of the concerned nations is negatively impacted by water contamination. The UN just released a report stating that freshwater availability is a global issue. The report also demonstrated that contaminated water is not any safer for living things in the twenty- first century. [2]. According to the WHO (World Health Organisation) water contamination has caused 4 billion people to suffer from various health problems and around 1.7 billion people to die. Unwanted material that is present in water bodies and renders them unfit for Activated sludge precipitation, flocculation, membrane separation, ion exchange, and photodegradation are a few water purification techniques that effectively remove contaminants from water, but it can be challenging to identify a method that effectively removes harmful water contaminants [12]. Fruit peel extracts as adsorbents are thought to be a more effective method for wastewater management in this case than traditional wastewater treatment methods [13–15]. Fruit peel extract has many benefits when used as bioadsorbants, including low cost, environmental friendliness, accessibility, and high efficacy (Hossen & Pauzi, 2025).

Orange peels, tea waste, banana peels, pine bark, rice husk, sugarcane bagasse, and other fruit peels are some of the fruit peel extracts used as bioadsorbants for the extraction of heavy dyes and ions [16, 17]. This fruit's peels emit more substantial soluble organic chemicals into the water, which restricts its use on a broad scale. Adsorbents that are effective and affordable effectively lower water contamination for purification [18]. Because bio peels have several functions, they can combine ion exchange, electrostatic interaction, and complexation to adsorb contaminants. Functional group characteristics like OH, NH2, and COOH are visible on the surface of the fruit peels. This fruit's peels are used to remove heavy metal ions including Pb2+, Ni2+, and Cr2O7 2 from water pollution. Fruit peels are also used in the removal of dyes including methylene blue, alcian blue, brilliant blue, and neutral red from water (Hossen & Pauzi, 2025)

Waste Water Treatment

Organic contaminants found in wastewater include polynuclear, ketones, hydrocarbons, detergents, and greases. Heavy metals are regarded as inorganic pollutants in water that are poisonous and hazardous to living things. The various water pollution-causing factors are shown in Figure 1.

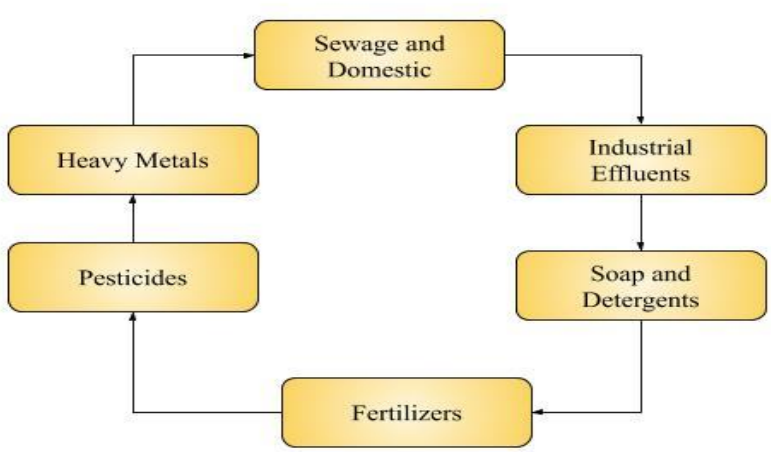

Figure 1: Schematic of Pollutants in Water

The primary, secondary, and tertiary treatments of wastewater are included in waste water management, which also includes other wastewater treatment technologies. Figure 2 shows a water management strategy for trash removal.

The principal treatment used in the first phase of the water purification process is depicted in figure 2. Grinding, sedimentation, and screening are the main treatment procedures used to remove grit. The third stage of water management is regarded as an advanced water management technique, while the secondary treatment makes use of biological techniques. Water quality has greatly improved when the three steps of wastewater management are finished, making it appropriate for drinking, medical use, and industrial use. 99% of water contamination is removed from water throughout the water treatment process, turning the water into high-quality water (Rashed et al., 2025).

Primary Treatment

The first step in water treatment is to remove serious pollutants. Sand, floatable matter, and suspended solid solids are typically removed in this way. Oil and grease surfaces, as well as waste from pharmaceutical and personal care products (PPCPs), respond well to this treatment. 90% of contaminants are removed from water after initial treatment, and between 40% and 60% of suspended and settable solids are also removed (Mohd Pauzi & Shahadat Hossen, 2025).

Nanomaterials for Waste Water Management

Nanomaterials are substances with a minimum size of 100 nm in one dimension. Nanomaterials exhibit a number of size-dependent features at this scale, making them useful in the treatment of wastewater. Some of the important properties of nanoparticles are size-dependent properties that are connected to the specific surface area of the substance. Fast dissolving, high reactivity, and potent adsorption are just a few of the traits this demonstrates. Surface plasmon resonance, quantum confinement, and super para magnetism are some further benefits of nanomaterials. The following is a list of nanomaterials' adsorbent properties:

Adsorption

When waste water is treated, the features of material adsorption are used to remove both biological and inorganic waste from water. The surface properties of conventional adsorbents, such as material surface area, kinetic adsorption ability, and lack of material selectivity, are all dependent on these properties. With enhanced surface area, site of adsorption, size of tunable pore, surface chemistry, and diffusion distance, nano-adsorbents perform significantly better than conventional adsorbents.

Nano-technology for removal of Organic components in Water

Carbon made with nanotechnology is more effective at adsorbing various organic compounds from water. For a given surface area and discrete contamination zones of carbon interaction, adsorption capacity is comparatively larger. Carbon-based nano absorbents in aqueous media offer a loose bundle of hydrophobicity over graphite surface and lessen the efficiency of the surface area. The aggregation of interstitial space and grooves for greater energy organic molecule adsorption, however, was a function of carbon-based nanotechnology [23]. The estimate of large organic molecules like medicines and antibiotics was made possible by the use of carbon nanomaterials in a significant number of micropores [24]. Additionally, the existence of large pores and accessibility of organic material performance in the adsorption site in carbon nanomaterials results in a higher rate of organic molecule adsorption capacity.

Metal based nano-adsorbents

The heavy metals and radionuclides contained in water are easily absorbed by the metal oxide-based nanotechnology. These metal oxides include alumina, iron oxides, and titanium dioxide. The difference between metal oxides and dissolved metals in terms of oxygen content limits the properties of metal adsorption. This nanotechnology is implemented in a two-step process that combines rapid metal ion adsorption from exterior surfaces with rate-limiting intraparticle diffusion behaviour in micropore walls. Due to its enhanced surface specific area, reduced distance for intraparticle diffusion, and increased number of diffusion sites, this nanoscale structure displays better adsorption capacity and higher kinetics. Take as an example how, with an increase in arsenic adsorption capacity that is 100 times larger, the size of nanoparticles drops from 300nm to 11nm [29]. This suggests that the material's adsorption properties grow when the manomaterial surface area of 300 nm and 20 nm surface rises, with the capacity value of arsenic's adsorption normalised at 6 mmol m2 or 3.6 atoms nm. Figure 3 details the performance of metal-based nano-absorbents while taking into account various particle sizes that are lowered to 20 nm. The "nanoscale effect" is defined as the specific surface is normalised adsorption capacity increased with 11nm nanoparticles which is three times greater than arsenic 18 mmol m2 or 11 atoms nm2. With the emergence of additional adsorption sites, this impact is described as a modification in the characteristics of magnetic surface structure [30].

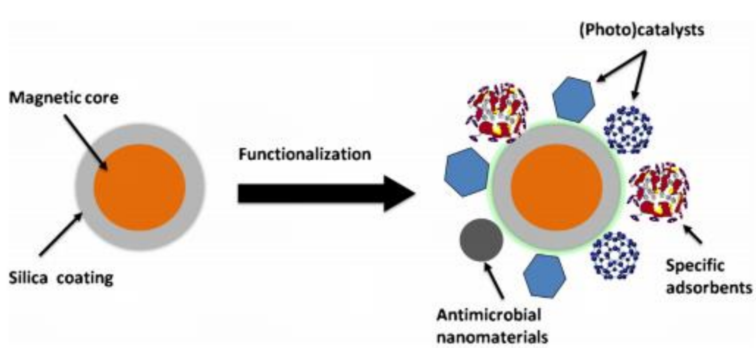

Figure 2: Structure of Multi-Functional Nano-material

Metal-based nanomaterials investigated a substantial usefulness for purifying heavy metals from water. Copper, mercury, arsenic, chromium, cadmium, and lead are the heavy metals that exhibit notable potential features of activated carbons. Arsenic is one of those heavy metals that has attracted a lot of attention due to its effectiveness as an organic and inorganic pollution adsorbent, which restricts the capacity of activated carbon [31]. Other nanomaterials, like nanosized magnets and TiO2, have good arsenic adsorption properties, much like activated carbon [32].

Potential Composites of Fruit Peel Waste

Synthetic resins that are naturally occurring and unconventional adsorbents are used to remove those contaminants from wastewater. [36] presents a review of the phenolic compound adsorption using inexpensive adsorbents. These natural adsorbents include organic substances including bioadsorbents, waste products, and agricultural and industrial leftovers. [37] investigated the phenol adsorption mechanism in water using inexpensive adsorbents and synthetic resins. Various microorganisms engaged in eliminating organic contaminants from waste water were presented in [38]. In order to remove dyes from water, the concept behind the adsorption of heavy metal created from agricultural waste is provided in [39]. There are materials like chitosan, siliceous materials, activated carbons, zeolite, chitin, and solid wastes contained in [40] reviews about waste removal in water with low costs. This is accomplished by using waste materials or agricultural byproducts as absorbents. This review investigates the function of FPW in the removal of organic, inorganic, dyes, and heavy metals. The entire analytical analysis of the material reviewed about FPW in eliminating pollutants is shown in table 4.

Banana Peel (BP) Fruit Extract for Waste Water Management

Among the review of the literature that is currently available, which is confined to the five fruit peel wastes shown in table 2, BP shows notable performance to remove contaminants from waste water. Living things are severely threatened by pesticide use, which has a negative effect on them [41, 42]. BP performs admirably in eliminating this pesticide-laden wastewater that is combined with natural water bodies. The features of banana waste as an adsorbent for several water-soluble insecticides are studied. The characteristics that were measured for banana peel are shown in table 5 for the treatment of wastewater.

According to [43], banana stalk activated carbon (BSAC) undergoes a chemical activation process when CO2 and N2 gas are present. For different contact times, pH levels, carbon concentrations, and temperatures, the adsorption analysis is carried out for BP. For the elimination of ethanol, the performance of the BSAC is evaluated across three cycles. After each cycle, the regeneration effectiveness of BP varies between 96.97 and 97.35%. However, the adsorption capacity falls from 98.40 to 85.00% from the first to the third cycle. In [44] also looked at the ability of bentazon, insecticides 2, and 4-Dichlorophenoxyacetic acid to be removed from aqueous solution using banana stalk activated carbon (BSAC). Through study, it is discovered that bentazon and 4-dichlorophenoxyacetic acid have BSAC's maximum adsorption capacities at rates of 115.07 and 196.33 mg/g, respectively. The ability of insecticides to absorb substances decreases as temperature rises between 30 and 500 C [45]. Additionally, it is mentioned in [45] that BP has a higher adsorbent effectiveness than any other species. Ametryne and atrazine may be desorption with high adsorption and desorption capability thanks to the comparison adsorption study of BP. Furthermore, it was reported that BP did not require any chemical alterations to the surface or pH level in order to increase adsorption. In the literature [46], information regarding the absorbents' performance for ZnCl2 in the presence of carbaryl (1-naphthyl-N-methylcarbamate) solution is published. Table 6 lists the performance of the carbaryl solution.

Conclusion and Future Perspective

Water act as an essential source for living beings but water contamination affects the utilization. The utilization of nanomaterials for the removal of water pollutants is increasing drastically. Nanomaterial techniques involved in nanosorbents, nanostructured catalytic membranes, etc with effective removal of waste in water in less time, minimal energy, an eco-friendly technique. But these nanotechnology techniques are not cost-effective and not suitable for commercial purposes. This review examined the wastewater management technique and nanomaterial components of FPW utilized for water management are presented. Form the analysis of review it is observed that banana peel exhibits excellent characteristics for waste adsorption characteristics. Banana peel act as a low-cost agent for waste removal and protect the environment with the prevention of methane/CO2 gas formation. It is observed that publication related to banana waste as adsorbents for water management is increased.

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