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Water Pollutants Removal by using Adsorption

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Abstract: The increasing contamination of water bodies due to industrial effluents, agricultural runoff, and domestic waste has necessitated the development of efficient and cost-effective water purification techniques. Adsorption has emerged as a promising method for the removal of a wide range of pollutants, including heavy metals, dyes, and organic compounds, due to its simplicity, versatility, and effectiveness. This paper reviews various adsorption techniques, focusing on the different adsorbents used, their properties, and their effectiveness in removing specific pollutants from water. The potential of novel adsorbents, such as biochar, carbon nanotubes, and metal-organic frameworks, is also discussed. The study concludes that while adsorption is a highly effective method for water purification, challenges such as adsorbent regeneration, pollutant selectivity, and large-scale implementation need to be addressed to enhance its practical application.

Keywords: Adsorption, Water Pollutants, Heavy Metals, Organic Pollutants

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INTRODUCTION

Water pollution is a significant global concern, driven by the discharge of contaminants into water bodies from various anthropogenic activities. The presence of pollutants such as heavy metals, organic compounds, and dyes in water poses severe risks to human health and aquatic ecosystems. Traditional water treatment methods, including coagulation, flocculation, and chemical precipitation, often fall short in effectively removing these pollutants, particularly at low concentrations [1]. Adsorption has gained considerable attention as an alternative water treatment method due to its high efficiency, ease of operation, and cost-effectiveness.

Adsorption is a process where contaminants adhere to the surface of a solid material (adsorbent), effectively removing them from the water. The effectiveness of the adsorption process is influenced by several factors, including the nature of the adsorbent, the properties of the pollutants, and the environmental conditions. This paper aims to explore the different adsorbents used in water treatment, assess their performance in pollutant removal, and discuss recent advancements in the field. Special attention is given to novel adsorbents such as biochar, carbon nanotubes, and metal-organic frameworks, which have shown great potential in enhancing the efficiency of the adsorption process [2].

WATER POLLUTION AND POLLUTANTS

When unwanted, foreign substances are present in water and deteriorate its quality, this is referred to as water pollution. When the physical, chemical, and biological characteristics of water are dramatically changed, and this change has a negative impact on living things, this is called water pollution [3]. Compounds that change the physical, chemical or biological characteristics of water are referred to as pollutants. The primary properties of these contaminants are listed below:

WATER POLLUTION EFFECTS

- Respiratory infections, encephalitis, hepatitis, diarrhoea, gastroenteritis, stomach pains, and vomiting; multiple sclerosis, Parkinson's disease, heart disease, Alzheimer's disease, and even mortality are all waterborne illnesses.
- Cancer, such as non-Hodgkin lymphoma and prostate cancer
- Negative effects on the nervous system, liver, kidneys, DNA, and marine life.
- Hormone issues that may impair growth and reproduction;
- Vegetable crops cultivated or washed in contaminated water may harm humans.

WATER QUALITY PARAMETERS

To evaluate the water's quality, a variety of factors are taken into account [4, 5]. Table 1 lists a few metrics with the Bureau of Indian Standards' permitted limitations for household water supply.

Table 1: Drinking water Specification from Indian standard IS: 10500 (Unit; mg/l, otherwise mentioned).

Fluoride	Not less than 0.6 and max limit 1.5	0.6 to 1.2
Phenols	0.002	0.001
Hg	No relaxation	0.001
Cd	No relaxation	0.01
Se	No relaxation	0.01
As	No relaxation	0.05
Cyanide	No relaxation	0.05
Pb	No relaxation	0.1
Anionic detergents	1	0.2
Cr(VI)	No relaxation	0.05
Polynuclear aromatic Hydrocarbon	--	--
Mineral oil	0.03	0.01
Residual free chlorine		0.2
Pesticide	--	Absent

Radioactive	--	--
Alkalinity	600	200
Al	0.2	0.03
B	5	1

WATER POLLUTANTS CLASSIFICATION

There are two types of water pollution: point sources and non-point sources. When dangerous pollutants are released into a body of water, this is referred to be a point source of pollution. Pollutants are indirectly delivered by a non-point source via changes in the environment. When fertilizer from a farm is pushed into a stream by rain and then affects aquatic life, it is an example of this sort of water pollution [6]. Most of the pollutants in streams and lakes are the result of pollution from non-point sources.

Particularly in urban settings, organic materials make up a potentially sizable category of contaminants. Long-term exposure to certain of these organic pollutants, even at low concentrations, may be hazardous to human health. To a lesser extent, a select group of organic pollutants plays a significant role in the development of photochemical haze. Other important sources of these pollutants are the petroleum and chemical industries as well as waste incinerators, gas stations, residential solid fuel and gas burning, cigarette smoke, spray painting, dry cleaning, and other solvent usage. Cholera, typhoid, dysentery, polio, and hepatitis are all spread from person to person by contaminated water [7]. Industrial chemicals such as pesticides, detergents, insecticides, and dyes pose a threat to aquatic life when they are released into the water supply, either by accident or on purpose. The capacity of maritime plants to photosynthesise is hindered by oil pollution because less light reaches the surface waters. Additionally, it decreases the amount of dissolved oxygen in the water, putting waterfowl, coastal [8] plants, and animals in peril. As a result, oil contamination causes unpleasant and dangerous circumstances that are harmful to marine life and seafood.

Natural streams often include inorganic contaminants including mineral acids, inorganic salts, finely divided metals or metal compounds, trace elements, cyanides, sulphates, nitrates, and complexes of metals with organics. Natural organic species are involved in the metal-organic interactions. Redox equilibrium, acid-base reactions, colloid formation, and reactions involving water-borne microbes all have an impact on these interactions. These interactions also have an impact on metal toxicity in aquatic habitats. The amount of different metals and metallic compounds found in water as a result of human activities reach their baseline values [9]. Even though some of these trace elements are vital to biological functions, their toxicity to biota at larger amounts is a possibility.

WASTEWATER TREATMENT

The following are some of the several treatment techniques used to treat sewage and industrial wastewater.

Pretreatment is done so that large particles including floating and suspended solids, grit, oil, and grease may be removed before further processing. Wastewater debris, such as cans, fabric, wood, and other materials that float to the top, is generally removed during the earliest stages of treatment.

The remaining suspended particles are next removed as completely as possible, after the bulk solids, grit, and excessive quantities of oil and grease have been removed in the first treatment. The goal is to reduce the effluent's potency and facilitate its subsequent treatment.

In biological processes, dissolved and colloidal organic debris in wastewater is removed by bacteria and other microorganisms. They might be aerobic or anaerobic processes. In addition to lowering BOD, the secondary treatment also significantly decreases oil and phenol. However, secondary treatment system commissioning and upkeep are pricey.

The purpose of this last treatment is to further enhance quality by "polishing" the effluent from the secondary treatment procedures. Bacteria, viruses, microorganisms, suspended particles, and inorganic and organic compounds left behind after secondary and primary treatment are the major targets of tertiary treatment. A treatment scheme of wastewater is shown in Figure 1 [10].

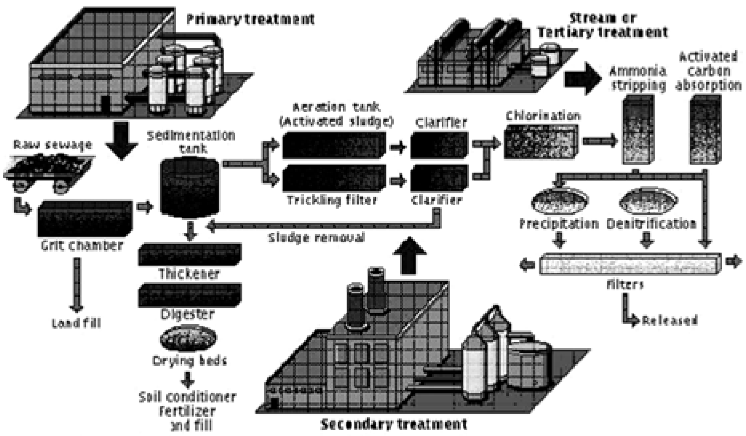

Figure 1: Treatment of wastewater [10]

The basic methods for treating colored wastewater may be broken down into three classes, each corresponding to a different ultimate effluent quality and treatment budgetary constraints:

- Biological treatment
- Chemical treatment
- Physical treatment

BIOLOGICAL TREATMENTS

Processes for biological treatment are highly helpful and get rid of all kinds of dissolved degradable chemicals. Biodegradation refers to the breakdown of organic matter by microorganisms and larger organisms. Anaerobic (without oxygen) and aerobic (with oxygen) degradation of organic material are both possible. Biomineralization, the process through which organic matter becomes minerals, is a word associated with biodegradation. Utilizing enzymes like lignin peroxidases (LiP) and manganese-dependent peroxidases, the white-rot fungus may break down dyes (MnP). Other enzymes employed for this purpose include lactase, a phenoloxidase enzyme, and H_2O_2-producing enzymes including glucose-1-oxidase and glucose-2-oxidase [11-13].

Numerous research teams have looked at the capacity of bacteria to decolorize wastewater under both aerobic and anaerobic conditions. [14-16]. Due to the disadvantage of needing a fermentation process, these microbial systems are unable to handle higher amounts of textile effluents. The removal of numerous harmful substances during this procedure is time-consuming, and may need fertilisers, extremely large aeration tanks, lagoons, and land expanses.

Dye-containing effluents have also been treated by using dead yeast, bacteria, and fungus. The chemistry of textile dyes varies widely, and as a result, interactions with microorganisms rely on both the chemistry of the particular dye and the microbial biomass in question [17]. Utilizing biomass provides benefits, particularly if the effluent containing the dye is very hazardous. When circumstances aren't always ideal for the development and maintenance of the microbial population, biomass adsorption is beneficial. Ion exchange is used by biomass for adsorption.

CHEMICAL TREATMENT

Photochemical Treatment

Photochemical treatment is the process of breaking down photodegradable molecules by exposure to light, especially photons of wavelengths common in the sunlight such as infrared radiation, visible light, and ultraviolet light. Ultraviolet light's ability to cause the production of free radicals is essential to several photochemical reactions. It has also been demonstrated that the UV-based techniques dramatically accelerate colour removal when a catalyst is present, such as a semiconductive material like TiO_2 or ZnO. As a result, several other combinations have been researched; however, their efficiency is greatly dependent on the kind of dye, the concentration of dye, and the pH [18].

Ozone Treatment

The extensive and efficient oxidation process used in ozone wastewater treatment makes it a good disinfectant for the organic material contained in wastewater. Due to its high instability (oxidation potential - 2.07) in comparison to chlorine, another oxidizing agent (1.36), and H_2O_2, ozone is a particularly effective oxidizing agent (1.78). The total amount of colour and leftover COD that must be removed from the effluent without leaving behind any residue or sludge determines the dosage that must be applied to the effluent [19]. When dyes are exposed to ozone, the molecule fragments that make up the chromophore groups—often conjugated double bonds in organic compounds—may lose their ability to impart colour. Ozonation may be used in conjunction with a physical approach to avoid the enhanced carcinogenic or poisonous qualities that these smaller molecules could have. Decolorization takes place in a brief period of time.

Electrochemical Destruction

This method is relatively recent, having been created in the middle of the 1990s. It offers a number of important benefits for usage as an efficient technique for dye removal using electrically-powered oxidation processes. Chemical use is minimal or nonexistent, and there is no sludge buildup. Releasing cleaned wastewater back into waterways is safe since the breakdown byproducts are often not dangerous. It demonstrates effective and affordable dye removal as well as excellent colour removal and refractory pollutant degradation efficiencies [20]. The primary drawback of this system is the high cost of power, which directly reduces dye removal at relatively high flow rates.

PHYSICAL TREATMENT

Coagulation/Flocculation

In the coagulation/flocculation procedure used in water and wastewater treatment, compounds like ferric chloride or polymer are frequently added to wastewater to destabilise the colloidal components, causing the microscopic particles to agglomerate into larger settleable flocs. In the first procedure, known as "coagulation," a coagulant is mixed with the effluent. The coagulant might destabilise the colloidal particles in the solution, causing them to clump together. To remove the destabilised particles from the solution, flocculation physically brings them together to create bigger flocs. The fundamental benefit of traditional processes like coagulation and flocculation is that they remove dye molecules from dye bath effluents, as opposed to partial degradation of dyes, which may result in an even more potentially dangerous and hazardous aromatic compound. A significant drawback of coagulation/flocculation operations is sludge generation [21].

Filtration Method

Several filtering technologies, including reverse osmosis, nanofiltration, and ultrafiltration, have been used to the problems of water reuse and chemical recovery. These techniques may be used to treat wastewater to remove colour, concentrate it, and most crucially constantly separate it [22]. The capacity of membrane filtration to endure high temperatures, high chemical concentrations, and the presence of microbes sets it apart from other approaches. A filter of a specified sort and pore size will be used depending on the temperature and chemical content of the effluent. The main disadvantages of membrane technology are its high initial costs, the possibility of membrane fouling, and the creation of a concentrated dye bath. Concentrates used in the mercerizing process, such as sodium hydroxide, or sizing agents, such as polyvinyl alcohol, may be recovered from membranes, lowering treatment costs (PVA). Reverse osmosis has been used effectively to recover dye bath effluents. To prevent membrane fouling, pretreatments like coagulation and micro-filtration have to be used. The recycling of water is best accomplished via the use of anaerobic pre-treatment, aerobic treatment, and membrane post-treatment [23].

Ion-Exchange

Ion exchangers are often used to demineralize water. Because it is believed that ion exchangers cannot tolerate a variety of colours, ion exchange has not been extensively employed to treat effluents containing dyes. Ion exchange resin is subjected to wastewater until the accessible exchange sites are saturated. This method may be used to extract both cation and anion dyes from effluent that contains dye. This approach has the benefits of removing soluble dyes, recovering solvent after use, and not losing adsorbent during regeneration. Despite its convenience, the ion-exchanger has a number of downsides. These include its high price, a lengthy regeneration process, and a lack of efficacy across the board for dye treatments [23].

Adsorption

One of the most effective ways to remove odour, colour, organic, and inorganic contaminants from industrial effluents is adsorption. Because of its comfort, simplicity of use, and ease of operation, the adsorption method is said to be superior in the treatment of water. Adsorption processes take use of a solid's preference for concentrating a given material from solution onto its surface.

This method employs both typical and unusual adsorbents [23]. As a result of its high adsorption capacity, huge surface area, microporous structure, and strong surface reactivity, activated carbon is the most often employed traditional adsorbent for this purpose. Several of these technologies are not widely used in wastewater treatment due to their high cost and poor regeneration capacity.

ADSORPTION: THEORETICAL ASPECTS

Adsorption

The term "adsorption," coined by "Kayser" in 1881, refers to the phenomena in which the concentration of a material in a liquid or solid phase is greater at the surface than in the bulk. Adsorption may take the form of either a chemical reaction or a physical process. In most cases, it is weak forces like the Van der Waals force, ion-dipole, dipole-dipole, polarisation, induced dipole, etc., that lead to physical adsorption. Adsorption due to physical forces is temporary and reversible. There is often less heat transfer. In contrast, the formation of chemical bonds between the adsorbent and the adsorbate is the outcome of chemical adsorption. Chemical adsorption requires high temperatures and is irreversible. Its hallmark is a drastic change in temperature upon adsorption.

Adsorption Mechanism

When a solid surface is placed in contact with a solution, a layer of solute molecules is commonly deposited at the interface due to an imbalance in the surface forces between the two. Both the attracting and repulsive interactions between the solution and the adsorbent are included within this molecular structure. Only a small percentage of the solute ions or molecules that have collected at the interface get adsorbed on the adsorbent's outer surface because its surface area is so much lower than that of its pores. The amount of impact that solute and solvent molecules exert on accessible adsorption sites in an aqueous solution is substantial. In the presence of a high solute-solvent affinity, the adsorption probability of a particular solute is set by the difference in adsorption potential between the solute and the solvent [24]. An example of this phenomenon is the reduced solute adsorption capability of zeolite and other polar adsorbents in polar solvents like water. Reduced adsorbent affinities for their respective solvents tend to go hand in hand with increased solute adsorption capabilities.

Adsorption Isotherm

The equilibrium position in the adsorption process is often characterised by one or more of a variety of isotherm models, which define the connection between the dye concentration in the bulk and the amount adsorbed at the interface. The effectiveness of these isotherms as models of experimental data is highly context-dependent, depending on the nature of the interactions between the adsorbate and adsorbent [24].

CONCLUSION

The study highlights the critical role of adsorption in the removal of water pollutants, offering a versatile and effective solution to the growing issue of water contamination. The review of various adsorbents demonstrates that while traditional materials like activated carbon remain widely used, novel adsorbents such as biochar and metal-organic frameworks are paving the way for more efficient and sustainable water treatment methods. However, challenges such as adsorbent regeneration, pollutant selectivity, and the feasibility of large-scale applications must be addressed to optimize the use of adsorption in water purification. Continued research and innovation in the development of adsorbents and the optimization of adsorption processes are essential to achieving cleaner water and a healthier environment.

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