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Nano Silica Based Adsorbants for Removal of Heavy Metals and Microbial Contaminants from Water

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In aquatic biosystems, where symbiotic activities could be affected, such as by reducing photosynthetic activity, toxic dyes, metal ions, and organic contaminants present a serious environmental risk (Ghorai et al., 2014). Water is still essential to modern society, the environment, and human development, but the byproducts of water use are industrial and municipal wastewaters. Consequently, treating wastewaters to make them reusable is not only a crucial task but also a pressing issue that needs to be resolved. Metals like zinc, copper, lead, cadmium, nickel, and chromium found in industrial wastewater from numerous factories can harm the environment. Chemical precipitation, which employs an alkaline solution to increase pH and facilitate the development of heavy metal hydroxide precipitate, is the method most frequently employed for treating wastewaters containing heavy metals. Filtration or other solid/liquid separation procedures are then performed. Even though the chemical precipitation procedure is a highly effective way to remove heavy metals, the heavy metal sludge it produces is classified as hazardous solid waste and must be treated properly (Lee et al., 2007).Pollution is a severe worldwide issue at the moment due to its negative outcomes on human health and the environment. Heavy metals, which include Pb, Cd, Hg, As, Ag, Cr and Cu are dangerous pollutants because they cannot be broken down. Those metals are emitted into the surroundings by both organic and man-made activities, like those in the mining, cosmetics, and aerospace industries. Among the most severe types of pollution is water contamination, for which millions of dollars are spent annually to lessen the consequences on public health (Rivera et al., 2019).Since its initial introduction for the elimination of metals, activated carbon has emerged as the most popular and commonly used adsorbent in wastewater treatment applications globally. Despite its extensive use, activated carbon remains an expensive material because its quality increases with cost. For activated carbon to be more effective at removing inorganic materials, complexing agents are required. It is no longer desirable to be extensively employed in small-scale companies due to this cost inefficiency (Babel, 2003). Heavy metals like Pb^{2+} are found in high concentrations in the wastewater of many industries, including mining, tanneries, printing and pigment, battery manufacturing, and metal plating. Heavy metals are carcinogenic and toxic in nature. It enters the ecosystem through soils and water streams, where it accumulates along the food chain. The condition of people is thus continuously at risk. since they don't age organically. It is becoming more and more crucial in current frontier research to remove dangerous heavy metals from commercial garbage toxic heavy metals from commercial garbage efficiently using a low-cost and environmentally acceptable material because they have the worst effects on the human health and the environment. For aquatic species in addition to those that depend on water for survival, it is crucial to minimize Pb^{2+} pollution. To remove heavy metals from industrial wastewater, numerous physicochemical methods and materials based on polymers and inorganic matter have been developed (Ghorai et al., 2013). Heavy metal contamination is among the primary environmental problems that jeopardize ecological and human health. The major glands and organs of a person, like the liver, brain, kidneys, bones, and heart, can become contaminated. It is essential to develop new, effective materials for the elimination of dangerous metals from the H2O so that protect ecosystems and human life. The US Environmental Protection Agency has classified Pb, Cd, and Zn as priority pollutants; these are the most dangerous metals. on the US Environmental Protection Agency's list of priority contaminants. The main sources of cadmium contamination are the primary metal industries, coal combustion, incineration of sewage sludge, and excessive utilize of chemical fertilizers. Lead is discharged inside the environment through the emission of petrochemicals, acid batteries, paint, smelting, mining, metal plating, fertilizers, and pesticides. Zinc finds wide usage in different industries, such as polymer stabilization, printing inks, batteries, cosmetics, alloy production, galvanization, and rubber manufacturing. Harmful metal wastewaters primarily originate from metal finishing operations, metal mining, and metal smelting (Wieszczycka et al., 2021). Exposure to heavy metals is extremely harmful to living things and can seriously impair biological processes, even at very low quantities. The high potential for heavy metal accumulation in food systems and the environment is the cause of this. Due its high toxicity, ability to gather in living things to dangerous levels, and potential for absorption through the skin, lungs, and digestive system, among the heavy metals mercury is the most dangerous and is considered as one of the most dangerous substances for humans. Many policies have been suggested to lessen the serious risk that mercury poisoning poses to both humans and the environment. Many policies have been suggested to lessen the serious risk that mercury poisoning poses to both humans and the environment. According to recommendations from the World Health Organization (WHO), the maximum amount of mercury that can be present in drinking water is one gram per liter, and humans should not be exposed to more than 0.3 mg of mercury per week (Morsi et al., 2018).

Water is among the most vital natural resources on the planet, necessary for both human growth and survival in addition to the survival of all other living creatures. Water scarcity is an important obstacle to economic growth caused by the sharp increase in industrialization and urbanization that has also led to a rise in water consumption. Meanwhile, the global environmental community is increasingly concerned about water contamination, especially that which is brought on by heavy metals. The main industries that free heavy metals into water include mining, electroplating, metallurgy, chemical plants, agriculture, and residential wastewater treatment. Because heavy metals can naturally build up in the food chain, these industries may pose a serious risk to public health. The metals Pb, Zn, Cu, and Hg are among these. The lungs, kidneys, central and mental nervous systems, and other organs, for example, may harm damage from exposure to heavy metals. It has even been shown that most heavy metals are carcinogenic, which makes them incredibly toxic. Because of this, eliminating heavy metals from water is essential and has drawn a large number of attentions. Numerous technologies have been produced to date to address this problem, including ion exchange, chemical precipitation, adsorption, membrane filtration, electrochemical treatment, and others. Frequently, it has been found that combining different procedures produces better removal results. Among all the techniques discussed above, adsorption is among the most frequently used because its low cost and simple functioning (Yang et al., 2019).

Nanomaterials Applied for the Removal of Metallic Ions from Water

Because of its properties, which include high porosity, surface functions, and particular surface area, and ion binding abilities, nanomaterials (NM) have been the subject of much research over the past 20 years for applications related to water and wastewater treatment. They really show a large amount of promise for getting rid of metallic ions, rather in trace amounts. Various categories of nanomaterials exist, including silica-based, carbon-based, metal and metal oxide nanoparticles (which encompass zero-valent iron (ZVI), magnetic nanomaterials derived from iron oxide, and nanocomposites. Several factors, such as flow rate, contact time, and adsorbent concentration, control the adsorption procedure of metallic ions. However, a key factor in the extraction process is the concentration of nanoparticles (adsorbent)(Kumar et al., 2021).

Nanomaterials Based on Carbon

Carbon-Based Nanomaterials: These resources, which are commonly used in drug delivery, energy storage, electronics, sensors, and water purification, include activated carbon, graphene, fullerenes, carbon nanotubes, and graphene oxide. Additionally, because of their distinct qualities, both inorganic and organic contaminants can be removed, making them a good alternative to wastewater treatment. They are among the assess to be most promising adsorbents for metallic contaminants as a result(Kumar et al., 2021).

Zero-Valent Iron Nanoparticles

Zero-valent metal nanoparticles have proven effective in treating various pollutants found in wastewaters. Silver nanoparticles (Ag NP) are preferred for their antibacterial and antifungal properties when it comes to wastewater purification. Another compound known as zero-valent iron at the nanoscale (nZVI), which consists of a coating of ferric oxide and Fe (0), is also utilized. The nanosized nature of nZVI results in a higher specified surface area and surface to volume ratio, enabling better elimination of contaminants(Kumar et al., 2021).

Magnetic Nanoparticles

The previously mentioned nanomaterials have exhibited exceptional potential in the extraction of heavy metals. Nevertheless, certain constraints regarding their cost-effectiveness, reusability, separation from aqueous solutions, and intricate synthesis routes impede their commercial scale utilization(Kumar et al., 2021).

Silica based nanomaterials for expulsion of heavy metals.

Silica-based nanoparticles are another important class of nanomaterials with broad applications to eliminate ions of heavy metals as a reason of their superior surface properties and shortage of toxicity. Furthermore, mesoporous silica's surface can be functionalized with groups such as amine (-NH2) and thiol (-SH) to enhance interactions between ions of heavy metal and facilitate possible extraction from water. Studying the elimination of $Cd^{2+,}$ $Ni^{2+,}$ and Pb^{2+} in batch mode using functionalized hollow silica nanospheres. Pb^{2+}'s higher electronegativity, depend on the scientists, resulted in stronger interactions with the adversely charged adsorbent surface, which is why the capacity for adsorption was observed to decrease for all of the adsorbents in the following order: $Pb^{2+} > Cd^{2+} > Ni^{2+}$. When utilized as an adsorbent, uncoated silica hollow nanospheres were discovered to have maximum adsorption capacities (qm) of 8.375 mg/g (Ni^{2+}), 25.924 mg/g ($Cd^{2+),}$ and 31.291 mg/g ($Pb^{2+).}$ This adsorption increased to 26.858 mg/g, 54.351 mg/g, and 96.786 mg/g for amino-functionalized silica gel. In a different study, the elimination of Cu^{2+}, Cd^{2+}, Hg^{2+}, and Pb^{2+} from nano polyaniline and crosslinked nano polyaniline-based nanocomposites was examined using a batch technique. The adsorption capacities of Pb^{2+}, Cu^{+2}, $Hg^{2+,}$ and Cd^{2+} were determined to be 341.4 mg/g, 289.8 mg/g, 162.9 mg/g, and 146.7 mg/g, in that order. The thiol-functionalized, organic polymer-based, porous nano-trap with an adsorption volume of more than 1000 mg/g selectively removes Hg^{2+}. Owed to the material's strong C–C bond, it showed remarkable stability in water across a wide pH range. Even at temperatures as high as 270 °C, it remained stable. The elimination of 10 ppm of Cu^{2+} and cationic thiazine dyes was investigated in a static mode using 3-aminopropyl and phenyl groups-based silica nanospheres. The percentage of Cu^{2+} ions absorbed rose from 70% to 80% in just one hour and 2.5 hours, respectively (Kumar et al., 2021).

Silica based nanomaterials for expulsion of microbial contaminants.

Different antibiotics have varying environmental half-lives; some are very persistent; hence the degree of environmental contamination has been rising. Numerous research investigations have demonstrated the substantial effects that antibiotic exposure (µg/L–mg/L) may have on aquatic species' body weight, growth, and survival. The effluents of pharmaceutical manufacturing facilities and municipal sewage treatment plants (STPs) are the primary sources of antibiotic releases into natural water bodies. Antibiotics and ARGs released into the environment are likely to be concentrated around urban wastewater treatment plants. Antibiotics, in particular, are now recognized as hazardous and toxic pharmaceutical chemicals as they are categorized as recalcitrant bio-accumulative compounds, which is how they are classed as emerging environmental pollutants. Antibiotic residues must be eliminated before wastewater is released into the environment; however, this usually comes at a great expense Although techniques like advanced oxidation can entirely mineralize or reduce antibiotic molecules to simpler compounds, they are exceedingly costly and challenging to maintain for the complete elimination of chemicals, including antibiotics, on an industrial scale. Therefore, it is becoming increasingly clear that physicochemical methods are an excellent choice for treating organic pollutants. The adsorption process is comparatively affordable, easy to develop and run, very efficient, and not susceptible to potential toxicity like biologically based methods. Although the implementation of adsorption techniques to the elimination of antibiotics is only known to have occurred around thirty compounds to date, these processes are regularly applied to extract organic contaminants from contaminated streams onto adsorbent surfaces (Ahmed et al., 2015).

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