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REVIEW ARTICLE

Industrial Wastewater: Health Concern and Treatment Strategies

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Abstract:

Water is a basic need for the functioning of all life forms that exist on earth. However, current water resources are being polluted by anthropogenic sources, which include social unit, as well as agricultural and industrial waste. People all over the world have concerns about the impact of effluent pollution on the atmosphere, which is increasing day by day. It is hard to purify wastewater before it flows into water reservoirs. Hence, the treatment of wastewater remains an essential need before it is allowed to enter natural water streams. Wastewater treatment is relatively a modern practice. This review will particularly discuss the ways of heavy metal ion removal from wastewater. The ultimate purpose of wastewater management is to improve the health of human and environmental aspects.

Keywords: Wastewater, Pollution, Health concern, Industrial waste, Wastewater treatment, Heavy metal.

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1. INTRODUCTION

Water that is polluted through any means is called wastewater. It is the water that has already been used and originated from any combination of industrial, domestic, agricultural activities or commercial, any sewer infiltration or sewer inflow or surface runoff. Wastewater can contain physical, chemical, and biological pollutants. Water resources are becoming scant worldwide because of the rising inequity between freshwater utilization and their accessibility. Therefore, the availability of clean water has become one of the main challenges [1].

There are three ways to reduce the waste from the wastewater, *i.e.*, regeneration, reuse, and recycling. Wastewater can directly be reused in alternative operations during the process of reuse. Wastewater is turned into usable water that can further be reused easily for various purposes. In the regeneration reuse process, partial treatment regenerates wastewater to eliminate pollutants, which can be reused in different operations. In the regeneration recycling process, wastewater is often regenerated to get rid of contaminants that are man-made in order to recycle it. During this process, water may get into the process during which it has been previously used [2].

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In recent years, the frequency of metals released into environments from different industries, auxiliary processes, and human activities has significantly increased. In the water sources, metal ions can also be released, which cause water contamination. Depending on the form of pollutants, various procedures are used to clean wastewaters. Wastewater treatment is a process that divides and removes debris from industrial wastewater or effluents. Wastewater can be treated at wastewater treatment plants that involve biological, chemical, and physical processes of treatment. The main objective of wastewater treatment is to remove pollutants that can harm the aquatic environment [3].

Over the past decade, potential adsorbents, such as hydrogels, have been used in the removal of water contamination. To increase the performance of adsorption, many different substances are chosen for the preparation of hydrogels and every substance has its own benefits. The most widely used hydrogels in wastewater treatment are classified into three groups which include hydrogel films, hydrogel beads, and hydrogel nanocomposites. Hydrogels are polymer hydrophilic chains of a three-dimensional network, and they are often used as a colloidal gel in which the dispersing medium is water. These are held together by cross-links. Hydrogels are available at a low cost, have high water retention and attract great attention due to their adsorption properties [4].

Toxic metals are hazardous to every biological organism as well as the surroundings when their concentration reaches the specified limit. Approximately one million dyes are used

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annually in industries around the world, over 100% of which are released as wastewater that severely pollutes the surroundings and causes harm to humans and aquatic organisms. Besides metals and dyes, radioactive materials containing wastewater are also harmful to human health and the surrounding [5].

In general, physicochemical treatments provide various advantages like their fast method, simple process and management, and temperature fluctuations flexibility. Unlike the biological system, physicochemical treatment handles the variable inputs and flows, such as seasonal flows and complicated discharge. When needed, chemical plants may be modified. Therefore, the treatment system requires less space and a lower installation value. However, their merits are offset by a variety of disadvantages like the use of chemicals, which increases the operational prices, consumption of high energy, and sludge disposal handling prices. However, physico-chemical remedies are found to be effective treatments for effluent removal with decreased chemical prices (like the use of low-priced bents) and possible sludge disposal [6, 7].

Sewerage systems of every nation have paramount underground infrastructure properties. They are old, and in most cities, they have been subjected to severe microbial mediated corrosion. As it poses risks to public health and economic consequences for water utilities, this is a major global problem. It is important to predict the rate of corrosion to maintain the effectiveness of sewer assets. Sewer corrosion predictive models are integrated for the measurements of concrete surface temperature. However, due to the unavailability of a proven sensor, it has not been completely exploited at present.

The feasibility of calculating various temperature variables in the sewer has been shown by recent studies. For example, in different Australian cities, the gaseous temperature of sewer air was measured within the corrosive sewer pipes. Similarly, the effluent and ambient temperature of the sewers were measured in two sewer manholes of the city of Kent in England and the average effluent temperature was also measured and found to be higher than 3.5°C. A considerable amount of research has been carried out using Distributed Temperature Sensing (DTS) technology, which uses fiber optic cables to monitor wastewater temperatures in sewage networks [8].

For the measurement of temperature gradients at various sewer pipe locations, the use of DTS technology has been demonstrated by putting the fiber optic cable near soffit (top), wastewater level (floating), and invert (bottom). While researchers have concentrated on the measurement of various sewer temperature variables, no studies on the calculation of concrete surface temperatures in sewers have been published in the scientific literature. As sewer corrosion depends on the surface temperature variable, sensor technology is used to calculate the surface temperature of the sewer pipe crown.

In recent years, researchers have hit many milestones by using ambient temperature, Relative Humidity (RH), and H_2S levels in sewer corrosion modeling. There is still a significant proportion of uncertainty consistent with the model prediction, even though certain works are advancing towards conceivable corrosion prediction performance. Therefore, it is necessary to provide new data on the concrete surface temperature as it favors bacterial activity [9].

Due to Hydrogen Sulphide (H_2S) induced concrete corrosion, the concrete sewer pipes experience a severe level of deterioration. It is well known that microbial activities turn the H_2S present in the sewer air and on the concrete sewer walls into sulphuric acid (H_2SO_4). The microbiologically developed H_2SO_4 penetrates the concrete pores and begins to react chemically with the cementitious content of sewer pipes and eventually corrodes the concrete reinforcement bars (rebars) [10]. Water utilities rely on sensor monitoring systems that acquire information-rich corrosion data to efficiently manage the sewer infrastructure. In this context, the temperature on the concrete surface is established as an essential observation that can provide critical data for the models predicting the rate of sewer corrosion [11].

India produces 1.7 million tonnes of wastewater daily. Official statistics show that 78% of the wastewater is not treated and disposed of in groundwater, lakes, and rivers. Two main sources of water pollution are industrial and sewage waste. The population of India and its industrial landscape are increasing at an alarming pace, therefore, the volume of wastewater being produced is also increasing. Also, freshwater resources such as rivers, wells, and groundwater are getting diminished. In India, the Legal Mechanism for Wastewater Regulation includes the Water (Pollution Prevention and Control) Act, 1974, which was amended in 1988. The law was introduced to control and avoid pollution of water and to restore or maintain the health of the water. It is also established to control water pollution. The recent status of wastewater treatment in India explains that about one-third of wastewater of India is getting purified now with different methods of treatment. The untreated wastewater leads to an increase in waterborne diseases. Although the availability of urban water supply is above average, there are major disparities across the country, and sewage treatment remains at a national average of 33%. In Punjab, Gujarat, Maharashtra, and Uttar Pradesh, large generators are used for wastewater treatment, which can purify 65-100% of urban wastewater. However, many populous states like Bihar, Madhya Pradesh and Andhra Pradesh can treat less than half of their wastewater. In many Himalayan and North Eastern states, there are barely any or no treatment policies of wastewater that could be utilized to clean the water [12, 13].

2. WASTEWATER CHARACTERISTICS

The wastewater can be described based on physical, chemical, and biological characteristics:

2.1. Physical Characteristics

The physical properties include color, odor, and turbidity. Fresh sewer water is sometimes lightweight and brownish-grey in color. However, typical sewer water is grey and includes a cloudy look. Typical septic sewer water can have a black color. Fresh domestic wastewater features a musty odor. If the wastewater is allowed to go septic, the odor can considerably be modified as a rotten egg odor associated with the production of hydrogen sulphide. Turbidity is measured to determine water clarity [14].

2.2. Chemical Characteristics

The chemical property mainly includes pH and oxygen demand. The determination of the hydrogen ion concentration value of sewerage is a vital process. River water containing ferric sulphate 0.3 mg/L cadmium showed that removal is get increased up to 20% at pH 7.2 and 90% at pH > 8. The results of alum coagulation also increased with increasing pH; however, removals above pH 8 were dependent on raw water turbidity. In the pH range of 6-10%, both ferric sulphate and alum coagulation achieved more than 97% lead removal from river water containing 0.15 mg/L of lead. Over the pH range of 6.5-9.3, ferric sulphate coagulation achieved excellent Cr^{+3} removal, about 98%. For the pH range of 6.7-8.5, alum coagulation is less efficient, and obtained removals exceeding 90%. Removals started to decrease above pH 8.5; at pH 9.2, the removal decreased up to 78% [15].

2.3. Biological Characteristics

The biological characteristics of waste material include the presence of bacterium and other living microorganisms, like algae, fungi, protozoa, *etc* [16]. Wastewater treatment is a matter of caring for our surroundings and our health [17]. Many opportunistic pathogens (*e.g.*, *Enterobacter cloacae, Enterococcus faecalis, Escherichia coli, Klebsiella pneumoniae, Proteus vulgaris or Pseudomonas aeruginosa*) may be carried by wastewater, which can cause numerous systemic infections, especially in people with a weakened immune system. Compulsory pathogens of the *Salmonella* and *Shigella* genera or enteropathogenic strains of *Escherichia coli*, responsible for salmonellosis, shigellosis or gastroenteritis, are also found in the wastewater. In the sewerage system, 18 species of the genus *Longilinea, Georgenia, Desulforhabdus, Thauera, Desulfuromonas,* and *Arcobacter* have been reported. *Methanosarcina, Methanosaeta,* and *Clostridium* are among the bacterial genera involved in the process of anaerobic methane fermentation. The treated effluent contains fecal bacteria of the genera *Bifidobacterium* and *Bacteroides,* as well as *Clostridium perfringens* [18].

2.4. Heavy Metals in Wastewater

Heavy metals, known as trace metals, are one of the most enduring pollutants in waste products. Discharge of high quantities of metals into water bodies results in harmful impacts on the environment and health. Human exposure to metals can occur through several routes, which involve inhalation of fume or dirt, through drinks and food. Few negative impacts of metals on aquatic environments include marine life mortality, algal blooms, environmental destruction due to debris, sedimentation, increased water flow, and short- and long-term toxicity due to chemical contaminants. Voluminous quantities of essential metals are found in soils, which contribute to a decrease in food quality and quantity, nutrient uptake, as well as metabolic and physiological processes. On animals, severe effects of metal ions include decreased development and growth, organ and system harm, cancer, and at an extreme level, cause death. To mitigate the harmful effects of metals on human health, animals and surroundings, a number of remedial processes for the treatment of wastewater exist. These remedial processes are generally classified into biological and chemical processes, which are used at present. Biological remedies (microbial remedy and phytoremediation) are effective in the treatment of metal contaminants found in waste products. Microbial remediation helps to restore the surroundings and its quality by using microorganisms, like protozoan, fungi, and alga, whereas phyto-remediation is the process in which the plants are used to degrade or absorb toxic metals, thereby resulting in a reduction in the bioavailability of the material within water or soil [19, 20].

Toxicity reduction methods that meet technology-based treatment requirements are used for the treatment of industrial wastewater that contains toxic metals. In biological treatment systems, microorganisms play a role in the resolution of sinking solids. Activated sludge, stabilization ponds, trickling filters are widely used for the treatment of industrial waste material. Biosorption could be a new biological methodology in which low price adsorbents (agricultural waste, industrial waste, forest waste, algae, *etc*.) are utilized for maximum removal of toxic metals from waste material. Biosorption methods are environmentally safe and a better approach to remove metals from wastewater, instead of physicochemical ways. But chemical ways are best suited for treating ototoxic inorganic compounds produced from numerous industries that cannot be extracted from any physical and biological process [21, 22].

Hazardous metals are sometimes present in municipal, industrial, and concrete runoff, which may be dangerous to biotic and human life. Raised urbanization associated with industrialization is a curse for waterways because it causes an increase in trace metal levels, mainly heavy metals. Many dangerous chemical components, if released into the atmosphere, get accumulated within the soil and sediments in the water bodies. There are over fifty heavy metals that are released in water, seventeen of that are considered to be poisonous, and results showed that they affect human health [23].

Monitoring of structural health is an important element of evaluating the circumstances of aging civil infrastructures, such as underground concrete sewer pipes. Most of these pipes are affected by concrete corrosion, which is occurring more commonly due to bacterial sulphate-reducing activities that are held on concrete sewer pipe walls. Corroded sewage pipes are costly to repair. Water utilities use pipe lining technology to reduce rehabilitation costs. To improve the structural integrity and mitigate the effects of corrosion, the linings are the protective coatings added to the degraded host structure. In general, calcium aluminate cement or geopolymer based products are used for the sewer pipe linings. They provide high resistance to the sulphuric acid created by the concrete sewer pipes on the walls. However, because of the permeation of acids, the linings will deteriorate in the long term. Therefore, long-term monitoring of sewer pipe linings is important for water utilities. Information about the long-term performance of the linings can be provided by reliable sensing technologies [24].

3. IMPACT OF METALS IONS AND THEIR CONCENTRATION ON HEALTH

The level of toxicity depends on the metal type, its biological function, and the type of organisms that are exposed to it. Heavy metals can significantly influence the aquatic fauna and flora. The heavy metals, usually related to human toxicity, are lead, cadmium, iron, copper, chromium, zinc, *etc.* The body needs the metals in minimum amounts; therefore, their excess causes cytotoxicity. For instance, heavy metals such as copper are important trace components but show toxicity when found in excess amounts in drinking water [25].

Also, cadmium is very toxic, even at low concentrations and can bioaccumulate in ecosystems and organisms. It has a biological half-life in the body, starting from 10 to 33 years. Additionally, long term exposures to cadmium induce renal harm. In most countries and international organizations, cadmium is considered a pollutant [26].

The standard of surface and groundwater supplies needs to be constantly assessed. The identified serious effects of heavy metal toxicity by drinking water include decreased central nervous system and mental function and lower levels of energy. They additionally cause blood composition irregularity, which can harm important organs like the liver and kidneys. The potential use of such metals contributes to persistent physical, neurological, and muscular processes that trigger Parkinson's disease (disease of brain degeneration), Alzheimer's disease (a disorder of the brain), multiple sclerosis, and muscle dystrophy (skeletal progressive muscle weakness) [27, 28].

The presence of lead in drinking water, which is one of the most dangerous heavy metals, is also a serious concern. Lead has the power to switch calcium in the bone to create sites for future replacements. Heavy metals like copper can also show toxicity on excess consumption. This type of toxicity may be overcome if the amount of metal ions present in drinking water is decreased, *i.e.*, within their limits [29].

Drinking water is obtained from various sources like wells, lakes, rivers, ponds, reservoirs, *etc.* Water also poses a risk to human health because of the pollution of these sources. Contamination of water is caused by various matters called water pollutants. Water contaminants consist primarily of heavy metals, fertilizers, microorganisms, and harmful organic compounds. Heavy metals only exist at low levels in water; however, they are more harmful to the human body. To minimize the toxicity of heavy metals in water and also to protect human health, different International organizations, such as USEPA, Environmental Protection Agency, WHO, and also the European Union Commission, have set a limit for the amount of the heavy metal in drinking water [6, 30].

4. STAGES OF WASTEWATER TREATMENT

New pollution issues have put additional pressures on systems for the handling of wastewater. Today the toxins like heavy metals, organic products, and radioactive substances are more problematic to extract from wastewater. The problem is only aggravated by rising demands on the water supply. The water demands grow the need for wastewater reuse as well as better strategies for its treatment. These problems are solved by improved approaches that help to eliminate the pollutants at treatment plants or by preventing pollution at the source. For example, industrial waste pre-treatment eliminates many troubling pollutants from the pipeline at the beginning, not at the end. New methods for eliminating contaminants are being established to clean the water before discharging it in the lakes and other water streams. The physicochemical separation methods like carbon adsorption, filtration, reverse osmosis, and distillation are also used in wastewater treatment. Such wastewater treatment systems can attain approximately the desired degree of pollution control; waste effluents treated with such method can be used for manufacturing, recreational and agricultural purposes, or even for the purpose of drinking [31, 32].

4.1. Preliminary Treatment Stage

In this stage, the materials get removed, which will cause operational problems. Initial raw waste product screening happens at the preliminary treatment, and the grit, large floating objects, and dense inorganic solids are eliminated. The small quantity of organic materials is far from the screens. Very little or no elimination of steroid hormones and organic micropollutants has been discovered at this stage [33].

4.2. Primary Treatment Stage

It is the second step toward treating wastewater. This permits the solids and greases to be physically segregated from the wastewater. The screened wastewater flows into a primary subsidiary tank where it is stored for many hours, permitting solid particles to settle down to the bottom of the tank and oils and greases to float up to the top [34].

4.3. Secondary Treatment Stage

In this stage, the organic compounds and pathogens are removed from the effluent exploitation microorganisms. Removal is typically achieved by biological processes during which microbes consume the organic impurities as food, changing them into water, carbon dioxide, and energy for reproduction and growth. For this natural organic treatment, the sewerage processing plant provides an acceptable atmosphere, but with concrete and steel. Removal of soluble organic matter at the treatment plant helps to protect the dissolved oxygen balance of a receiving source like a lake or river [35].

4.4. Tertiary Treatment Stage

Tertiary wastewater treatment is intended to increase the standard of water as per domestic and industrial requirements or to satisfy particular needs around the safe water discharge. In the case of municipally treated water, tertiary treatment often includes the removal of the pathogen that ensures water safety and is used for drinking purposes. Treated water is disinfected so that it is sent out for disposal into river streams or for wastewater reuse activities. Chlorination and UV irradiation are employed primarily in the process of disinfection [36].

5. TREATMENT STRATEGIES FOR REMOVAL OF HEAVY METAL IONS AND DYES

Due to industrial processes, wastewater is generated, which contains heavy metals and causes severe threats to the health of the general public and ecological systems. The hazardous metal ions removal from numerous water resources achieves sensible and scientific interest. Hydrogels composed of synthetic cross-linked polyacrylate are accustomed to the removal of metal toxicity from liquid media. However, the application of those artificial materials on massive scales might not be a sensible process because they are expensive. Pollution caused by serious metal ions is often eliminated by well-known processes of surface assimilation that have the advantage of reusing the treated effluent, aboard flexibility in style and operation. Conjointly attributable to the general changeability of the surface assimilation method, it is sometimes doable to regenerate the adsorbent to create the most cost-efficient method [37, 38].

The use of hydrogels as adsorbents has been studied for metal removal, dye recovery, and elimination of cyanogenetic parts from varied effluents. The hydrogels were proved as wonderful dye adsorbent materials having very high amounts of surface assimilation of methylthionine chloride. Polyelectrolytes have a special significance in the removal of serious metal ions among the other hydrogel-forming materials. Several polyelectrolytes have the ability to bind with oppositely charged metal ions to make the complexes. The cationic and anionic charges on the nanogel or microgel, at the same time, provide more benefits for the two distinct species removal. Mainly, the hydrogels comprise versatile units and viable materials that demonstrate the potential of the hydrogel for environmental applications. Hydrogels derived from the chitosan, starch, alginate, and polysaccharide are based on a biopolymer unit, which is used in the removal of metal ions from binary compound media. The mechanism of action and action capability of gel is determined for the serious metal ions removal. This can be attributed to alternative methods for wastewater treatment [39, 40]. Conventional methods for the removal of heavy metals are described below:

5.1. Coagulation/ Flocculation

The process of coagulation-flocculation relies on the calculation of zeta potential. To control the electrostatic repulsion process, the coagulation process reduces the net surface charge of the colloidal particles. Through additional collisions and interaction with inorganic polymers formed by the additional organic polymers, the flocculation process frequently enhances the particle size of distinct particles. Once distinct particles have been flocculated into larger particles, they are removed or separated by the mechanism of pressure, filtration or flotation. The key disadvantages of this approach are sludge production, application of chemicals, and the transfer of cytotoxic compounds into the solid component [41, 42].

5.2. Membrane Filtration

This is used to isolate the suspended solids or colloidal particles from the solution ranges in diameter between 0.1 and 10 µm. Membrane filtration for the treatment of inorganic effluent has received considerable attention. It is capable of removing heavy metals, suspended solids, inorganic and organic compounds contaminants. Looking at the dimensions of the particle that may be maintained, numerous styles of filtration membrane-like nanofiltration, ultrafiltration, and reverse osmosis can be used for the removal of heavy metals from wastewater [43, 44].

5.3. Biological Treatment

Heavy metals removal from wastewater requires the utilization of biological methods for pollutant elimination. Microorganisms play a part in addressing the subsidisation of solids. Activated sludge, stabilization ponds, and trickling filters are commonly used to treat wastewater. Activated sludge is the most typical option in which microorganisms are used for the treatment method to break down organic material with agitation and aeration that permits the solids to settle down. Bacteria that produce “activated sludge” is frequently recirculated back into the aeration basin in order to extend the organic decomposition rate [45, 46].

Ion exchange: This method is used with success for the removal of heavy metals from effluents within the industry. When compared to the other approaches, it is comparatively pricy. It can realize (parts per billion) ppb levels of clean-up, whereas it handles a comparatively large volume. An ion exchanger may be solid and efficient to exchange either anions or cations from the materials encompasses. Artificial organic ion exchange resins are widely used matrices in the ion exchange process. The disadvantage of this approach is that it cannot accommodate targeted metal resolution because the matrix gets simply fouled by organics materials and different solids materials inside the sewer water. It has a more natural action, which is very sensitive to the solution pH as well as non-selective [47, 48].

5.4. Electrodialysis

Electrodialysis is a process of membrane separation in which ionized species are passed through an ion-exchange membrane with the application of electrical potential within the resolution. The membranes are thin sheets of plastic materials containing either cationic or anionic properties. The solution of ionic species passes through the cell compartments, the cations migrate toward the cathode and the anions migrate toward the anode, which helps in the treatment of wastewater [49].

5.5. Photocatalysis

Photocatalysis is the process based on a very simple procedure and used in the treatment of contaminated water. Photocatalysis seems to be a stimulating method for the purification of water, with the possibility of utilizing sunlight as a renewable and sustainable source of energy. This technique suggests the utilization of a semiconductor that may be excited by lightweight, which is associated with the energy more than its bandgap, causing the creation of energy-rich electron-hole pairs that might be concerned with redox reactions. Recent research has investigated the nanoscale semiconductors' chemical nature to improve their optical and electronic properties. It has also been shown to improve their photoresponse to the actinic radiation. Generally, nanomaterials have a high degree of flexibility and high activity, are size-dependent, and have large specific area properties that make them suitable for use in the purification of water. The principle of photocatalysis is incredibly simple. A catalyst harnesses the sunlight UV radiation and uses the energy to interrupt and break the substances. Photocatalysis will be used to break down a large variety of organic acids, organic materials, dyes, pesticides, crude oil, microbes (including gas organisms and viruses), as well as inorganic molecules like nitrous oxides (NOx). Because of its universal applicability, photocatalysis with nanoparticles are used as catalysts to scale back pollution, additionally to the purification of water and in building materials for self□cleaning surfaces [50, 51].

5.6. Adsorption

The adsorption method is a promising and economically established technique for long term treatment. Heavy metals can be removed in this process and the decrease in heavy metals even to a low concentration increases the use of adsorption as a sensible treatment. Also, the adsorption method offers top-quality effluent treatment and flexibility in design and operation. The used adsorbents can be regenerated due to their reversible characteristics. Parameters that embrace the chemical and physical properties of adsorbents and adsorbate are temperature, pH, and contact time. The adsorption method does not have a specific mechanism; however, sorption isotherms are used to describe it [52, 53].

5.7. Ozonation/Oxidation Process

Advanced oxidation processes are explained as those process which involve the production of enough quantity of hydroxyl radicals to effect purification of water. Ozone has been used for more than eight decades as a chemical agent, an industrial chemical, and an oxidizer for the treatment of water. Ozone is considered to be a strong disinfectant and oxidant, with the best thermodynamical oxidation potential. In theory, ozone should be ready to oxidize inorganic substances to their highest stable oxidation states and organic compounds in the water and carbon dioxide. Inorganic chemistry is most beneficial for multiple bonds and aromatic systems cleavage, however, even in these cases, the rates of chemical reaction could be quite slow for water treatment applications [54].

5.8. Chemical Precipitation

It is a well-known technique of expelling and breaking up harmful metals from wastewater. To convert the broken metal into strong molecule structure, a precipitation reagent is added to the blend. A concoction response occurs, which is activated by the reagent and breaks down the metal structure into strong particles. Filtration would be utilized to expel the particles from the blend. This strategy includes modification of the ionic harmony to create insoluble particles that can be effectively evacuated by sedimentation [55].

6. BIOLOGICAL THERAPIES FOR WASTEWATER TREATMENT

It mainly includes the bioaccumulation and biosorption process.

6.1. Bioaccumulation

Bioaccumulation is an active mechanism mediated by metabolism, in which the biosorbent is absorbed intracellularly by metal ions in living cells. The process takes place in two phases: the first phase is the adsorption of metal ions into cells, which is rapid and similar to biosorption, and the second phase is slower, which involves the active transport of metal species inside the cells. It is an irreversible, complex process, unlike biosorption, which depends on the cell's metabolism. The bioaccumulation process takes place by cultivating a microorganism's biomass in the vicinity of the metal to be deposited. The organism starts its metabolic processes and activates the intracellular transport systems for the accumulation of sorbate, as the solution contains the growth medium [56].

Bioaccumulation is an active process that is regulated by the metabolism of the microorganism used by a living biosorbent. The process is operated by cultivating the microbe in the presence of a metal ion that has to be extracted. Inside the cell, part of the biosorbate accumulates, allowing the biomass to raise and bind with higher concentrations of metal ions. Organisms that are capable of resisting high metal ion loads are ideally suited to collecting the species of metal [57].

By choosing the microbes that are screened from contaminated habitats, effective bioaccumulation can be achieved. *Pichia stipitis* yeast was able to bioaccumulate copper ions and chromium ions with a maximum absorption ability of 15.85 and 9.10 mg/g, respectively, from aqueous solutions with an initial concentration of 100 ppm at pH 4.5. *Aspergillus niger* was able to extract copper ion and lead ion with a maximum absorption ability of 15.6 and 34.4 mg/g, respectively [58].

6.2. Biosorption

Biosorption can be characterized as a simple, metabolically passive physicochemical process involving the binding of metal ions (biosorbate) to the biological-origin biosorbent surface. The use of microorganisms, plant-derived materials, agricultural or industrial waste, biopolymers, and so on requires biological elimination. It is a rapidly reversible mechanism involved in attaching ions to the functional groups present in aqueous solutions on the surface of the biosorbent by different interactions rather than oxidation by aerobic or anaerobic metabolism [59].

The benefits of this method include easy operation, no additional nutrient requirement, low sludge generation quantity, low operating costs, high performance, biosorbent regeneration, and no increase in water Chemical Oxygen Demand (COD), which are otherwise the key constraints for most traditional techniques. Even in dilute concentrations, biosorption can remove contaminants and has special relevance for heavy metal removal due to toxicity at ppb levels. For the biosorption process, microorganisms (live and dead) and other industrial and agricultural by-products can be used as biosorbents. The biosorption method is beneficial because it is reversible, needs no nutrients, is a fast-range single-stage method, has no risk of toxic effects and cell growth, allows intermediate balance concentration of metal ions, and is not controlled by metabolism [60]. Various processes of wastewater treatment and their advantages and disadvantages are summarized in Table **1**.

6.3. Applications of Hydrogels in Wastewater Treatment

The exceptional physical and chemical properties of the hydrogel, including swelling, hydrophilicity, and modification, are growing the interest of researchers in the development and use of new hydrogels for the treatment of wastewater. Hydrogels demonstrated excellent functioning in eliminating a large range of aqueous pollutants, such as nutrients, heavy metals, and toxins. Though some problems do occur while designing the hydrogel-based therapeutic systems, from laboratory-level to practical applications [67]. Table **2** describes the applications of different hydrogels in wastewater treatment.

7. FACTORS AFFECTING THE ADSORPTION OF HEAVY METALS

Several factors affect the potency of adsorbents to remove metal from waste material. These factors include temperature, initial concentration, adsorbent dose, contact time, pH and stirring speed. Significant removal percent of metal is affected by the initial concentration, adsorbent dose, temperature, contact time, and stirring speed increment.

7.1. Effect of Solution pH

The pH of the metal solution has a significant influence on the absorption of metal ions from toxic waste. It has been discovered that an increase in solution pH can also raise the adsorption up to a certain limit and *vice versa*. The pH of the solution additionally affects metal hydrolysis, combine ion formation, solubility of organic matter, and iron and aluminum oxides surface charge and organic matters [76].

7.2. Effect of Initial Concentration and Interaction Time

The rise in initial metal particle concentration and adsorption capability is multiplied because of the increased driving force that overcomes all mass transfer resistance between the solid and liquid phases. Interaction time between the industrial waste and the metal particle with the adsorbents also influences the removal potency of heavy metals [76].

Table 1. Various processes of wastewater treatment and their advantages and disadvantages.

Process	Advantages	Disadvantages
Coagulation/flocculation	Inexpensive capital cost, Good sludge settling and dewatering characteristics, Significant reduction in the chemical oxygen demand and Bacterial inactivation capability.	Requires adjunction of non-reusable chemicals (coagulants, flocculants, aid chemicals). Physicochemical monitoring of the effluent (pH). Increased sludge volume generation (management, treatment, cost), Low removal of arsenic [61].
Membrane filtration	Small space requirement, simple, rapid, and efficient, even at high concentrations. No chemicals required. Low solid waste generation. Eliminates all types of dyes, salts, and mineral derivatives.	Investment costs are often too high for small and medium industries. High energy requirements. The design of membrane filtration systems can differ significantly [62].
Biological methods	Biodegradation of organic contaminants is simple, economically attractive, and well accepted by the public. White-rot fungi produce a wide variety of extracellular enzymes with high biodegradability capacity. High removal of biochemical oxygen demand and suspended solids.	Requires management and maintenance of the microorganisms and/or physicochemical pre-treatment. Slow process (problems of kinetics). Low biodegradability of certain molecules (dyes). Poor decolorization, possible sludge bulking and foaming [63].
Ion exchange	Wide range of commercial products available from several manufacturers. Technologically simple (simple equipment). Well-established and tested procedures; easy control and maintenance.	Large volume requires large columns. Rapid saturation and clogging of the reactors. Saturation of the cationic exchanger before the anionic resin (precipitation of metals and blocking of the reactor) [64].
Photochemical	No sludge production.	Formation of by-products [65].
Chemical precipitation	Technologically simple and integrated physicochemical process. It is economically advantageous and efficient. Very efficient for metals and fluoride elimination. Significant reduction in the chemical oxygen demand.	Chemical consumption (lime, oxidants, H2S, *etc.*). Ineffective in the removal of the metal ions at low concentration, high sludge production, handling, and disposal problems (management, treatment, cost) [61].
Adsorption	Technologically simple (simple equipment) and adaptable to many treatments. Target a wide variety of contaminants. Highly effective process.	Relatively high investment, non-destructive processes, non-selective methods. Performance depends on the type of material [66].

Table 2. Applications of various hydrogels in wastewater treatment.

Hydrogel	Application
Polyacrylamide	Used as flocculants or coagulants in industrial wastewater treatment [68].
Guar gum	Used to reduce raw water turbidity from 26.5 to 1.0 [69].
Gum tragacanth	Used as an emulsifier, thickener, and binder in industries [70].
Gum Arabic	Used to reduce the high concentration of alum needed for water treatment [71].
Gum ghatti	Widely used as adsorbents for removing different impurities from wastewater, like synthetic dyes and toxic heavy metal cations [72].

(Table 2) contd.....

Hydrogel	Application
Xanthan gum	Used as a novel flocculant [73].
Alginate	Used as a physical barrier against native microorganisms in wastewater [74].
Chitosan	Used for the heavy metals and dyes adsorption [75].

7.3. Effect of Ionic Strength

Ionic strength is a property of solution by virtue of which the affinity between the solute and solution phase gets affected. In certain cases, sorption gets reduced with the increase in liquid media ionic strength. This could ensure changes in the activity of metal or an electrical double layer property. When two phases (metal species and industrial wastes) are connected in solution, due to electrostatic interaction, they are absolute to be fenced by an electrical double layer [77].

7.4. Effect of Industrial Waste Particle Size

The decrease in particle size rises in the extent of the material and consequently increases the adsorption [78].

7.5. Effect of Temperature

The temperature shows a small effect on the adsorption of metal within the variation range. This is explained by adsorbent molecules' nature. The increase in adsorption with increased temperature suggested that metal ions adsorption by adsorbent could require not only physical but also chemical methods. The rise in active sites occurs due to the rupture of the bond. This result may be found due to a higher temperature [79].

7.6. Effect of Contact Time

The functional cluster interaction occurs between the solutions, and therefore, the adsorbent surface contributes to the adsorption capacity of the adsorbate. A specific time is needed to establish the interaction equilibrium so that the adsorption process is completed [80].

CONCLUSION

From the literature survey, it can be concluded that industrial wastewater shows a significant effect on human health. Various methods that are used for the treatment of wastewater are also described in the manuscript. Recent studies suggest that biological therapies are an eco-friendly approach that is better for the removal of metals and is cost-effective. Toxic sludge, which cannot settle down easily, is treated by physical and other chemical methods. The treated water is easily dumped into water streams. Treatment of wastewater does not cause any type of environmental, aquatic, and human disease-related harm. Therefore, the treatment of wastewater before dumping it into the atmosphere is necessary.

CONSENT FOR PUBLICATION

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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