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Removal of Organic and Inorganic Contaminants from Water by Chemical and Biological Techniques – A Review

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ABSTRACT

Water is an essential component for survival of living beings globally. Water is being polluted day by day by anthropogenic sources. Rapid industrialization and urbanization play key roles for polluting the water. A lot of soluble and insoluble materials act as contaminants or pollutants for making water not usable. Inorganic materials such as heavy metals, ions and organic materials such as phenol and phenolic compounds are heavily released by the industry in the water. WHO and EPA recommended some values for these contaminants in water. Above the value of these contaminants from the recommended values may cause harmful effects for human beings as well as other living organisms. The aim of this study is to identify the sources of various types of inorganic and organic contaminants and their removal techniques from the water.

***Key words**: Inorganic contaminants, Heavy metals, Organic contaminants, Phenolic compounds.*

Introduction

Environmental pollution is one of the most disastrous ecological crisis to which we are exposed today. The most important components of life are air, water and soil. Earlier important amenities were very pure, uncontaminated and undisturbed for living organisms. But situation is not same today. Increasing population and urbanization is one of the main causes for increasing the pollution level in the environment (Chawla *et al*., 2015). The contaminants present in water are hazard to life. The impurities present in water and wastewater is decisive factor for selection of treatment scheme (Jabin and Kapoor, 2020). They are present in water in suspended and dissolved form. Phenolic compounds and heavy metals impurities present in water are non-biodegradable in nature (Motamedi *et al*., 2022, Miserli *et al.,* 2022, Kumar and Chawla, 2013; Kumar *et al*., 2015). So it is important to go through the details of contaminants present in wastewater and water. Presence of phenolic compounds in water and wastewater are due to pollution from different industries like sugar industries, textile industries and many others (Shahrezaei *et al.,* 2012). They are toxic and having long lasting effects on human health (Shahrezaei *et al*., 2012). They are carcinogenic in nature. It is further noted that these compounds combine with other organic and inorganic compounds in water and become more lethal.

Phenolic compounds are categorized into various categories viz; simple phenols, phenolic acid, acetophenones, hydroxycinnamic acids, phenylpropenes, naphthoquinones (Archivio *et al.,* 2007). Phenolic compounds are also divided as simple phenol, polyphenols and biphenols depends on the number of phenol groups attached in a specific molecule (Archivio *et al*., 2007). Simple phenols have only one substituted phenolic ring. Pharmaceutical, food industries, oil refining, paint, petrochemicals, resin manufacturing, plastics, paper and pulp industry are having phenolic compound impurities in wastewater effluents (Sun *et al.,* 2015,)The heavy metals present in wastewater is also growing gradually due to growth of industries such as pesticides, electroplating industries, mining industries, tanning industries and petrochemical industries. The heavy metals are non-biodegradable in nature. That's why they are more carcinogenic in nature. WHO and EPA have recommended permissible values of heavy metals in the drinking water (Kumar *et al.,* 2015). Greater value of these heavy metals in drinking water can cause various health effects for living organism. Thus, it is very important to remove the phenol and phenolic compounds as well as heavy metal ions from water for drinking purpose. Lots of synthetic and natural materials in pristine and in their modified form have been applied for removal of these materials from water. Moreover, many technologies have been invented and tested for the removal of these contaminants present in water. Recently extraction, coagulation flocculation, membrane technology and adsorption are widely used and eco-friendly method for removal of these contaminants (Mohamad *et al*., 2011). The aim of present work is to identify efficiency of different techniques for removal of these contaminants from water.

Table 1 represents permissible value of heavy metals in water, their sources and their adverse effects. Most important heavy metals are lead, mercury, nickel, zinc, cadmium, copper, arsenic and chromium (Demiral *et al.,* 2021).The literature shows that most of the impurities are associated with dissolved impurities. So it is mandatory to study the characteristics of contaminants present in wastewater and water. From the standpoint of colloidal science, water is a complex system containing distinct types of impurities.

Technology for removal of phenolic compounds and heavy metals from water

Removal of inorganic and organic elements present in the water is a necessary need to safeguard the

Table 1. Types, sources, adverse effects and permissible limits of heavy metals in water.

Heavy Metals	Main Sources	Adverse Effects	Permissible Limits (µg)
Lead	Cable sheathing pigments, alloys, solder, ammunition, stabilizers, plastics, rust inhibitors, lead batteries.	Brain, liver, bones, lungs, spleen, kidney reproductive system, cardiovascular system, hematological system, immunological system.	10
Copper	Corroded plumbing systems, electronics and cable industry.	Brain, Cornea, liver kidneys, lungs cornea, hematological system, immunological system gastrointestinal system, lungs,	2000
Arsenic	Glass and electronic production.	Skin, kidneys, lung, brain, cardiovascular system, metabolic system, endocrine gland and immunological system.	10
Chromium	Steel and pulp mills, tanneries	Liver, kidney, brain, skin, pancreas and lungs, reproductive system	50
Mercury	Runoff from landfills, agriculture, caustic soda, electrolytic production of caustic soda and chlorine, industrial, laboratory apparatus	brain, kidneys, lungs, cardiovascular system, liver, immunological system and reproductive system	6

presence of individuals on land and in aquatic atmosphere. This section discusses various strategies being used to effectively remove inorganic and organic compounds from the water.

Membrane Technology

Membrane technology is generally used in the process of filtration. It can be classified as follows:

- Conventional membranes.
- Commercial composite thin film (TFC) membranes.

In TFC a layer made up of polyamide (PA) (<200 nm) is formed by interfacial polymerization and it is deposited on a layer of polysulfone (PSU) or polyethersulfone (PES) (Rezakazemi *et al.,* 2018). polysulfone (PSU) or polyethersulfone (PES) are basically porous in nature. Membrane filtration requires external pressure to separate the desired contaminants which are determined by the pore size. The conventional membrane technology includes ultrafiltration (UF), microfiltration (MF), reverse osmosis (RO) and nanofiltration (NF) (Hosseini *et al*., 2016). Microfiltration method is based on membrane with porous structure which allows the separation of particles on the basis of size of particles and at the pressure of 1 - 3 atm. However ultrafiltration membranes are having pore size ranging from 0.01 µm - 0.1 µm with higher operating pressures of 2 - 7 atm. Further, nanofiltration gives good results with an average pore diameter ranging from 1 nm - 10 nm. It is efficiently used to remove micropollutants and divalent salts. Reverse osmosis (RO) process is one of the most significant processes in the removal of dissolved impurities based on organic and inorganic salts. However, the RO membranes need higher pressures ranging from 30 - 50 atm to reverse the spontaneous flow of the water (Rezakazemi *et al*., 2018). RO process requires more energy as compared to other membrane techniques. Literature on application of membrane technology in removal of different kinds of contaminants have been assessed and tabulated in Table 2.

Nowadays nanomaterials have been studied with significant contributions in the field of water treatment. The properties of nanomaterials with high reactivity and large specific surface areas are important to be used in water engineering (Cai *et al*., 2018). Further, the latest technologies in the field of nanotechnology have permitted the design of smart artificial membranes for water treatment with improved functions and efficient separation properties. These nanomaterial-based membranes include nanofibers, nanoparticles, two-dimensional layered materials, and nanostructured compounds. They are having high permeation properties (Ying *et al*., 2017).

Coagulation-Flocculation Method

Among all chemical treatment techniques, coagulation- flocculation is the most preferred one. The most common method of removing organic and inorganic waste is coagulation - flocculation method (Razali *et al*., 2011). It is used in water treatment method to remove the contaminants. It is a technique for destabilization of colloidal suspension, aggregating them and binding them together for ease of sedimentation. It comprises the formation of chemical flocs that adsorb, capture and bring together all contaminants that are mostly divided as colloids (Sarika *et al.,* 2005). In conventional chemical treatment, inorganic coagulants viz; iron and aluminium salts are utilized as major coagulants. However a large sum of inorganic coagulants is required

Table 2. Types of pollutants removal with different kinds of membrane technologies

Type of pollutants	Type of Membrane Technology	Percentage of Removal (%)	Reference
Fungicides	Nanofiltration	64-100%	Mukherjee *et al*, 2020
Insecticides	Nanofiltration	86-92%	Kiso *et al*., 2001
E.Coli Pathogen	Ultrafiltration	80-85%	Damodar *et al*.,2009
Bacillus Subtiles	Nanofiltration	100%	Kacprzynska *et al.,* 2020; Kacprzynska *et al*., 2021
Methylene Blue Dye	Ultrafiltration	82-94%	Rajeswari, *et al*., 2019
Reactive Green Dye	Nanofiltration	90-99%	Safarpour *et al.,* 2016
Heavy Metal-Arsenic	Ultrafiltration	80-83%	Rezaee *et al*., 2015
Heavy Metal-Chromium	Ultrafiltration	94-99%	Shah *et al.,* 2013
Heavy Metal-Cadmium	Ultrafiltration	71-79%	Shah *et al.,* 2013

and as a result in large volume of sludge generation.

In contrast a proper use of organic polymers can remove organic and inorganic pollutants successfully. In water treatment, polymers are also used as primary coagulants as per literature. It is particularly advantageous in dealing with slow settling flocs in coagulation at low temperature and in treatment of light coloured water where they increase the toughness of flocs and settleability (Jabin *et al.*, 2021). Polymers are cationic and anionic in nature. Cationic polymers are more effective in removal of turbidity and suspension as compared to anionic and non-ionic polyelectrolytes. However anionic polymers remove dissolve impurities more efficiently. As per Bolto, the efficiency of cationic polyacrylamide with low molecular weight is better than polyacrylamide with a high molecular weight (Bolto *et al.,* 2019). In municipal wastewater, only cationic polymers are efficient for the removal of solids. Large flocs are formed with the help of cationic polymers when the coagulated solids have a slightly negative charge. A few non- ionic polymers have also received attention in water treatment. They include starches, cellulose derivatives, gelatins and glues. They are used as flocculants in solid-liquid separations. They vary in structure and molecular weight. They are easily acceptable because of biodegradable nature. Proper coagulation is important for good clarification and filtration performance as also for the control of the pathogens. Improper coagulation can lead to high coagulant residuals which increases the turbidity of water. Mechanism of flocculation can be explained under the polymer bridging and charge neutralization. The summary for mechanism of polymers is tabulated in Table 3.

There is no formula to determine the effective dose of coagulants and flocculants. However, jar test is the most accurate method to determine the effective coagulant and its dosage. The advantages of jar test method are optimization of coagulant type, dosage selection, determination of optimal pH, optimization of mixing time and outcome of rapid and slow mixing.

Extraction Method

This technique is applied for removing phenolic compounds from wastewater and water using polar regular solvents extraction method. The extraction strategy for phenolic compounds elimination from wastewater can be fabricated as solid stage extraction and liquid-liquid extraction (Kazemi *et al.*, 2017). Liquid- liquid extraction method is a non-destructive technique for removal of phenolics from water. It depends on the concentration, pH, temperature and contact time of the reactions. Removal depends on solubility of the phenolic compounds in extracted mixture. Hexanol, octanol, heptanol and castor oil are widely used as extractants. Where as in solid phase extraction method dissolved material in a liquid mixture is separated from other materials according to their physical and chemical properties. Patel and Desai in 2022 have used liquid-liquid extraction method for elimination of phenol from polluted water (Patel and Desai, 2022). 5% solution of phenol was used for experiment. COD was measured at various pH (4-7) and different percentage of toluene (20-40). Two layers, one aqueous (water + some amount of phenol), and other organic (toluene + phenol) were formed after extraction. Optimum results were obtained at pH 7 where 20 % of toluene. 60% phenol was removed for 5% aqueous solution of phenol and 68% phenol was removed from phar-

Table 3. Summary of mechanism of polyelectrolytes (Kapoor *et al.*, 2011)

Parameters	Bridging	Electrostatic patch mechanism
Molecular mass of polyelectrolytes	Higher the mol. mass, more effective is the bridging.	Mol. mass does not have much effect
Charge density	Bridging more effective at higher charge density due to larger loop.	Higher the charge density, more effective will be destabilization
Polyelectrolytes of similar charge to particle surface	Destabilization by bridging mechanism	Inoperative
Polyelectrolytes of opposite charge to particle surface	Destabilization by bridging mechanism	Destabilization byelectrostatic patchmechanism possible
Nonionic polyelectrolytes	Destabilization by bridging mechanism	Destabilization byelectrostatic patchmechanism inoperative
Ampholytic polyelectrolytes	Destabilization by bridging mechanism possible	Destabilization byelectrostatic mechanism possible

maceutical effluent. Dipin *et al.,* (2021) have removed heavy metal as well as phenolic compounds with the use of phosphonium based ionic liquids from industrial water Three ionic liquids of phosphonium based is consist of tri-hexyl-tetra-decyl-phosphonium ($PC_6C_6C_6C_{14}$), with various inorganic.organic anions, *i.e.* chloride dicyanamide ($N(CN)_2$) and bis (tri-fluoro-methyl sulfonyl) amide (NTf_2) in processes of extraction of heavy metals (Cr, As, Cu, Cd, Pb, Hg, and Zn) as well as phenolic compounds from rice and cashew industrial waste water. Results showed that {($PC_6C_6C_6C_{14}$)(Cl)} IL exhibited complete removal of contaminants from cashew and rice industrial waste water and three ILs showed best approximately 100% efficiency for all heavy metals. Skoronski *et al*., (2020), have used phosphonium ionic liquids for removal of phenolic compounds from wastewater (Skoronski *et al.,* 2020). Tri-hexyl-tetra-decyl-phosphonium cations with deca-noate or bis (2,4,4-try-metylpentyl) phosphinate anions were used for extraction of phenol and 2,4-dichlorophenol. More than 89% and 99% phenol and 2,4-dichlorophenol were extracted from water using these iconic liquids.

Biological Methods

In there method microorganism such as bacteria, enzymes and other small organisms are used to break down organic phenolic compounds as well as some inorganic contaminants into decomposable wastes materials in water (Mahugo-Santana *et al*., 2010; Kukadiya *et al*., 2016).

Decomposition and type of waste materials depends on the amount of bacteria, time of contact, pH of water and other viable conditions for microorganism. Researchers have used poly-vinyl alcohol or sodium alginate with bio-char gel beads immobilized bioreactor for the removal of phenol from water (Kukadiya *et al*., 2016). The removal efficiency of phenol was found to be 93.97%. Benit *et al*., 2022 used *Halomonas halodurans* and *Bacillus haodurans* in packed bed bioreactor for removing phenol from wastewater (Benit *et al*., 2022) Six bacterial strains were identified and applied for eliminatimg phenolic compund from water. *Bacillus halodurans* PD22 and *Halomonas halodurans* PD8 were present in maximum growth in phenol-enrich medium. Lyophilized enzyme of *Bacillus halodurans* and *Halomonas halodurans* and were sabotage with 1% alginate beads with binding efficiency 40.2 ± 2.9% cross liked with divalent cations. It was improved upto 2.0% with binding efficiency. Maximum efficiency for phenol degradation was achieved within 10 hours.

Adsorption

It is one of the very important techniques widely used for the removal of phenolic compounds from water. It is very cheap, easy to operate and eco-friendly method for elimination of contaminants present in water (Duan *et al.,* 2020). Lots of synthetic and natural materials in their pristine and modified form have been applied as adsorbent for removing phenolic compounds from water. Mishra *et al.,* 2021 used H_2SO_4-treated pea shells as adsorbent for removal of phenol from water (Mishra *et al*., 2021). The adsorption was performed using varying phenol concentration (50–500 mg/l), temperature (25–45 °C), pH (2–9), adsorbent dose (0.1–0.6 g/100 ml) and inorganic salt, i.e. 0.1 M $CaCl_2$ and 0.1 M KCl. Maximum adsorption was found at the dosage of 125.77 mg/g (500 mg/l of phenol) at pH value of 7 and temperature of 25 °C with 0.1 g/100 ml of the adsorbent dosage. Adsorption was inversely related to temperature, adsorbent dose, 0.1 M KCl, and d 0.1 M $CaCl_2$ concentrations. Maximum adsorption decreased from 125.77 mg/g - 103.45 mg/g and 84.11 mg/g, respectively in the presence of 0.1 M KCl, and d 0.1 M $CaCl_2$ concentrations.

Other Methods

Many other advanced techniques have been useful for successful elimination of phenol and phenolic compounds and other heavy metal from waste water. Chemical oxidation, electrochemical treatment, ion exchange, chemical precipitation, filtration, reduction method, coagulation-sedimentation, membrane and RO (Reverse Osmosis) technologies have been widely used conventional methods for eliminating of inorganic or organic contaminants found in water (Kumar and Chawla, 2013; Kumar *et al*., 2015; Chawla *et al*., 2015; Jabin *et al*., 2021). Out of these some are quite expensive, little bit complicated and sometime less efficient and some are cost effective, occupied less space, easy to operate, and highly efficient.

Conclusion

Rapid industrialization and urbanization make the water pollute. Inorganic and organic impurities are the main soluble contaminants in waste water. Extraction method, biological method, adsorption, chemical oxidation, electrochemical treatment, chemical precipitation, ion exchange, filtration, reduction method, coagulation-sedimentation, reverse osmosis, and membrane technologies are accessible for eliminating organic or inorganic contaminants found in water (Jabin *et al*., 2021). Out of this adsorption is cost effective, occupied less space, easy to operate, and highly efficient method compared to other techniques. Moreover, other methodology is widely in demand for successful elimination of these contaminants found in water but sometime they are quite expensive, little bit complicated and less efficient.

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Competing Interests

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