Jr.of Industrial Pollution Control 37(7)(2021) pp 1-12
www.icontrolpollution.com
Research Article

APPLICATION OF ELECTROCHEMICAL AND NANOMATERIAL TECHNOLOGIES FOR THE TREATMENT OF INDUSTRIAL WASTE-WATER: AN OVERVIEW

SAGNIK DAS[1] AND SUKANCHAN PALIT[2*]

[1] Department of Chemical Engineering, Jadavpur University, Kolkata-700032, India
[2] Department of Chemical Engineering, University of Petroleum and Energy Studies, Energy Acres, Post-Office-Bidholi *via* Premnagar, Dehradun-248007, Uttarakhand, India

(Received 22 April, 2021; Accepted 05 May, 2021)

Key words: Environment, Pollution, Water, Electrochemical, Sustainability, Industrial wastewater.

ABSTRACT

Environmental engineering, environmental protection and chemical process engineering are today in the avenues of newer scientific revelation and deep scientific regeneration. Industrial wastewater treatment and water purification stands in the midst of vast scientific introspection and scientific comprehension. Both conventional and non-conventional environmental engineering techniques are today the needs of the hour. Non-conventional environmental engineering techniques involve electrochemical treatments and advanced oxidation processes. This treatise investigates the scientific vision in the application of electrochemical technologies for the treatment of industrial wastewater. The authors in the article portray profoundly the immediate need and the immediate concerns of electrochemical treatments of industrial wastewater. Recent advances in the field of industrial wastewater treatment are also delineated in minute details. Application of nanotechnology, nanomaterials and engineered nanomaterials in environmental protection and water remediation are the other cornerstones of this treatise.

INTRODUCTION

The rapid and enormous growth of industrial civilization for meeting the daily needs of the human population have resulted in the contamination of toxic chemicals in water and air, posing a threat to the environment. Ground water is gradually becoming depleted and/or contaminated due to percolation of the surface water already contaminated by various metal-salts, dyes etc. because of the industrial and domestic effluents discharged into the rivers and oceans through porous beds of soil and rocks, as also due to sliding in mineral deposits of arsenic and other detrimental metals. Many researchers, scientists and engineers have carried out the research in this field. One of the important pollutants from this point of view is phenol. It has its presence in the effluent from major chemical and pharmaceutical industries such as coal gasification operations, dye synthesis units and liquefaction processes. The textile industry, being no exception in this regard uses high volumes of water throughout along with detergents, emulsifiers and dispersants in its operations essentially contributing to effluent aquatic toxicity and BOD. Hence, at present it is very important to remove the pollutants and pathogens from wastewater to fulfil the needs for irrigation, industrial and domestic purposes.

Additionally, fairly intensive studies have inferred that these pollutants may undergo chemical and biologically assimilations; eutrophication consumes dissolved oxygen that prevents re-oxygenation in receiving streams and has a tendency to sequester metal ions accelerating genetoxicity and microtoxicity. In a wider sense, sporadic and excessive exposure to such effluents in water bodies is susceptible to a broad range of neurobehavioral, circulatory, respiratory and central nervous disorders such as allergy, insomnia, jaundice, irritation to even lung edemia. Today 70% of all illness in developing countries is related to water contamination.

In the past years, conventional biological and physical treatment method like adsorption, ultrafiltration, coagulation etc. have been used to remove the organic pollutants. These methods are not efficient and cost effective for wastewater containing high concentration of toxic pollutants.

***Corresponding author's email: spalit@ddn.upes.ac.in**

The increasing levels of pollutants in wastewater are a problem that needs urgent solution at a global scale. The intensity of their toxic effects varies with time, dose and environmental presence. Electrochemical treatments have emerged in recent decades as an effective environmentally friendly, aesthetic and low-cost technology for the treatment of a wide variety of harmful pollutants. In this work, different novel electrochemical techniques including: Electro-Dialysis, Electro-Coagulation and Electro-Oxidation processes (indirect and direct process) and their recent developments have been critically reviewed in order to make a comparative analysis between the processes and acquire the best one depending on the optimum conditions for the treatment of wastewater.

MATERIALS AND METHODOLOGY

The Most Common Methods for Removal of Metals from Industrial Effluents

Chemical precipitation: Precipitation of heavy metals is achieved by the addition of coagulants such as alum, lime or other organic polymers. However, the large amount of sludge containing toxic compounds produced during the process is the main disadvantage.

Ultrafiltration: They are pressure driven membrane operations that use porous membranes for the removal of heavy metals. The main disadvantage of this process is the generation of sludge.

Reverse osmosis: It is a process in which heavy metals are separated by a semi-permeable membrane at a pressure greater than osmotic pressure caused by dissolved solids in wastewater. The disadvantage of this method is that is it expensive.

Ion-exchange: In this process metals ions from dilute solutions are exchanged with ions held by electrostatic forces on the exchange resin. The disadvantages include: High cost and partial removal of certain ions.

Phyto-remediation: Phyto-remediation is the use of certain plants to clean up certain soils sediment and water contaminated with metals. The disadvantage include that it takes a long time for removal of metals and regeneration of the plant for further bio-sorption is difficult.

Hence, we need to incorporate some novel techniques to transfer the highly toxic pollutants, chemically into benign species. Newer technologies such as electrochemical methods have been developed now-a-days as they are more efficient, cheap, and eco-friendly in the degradation of any kind of toxic pollutants. Instead of chemicals, these methods only require the addition of electrons to enhance the reactions. The use of electricity in wastewater treatment gained its attention in late 20th Century. However, due to high cost of electricity and high capital investment, the technology did not widely spread in the world. After prolong period of research and development of such treatments in wastewater in developed countries; allowed such technologies to be practised in past few decades. The treatments was found to be cheaper and higher efficient as compared to the native techniques. Additionally, the process does not require any consumption of chemicals; instead it only requires the addition of electrons to stimulate the reaction combination. These methods mainly includes: Electro-Dialysis, Electro-Coagulation and Electro-Oxidation processes.

The Need and Rationale of the Study

Regardless of the existence of the native technologies, there is no full-scale utilization of electricity for the treatment of water and wastewater industry. This is due to difficulties and challenges associated with:

• The absence of sufficient exploration exhibiting its abilities and focal points over existing water and wastewater treatment and

• High yield on cost of electricity depending on its method of preparation. Therefore, to solve the above-mentioned difficulties, fundamental study must be carried out to discover the novel electrochemical methods, focusing on increasing production yield and treatment efficiency.

Characteristics of Industrial Wastewater

There are many types of industrial wastewater based on the different industries and the contaminants; each sector produces its own particular combination of pollutants:

• Iron and Steel: BOD(Biochemical Oxygen Demand), COD(Chemical Oxygen Demand), oil, metals, phenols

• Textile and Leather: BOD, sulphates, chromium, colourful dyes

• Pulp and Paper: BOD, chlorinated organic compounds, COD

• Chemicals: Heavy metals, cyanides, Fluorine, sulfates

• Mining: Metals, acids and salts

• Petrochemicals and Refineries: Mineral oils, phenol, BOD, COD

• Pharmaceuticals: Drugs, dyes, other organic compounds

Generally, characteristics of industrial wastewater is broadly divided into two types-

Physical Characteristics

Total solids: Analytically the total solids content of a wastewater is defined as all the matter that remains as residue upon evaporation at 103°C-105°C. It composed of floating matter, colloidal matter and matter in solution. Matter that has a significant vapour pressure at this temperature is lost during evaporation, is not considered as solid. Settable solids are those solids that will settle to the bottom of a cone-shaped in a 60 min period.

Total solids upon evaporation can be further classified into suspended and non-suspended solids by passing a known volume of liquid through a filter. The filtered solids consist of colloidal and dissolved solids. These solids consist of organic and inorganic molecules and ions that are present in true solution in water, lest it cannot be removed by settling. Therefore coagulation followed by sedimentation is required to remove these particles from suspension. The suspended solids are found in considerable quantity in many industrial wastewaters. Solids removed by settling (suspended solids) are separated from wastewater known as sludge which may be pumped to drying beds or filtered for extraction of additional water. Each of the categories of solids may be further classified on the basis of their volatility at 550°C ± 50°C. The organic fraction will oxidize and driven out as gas at this temperature whereas inorganic fraction remains behind as ash.

Temperature: The temperature of water is a very important parameter because of its effect on chemical reactions and reaction rate, aquatic life, and sustainability of the water for beneficial uses. Increased temperature causes a change in species of fish that can exist in the receiving water body. Industrial establishments uses surface water for cooling purposes, are particularly concerned with temperature of intake water. In addition, oxygen is less soluble in warm water than in cold water. The increase in the rate of biochemical reactions that accompanies an increase in temperature combines with the decrease with the decrease in the quantity of oxygen present in surface waters can often cause serious depletions in dissolved oxygen concentration in summer months. When significantly large quantities of heated are discharged to natural receiving water, these effects get magnified. Moreover, abnormally high temperatures can foster the growth of undesirable water plants and wastewater fungus.

Colour: Colour of industrial wastewater varies according to the type of industry. Knowledge of the character and measurement of colour is essential. Since most coloured matter is in a dissolved state, it cannot be altered by conventional primary devices. Although secondary treatment units, such as activated sludge removes a certain percentage of some types of coloured mater.

Odour: Odour is usually caused by gases produced by the decomposition of organic matter or by substances added to wastewater. Industrial wastewater may contain either odorous compounds or compounds that produce odour during the process of wastewater treatment.

Chemical Characteristics

Organic matter: Organic compounds are normally composed of a combination of carbon, hydrogen and oxygen together with nitrogen in some cases. Other important elements such as sulphur, phosphorus, iron may be present. Also industrial wastewater may contain small quantities of a large number of different synthetic organic molecules ranging from simple to extremely complex in structure. Typical examples include surfactants, organic priority pollutants, volatile organic compounds or agricultural pesticides. The presence of these substances has complicated industrial wastewater treatment because many of them either cannot be or very slowly decomposed biologically.

Fats, oils and grease: Fats are among the most stable compounds of organic compounds and are not easily decomposed by micro-organisms. Kerosene, lubricating oils reach the sewer from workshops and garages for the most part they float on the wastewater, although a portion is carried into the sludge on settling solids. To an even greater than fats, oils and soaps, the mineral oils has the tendency to coat surfaces causing maintenance problems. If grease is not removed properly before entering into wastewater, it interferes with the biological life in the surface water and creates unsightly floating matter and films.

Surfactants: Surfactants are large organic molecules that are slightly soluble in water and cause foaming in wastewater treatment plants and in surface water into which wastewater effluent is discharged. Surfactants tend to collect at the air-water interface. During aeration of wastewater, these compounds collect on the surface of the air-bubbles and thus create very stable foam.

Phenols: Phenols are also important constituents of wastewater. They are produced primarily by industrial operations and find their way to surface water industrial wastewater discharges. It cause taste problems in wastewater, particularly when water gets chlorinated. It can be biologically oxidized at concentrations up to 500 mg/L.

Pesticides and agricultural chemicals: Trace of organic compounds such as pesticides, herbicides and other agricultural chemicals are toxic to most life forms and therefore can be significant contaminants of surface waters. Due to common usage of pesticides in agriculture and their property as stability, toxicity, and ability to accumulate these compounds are particularly hazards to the living organisms. Mutagenic, carcinogenic and teratogenic characteristics of pesticides have been reported multiple times.

Inorganic matter: Inorganic industrial wastewater is produced mainly in coal and steel industry, in the non-metallic minerals industry, and in commercial enterprises and industries for the surface processing of metals. These wastewaters contain a large proportion of suspended matter, which can be eliminated by sedimentation, often together with chemical flocculation through the addition of iron or aluminium salts, flocculation agents and some kinds of organic polymers. Concentrations of inorganic constituents also get increase by natural evaporation process, which removes some of surface water and leaves inorganic substances in the wastewater.

Toxic inorganic compounds: Because of their toxicity, certain cations are of great importance in the treatment and disposal of wastewater. Many of these compounds are classified as priority pollutants. Copper, lead, silver, arsenic, boron is toxic in varying degrees to micro-organisms and therefore must be taken into consideration in the design of a biological treatment plant. Many plants have been upset by the introduction of these ions to the extent that the micro-organisms were killed and treatment ceased. Other toxic cations include potassium and ammonium at 400 mg/L. Some toxic anions including cynanides and chromates are also present in industrial wastewater. These are found particularly in metal-plating wastewater and should be removed by pre-treatment at the site of the industry rather than mixed with the municipal wastewater.

PH: The hydrogen-ion concentration is an important quality parameter of wastewater. The concentration range suitable for the existence of most biological life is quite narrow and critical. Wastewater with an adverse concentration of hydrogen ion is difficult to treat by biological means and if the concentration is not altered before discharge the wastewater effluent may alter the concentration in natural waters.

Alkalinity: Alkalinity in wastewater results from the presence of hydroxides, carbonates, and bicarbonates of element such as calcium, magnesium, sodium, potassium or ammonia. Of these calcium and magnesium bicarbonates are most common. Borates, silicates, phosphates and similar compounds can also contribute to alkalinity. The alkalinity in wastewater helps to resist changes in pH caused by addition of acids. The concentration of alkalinity is important where chemical treatment is to be used in biological nutrient removal and where ammonia is to be removed by air stripping.

Heavy metals: Trace quantities of many metals such as Nickel, Manganese, Lead, Chromium, Zinc, Copper and Mercury are important constituents of some industrial wastewaters. The presence of any metals in excessive quantities will interfere with many beneficial uses of the water because of their toxicity; therefore, it is frequently desirable to measure and control the concentration of these substances.

Electrochemical treatments and the vast vision for the future: Electrochemical Techniques has proved to be one of the most relevant treatment strategies for handling wastewater with high level of contaminants. These techniques have pulled a great deal of thought because of their adaptability and ecological similarity. They are categorized into two-separation and oxidation methods.

Separation methods mainly include Electro-coagulation and Electro-Dialysis. The only difference between coagulation and electro-coagulation is that in the latter process, chemicals are added externally into the effluents for the removal of pollutants which later on changes the composition of effluents, whereas in the former process only the sacrificial anodes are introduced in the water direct source current. The electro-coagulation process involves the application of electric current, which on passing through a metal electrode dissolves its cation and forms metal hydro complexes, which acts as a coagulating agent, having high adsorption property combines with pollutants forming strong aggregates. At the same time water is reduced to gas bubbles. The gas bubbles generated combines with these agglomerates, creates a floatation effect, resulting in most of the pollutants being floated in the surface. The nature of the metal hydro complexes solely depends upon pH of the solution and type of electrodes used. Highest removal efficiency is generally obtained at slightly neutral pH conc., as it provides maximum surface area for gas-liquid interface to form aggregates of tiny colloidal particles.In most of the research studies Aluminium or Iron have been used as an electrode in treatment process. The flocs formed by Aluminium or Iron are usually much denser and easy to dewater which leads to a high removal efficiency of the pollutants. For Electro-Dialysis; the main aim of the process is to remove dissolved salts from an aqueous solution by introducing an ion-exchange membrane into the solution. The cell is connected with suitable electrodes and between the compartment cation and anion exchange membrane is introduced. When the solution is passed through each compartment, anions will pass only through anion exchange membrane, barricading the passage of cations and vise-versa, leading to a decrease in the salt concentration in the compartment. In this similar manner when a number of compartments are introduced in the system, an increase in salt concentration will be observed in every alternative compartment thus we can separate out the concentrate water from the potable water. This process is widely used in the industries for separating out desalinated water from wastewater. It showed removal efficiency 99% of dissolved source pollutants from various wastewaters. No phase transfer occurs in this process. However, continuous use of this process leads to fouling due to accumulation of long-chain organic compounds that is present in the wastewater, causing a blockage at the surface of the membrane leading to a high requirement of energy for the process. To get rid of fouling current direction should be reversed leading to a change in polarity of electrodes.

Electrochemical oxidation is considered highly efficient for chemical oxygen demand reduction, especially for the destruction of emerging contaminants that are refractory to conventional methods. It has been used as a wastewater treatment method to remove organic contaminants for decades. It is accomplished in two different mechanisms. During electrolysis, electron-rich organics are 1) directly oxidized on anode surface or 2) indirectly oxidized by oxidants that generated from the anode. However, its large-scale applications are hampered by high electrode cost, high energy consumption, and low oxidation efficiency.

• In direct oxidation process, pollutants gets oxidised in anode itself. The pollutant from the wastewater diffuses with the anode, then the anode partially oxidises the pollutants and converts the rest in form of carbon-dioxide, water and other inorganic substances. The mechanism of the process totally depends on current density and electrode activity which will determine the rate of electron transfer at the anode surface.

• In indirect oxidation process, a strong oxidizing agent is produced electrochemically in the anode, which gets in contact with the pollutants in the wastewater and completely oxidises them.

Electro-Chlorination is one of the emerging indirect electrochemical oxidation techniques for the treatment of polluted water. Chlorination is process of disinfecting water with application of chlorine gas in the water. Chlorine is a high oxidizing agent. It has the ability to break the proteins and chemical bonds of bacteria and ruptures the shape of the hydrogen molecule when chlorine comes in contact with them. However on adding excess chlorine in water might result in various health problems due high toxic in nature. Electro-Chlorination is the method which follows the process of chlorination using an electrolysis process. When direct current is passed to the saline through the electrodes, electrolysis of the metal salts takes place leading to a formation of hypochlorite solutions and hydrogen gas. Hypochlorite solution produces chlorine that is less toxic in nature (below 1% chlorine) as well as acts a strong disinfectant. This treatment is cost-effective, easy to maintain and is highly introduced in wastewater containing dyes since chlorine has the property to oxidize colour compounds. Furthermore, no dependency on external sources of chlorine supply because chlorine can be produced onsite using common salt as a raw materials.

Electrochemical Advanced Oxidation Process (EAOP) is a new type of electrochemical oxidation. As an indirect electrochemical oxidation method, EAOP can generate Hydroxyl Radicals (HO) from water on the anode. Hydroxyl radicals is a highly reactive oxidant that can react with nearly all organic contaminants and eventually mineralize them to CO_2 and H_2O non-selectively in ambient pressure and atmospheric temperature. In this process Fe^{2+} and H_2O_2 (Fenton's Reagent) is generated simultaneously at the cathode with the reduction of $Fe^{3+}$and O_2 respectively, leading to the formation of hydroxyl ions. Initially to start the process, a small amount of Fe^{2+} (use of sacrificial iron electrode serves the purpose) is added in the solution which electrochemically reacts with H_2O_2 to form Fe^{3+} in the solution. The process solely depends on pH and temperature of the medium. Lesser pH in the medium has showed an efficient reduction for the removal of dyes, phenols from the effluent by this treatment.

RESULTS AND DISCUSSION

Recent Advances in Industrial Wastewater Treatment

In general, customary wastewater treatment comprises a mixture of physical, chemical or biological processes and operations to remove solids including colloids, organic matter, nutrients, and soluble contaminants/toxins from effluents. Numerous techniques classified in regular/native methods, established recovery or removal methods can be used as shown in Table 1. Determination of a technique solely depends on the wastewater attributes. Each technique has its own constraints not only in terms of cost but also in terms of feasibility, efficiency, practicability, reliability, environmental impact, sludge production, operation difficulty, pre-treatment requirements and the formation of potentially toxic by-products. However, among the various treatment processes currently cited for wastewater treatment, only a few are commonly employed by the industrial sector for technological and economic reasons.

Table 1. A brief review of recent developed methods for the treatment of industrial wastewater.

Process	Principle	Discussion
Chemical precipitation	Uptake of the pollutants and separation of the products formed	Integrated physicochemical process Both economically advantageous and efficient Technologically is simple Adapted to high pollutant loads Very efficient for metals and fluoride elimination Not metal selective Significant reduction in the chemical oxygen demand Chemical consumption (lime, oxidants, H2S, etc.) Physicochemical monitoring of the effluent (pH) Ineffective in removal of the metal ions at low concentration Requires an oxidation step if the metals are complexed High sludge production, handling and disposal problems (management, treatment, cost)

Froth floatation	Uptake of the pollutants and separation of the products formed	Integrated physicochemical process Different types of collectors Efficient for removal of small particles and can remove low-density particles which would require long settling periods Useful for primary clarification Metal selective Low retention time Used as an efficient tertiary treatment in the pulp and paper industry Mechanisms: true flotation, entrainment and aggregation High initial capital cost Energy costs Maintenance and operation costs no negligible Chemicals required (to control the relative hydrophobicities between the particles and to maintain proper froth characteristics) Selectivity is pH dependent
Ion exchange/ Chelating resins/ Selective resins/ Macroporous resins/ Polymeric adsorbents/ Polymer-based hybrid adsorbents	Non-destructive process	Wide range of commercial products available from several manufacturers Technologically is simple Well-established and tested procedures Easy control and maintenance Easy to use with other techniques (e.g., precipitation and filtration in an integrated wastewater process) Can be applied to different flow regimes (continuous and batch) High regeneration with possibility of external regeneration of resin Rapid and efficient process Produce a high-quality treated effluent Concentrates all types of pollutants, particularly minerals Relatively inexpensive and efficient for metal removal; cleanup to ppb levels Can be selective for certain metals (with suitable resins) Efficient technology for the recovery of valuable metals Economic constraints (initial cost of the selective resin, maintenance costs, regeneration, time-consuming, etc.) 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 reactor) Beads easily fouled by particulates and organic matter (organics and oils); Requires a physicochemical pre-treatment (e.g., sand filtration or carbon adsorption) to remove these contaminants Matrix degrades with time and with certain waste materials (radioactive, strong oxidants, etc.) Performance sensitive to pH of effluent Conventional resins not selective Selective resins have limited commercial use Not effective for certain target pollutants (disperse dyes, drugs, etc.)

Coagulation	Uptake of the pollutants and separation of the products formed	Process simplicity Integrated physicochemical process A wide range of chemicals are available commercially Inexpensive capital cost Very efficient for colloidal particles Good sludge settling and dewatering characteristics Significant reduction in the chemical oxygen demand and biochemical oxygen demand Interesting reduction in total organic carbon and absorbable organic halogen (pulp and paper industry) Bacterial inactivation capability Rapid and efficient for insoluble contaminants (pigments, etc.) removal 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
Chemical oxidation/ Ozone/ Hypochlorite treatment/ Hydrogen peroxide	Use of an oxidant (O_3,Cl_2,CO_2 , H_2O_2)	Integrated physicochemical process Simple, rapid and efficient process Generation of ozone on-site (no storage-associated dangers) Quality of the outflow (effective destruction of the pollutants and efficient reduction in color) Good elimination of color and odor (ozone) Efficient treatment for cyanide and sulphide removal Initiates and accelerates azo bond cleavage (hypochlorite treatment) Increases biodegradability of product High throughput No sludge production Possibility of water recycle Disinfection (bacteria and viruses) Chemicals required Production, transport and management of the oxidants (other than ozone) Pre-treatment indispensable Efficiency strongly influenced by the type of oxidant Short half-life (ozone) A few dyes are more resistant to treatment and necessitate high ozone doses Formation of (unknown) intermediates No diminution of chemical oxygen demand values or limited effect (ozone) No effect on salinity (ozone) Release of volatile compounds and aromatic amines (hypochlorite treatment) Generates sludge

Biological Activated Sludge (BAS)/ microbiological treatments/ Enzymatic decomposition	Use of pure or mixed biological cultures	The application of microorganisms for the biodegradation of organic contaminants is simple, economically attractive and well accepted by the public Large number of species used in mixed cultures (consortiums) or pure cultures (white-rot fungus) White-rot fungi produce a wide variety of extracellular enzymes with high biodegradability capacity Efficiently eliminates biodegradable organic matter, NH_3, NH_4^+, iron Attenuates colour well High removal of biochemical oxygen demand and suspended solids (BAS) Decisive role of microbiological processes in the future technologies used for the removal of emergent contaminants from waters Necessary to create an optimally favourable environment Requires management and maintenance of the microorganisms and/or physicochemical pre-treatment (inefficient on non-degradable compounds or when toxic compounds are present) Slow process (problems of kinetics) Low biodegradability of certain molecules (dyes) Poor decolorization (BAS) Possible sludge bulking and foaming (BAS) Generation of biological sludge and uncontrolled degradation products The composition of mixed cultures may change during the decomposition process Complexity of the microbiological mechanisms Necessity to have a good knowledge of the enzymatic processes governing the decomposition of the substances
Electro-coagulation (EC)/ Electro-flocculation (EF)/ Electro-flotation/ Electro-oxidation/ Electrochemical oxidation/ Electrochemical reduction	Electrolysis (E) Process	Efficient technology for the recovery/recycling of valuable metals (E) Effective method for the recovery of gold and silver from rinse baths Adaptation to different pollutant loads and different flow rates (E) Increases biodegradability (E) More effective and rapid organic matter separation than in traditional coagulation (EC) pH control is not necessary; generation of coagulants in situ; economically feasible and very effective in removing suspended solids, dissolved metals, tannins and dyes (effluents from textile, catering, petroleum, municipal sewage, oil–water emulsion, dyestuff, clay suspension, etc.) Efficient elimination of SS, oils, greases, colour and metals (EC, EF) EF: widely used in the miming industries Effective in treatment of drinking water supplies for small- or medium-sized communities (EC) Very effective treatment for the reduction, coagulation and separation of copper (EC) High initial cost of the equipment Cost of the maintenance (sacrificial anodes, etc.) Requires addition of chemicals (coagulants, flocculants, salts) Anode passivation and sludge deposition on the electrodes that can inhibit the electrolytic process in continuous operation Requires post-treatment to remove high concentrations of iron and aluminum ions EF: separation efficiency depends strongly on bubble sizes Filtration process for flocs Formation of sludge (filtering problems) Cost of sludge treatment (electro-coagulation)

Microfiltration (MF)/ Ultrafiltration (UF)/ Nanofiltration (NF)/ Reverse osmosis (RO)/ Dialysis/ Electrodialysis (ED)/ Electro-electrodialysis (EED)	Semi-permeable Barrier	Wide range of commercial membrane available from several manufacturers Small space requirement Simple, rapid and efficient, even at high concentrations Produces a high-quality treated effluent No chemicals required Low solid waste generation Eliminates all types of dyes, salts and mineral derivatives Efficient elimination of particles, suspended solids and microorganisms (MF, UF, NF, reverse osmosis), volatile and non-volatile organics (NF, reverse osmosis), dissolved inorganic matter (ED, EED), and phenols, Possible to be metal selective A wide range of real applications: clarification or sterile filtration (MF), separation of polymers (UF), multivalent ions (NF), salts from polymer solutions (dialysis) and non-ionic solutes (ED), desalination and production of pure water (reverse osmosis) Well-known separation mechanisms: size exclusion (NF, UF, MF), solubility/ diffusivity (reverse osmosis), charge (electrodialysis) Investment costs are often too high for small and medium industries High energy requirements The design of membrane filtration systems can differ significantly

Recent Scientific Endeavour in the Application of Nanotechnology in Water and Wastewater Treatment

Science and engineering of water and industrial wastewater treatment today stands in the middle of scientific vision and vast scientific redeeming. In this section, the authors deeply elucidates the recent endeavour in the application of nanotechnology in water and wastewater treatment. Nanomaterials applications in water and wastewater treatment are the utmost needs of humanity today. Application of carbon nanotubes, graphene and fullerenes in water treatment and wastewater management are the marvels and wonders of environmental engineering science and nanotechnology today.

Renu et al. discussed with scientific vision and scientific insight heavy metal removal from wastewater using various adsorbents in a review paper. Heavy metals are discharged into wastewater from various industries. They can be highly toxic or carcinogenic in nature and can cause serious illnesses. It can cause severe problems for humans and aquatic ecosystems. The adsorption process is widely used for the removal of heavy metals such as arsenic and cadmium because of its low cost, availability and eco-friendly in nature. Human society today stands in the midst of vision, scientific perseverance and deep scientific girth. Both commercial adsorbents and bio adsorbents are used for removal of heavy metals from industrial wastewater. This review article veritably aims to compile scattered information on the different adsorbents that are used for heavy metal removal. The heavy metals of most concern from various industries include lead, zinc, copper, arsenic, cadmium, chromium, nickel and mercury. This is a serious environmental protection issue in the global scenario. Various treatment technologies employed for the removal of heavy metals include chemical precipitation, ion exchange, chemical oxidation, reduction, reverse osmosis, ultrafiltration and various membrane separation processes. The authors discussed in minute details adsorbents used for removal of heavy metals from wastewater, the various adsorbents, graphene, carbon nanotubes, fullerenes, bioadsorbents for chromium removal from wastewater, and commercially available adsorbents for cadmium removal from wastewater. Bioadsorbents for removal of cadmium from industrial wastewater are the other pivots of this well researched treatise. Commercially available adsorbents for copper removal from wastewater are the other cornerstones of this paper. The other areas of scientific research pursuit are factors affecting adoption of heavy metals. Also future perspectives and challenges in the removal of heavy metals from industrial wastewater are delineated in minute details in this paper. This review vastly shows the potential of commercial and agricultural adsorbents for the removal of chromium, cadmium and copper from wastewater. A wide range of adsorbents has been studied for removal of heavy metals from wastewater. Thus the immense scientific and knowledge prowess of environmental engineering science and environmental protection science will usher in a new era in global research and development initiatives (Renu, et al., 2017).

Abdullah et al. deeply discussed with cogent insight recent trends of heavy metal removal from water and wastewater treatment by membrane technologies. A comprehensive literature search revealed the lack of proper investigations on the use of membrane technologies in industrial wastewater. Thus this article provides a comprehensive review of the performance and capability of different membrane separation processes and discusses the advantages and disadvantages of each process. Heavy metals are basically described and delineated as elements that have atomic weights between 63.5 and 200.6 and a density greater than 5 g per cubic meter. Some heavy metals such as copper, zinc, manganese, iron and cobalt play important roles in many biochemical processes in the human body. Till date, the common techniques used to sequester heavy metals from water are precipitation, coagulation-flocculation, ion exchange, adsorption and membrane separation processes. The authors discussed in details membrane technology, membrane theory of water pollutants removal, size exclusion/steric hindrance, adsorption, charge-charge repulsion, mass transfer of solutes in the membrane, micellar enhanced ultrafiltration, ultrafiltration using adsorptive mixed matrix membrane and membranes with thin layer. Today, membrane separation processes and water/wastewater treatment are two opposite sides of the visionary coin. A new dawn in the field of environmental and water remediation will surely emerge if science and engineering research and development initiatives are targeted towards greater vision, determination and insight (Abdullah, et al., 2019).

Bhateria et al. deeply discussed with vast scientific vision and scientific forbearance nanotechnological applications of magnetic iron oxides for heavy metal removal. Heavy metal drinking water contamination status today stands in the middle of vision, comprehension and vast introspection. With increasing industrialization and mass manufacturing, heavy metals pose a serious threat to the environment due to their discharge in water. Zero valent iron and iron oxide nanoparticles are found to be the best candidate for heavy metals removal and adsorption. The authors discussed in minute details the concept of nanotechnology, nanomaterials as building blocks of nanotechnology and synthesis of magnetic nanoparticles. Application of iron nanoparticles and iron-oxide nanoparticles are the other hallmarks of this well researched treatise. Potential application of nanoparticles for heavy metal removal is the other cornerstones of this article. In this paper, the current progress of nanotechnology with a view on synthesis, characterization, and applications of iron oxide has been reviewed in minute details in this paper. Nanomaterials have great potential for removal of recalcitrant pollutants in industrial wastewater due to their unique physical and chemical properties. A new scientific genre and a visionary scientific ingenuity will surely evolve if science and mankind progresses in the right direction in the field of nanotechnology. Humankind's immense scientific and engineering prowess is in a state of disaster as regards global warming, climate change and degradation of environment. The role and application of nanotechnology in water and wastewater treatment are the utmost need of the hour. In this article, the authors stresses on these scientific and engineering issues (Bhateria, et al., 2019).

Recent Scientific Research Pursuit in the Field of Application of Nanomaterials and Engineered Nanomaterials in Environmental Remediation

Application of nanomaterials and engineered nanomaterials in environmental protection and water remediation are the utmost needs of human society today. In this section, the authors deeply elucidates some of the most important scientific endeavour in the field water and wastewater treatment. The vision and sagacity of technology and engineering science of environmental protection and the mitigation of climate change and global warming are also the needs of the hour.

Nasreen et al. deeply discussed with lucidity and scientific insight nanomaterials and solutions to water – concomitant challenges. The application of nanomaterials and engineered nanomaterials in industrial wastewater treatment are in the path of newer scientific rejuvenation. Plenty of fresh water resources are still inaccessible for human use. There is a large environmental issue today in developing and developed nations around the world-arsenic groundwater poisoning. Calamities such as pollution, global climate change and global warming are today immense threat to the human eco-systems. Today, there is plenty of room for enhancements in technology and material science perspectives to reduce harm and maximize resources. Materials in the form of nanofiber membranes and nanomaterials are the promising areas of scientific research pursuit today. In this review the authors discussed in minute details few key materials that have shown immense effectiveness in removing pollutants from waste water. The role of nanomaterials for effective pollutant removal such as heavy metals, dyes and antibacterial activity are the other cornerstones of this paper. Nanofiber membranes or recalcitrant pollutant removal are the other hallmarks of this paper. Dye removal using metal oxide as a sorbent are the other areas of scientific research pursuit in this paper (Nasreen, et al., 2019).

Werkneh et al. deeply discussed with scientific vision applications of nanotechnology and biotechnology in sustainable water and wastewater treatment. In recent years, water pollution and fresh water scarcity have become a serious scientific and engineering issue causing concern to public health engineering and the human environment. This article focuses on new and emerging nano-and bio-technologies for the sustainable removal of pollution causing contaminants during water and wastewater treatment. Besides toxicological and safety aspects of different nanotechnologies are discussed in minute details. The authors discussed in minute details sustainable water and wastewater treatment technologies in nanotechnology perspective (Werkneh, et al., 2018). Various nanomaterials for the disinfection of pathogenic microbes stand as a major cornerstone of this treatise.

Science and technology of water purification are today in the avenues of newer regeneration. Industrial wastewater treatment today stands in the middle of vision, scientific redemption and vast knowledge prowess. In this paper, the author deeply addresses these scientific and technological issues.

Heavy Metal and Arsenic Groundwater and Drinking Water Treatment and the Vast Vision for the Future

Heavy groundwater contamination of drinking water in South Asia particularly India and Bangladesh is a burning global environmental engineering issue. The vast vision for the future in application of environmental techniques needs to be reorganized as science, engineering and civilization moves forward. Drinking water treatment and membrane science are two opposite sides of the visionary scientific and engineering coin. Today scientific abundance and scientific alacrity are the needs of global water research and development initiatives. Rapid industrial advancements and mass industrial manufacturing in developed and developing nations around the world are veritably threatening the human habitat and the global environment (Palit, et al., 2020; Hussain, 2018). A deep scientific introspection and engineering comprehension in the field of both advanced oxidation processes and electrochemical treatment are the needs of the hour. Man's vast scientific discernment and engineering redeeming will surely go a long way in unravelling the scientific truth of water and wastewater treatment and management. Today the world stands mesmerized in the research progress in environmental engineering and chemical process engineering. This treatise deeply targets these issues and the interfaces with environmental sustainability. Sustainable development mainly energy, environmental, social and economic are today in the process of newer regeneration. This article deeply and with scientific vision targets these engineering and technological issues. Today humankind is in search of deep scientific truth and profundity. The author deeply pronounces and stresses on these environmental engineering problems. Globally researchers and scientists around the world are targeting water and industrial wastewater issues with scientific might and scientific determination. Also environmental sustainability and its global applications are in the avenues of scientific rejuvenation. The authors in this article deeply address these issues.

Environmental Sustainability and the Progress of Human Civilization

Environmental, energy and socio-economic sustainability are needed in the future path of human civilization. The visionary words of Dr.Gro Harlem Brundtland, the former Prime Minister of Norway on the science of "sustainability" needs to be readdressed and re-envisioned with the progress of global science and technology. The progress of human civilization today depends on the re-envisioning of sustainability issues. The science and technology of "sustainable development" in the global scenario also should be readdressed as civilization grapples with global warming, global climate change and environmental disasters. Arsenic and heavy metal drinking water contamination in South Asia particularly India and Bangladesh are world's largest environmental catastrophe. Thus environmental sustainability and application of non-conventional environmental engineering tools are the utmost needs of humankind today (Chong, et al., 2020; Palit, 2017; Palit , 2016). Developing and developed nations around the world are in the midst of a serious environmental catastrophe that is arsenic drinking water contamination which can cause serious illnesses. Thus human civilization, science and technology needs to take appropriate steps in mitigating this global scientific and engineering disaster. Traditional and non-traditional environmental engineering techniques will surely go a long way in the proper realization and proper application of nanotechnology and nanomaterials (Palit, 2016). Electrochemical treatment of industrial wastewater also stands as a major pillar of this paper. Surely environmental and energy sustainability will open newer windows of innovation, instinct and scientific acuity in decades to come.

Futuristic Recommendations of this Study and Futuristic Flow of Scientific Thoughts

Environmental degradation and heavy metal water contamination are degrading the vast scientific landscape today. The future of environmental and water remediation in the global scenario are bleak and disastrous. Thus the need of a concerted effort globally in the field of environmental engineering, chemical process engineering, nanotechnology and wastewater and water management. The domain of systems engineering, human factor engineering and integrated water resource management are today aligned with each other. Future recommendations of this study and futuristic flow of scientific thoughts should be veritably directed towards nanomaterials and engineered nanomaterials applications in water and wastewater treatment. Man's immense vision and mankind's vast scientific ingenuity and prowess needs to be revamped as regards nanotechnology applications in water and industrial wastewater treatment. The future of the science of nanotechnology is today promising and visionary. In such a critical situation, scientific intuition and scientific and engineering vision are the utmost needs of the hour. The futuristic vision of chemical process technology, chemical process engineering and nanotechnology in the similar vision needs to be targeted and re-envisioned if nature needs to be mitigated as regards to environmental degradation and scientific breach of environmental sustainability. A new world order in the field of environmental protection and environmental and energy sustainability will surely emerge if proper scientific thoughts are targeted and envisioned. The other areas of scientific vision are integrated water resource management and integrated wastewater management. The future of industrial systems engineering and human factor engineering also needs to be re-organized as the future avenues in environmental and water remediation are also envisioned (Hussain, et al., 2017). Technology and engineering science of environmental protection will thus witness a new revamping and regeneration if the future of nanotechnology and nanomaterials are revamped and re-mitigated at the utmost. In this article, the authors deeply pronounce the application of nanotechnology in environmental protection, water remediation and environmental sustainability. Environmental, energy and socio-economic sustainability are today the utmost needs of humankind. The authors discuss and stresses on these scientific and engineering areas. Future recommendations in this study should be directed towards the areas of sustainable development. A new age in the field of nanotechnology will thus usher in if these future recommendations in environmental engineering tools are envisioned.

CONCLUSION

Today environmental engineering and chemical process engineering are moving ahead with much scientific vigour and scientific profundity. Today the domain of environmental protection and nanotechnology needs to be envisioned as humankind treads forward. Heavy metal and arsenic groundwater and drinking water contamination are degrading the environment and human habitat. Thus the need of scientific innovation and scientific and engineering vision in global research and development initiatives. In this article, the authors primarily focus on electrochemical treatments of industrial wastewater. Rapid industrialization and increased global manufacturing scenario are degrading and destroying the human environment and humankind. Chemical engineering science, composite science and material science are also in the path of divination. In this article, the authors deeply stresses on conventional and non-conventional environmental engineering techniques such as advanced oxidation processes and electrothermal treatments. The vast scientific and knowledge prowess of environmental engineering and water remediation are elucidated in minute details in this treatise. A new dawn in human civilization will surely emerge if concerted efforts are taken by engineers, scientists, researchers, governments and civil society to mitigate global warming, global climate change and environmental remediation. In such a situation, the only feasible situation is to target innovations and scientific instinct in the field of environmental engineering and nanotechnology. Nanomaterials and engineered nanomaterials are the marvels of science and engineering today. The application of nanomaterials in environmental remediation are in the similar vein are the marvels and wonders of science and technology today. The other areas of scientific introspection are the areas of integrated water resource management and wastewater management. Industrial wastewater management are highly neglected in developing and developed nations around the world. Thus also the need of nanotechnology applications and non-conventional environmental engineering tools. Surely, a new era in science and engineering will evolve if scientists and engineers are successful in tackling and mitigating global water contamination, global warming and global climate change. These areas are dealt with scientific vision and lucidity in this article.

REFERENCES

Renu AM and Singh K. 2017. Heavy metal removal from wastewater using various adsorbents: A review. J *Water Reuse Desalination*.7:387-419.

Abdullah N, Yusof N, Lau WJ, Jaafar J and Ismail AF. 2019. Recent trends of heavy metal removal from water/wastewater by membrane technologies. J *Industr Engin Chem*. 76:17-38.

Bhateria R and Singh R. 2019. A review on nanotechnological application of magnetic iron oxides for heavy metal removal. *J Water Process Engin*. 31:100845.

Nasreen SAAN, Subramanian S, Nizar SAS and Ramakrishna S. 2019. Nanomaterials: Solutions to water-concomitant challenges. *Membranes*. 9:40.

Werkneh AA and Rene ER. 2018. Applications of nanotechnology and biotechnology for sustainable water and wastewater treatment. *Energy, Environ and Sustain*. 405-430.

Palit S and Hussain CM. 2020. Functionalization of nanomaterials for industrial applications: Recent and future perspectives. *Elsevier*. 1:3-14.

Hussain CM and Palit S. 2018. Engineered nanomaterial for industrial use. *Elsevier*. 1:3-12.

Chong WC, Koo CH and Lau WJ. 2020. Mixed-matrix membranes incorporated with functionalized nanomaterials for water applications. *Elsevier*. 2:15-47.

Palit S. 2017. Application of nanotechnology, nanofiltration and drinking and wastewater treatment: A vision for the future. *Academic Press*. 17:587-620.

Palit S. 2016. Nanofiltration and ultrafiltration: The next generation environmental engineering tool and a vision for the future. *Int J Chem Tech Res*. 9:848-856.

Palit S. 2016. Filtration: Frontiers of the engineering and science of nanofiltration:A far-reaching review. *Taylor and Francis*. 205-214.

Palit S. 2017. Advanced environmental engineering separation processes, environmental analysis and application of nanotechnology: A far-reaching review.*R Soc Chem*. 1:377-416.

Hussain CM and Kharisov B. 2017. Advanced environmental analysis: Application of nanomaterials. *R Soc Chem*. 1:40.