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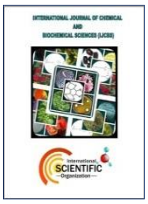

Advancements in environmental (water, air, soil) protection technologies: A review

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Abstract

Technologies for environmental preservation are undergoing a revolution that bodes well for the water, air, and soil of our world in the future. Modern AOPs and nanofiltration membranes are two examples of water treatment innovations that greatly enhance disinfection and quality of water. In dry areas, desalination provides a vital source of clean water, while cloud-based analytics and smart water management technologies maximize distribution. Scrubbers and catalytic reduction techniques are two efficient ways to reduce air pollution. Other ways to improve air quality include the growing popularity of electric cars and real-time air quality monitoring.Innovative approaches to erosion prevention and cleanup are demonstrating promise in soil protection. Using plants to clean up contaminated soil is a sustainable method that will benefit future generations: phytoremediation. Furthermore, evaluations of the health of the soil and water quality guarantee the long-term viability of this essential resource. These developments make Future sustainability possible, and more ground-breaking discoveries are likely in store for us in the years to come thanks to ongoing research and development. Furthermore, as these technologies advance and become more affordable, their applicability will grow, enabling broader use and substantially improving the environment.

Keywords: Environmental protection technologies, water treatment, desalination, air pollution control.

Full length review article

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1. Introduction

The continuous development of urbanization and industrialization processes, which include mineral extraction, transportation, manufacturing, building, and refining of petroleum, depletes natural resources and generates tremendous quantities of dangerous substances that pollute the soil, water, and air, endangering public health and the sustainability of the environment[1].Improved efficiency, lower energy requirements, and the capacity to successfully address challenging environmental issues are all necessary for existing conventional treatment techniques [2]. The natural environment will be an important platform for economic competitiveness in this decade and the next century. Environmental concerns about energy, resources, waste, and pollution present both opportunities and challenges for competition, and they are altering the competitive environment across a wide range of industries. Companies that manage environmental variables can obtain a competitive advantage. 'Environmental technologies' are defined in this study as a force for competition and a tool for gaining a competitive edge. To minimize the ecological effects of economic production while increasing a firm's competitiveness, environmental technologies provide a new substantive orientation and management method [3]. Comparing the current economy and environmental preservation, not much has changed, the issues that already exist are getting worse rather than getting resolved. Three fundamental problems still plague humanity today: insufficient food supply, scarcity of clean drinking water, and low levels of energy. Additionally, they are linked to the risks of additional environmental deterioration, a generalized fear of violence and conflict, the introduction of diseases for which there is currently no treatment in contemporary medicine and the possibility of surpassing the worldwide challenge. When traditional fossil resource sources are utilized as energy sources, the environment suffers greatly and energy remains an aspect of economic development[4].

Since contaminants from the environment can enter the human body by swallowing, absorption, or breathing, they have a significant potential to impact our health negatively. Furthermore, certain toxins tend to build up in food chains. For example, fish and biota can accumulate heavy metals, which is extremely dangerous for both humans and wildlife. Thus, there is an urgent requirement to develop cheap, effective, and sustainable technology for monitoring and appropriately treating hazardous environmental pollutants[5]. The purpose and motive of environmental protection technologies is to increase environment quality encourage sustainability and address and tackle environmental challenges. Ecological protection technologies are essential to building a greener, more sustainable future because they use cutting-edge tools like the Internet of Things to collect real-time data, switch to renewable energy sources, promote electric vehicles, improve waste management, and use artificial intelligence and machine learning. Their main objectives are reducing environmental harm, improving resource use efficiency, and promoting environmentally sound economic development locally, regionally, and globally.

2. Advancements in Water Treatment Technologies

2.1. Membrane Filtration

Direct pressure-driven membrane processes have been attempted to treat various wastewater types, such as greywater, pre-treated municipal wastewater, raw municipal wastewater, and industrial wastewater. Membrane filtering has a major role in removing particles, organics, nutrients, and pathogens from wastewater, resulting in improved permeate water quality for nondrinking applications (e.g.,horticulture, Cleaning the toilet, soil nourishing, etc.).There are several methods to perform membrane filtration: such as reverse osmosis, a variety of microfiltration, ultrafiltration, and nanofiltration [6].

2.1.1. Microfiltration

Microfiltration, which operates at relatively low pressures and high extract fluxes, is one of the earliest pressure-driven membrane processes. According to the idea of physical separation, MF can remove materials that are micrometers in size, including suspended particles, considerable pathogens, big microbes, protein molecules, and yeast cells. MF is a flexible membrane process that can reject a variety of large-scale pollutants. However, because of its large pore size range, MF can be used in a variety of industries, such as microbiology, pharmaceuticals, treatment of wastewater, desalination, and food processing. There are two types of MF membranes: rectangular sheet and spiral-wound. Similar to this, the filtering units and modules with membranes can be altered to meet particular application needs[7].

2.1.2. Ultrafiltration

Treating deep wastewater derived from oils and petroleum products is one of the challenging problems that need to be overcome. UF membranes, one of the well-known technologies, have a broad industrial use and are highly effective in eliminating a variety of pollutants from wastewater. It is demonstrated that finding and creating UF membranes for the treatment of oily wastewater that are incredibly effective, long-lasting, and highly resistant to oil pollution is an urgent research task. Enhancing the membranes' water absorption (hydrophilic properties) and foaming characteristics are crucial factors in raising UF membrane performance[8].

2.1.3. Nanofiltration

Nanofiltration is a relatively recent membrane filtration method that is mostly utilized on fresh groundwater and surface water with lower dissolved solids content. The two main goals of nanofiltration are to soften (remove polyvalent cations from) water and remove precursors of DOB (dimethoxybromoamphetamine), like natural and artificial organic materials. The filtration membranes' pore diameters determine the different types of substances that can be filtered out. Reverse osmosis and ultrafiltration can be sandwiched by the cross-flow filtration technique known as nanofiltration. The nanofiltration membrane's pore size can drop to around 1 nm [9].

2.1.4. Reverse Osmosis

Reverse osmosis (RO) is becoming increasingly used worldwide for desalination and water treatment applications. The process is powered by pressure, and a semi-permeable membrane rejects items that have dissolved in the supply water. The reason for the rejection is that the solute, solvent, and membrane's physical-chemical interactions, as well as size and charge, were not considered. Currently, reverse osmosis systems are used in a variety of industries, including electronic components, food processing, pharmaceuticals, seawater extraction, biotechnology, textiles and clothing, pulp and paper, mining and farm effluent, process and boiler water, tanneries, and the beverage industry [10].

2.2.1. Advanced Oxidation Process

The basic principle of AOPs is the in-situgeneration of strong oxidizers for the oxidation of organic substances. It involves procedures based on various oxidizing species that favor sulfate or chlorine radicals, as well as processes based on OH-radicals (radical dot OH), which make up the majority of accessible AOPs. Several AOPs are already well-established and run at full capacity in drinking water treatment and water reuse facilities, particularly those that involve ozonation and UV irradiation. Nonetheless, multiple researchers are consistently publishing new studies on a variety of developing AOPs for water treatment (such as electrochemical AOP, plasma, electron beam, ultrasound, or microwave-based AOPs)[11].

2.2.2. Hydroxyl Radical-Based AOPs

The hydroxyl radical, whose oxidation potential ranges from 2.8 V (pH 0) to 1.95 V (pH 14) about SCE (Saturated calomel electrode), is the commonly utilized reference electrode and is the most reactive oxidizing agent in the water treatment industry. OH· interacts rapidly with a wide spectrum of species and shows extraordinarily nonselective behavior, with rate constants on the order of

108-1010 M−1 s−1. Radical addition, radical abstraction, radical transfer, and radical combination are the four primary ways that hydroxyl radicals attack organic pollutants [12].

2.2.3. Ozone Based AOPs

Ozone (O_3) is a powerful oxidant in and of itself, with an oxidation potential of 2.07 V vs. SCE. Conversely, direct O_3 oxidation is a preferential reaction in which O3 selectively interacts with organic compounds in their ionized and dissociated forms as opposed to their neutral forms. For this process, average reaction rate constants are 1.0 × 100–10^3M^{-1} s^{-1} 8.In certain situations, O_3 can produce OH·, which initiates the process of indiscriminate oxidation (indirect reactions) [13].

2.2.4. UV Based AOPs

Hydroxyl radicals can arise when photons are exposed to oxidants or catalysts. The most common catalyst is TiO_2, a semiconductor of the RO type. When TiO_2 particles are excited, positive holes with an oxidative capacity are created in the valence band (hv + vb). while negative electrons with a reductive capacity are created in the conduction band (e − cb).Advanced oxidation processes (AOPs) based on ultraviolet radiation (UV) have received increased interest owing to their superior efficiency, energy conservation, and eco-friendliness[14].

2.3. Ions Exchange Resins

During the ion exchange process, ions can be exchanged reversibly via the liquid and solid phases. The solidified phase, also known as an ion exchanger or ion exchange resin, contains exchangeable ions and does not structurally change much during the reaction since it is insoluble in the liquid phase [15]. IX resins have historically been utilized in the portable water purification process to eliminate naturally present organic materials as well as inorganic ions such as nitrates sulfates uranium, and arsenic. The removal of per- and poly-fluoroalkyl compounds (PFAS) is accomplishedbyPurofine (gel) and Purolite (macroporous) [16].

2.3.1 Radioactive Ion Exchange Resins

In nuclear power plants, ion exchange resins are widely used to eliminate radioactive pollutants including fission and neutron activation products that may have escaped from fuel elements. Spent ion-exchange resins, or IERs, are typically ejected during nuclear station procedures like decommissioning, demineralization of radioactive plant effluent, purification of radioactive infrastructure, and recycling of radioactive material. Spent IERs, which are loaded with materials such as uranium-235, uranium-238, cesium-137, strontium-90, and cobalt-60, are among the most significant radioactive low-level wastes (LLW)[17].

$$2HR+Sr^{+2} \leftrightharpoons SrR_2+2H^+$$

$$2RCl + SO_4^{2-} \leftrightharpoons R_2SO_4 + 2Cl^-$$

2.3.2. Magnetic Ion Exchange Resins

Nitrogen functional groups and a magnetic component inside its structure enable a potent base anionic in nature resin magnetic ion-exchange resin (MIER) to function as a weak single magnetic [18]. Pharmaceutical pollutants in aquatic environments have the potential to be hazardous to both the environment and human health. It looked at the removal of Advil,Voltaren, and sulfadiazine (SDZ), three widely available and often discovered drugs, using two magnetic ion-exchange resins (Jiang et al., 2015). Pharmaceutical medications like ibuprofen (IBU), diclofenac (DC), and the commonly used antibiotic sulfadiazine (SDZ) are adsorbed using it [19].

2.4. Desalination Technologies

The process of technologically extracting freshwater from marsh or saltwater is known as desalination. Water is drawn from the source (sea or brackish water) by pumps and pipes in the intake system. It is currently possible to desalinate using a variety of techniques. A desalination facility, which often entails multiple processes to obtain fresh water, has a desalination unit that consumes the most energy. Preselection, or removing particulates from raw water through filtration, and chemical addition to reduce the accumulation of salt and erosion inside the desalinating unit, are the usual components of a desalination plant. To alter pH and make sure the final usage standards are fulfilled after treatment, add certain salts [20].

2.5. Smart Water Management System

The application of technology in water systems is necessary for the development of smart techniques.By reducing inefficiencies and creating innovative business opportunities, a smart water system can lead to more economically viable water services that will benefit residents in both rural and urban locations. Among the main advantages of smart water management are improved system awareness, detection of leaks, preservation, and water quality monitoring [21].

2.5.1. Smart Water Metering

One kind of measuring instrument that can capture and transmit usage information at a predetermined frequency is the smart meter. Developing an efficient water management system involves setting up either actuators or sensors for tracking water distribution systems [22].

2.5.2. Geographic Information System

Since GIS offers a comprehensive record of all the network's components along with their precise locations, it has animportant function in smart water management. Thehandling of water systems is increasingly dependent on GIS, which makes it possible to incorporate spatial elements into an orientated model and enhance planning and management by observing the clear progression of spatial constituents within the network. GIS's primary benefit is its ability to simulate reality using data systems built to gather, store, exchange, alter, examine, and display spatially referenced information[23].

2.5.3. Cloud Computing and Supervisory Control and Data

The purpose of it is to describe how computers and servers that are connected and linked over the internet use their data storage and memory capacity by network computing standards. "A new style of computing in which the resources are continuously expandable and often integrated being provided as a service over the internet" is called cloud computing. Using the Internet (sometimes called "the Cloud") to deliver computer services enables more rapid advancement, massive savings, and dynamic distribution of resources. Computers, records, retrieval, applications, socializing, statistical analysis, and intelligence are examples of services [24].

2.5.4. Models, Tools of Optimization, and Decision Support System

The establishment of a common structure for assessing outcomes centered on an assortment of relevant markers and information services and interfaces to support the management organizations' making choices has allowed the interested parties to assess, establish confidence and trust, and monitor the changes.The system can reduce expenses associated with customizing treatment assemblies during the preparatory phase, eradicate errors during the preparation and creation stages, simplify decision-making by limiting the number of alternative solutions to those that best meet user requirements and existing conditions, take customer demand into account, and support environmentally friendly growth[25].

3. Advancements in Air Protection Technologies

3.1. Air Pollution Control Devices

Air pollution control devices (APCDs) have been installed in a large number of carbonized plants to reduce the effects of pollutants created during coal combustion. In addition to eliminating traditional pollutants, APCDs decrease emissions of volatile organic compounds (VOCs). This investigation used gas chromatography-mass spectrometry (GC–MS) to measure the VOC contents in flue gas samples taken from various locations in two industrial boilers and seven typical coal-fired power plants. Electrostatic precipitators (ESP) and selective catalytic reduction (SCR) systems work together to remove volatile organic compounds (VOCs) [26].

3.1.1. Electrostatic Precipitators

The pneumatic airflow systems of residential buildings have been using the electrostatic precipitator (ESP) as an air-cleaning device. It is possible to put electrostatic precipitators inside ducts or as freestanding units. Electrostatic precipitation systems (ESPs) function primarily by charging airborne particles with a strong electromagnetic field produced by a high-voltage source of electricity. Afterward, an inversely charged sheet gathers the charged impurities. Particulates travel swiftly to the capturing surface due to the charges [27].

Condensable particulate matter (CPM) is a type of principal particulate matter that, upondischarge quickly transforms into a particulate matter as a result of cooling and dilution. Before discharge, CPM exists as a gas or vapor phase. Because of its intricate makeup, CPM is dangerous for human health and the environment. An electrostatic precipitator (ESP) in conjunction with AC injection is a somewhat easy and practical way to remove CPM. This approach significantly lowers operating costs because it simply requires the placement of injection sites in front of the current ESP rather than procuring additional large-scale equipment[28].

3.1.2. Fabric Filters (Baghouses)

Baghouses consist of fabric bags that capture particulate matter as gas flows through them.collected particles are typically removed periodically by shaking or pulse jet cleaning. The
baghouse is frequently used to collect particle emissions from a variety of industrial units, such as those that process limestone powder, wood, milk, fly ash, and wood. Air permeability and pore size are two factors that are used to evaluate the filtering effectiveness of nonwoven filter fabrics.Permeation of air is typically one of the most important scientific metrics that companies are required to provide to their consumers.The development ofpackhouses frequently relies on filter sacks, which are usually round and intended to clean the air and create a hygienic environment[29].

The essential feature of FFPs(Fabric Filter Plants)is bag filters, which act as a physical barrier to prevent particulates from passing through while permitting flue gas to enter the stack. Therefore, during FFP design, several factors about bag filter size, material, and construction must be taken into account. The amount of particulate-laden exhaust gases that can be effectively purified in a fixed-flow rate (FFP) per unit of time depends greatly on the bag filter's dimensions. Nearly fifty percent of South Africa's carbonized power plants recently have FFPs installed, and some of the impacted power plants with ESPs may be able to switch to FFPs in the wake of the most recent minimum emissions regulations[30].

3.1.3. Scrubbers

High levels of sulfur dioxide emissions are linked to several health issues as well as ecological harm. In addition to being unhealthy, sulfur dioxide causes acidity in the soil and water. The burning of conventional fuels. such as hard and brown coal, oil, and natural gas pollute the atmosphere by releasing dust, nitrogen oxides (NOx), and sulfur oxides (SO_2 and SO_3). It appears doubtful that we will stop using these energy sources anytime soon. Therefore, the only workable option is to use the right technologies and tools to get rid of environmentally dangerous materials that are created from fuels or after waste gases are burned[31].

The elimination of sulfur dioxide and oxides of nitrogen from Ship emissions simulations was accomplished using a unique wet scrubber that consists of an oxidizing and a reduction section in series. The oxidizing and reducing stages were conducted using sodium chlorite ($NaClO_2$) and sodium thiosulfate ($Na_2S_2O_3$), respectively. The wet scrubber that is being utilized is a specially designed glass scrubber that has an adjustable height and an interior diameter of 100 mm. The scrubber's top was designed with a filter disk that served as a fog eliminator and kept the liquid within the scrubber. Temperature sensors built within Thermo Fisher Scientific's alkalinity and oxidation and reduction potential (ORP) detectors, were used to identify the cleaning fluid in the container, enabling automatic temperature compensation (ATC) [32].

$$4\mathrm{NO} + \mathrm{ClO_2^-} \longrightarrow 2\mathrm{NO_2} + \mathrm{Cl^-}$$
$$\mathrm{NO} + \mathrm{ClO_2^-} \longrightarrow \mathrm{NO_2} + \mathrm{ClO^-}$$

The advanced oxidation, ionic liquids, and solid-designed interface hybrid materials-based techniques of the hybrid wet scrubbing approach are attracting a lot of interest due to their low energy requirements, low installation costs, and ability to remove many air pollutants at once. With the hybrid technique, flue gas could be treated with over 90% efficiency and the inherent NOx solubility could be solved. Crucially, the hybrid wet scrubbing method might prevent the need to discard aqueous medium. Hybrid processes are a revolutionary technique that not only removes NOx and SO_2 but also generates usable chemicals and renewable energy resources due to their catalyst renewal capacity and appropriateness for on-site catalyst renovations [32].

3.1.4. Selective Catalytic and Selective Non-Catalytic Reduction

Nitric oxides (NOx, which includes NO and NO_2) are a primary source of air pollution. They have a major impact on several environmental issues, including acidic precipitation, sunlight-induced smog, decreasing ozone layer, and greenhouse gas effects.The most efficient technique for treating flue emissions from stationary oil and carbonized plants is selective catalytic reduction (SCR), which uses NH_3 as the reducer. This approach has been adopted globally. The NH_3-SCR method produces N_2 and H_2O without using up surplus O_2 when NH_3 selectively combines with NOx across a catalyst surface[33].

$$\mathrm{NH_3} + \mathrm{H^+} \longrightarrow \mathrm{NH_4^+}$$
$$\mathrm{NH_4^+} + \mathrm{N_2O_4} \longrightarrow \mathrm{NH_4N_2O_4^+} \longrightarrow \mathrm{N_2} + \mathrm{H_2O} + \mathrm{O}$$
$$\mathrm{NH_4^+} + \mathrm{NO_2^-} \longrightarrow \mathrm{NH_4NO_2} \longrightarrow \mathrm{N_2} + \mathrm{H_2O}$$
$$\mathrm{NH_4^+} + \mathrm{NO_3^-} \longrightarrow \mathrm{NH_4NO_3} \longrightarrow \mathrm{N_2} + \mathrm{H_2O} + \mathrm{O}$$

The ammonia-SCR, urea-SCR, and hydrogen-SCR processes were found to have high NOx removal effectiveness; though, these reducing agents are not economical since they require large amounts of storage or employ a costly gas (H2).In a packed-bed electrostatic barrier discharge ionized reactor, nitrogen oxide (NOx) hydrocarbon selective catalytic reduction (HC-SCR) over Ag/α–Al2O3 with temperature changes between 150 and 350 °C was investigated.Ag/Al2O3 catalysts are inexpensive and possess the necessary activity with high NOx removal efficiency; they have been investigated in conjunction with hydrocarbon-SCR for NOx removal [34].

$$\mathrm{NO} + \mathrm{O} + \mathrm{e\backslash M} \longrightarrow \mathrm{NO_2} + \mathrm{e\backslash M}$$
$$\mathrm{NO} + \mathrm{O_3} + \mathrm{e\backslash M} \longrightarrow \mathrm{NO_2} + \mathrm{O_2} + \mathrm{e\backslash M}$$
$$\mathrm{NO} + \mathrm{RO_2} + \mathrm{e\backslash M} \longrightarrow \mathrm{NO_2} + \mathrm{RO} + \mathrm{e\backslash M}$$

A common objective among power researchers is to pave the way for reasonably priced environmentally friendly coal technologies, especially in the area of cutting-edge NOx and SOx control technologies.SCR(selective catalytic reduction) is capable of reducing NOx levels by up to 90%, but the catalyst needed to do so is quickly fouled, and the entire procedure is known to be highly expensive.SNCR(selective noncatalytic reduction) is thought to be a less desirable option because of its substantially reduced removal rate.On the other hand, compared to SCR, it is much less expensive and easier to deploy. Being resistant to airborne dust and having great operational flexibility with other NOx reduction technology is another reason why SNCR is appealing.In the SNCR process, NO is reduced at a temperature window of 850 °C to 1175°C using areactant, often NH_3 or urea[35].

$$\mathrm{NH_3} + \mathrm{OH} \longrightarrow \mathrm{NH_2} + \mathrm{H_2} \text{ (propagation reaction)}$$
$$\mathrm{NH_2} + \mathrm{NO} \longrightarrow \mathrm{N_2} + \mathrm{H_2O}$$
$$\mathrm{NH_2} + \mathrm{NO} \longrightarrow \mathrm{NNH} + \mathrm{OH} \text{ (chain branching reaction)}$$
$$\mathrm{NNH} + \mathrm{NO} \longrightarrow \mathrm{N_2} + \mathrm{HNO}$$

3.1.5. Thermal Oxidizers

Volatile organic compounds (VOCs) are recognized for their detrimental effects on human health and the natural world. The thermal oxidation method is primarily used to handle large amounts of concentrated volatile organic compounds (VOCs), and it typically operates at temperatures of about 900°C. Specifically, the method of catalytic oxidation was thoroughly examined due to its ability to operate at temperatures below 400°C, which minimizes the requirement for auxiliary fuel and sophisticated thermal insulation or thermally stable building materials. Specifically, the method of catalytic oxidation was thoroughly examined due to its ability to operate at temperatures below 400°C, which minimizes the requirement for auxiliary fuel and sophisticated insulation against heat or thermally stable building substances [36].

3.1.6. Activated Carbon Adsorption

Because adsorption technology can collect and reuse both adsorbent and adsorbate, it has been identified as an effective and cost-effective control technique. Carbonaceous adsorbents are widely employed in gas purification, particularly for VOC treatment and recovery, because of their substantial area, rich, permeable framework, and loftyadsorption capability. The main source of activated carbon is biochar, which is created by thermochemically converting biomass through processes like gasification or pyrolysis. The process configuration, activation period, retention time, impregnation ratio, particle size, precursor qualities, and chemical substances all affect the activation[37].

The main man-made greenhouse gas (GHG) causing global warming on Earth is carbon dioxide (CO_2). At present, there exist three distinct systems for capturing carbon dioxide from flue gas: pre-combustion, post-combustion, and oxy-fuel combustion. Activated charcoal is a preferred all-purpose isolation material that has several benefits over the initial capture methods that rely on NH_2-based scraping and are intrinsically energy-intensive. The carbonization of carbon-based raw materials, which is typically carried out at temperatures below 800 °C without oxygen, and the activation step of the char produced from the carbonization stage are the two basic steps involved in the synthesis of activated carbonwhich is usually done in an oxygen-free environment at ambient temperatures below 800 °C, and the carbonizing phase's charcoal stimulation step are the two fundamental steps in the production of activated carbon [38].

3.1.7. Biofilters

Air pollutants that are emitted by companies that produce goods from organic materials, such as the paint and medicinal sectors, as well as by vehicles, city waste sources, procedures related to substance modification garbage dumps, distribution plants, etc., can be removed via the process of biofiltration. One important characteristic is that bacteria are good at eliminating pollutants, while fungi can speed up deterioration, particularly in paint application and factory emissions. Fungi have a greater toluene elimination efficiency when used as a reagent in the production of medicines, pigments, and fragrances, as well as a solvent in pigments, teeth, melodies, and elasticity [39].

Microorganisms adhered to a porous medium are used in biofiltration to decompose contaminants found in a stream of air. The microbes develop a biofilm on the medium's surface or are suspended in the surrounding water phase the particles in the media.Compost, peat, and other relatively inert materials make up the filter-bed media, which guarantees broad surface attachment areas and an extra source of nutrients. Biofilters and bio trickling filters can be used to remove a wide range of pollutants, including hydrogen sulfides (H_2S), stink, and chemical compounds that are volatile, such as aromatic hydrocarbons, ketones, aldehyde, ether, toluene, and chlorinated and non-chlorinated species.[40].

A complex mixture of gaseous pollutants, such as nitrogen oxides (NOx), ozone (O_3), and suspended particles, known as particulate matter (PM), creates urban air pollution.The concept of phytoremediation has been extended tothe technique of plant biofilters, It usually manifests as dynamic walls of vegetation. These devices use "active airflow" to push air through the growing material and leaves of plants manually.The plants are arrayed along a vertical glass, where the ambient air is reached upon exit. The growth matrix in this process mechanically filters PM, and air toxins including VOCs, O_3, and NO_2 can either stick to substrate adsorbents to be removed from the airstream or be[41].

3.2. Vehicle Emission Control Technologies

3.2.1. Catalytic Converters

Over the past few decades, the transportation sector's usage of fossil fuels has resulted in a rise in greenhouse gas (GHG) emissions.Hydrofluorocarbons (HFCs), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and carbon monoxide (CO) are among the exhaust gases released by fossil fuel-powered vehicles, such as gasoline and diesel. One of the main challenges to ending the currently known climate change cycle is reducing these emissions. Exhaust control catalysts are under more pressure due to advancements in engine technology. That is why catalytic converters are extensively used to reduce vehicle exhaust gasses and transform them into molecules that are not toxic. Since 1970, three-way catalytic (TWC) converters have represented the gold standard of catalytic converter technology[42].

One part of the catalytic converter is positioned between the exhaust manifold and the tailpipe and is known as the catalytic reactor. The waste product contains harmful gasses such as fumes, particulate matter, carbon monoxide, hydrocarbons, and nitrogen oxides. Before each of these emission contaminants enters the converter, they are all subjected to a chemical reaction with a catalyst that produces CO2, water, N2, and O2 (carbon dioxide, nitrogen, and water) without reacting with the pollutants. The reduction and oxidation monoliths make up the catalytic converter. According to the rules of the BS and EURO regulations, a catalytic converter must be installed. The best way to lessen emissions from gasoline and diesel engines is to use a catalytic converter[43].

$$\mathrm{Hydrocarbons(unreacted)} + O_2 \longrightarrow CO_2 + H_2O$$
$$2CO + O_2 \longrightarrow 2CO_2 \quad \text{(oxidation of CO)}$$
$$2NO_x \longrightarrow xO_2 + N_2 \quad \text{(reduction of NO)}$$

Liquefied petroleum gas, or LPG, powers a large number of taxis and public buses in Hong Kong. LPG-powered vehicles are now the main source of atmospheric photochemicals in Hong Kong due to their increased use.To reduce the released gases of nitrogen oxides (NOx) and volatile organic compounds (VOCs) from LPG-fueled vehicles, the Hong Kong government started an action plan in September 2013.Nitric oxide (NO), NOx, and volatile organic compounds (VOCs) linked to LPG were successfully reduced in the atmosphere, according to long-term real-time monitoring. Additionally, the findings of receptor modeling demonstrated that the following decreased when the program was implemented: 88.6 ± 0.7% for NO, propane, propene, i-butane, n-butane, and 35.7 ± 0.1; 40.8 ± 0.1; 45.7 ± 0.2; and 35.7 ± 0.1 [44].

3.2.2. Fuel Injection System and Design

There are currently many initiatives going on globally to find alternatives to internal combustion engines (ICEs) and petroleum-based conventional fuels due to emissions of CO2, particulates, nitrogen oxides (NOx), atmospheric carbon monoxide (CO), and petroleum products (HC), as well as concerns about climate change and local air quality related to transportation. Of course, the goals of economic expansion, energy security, and independence also have a significant impact on transport policy in many nations. Liquid petroleum gas (LPG), hydrogen, biofuels, natural gas, electro-fuels, synthetic fuels, and methanol are a few of the conventional fuel substitutes that could be utilized in place of internal combustion engines (ICE) [45].

The processes by which fuel/air mixes are created vary greatly based on the fuel injection technology. The fuel injector in a port fuel injection (PFI) engine is installed at the point of the intake tract with the intake valve as its target. To allow for uniform oxygen-fuel blending, both air and fuel are combined in the intake port before being fed to the piston. On the other hand, GDI (gas engines) have their fuel injectors at the head of the engine. While the rear installation injector is inclined at the cylinder head, the central mount injector is located at the higher center of the cylinder head. Fuel is poured into the combustion chamber, which is cooled by the latent heat of evaporation. [46].

3.2.3. Electric and Hybrid Vehicles

Automobile engines are currently being electrified and diversified to address worries about pollutants in the air and the safety of the power supply. Particularly in China, the manufacturing of entirely electrically powered automobiles has increased significantly in the past few years. Even said, it is still anticipated that by 2030, internal combustion engine vehicles—including hybrids—will make up over ninety percent of all light-duty automobile engines. electrically powered car technology has evolved in several countries to reduce dependency on foreign fuel and environmental harm. Using electric automobiles, especially electric ones with batteries, is thought to be the solution to the shortage of energy and pollution problems [47].

Since traction batteries are needed to power EVs'(electric vehicles) propulsion systems, their technological advancements have a significant impact on the EV industry. An EV was equipped with a rechargeable lead-acid battery once it was discovered. Better fuel efficiency for a given battery charge can be achieved by using more powerful and efficient electric traction drive systems, which are in demand due to increased electrification and altered mobility.Environmental benefits, reduced dependence on fossil fuels,energy efficiency, long-term sustainability, and urban air quality are the major advantages of electric and hybrid vehicles. To expedite the mass-market acceptance of electrical modes of transport, the motor vehicle sector and the United States Dept. of Energy (DOE) have published technological goals for light-duty electric vehicles (EVs) for 2025 [48].

3.3. Air Quality Monitoring Sensors

To evaluate the quality of the air we breathe, air quality monitoring sensors measure a variety of airborne pollutants as well as other factors. These sensors are used to determine the extent of pollution in a given area and to decide how best to prevent any negative impacts on the environment and public health. Both governmental authorities and citizen science attempts are rapidly adopting inexpensive sensors for air quality monitoring, partly due to the increased and commercial availability of micro-sensor technology. When monitoring air quality in city and village areas, the use of LCS offers the advantage of greater spatial coverage. Presently, the market offers hundreds of LCS (low-cost sensors) that can be purchased for several hundred to several thousand euros [49].

According to several studies sensor performance in the field was generally better in the winter than in the summer. This difference in performance was likely caused by the greater pollution concentrations in the winter. Ultimately, though, how well the sensors function in the long run will dictate how widely they are employed going forward. Long-term performance components include resilience, stability (which changes over time), and performance under all actual environmental circumstances, such as air pollution and weather. We conducted a thorough performance assessment of 13 KOALA(Knowing Our Ambient Local Air Quality)air quality indicators,located in different locations in Australia and China, that had been in operation for around 13 months, to provide fresh perspectives on the long-term efficacy of inexpensive monitors [50].

4. Advancements in Soil Protection Technologies

4.1. Soil Erosion Control Technologies

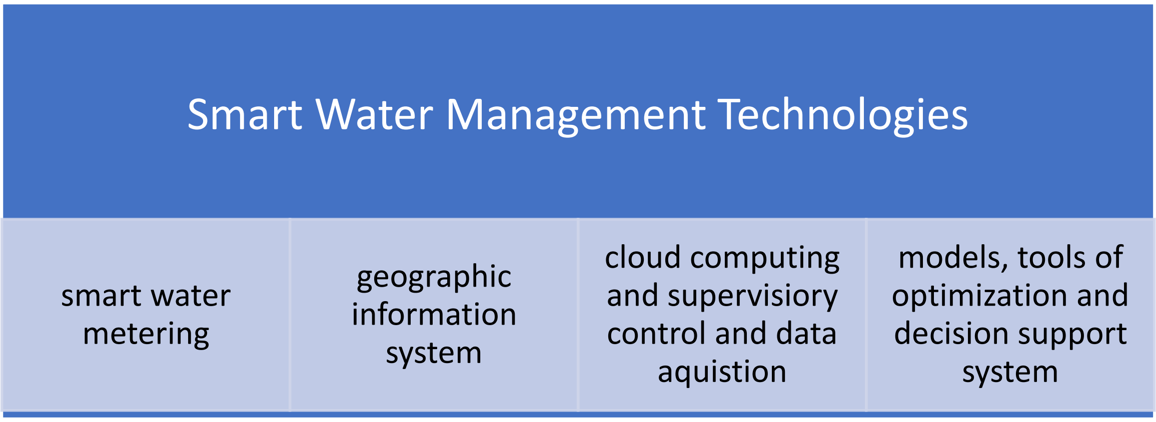
A common problem that is now of great concern in many countries is the eroding of soil. Generally speaking, soil erosion refers to the destruction of land brought about by a confluence of both organic and synthetic factors, such as extensive and intensive farming, and weather-related events, such as snowflakes, the breeze, and floods. Soil erosion can be classified as either an expedited or spontaneous process, depending on its severity. New soils are generated under normal circumstances via soil erosion, which happens in the first type over thousands of years. Deforestation, excessive grazing, and improper farming practices are the primary human-caused causes of increasing soil erosion in areas where soil loss outweighs soil production. Soil erosion is facilitated by several factors, such as topography, cover of vegetation, seasonal erosivity, and soil deterioration [51].

The primary cause of soil erosion in croplands and rangelands is improper land management and soil exploitation; water erosion, on the other hand, is mostly to blame for the global spread of degraded lands. Because of water pollution and decreased water availability for various uses, water erosion jeopardizes ecosystems' ability to support high levels of crop production and agricultural intensification. In addition to endangering the resilience of various ecosystems and agricultural production potential, soil erosion also contributes to the depletion of both terrestrial and aquatic ecosystems, the rise in rural migration due to erosion of land, the silting and contamination of water resources, the frequency of floods, the reduction in the capacity of hydroelectric facilities to produce power, and the increase in the expenses of purifying water [52].

Table 1: Different types of membrane filtration

Type of Filtration	**Pore Size**	**Contaminants Removal**
Microfiltration	100nm-10um	Large colloids, bacteria
Ultrafiltration	2-100nm	Macromolecules, proteins
Nanofiltration	1-2nm	Multivalent salts
Reverse Osmosis	0.1-1nm	Monovalent salts

Table 2: Smart water management technologies



Smart Water Management Technologies			
smart water metering	geographic information system	cloud computing and supervisiory control and data aquistion	models, tools of optimization and decision support system

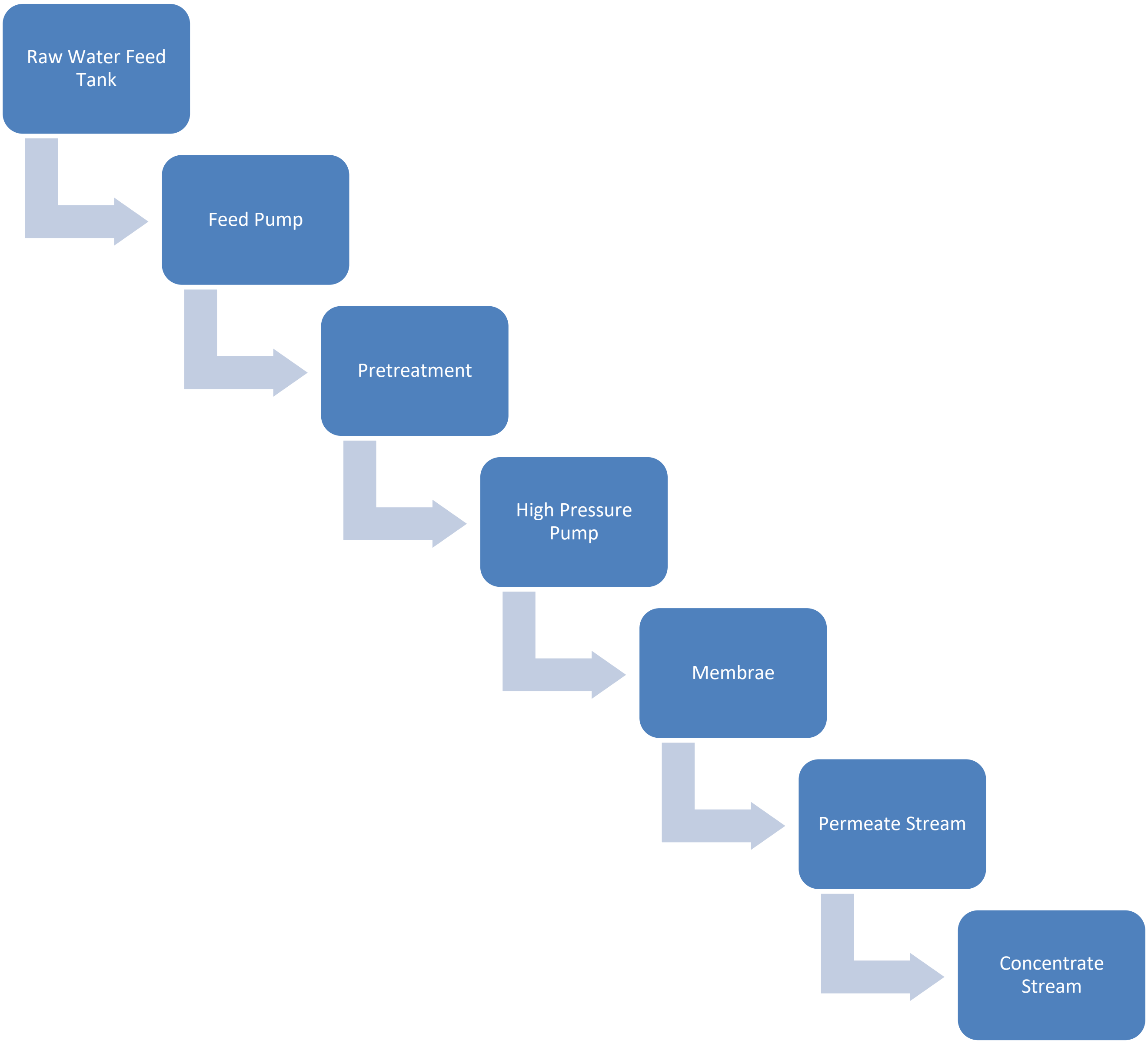


Figure 1: Schematic diagram of reverse osmosis

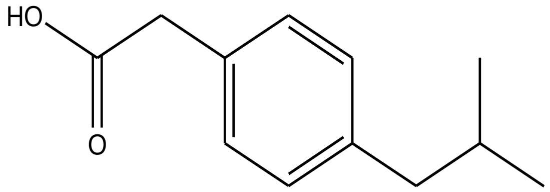


Figure 2: structure of ibuprofen (IBU)

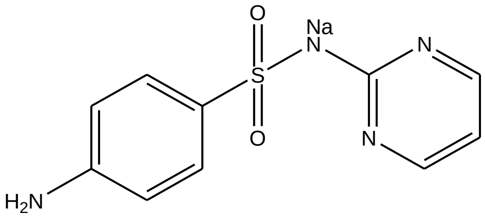


Figure 3: structure of diclofenac (DC)

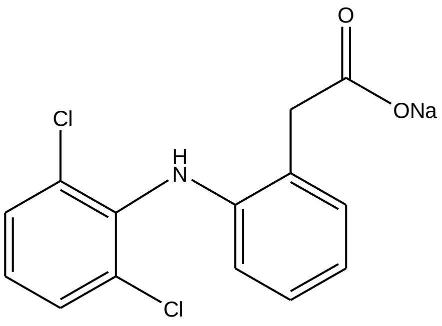


Figure 4: Structure of sulfadiazine (SDZ)

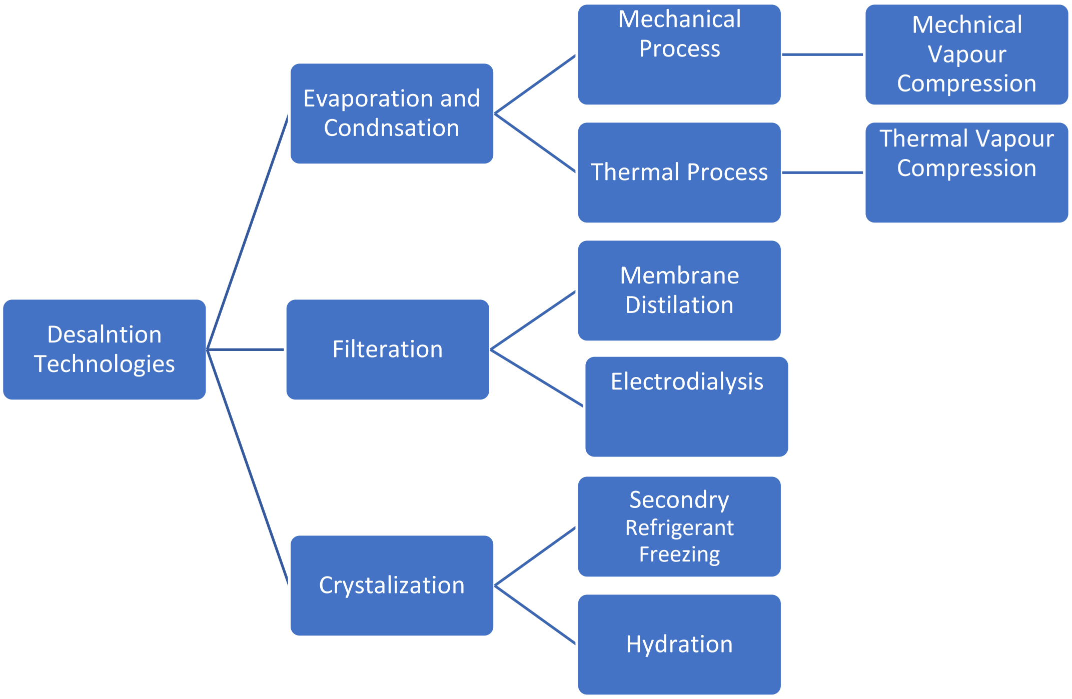


Figure 5: Schematic diagram of desalination technologies

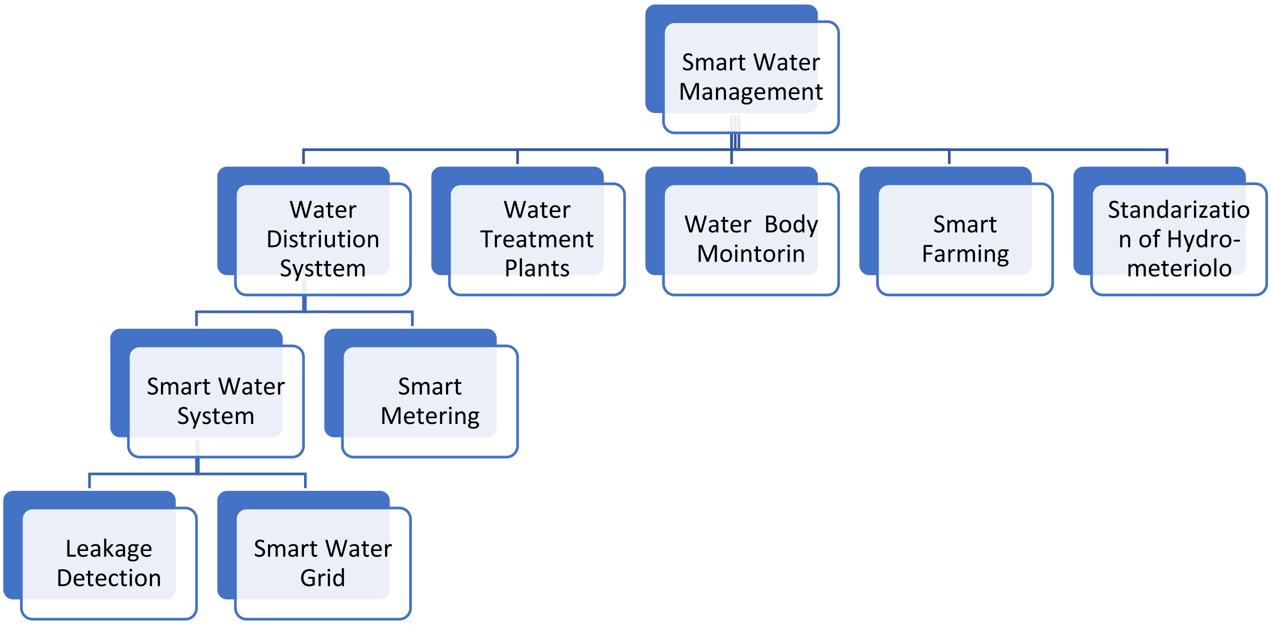


Figure 6: Smart water management system

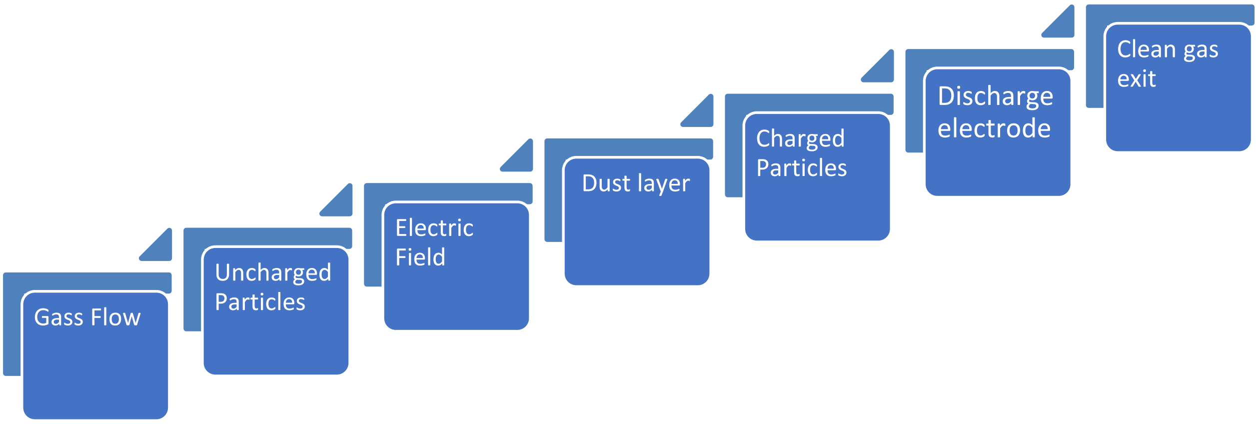


Figure 7: working principle of electro-precipitators

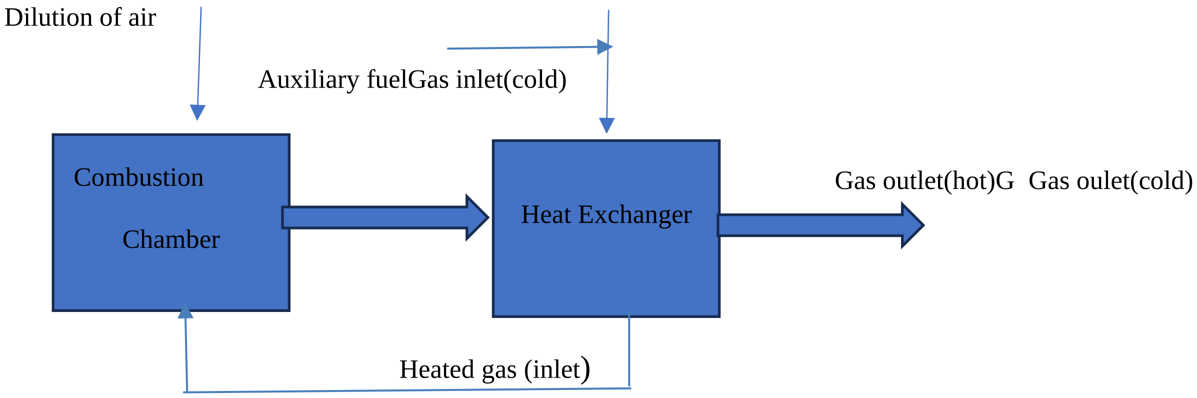


Figure 8:Schematic diagram of a recuperative thermal oxidizer

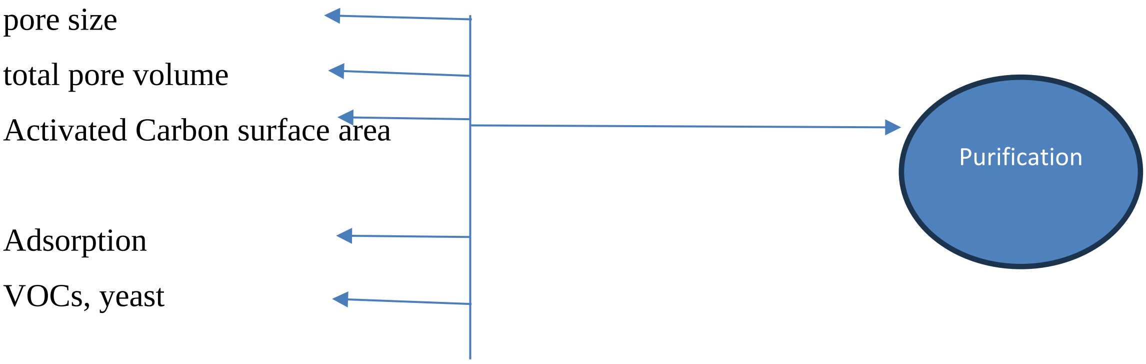


Figure 9: Schematic diagram of recuperative thermal oxidizer

Table 3: Characteristics of various filter media used in biofilters

Material	Porosity	Moisture capacity	Nutrient capacity	Useful life	Cost
Peat	Average	Good	Good	Good	Medium
Soil(heavy loam)	Poor	Good	Good	Good	Very medium
Compost(yard waste)	Average	Good	Good	Good	Low
Wood chips	Good	Average	Average	Average	Low
Straw	Good	Average	Poor	Poor	Low

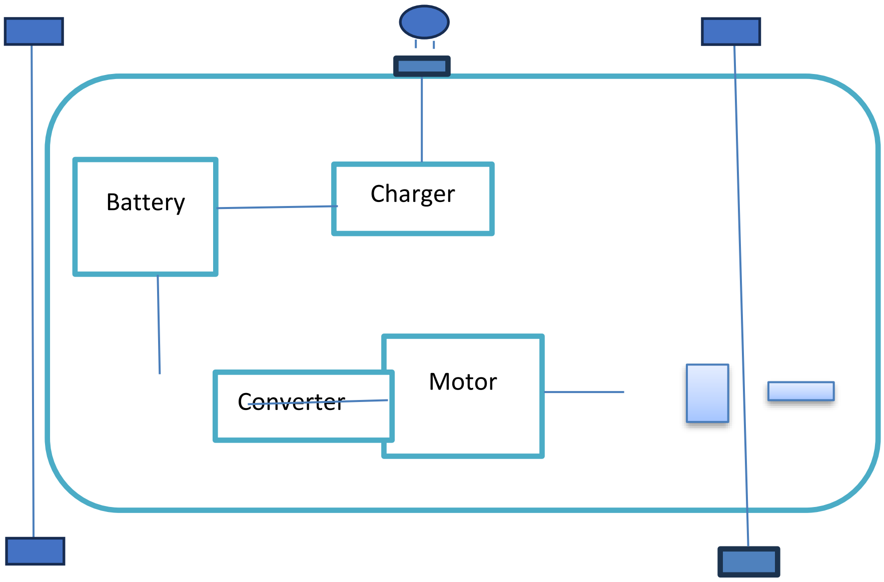


Figure 10: Simple design of battery electrical vehicle (BEV)

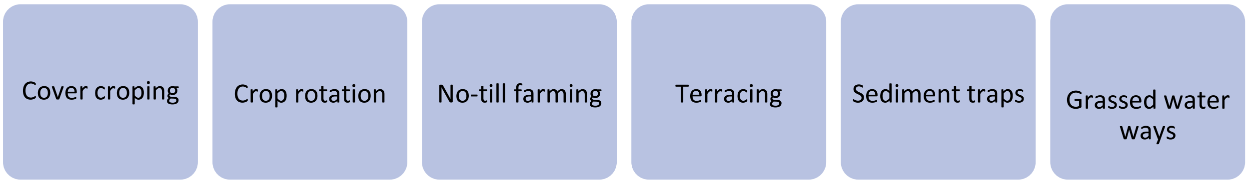


Figure 11: Soil erosion control technologies

Planning land use by its agricultural suitability is the first step in controlling soil erosion on a regional scale At the farm level, lands must be used by their capabilities and by suggested conservation practices. Restricting the water movement pattern in watered regions is one of the most important things you can do to stop agricultural erosion in those places; this involves opening the beds in a trapezoid shape, using a special device to provide irrigation, and measuring the amount of water required for cotton irrigation using a refractometer. Theprincipalobjective of utilizing the apparatus is to regulate the water flow in the field to a specific degree. The apparatus is made up of a hole-filled, level wall drilled into it at various sizes in the center. The water transmission portion of the device's characteristics was determined using the laws of motion regulating the water movement in the field [53].

4.1.1. Soil Remediation Technologies

Heavy metal-contaminated areas have become more noticeable as industry and urbanization remediation (chemical-based leaching, chemical stability, electrokinetic remediation-permeable reacting obstacle, and chemically oxidation/reduction), biological remediation (microorganism remediation and botanical remediation), and physiological remediation (soil desorption by heat and soil substitution) are some of Especially excessive emissions from electroplating, smelting nonferrous metals, mining tailings, etc. destroy the soil. The technology for cleaning up contaminated sites with heavy metals has advanced quickly in the last few years. As more successful real-world applications have so too have new and efficient remediation solutions. Chemically relevant the frequently used techniques for soil remediation for places polluted with toxic metals [54].

It is impossible to ignore contamination brought by oil use in sectors including mining, transportation, and petroleum, particularly soil contamination. One of the 21st century's vulnerabilities is soil degradation from oil contamination, as the repercussions can be disastrous if the issue is not properly handled. In the mineral extraction, transport, and petrochemical industries, the choice to remediate pollution is made according to its harmful impacts and timeliness [55].

4.1.2. Phytoremediation

The process of extracting, immobilizing, containing, and/or degrading pollutants from soil, water, or the air is known as phytoremediation. It can be a useful method for removing a variety of contaminants from soils on-site or in situ, such as metal(loid)s, salt (NaCl), radioisotopes, solvents (like trichloroethylene [TCE]), munitions waste (like 2,4,6-trinitrotoluene [TNT]), petroleum hydrocarbons (PHC), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Technologies for commercial phytoremediation seem to be underutilized worldwide. In more than 10 Canadian locations, we have employed our developed plant growth-promoting rhizobacteria (PGPR)-enhanced phytoremediation systems (PEPS) to remediate PHC to levels below general regulatory requirements over the past 20 years[56].

Recently, there has been a lot of interest in phytoremediation. It involves the processes of translocation, accumulation, transport, transformation, and volatilization and is based on plants. With few drawbacks, this technique is efficient and promising. Still, low plant biomass and inadequate heavy metal bioavailability in the soil limited this technology's effectiveness; nevertheless, its efficiency has been increased by a variety of techniques. It covers techniques from the fields of microbiology, physics, chemistry, agronomy, and genetic engineering. One emerging and promising green method for eliminating pollution from the environment is phytoremediation[57].

4.2. Water Monitoring and Soil Health Assessment

Determining the characteristics and mechanisms of soil that characterize its functionality serves as a foundation for the creation of soil health instruments to address this challenge. Numerous physical, chemical, and biological tests must be used to quantitatively evaluate their functions. The Cornell Soil Health Tool (CSHT) the Soil Management Assessment Framework (SMAF), the Agroecosystems Performance Assessment Tool (AEPAT), and the NRCS-USDA soil health assessment tool are a few examples of the indices that are created when multiple soil test results are combined into a full soil health assessment. To give future managers valuable guidance, there must be clear connections between management elements and soil health scores [58].

A healthy soil is defined as having the ability to act as a vital living system, within the ecosystem and land use boundaries, to support plant and animal productivity, preserve or boost the quality of the water and air, and encourage the well-being of plants and animals. Sustaining wholesome soils is crucial for guaranteeing the production of food worldwide. The notion of soil health (SH) was introduced as a result of growing recognition that soil provides other essential ecosystem services (ES) in addition to being a medium for crop growth [59].

One of the industries where the number of IoT solutions has expanded the greatest is agriculture. One of the primary functions of the PA systems is to automate the irrigation schedule. For this, agrometeorological information gathered by weather observatories that can be placed away from agricultural land is usually employed. The use of soil variables to improve scheduling precision has been facilitated by the development of soil monitoring nodes. To apply controlled deficit irrigation (RDI) tactics, data from soil moisture sensors have been incorporated into the waterbalance formula. Robots and drones are examples of vehicles on which monitoring nodes may be installed This monitoring procedure can be carried out in the field as well as by tracking the product to keep an eye on its manufacturing process [60].

5. Conclusion

The development of environmental protection technology lies in our persistent commitment to advancements that will keep our world safe for future generations. With an expanding toolkit of remedies, these advances address the complex problems of air, water, and soil pollution. Pure drinking water is being ensured by advanced water treatment systems that use ion exchange resins, enhanced oxidation, and membrane filtration. The Internet of Things (IoT)-)-enabled smart water management technologies are maximizing water efficiency and reducing waste. Seawater is becoming a feasible freshwater supply for desert areas thanks to desalination technologies. Even new approaches to water filtration are being offered by nanotechnology, which is making its mark. Hazardous contaminants are being captured from industrial emissions by air pollution control equipment. Transportation is becoming safer because of vehicle emission control systems, which lower pollutants and greenhouse gas emissions. Real-time data from air quality monitoring devices helps us locate pollution areas and take preventative action against them. Agriculture land is being protected by soil erosion control methods such as better land management practices and the application of technological techniques. Contaminated sites are being cleaned up using soil remediation technology so they can be safely reused. We can now take preventive action and guarantee the long-term health of the soil thanks to the vital insights into soil quality that advanced soil monitoring and health assessments are providing. But they are only the beginning of the advances. Sustained research and development expenditures are essential for improving current technologies, investigating novel approaches, and guaranteeing their cost-effectiveness and availability for all countries. We can make the earth greener and healthier for present and future generations by embracing these advancements and encouraging global cooperation.

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