Environmental Sustainability

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Published by
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Narukara (PO), Malappuram (DT), Kerala, India - 676122

ISBN: 978-93-5917-518-8

First Edition
Printed at *Apex Digital Services,*
Manjeri, Malappuram (DT), Kerala, India – 676121

RESEARCH GRADUATE DEPARTMENT OF CHEMISTRY

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January 2024

ISBN: 978-93-5917-518-8

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How Industries can be Modified to Achieve Environmental Sustainability?

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Since the inception of the Industrial Revolution, catalysed in part by the steam engine, extensive operations have elevated living standards and offered a plethora of choices beyond the imagination of our ancestors. However, it has also yielded unintended consequences, such as pollution The majority of industries currently rely on fossil fuels for power. To ensure a sustainable future, these industries should transition from fossil fuels to various renewable energy sources. While a complete shift to full electrification may be a significant challenge for many factories, some find hybrid equipment to be a practical step towards achieving long-term financial and environmental goals. Fossil fuels have been indispensable for powering the world's largest factories for over a century. Although a sweeping change won't happen overnight, electrification is gaining momentum. Our recent Global Energy Perspective indicates that by 2035, renewables could account for more than half of the world's electricity production, often at a lower cost than fossil-fuel generation. The decreasing costs of both electrical equipment and renewable electricity generation are expected to drive the electrification of industrial processes The costs of fossil fuels compared to electric power exhibit variability, and there's considerable uncertainty about when electric power will definitively and irreversibly become more cost-effective. Cost-effectiveness hinges not only on the current relative prices of fossil fuels and renewable electricity at a specific industrial site but also on factors like carbon pricing, where an increase could make industrial electrification more viable. Additionally, the long-term energy efficiency of electric equipment compared to conventional equipment plays a crucial role. Given that energy costs can surpass capital-investment costs by more than tenfold over the lifetime of a typical industrial furnace or boiler, the stakes are undeniably high.

Use of Hybrid Equipment

In certain situations, companies can take an initial step towards electrification by opting for a partial switch, incorporating hybrid solutions for specific applications. This involves utilizing equipment capable of running on either electricity or conventional fossil fuel. Another approach is the installation of additional electrical equipment, like electrical boilers, in a "dual" setup. Such dual or hybrid equipment is readily available for generating low- and medium-temperature heat, particularly in sectors such as chemical, petrochemical, and food industries that heavily rely on steam boilers. While partial electrification may not represent a final solution, hybridization presents substantial benefits for both industrial companies and society.

By incorporating hybrid equipment, businesses gain the flexibility to optimize energy expenses, strategically shifting to electricity during periods of lower costs and seamlessly reverting to fossil fuels when electricity prices surge. This dynamic approach intertwines with an added cost-benefit dimension: industrial companies stand to earn payments through "grid balancing" practices. These practices involve rewarding customers for efficiently utilizing excess electricity generated during peak renewable periods. By receiving such incentives, industrial facilities not only contribute to grid stability but also enhance their own financial prospects. In essence, these grid payments, along with associated fees and connection costs, emerge as pivotal elements that can either make or break a business case, often necessitating contractual adjustments or regulatory interventions. In addition, hybrid equipment can enable direct use of electricity from a nearby intermittent renewable-production site, such as a solar or wind farm. Such an off-grid setup could lower electricity costs for industrial companies significantly, as grid-connection costs, taxes, and other levies are mitigated or avoided. Industry could even be considered as a cheap battery, using electricity when available and switching back to fossil-fuel power when required, serving to help stabilize an entire grid.

Investing in hybrid equipment proves most pragmatic when a company is either retiring outdated machinery or embarking on the creation of a new facility. In the context of greenfield plants, a forward-thinking strategy leans heavily towards embracing full electric setups for future-proofing. However, in the immediate future, the installation of hybrid equipment during equipment replacements or new construction phases could render electrification more cost-effective than opting for conventional equipment now and transitioning to electric alternatives later on. As renewable-electricity prices witness a decline in various regions, the feasibility of hybridization as a near-term option gains momentum across a broader spectrum of industrial sites.

Switching can bring about positive, downstream effects. If industrial players ramp up their electricity usage due to falling prices compared to conventional fuel, the reduced price could establish a baseline in the power market. This might boost the energy transition by making investments in renewable-energy production more appealing.

Emission of Green House Gases

The industry's fuel consumption alone contributes to a third of all greenhouse gases (GHG), and oil and gas operations directly emit another 9 percent of GHG. This 42 percent total is the largest share attributed to any single industry. Consequently, the pressure on oil and gas producers to change is substantial and steadily increasing. Investors are demanding stronger emissions-reduction plans or are divesting from fossil fuels altogether. Meanwhile, wind and solar energy are becoming more effective and affordable. For fossil-fuel providers, the long-term implications of these trends are significant, even existential. To meet the Intergovernmental Panel on Climate Change's (IPCC) goal of keeping temperatures below the 1.5-degree threshold, the industry would need to cut its direct emissions by 90 percent by 2050, relative to today's levels. Achieving this target could be more feasible if the use of oil and gas declined. However, even if demand doesn't decrease significantly, the sector can still substantially reduce its direct emissions now, and more cost-effectively than companies might realize.

Hazardous by-products

Oil and gas companies' production-related activities contribute to 9 percent of global greenhouse gas (GHG) emissions. The major GHG contributor, linked to over 60 percent of the industry's emissions, is natural gas. Despite being primarily methane, this gas is often burned off during oil discoveries due to its lower value compared to oil. The intentional burning, known as flaring, transforms methane into CO2 and constitutes 14 percent of the industry's direct emissions. Unburned gas, whether released intentionally or accidentally, stands as the largest single source of the industry's direct GHG emissions, making up 48 percent. The release of methane into the atmosphere is concerning, given its potency—86 times more effective than carbon dioxide at trapping heat during the first 20 years of its release. The annual amount of methane released through oil and gas operations is substantial, equivalent to 6 percent of the global energy sector's total GHG emissions in 2017. Emissions sources within the oil and gas industry are scattered across its value chain, with downstream production activities contributing about 30 percent of the industry's direct greenhouse gas (GHG) emissions. An effective solution involves replacing on-site generators with a solar photovoltaic and battery setup, as demonstrated by one oil and gas company that significantly reduced emissions, breaking even on the investment within five years. Tackling such complex challenges will test the leadership of oil and gas executives, providing them with opportunities to signal the industry's commitment to decarbonization and pave the way for a new future. While acknowledging that the more significant challenge lies in the combustion of the industry's products, every improvement counts. The speed at which operational opportunities are implemented could generate valuable momentum for the demanding work ahead. The industrial sector, being a top energy consumer and responsible for over one-quarter of global CO2 emissions, faces the imperative of reducing its carbon footprint. Process optimization and increased energy efficiency are pivotal in achieving emission reductions, with digital technology playing a significant role in this transformation. The industries which are contributing mainly to the environmental pollution and trying to become more environmentally friendly are discussed below.

Mining Industries

The global mining industry confronts escalating physical risks due to a changing climate and is under growing pressure to decarbonize, making the creation of a climate strategy both challenging and increasingly urgent. Mining operations are accustomed to harsh climates, often operating in inhospitable conditions. However, forecasts predict more frequent and intense effects such as heavy precipitation, droughts, and heat, introducing new physical risks to mining operations. Simultaneously, the industry grapples with a significant decarbonization challenge. Mining operations directly contribute to 4 to 7 percent of global greenhouse gas (GHG) emissions, with at least three-quarters attributed to methane emissions from coal mining. Mounting pressure from climate change, governments, and investors is beginning to spur additional action within the industry. Further efforts are necessary, and as they unfold, they should enable mining companies to seize emerging opportunities in providing raw materials for new technologies while working towards a more sustainable future. The decarbonization challenge remains a central focus amidst these evolving dynamics.

Every industry holds a crucial role in the collective effort to limit global warming to 1.5 degrees Celsius above preindustrial levels—an objective deemed essential by the Intergovernmental Panel on Climate Change to mitigate the most severe risks of climate change. While the potential for decarbonization varies across mines, influenced by factors like commodity, type, and power source, our research indicates that mines could fully decarbonize their direct CO2 emissions, constituting approximately one-quarter of the industry's direct greenhouse gas (GHG) emissions. Achieving this involves a strategic combination of operational efficiency improvements, electrification, and the adoption of renewable energy. While capital investments are necessary to unlock most of this potential, certain measures are already economically viable for many mines today.

Shifting towards renewable electricity sources is expected to become more viable, even in off-grid environments, thanks to a projected 50 percent decline in the cost of battery packs by 2030. Remarkably, battery electric vehicles, in some cases, boast a 20 percent lower total cost of ownership compared to traditional internal-combustion-engine vehicles. However, the electrification of mining equipment, including diesel trucks and gas-consuming appliances, is only just becoming economically feasible, with only 0.5 percent of mining equipment fully electric at present. Addressing the remaining three-quarters of GHG emissions in the mining industry poses a more formidable challenge. These emissions stem from coal mining, particularly the release of naturally occurring methane found in many coal beds. While solutions exist for capturing this fugitive methane and converting it into power, these solutions are not universally applicable across all types of mines, and the required investment is often uneconomical in many cases.

Cement Industries

The cement industry stands out as a significant emitter, holding a prominent position in the sources of emissions. Cement, a crucial component of concrete and an integral part of our daily lives, is also a major contributor to global CO2 emissions. Specifically, two-thirds of the industry's emissions stem from the calcination process, involving the chemical decomposition of raw materials like limestone. Decarbonizing this process proves to be particularly challenging, given that carbon emissions are inherent to the calcination process itself.

Operational advances

Building on decades of efforts to enhance efficiency, traditional abatement strategies have the potential to reduce emissions by approximately one-fifth by 2050. The production of clinker, the essential component of cement, in cement kilns requires a substantial amount of heat. Alongside increasing the use of clinker substitutes, the industry could decrease energy intensity by improving plant utilization and enhancing equipment effectiveness. The recovery of waste heat also presents an opportunity to generate carbon-free electricity. Future cement plants could gain a competitive edge by integrating digital technologies into their operations, fostering both efficiency and sustainability.

Additionally, incorporating alternative fuels like waste and biomass, a trend in the industry spanning multiple decades, could contribute to a nearly 10 percent reduction in emissions by 2050. However, these endeavors come with challenges. Biomass availability varies by region, and competition from other industries adds complexity. Clinker substitutes face limitations, with natural pozzolans, such as volcanic rock and ash, not yet being extensively evaluated at scale. Furthermore, industrial byproducts serving as clinker alternatives, like fly ash from coal-fired power plants and slag from steel blast furnaces, may become scarcer as the power and steel industries decarbonize and produce less waste. Overcoming these challenges is integral to achieving sustainable and impactful emission reductions in the cement industry.

Technological innovation

Innovation is crucial for realizing the sustainability and performance potential of the cement industry, and promising avenues are already emerging. An intriguing development involves adding CO2 to concrete, which not only strengthens the material but also reduces the amount of cement required. Carbon-cured concrete presents another innovative solution by utilizing CO2 captured during cement production. While current methods can sequester up to 5 percent of the CO2 produced during production, newer technologies hold the promise of achieving much higher levels, ranging from 25 to 30 percent. Products like carbon-cured concrete, strategically positioned, could command a "green premium," providing companies with a competitive advantage among environmentally conscious buyers and potentially enhancing pricing power.

Realizing the full potential of technology and innovation in the cement industry will necessitate increased investment and a shift in mindset for companies that have grown accustomed to the status quo. Many players in the cement industry are not accustomed to relying on partnerships or operating within the ecosystems that are second nature in other industries. Breaking away from the comfort of familiarity is a crucial step toward achieving lasting change and sustainability in the sector.

New growth horizons

Sustainability may serve as the catalyst propelling the cement industry towards seeking growth through new business models, partnerships, and construction approaches. Cement-based concrete is likely to remain the global construction material of choice, but the emergence of "sustainable construction" value chains on regional and local levels is expected to prompt a reorientation of many corporate portfolios.

The decarbonization of the cement industry is poised to involve alternative building materials and other approaches, although the extent of emissions reduction remains uncertain. Opportunities for innovation extend beyond cement and concrete, and the industry is at a crucial juncture, facing challenges like decarbonization, ongoing value-chain disruption, and competition within the broader construction ecosystem.

Cement makers are approaching a moment of truth where the convergence of decarbonization and reinvention becomes imperative. Just as automakers redefine their role as providers of mobility rather than just manufacturers of cars, cement companies could similarly position themselves as providers of comprehensive construction solutions. As climate pressures intensify and traditional cement and concrete sales encounter threats, a combination of new thinking, innovation, and novel business models will be critical for ensuring a profitable and environmentally friendly future.

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Microplastics in clouds and their potential impact on weather patterns

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Microplastics are tiny particles of plastic less than 5 millimetres in size, and they can come from various sources, including the breakdown of larger plastic items, microbeads in personal care products etc. There are two main types of microplastics: primary microplastics and secondary microplastics. Primary microplastics are manufactured to be small in size, such as microbeads in cosmetics and personal care products. Secondary microplastics result from the breakdown of larger plastic items due to weathering, sunlight, and mechanical processes', and fibres from synthetic clothing. Microplastics in the atmosphere have been a growing concern, but the research on this topic is still evolving.

While much attention has been given to the presence of microplastics in oceans and other bodies of water, studies have also started to investigate their presence in the air. Here are some key points. The sources of microplastics in the atmosphere are diverse. They can originate from the fragmentation of larger plastic debris, road dust, industrial processes, and the breakdown of synthetic materials. Additionally, microplastics from aquatic environments can be transported into the atmosphere through processes like sea spray. Wind is a significant factor in transporting microplastics through the atmosphere. Once in the air, these particles can be carried over long distances before settling back to the Earth's surface. Some find their way into clouds, becoming an unseen presence within the atmospheric water cycle.

Detecting and measuring microplastics in the air pose significant challenges due to their small size and the complex nature of atmospheric particles. Research methods are continually being developed to improve our ability to quantify and characterize atmospheric microplastics. It's essential to note that the field of microplastics research is dynamic, and new findings may have emerged since my last update. Researchers and environmental agencies continue to investigate the presence, distribution, and effects of microplastics in various environments, including the atmosphere.

Cloud Nucleation and Microplastics

Clouds are formed when water vapor condenses around tiny particles called cloud condensation nuclei (CCN). These particles act as a nucleus for water droplets to form, eventually leading to cloud development. Microplastics, with their diverse shapes and sizes, can serve as additional CCN in the atmosphere. Their introduction into the cloud formation process alters the dynamics of cloud nucleation and affects the size and distribution of water droplets within clouds. Microplastic particles could even be acting as condensation nuclei, bits of debris that attract water vapor to form a cloud. Water-absorbing plastics may play an outsized role in the weather, while UV radiation from the sun breaks down the bonds of these toxic polymers, thus contributing to greenhouse gases in the atmosphere. Accumulation of microplastics in the atmosphere could lead to significant changes in the ecological balance of the planet, leading to severe loss of biodiversity. Microplastics can affect the formation of clouds, which means they have the potential to impact temperature, rainfall, and even climate change.

Cloud Albedo Effect

One significant consequence of microplastics in clouds is the alteration of cloud albedo, which refers to the cloud's reflective properties. Clouds regulate the amount of solar radiation absorbed by a planet and its solar surface irradiance. Generally, increased cloud cover correlates to a higher albedo and a lower absorption of solar energy. Cloud albedo strongly influences the Earth's energy budget, accounting for approximately half of Earth's albedo. Cloud albedo depends on the total mass of water, the size and shape of the droplets or particles and their distribution in space Thick clouds (such as stratocumulus) reflect a large amount of incoming solar radiation, translating to a high albedo. Thin clouds (such as cirrus) tend to transmit more solar radiation and, therefore, have a low albedo. Changes in cloud albedo caused by variations in cloud properties have a significant effect on global climate. The presence of microplastics can impact the size and concentration of water droplets in clouds, influencing how much sunlight is reflected back into space. Changes in cloud albedo can have profound implications for regional and global weather patterns, including shifts in temperature and precipitation. Smaller particles form smaller cloud droplets, which tend to decrease precipitation efficiency of a cloud, increasing cloud albedo. Additionally, more cloud condensation nuclei increases the size of a cloud and the amount of reflected solar radiation.

Cloud albedo indirectly affects global climate through solar radiation scattering and absorption in Earth's radiation budget. Variations in cloud albedo cause atmospheric instability that influences the hydrological cycle, weather patterns, and atmospheric circulation. These effects are parameterized by cloud radiative forcing, a measure of short-wave and long-wave radiation in relation to cloud cover. The Earth Radiation Budget Experiment demonstrated that small variations in cloud coverage, structure, altitude, droplet size, and phase have significant effects on the climate. A five percent increase in short-wave reflection from clouds would counteract the greenhouse effect of the past two-hundred years.

Modifying Precipitation Patterns

Microplastics in clouds may not only influence cloud formation but also precipitation patterns. The altered cloud microphysics can affect the coalescence and growth of raindrops, potentially leading to changes in the timing, intensity, and distribution of rainfall. This, in turn, can impact ecosystems, agriculture, and water resources, posing challenges for communities already grappling with the effects of climate change.

Research Challenges and Future Implications

Understanding the intricate relationship between microplastics in clouds and weather is a complex scientific puzzle. Researchers are confronted with the challenge of developing precise measurement techniques to detect and quantify microplastics in the atmosphere and clouds. Additionally, modelling studies are essential to unravel the full extent of the impact on weather patterns and predict future scenarios.

As we navigate this uncharted territory, it is evident that the consequences of microplastics in clouds extend beyond the visible pollution of our oceans and land. The invisible presence of microplastics in the atmosphere poses a new frontier for scientific inquiry, calling for interdisciplinary collaboration to unveil the full extent of this environmental challenge and its far-reaching implications for our planet's weather systems.

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Unravelling Nanoparticle-Based Strategies for Water Treatment

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1. Introduction

Water scarcity and pollution are global concerns that are compounded by rising urbanization, expanding industry, and growing populations. India, as a symbol of this dilemma, is confronted with a glaring disparity between its freshwater supplies and the growing water needs of an increasingly urban populace. This discordance worsens as industrial activity increases, causing increased water contamination from untreated industrial waste and posing major dangers to already depleted water resources.

Nanomaterials have emerged as game changers in the fight against water shortage and pollution. Nanotechnology advancements provide novel approaches to addressing these complex water treatment concerns. The effectiveness of nanomaterials in large-scale water purification operations is demonstrated by nanostructured filters designed to remove pesticides and arsenic from drinking water. These remedies, which are beneficial by significantly lowering pesticide levels, have been implemented. Water scarcity requires multidisciplinary cooperation to be addressed. Environmental engineering, biotechnology, chemistry, materials science, and nanotechnology are just a few of the subjects that nanotechnology unites. To provide comprehensive and long-lasting solutions that take into consideration the complex interdependencies between water, climate, food, and health, these multidisciplinary methods are essential. The collaboration of several fields encourages innovation by promoting the investigation of new materials, treatment techniques, and monitoring technologies, to guarantee that water resources are more accessible and cleaner for everyone.

In this article, we adhere our discussion first with a short historical perspective, and how it has changed over the years. It will then go into great detail on the main theoretical frameworks that have shaped the field's present study from a chemistry perspective. Kindly note that throughout this article, by nanomaterial, we limit our discussion to nanoparticles.

2. Historical Aspects of nanomaterials in water treatment and purification.

Ancient civilizations such as Egypt and Sumeria pioneered water filtration centuries ago, using wood charcoal approximately 3750 BC. This early approach served as the foundation for carbon-based filtering systems that have been used for millennia. The advent of activated carbon in the 1940s was a water filtration technology watershed event, laying the way for following breakthroughs in nanostructures such as carbon nanotubes, carbon nanofibers, and graphene-based materials. These nanoparticles excelled in water treatment processes such as adsorption, catalytic oxidation, membrane separation, disinfection, sensing, and monitoring.

Despite decades of development, nanomaterial-based water treatment systems have faced hurdles that have hampered their general adoption, including concerns with sensitivity, selectivity, increased prices, and operational constraints. Nonetheless, continued research efforts have hastened the development of nanomaterial applications, culminating in the development of low-cost and user-friendly water filtration equipment. The urgent need for water scarcity solutions, particularly with almost 40% of the world's population living near coastlines, emphasized desalination as a vital answer. Despite feeding millions of people worldwide, current desalination processes are energy-intensive and ecologically dangerous, causing researchers to look at nanomaterials to solve these problems.

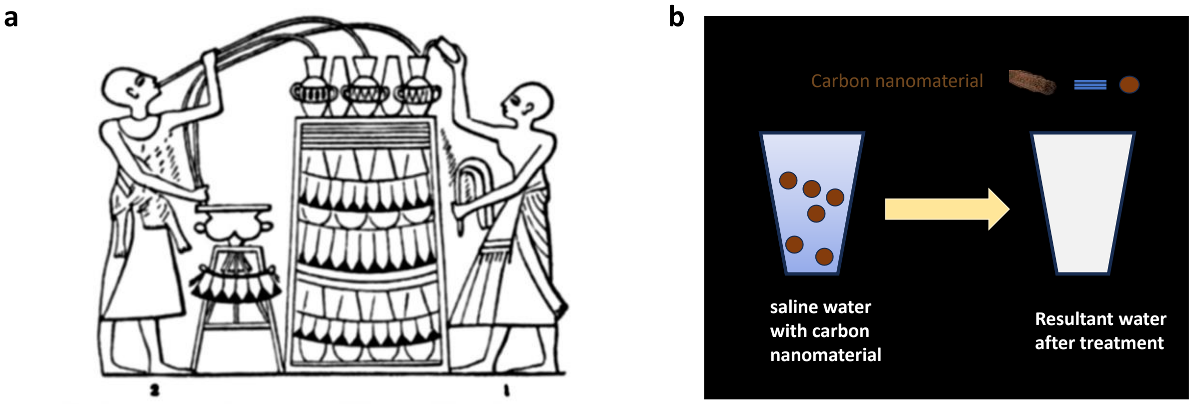

***Figure 1a**: Ancient Egyptians using water purification system. **b**) schematic of saline water purification utilizing carbon nanomaterial.*

Carbon nanomaterials, such as carbon nanofiber-ceramic nanoporous composite membranes, have rejuvenated many desalination processes, delivering considerable improvements in salt rejection and water flow over conventional polymeric membranes. The evolutionary path from ancient charcoal-based filtration to current nanomaterial-enhanced technologies exemplifies humanity's relentless search for breakthrough water treatment solutions, promising an efficient, sustainable, and cost-effective future in water purification.

3. Nanoparticle in wastewater treatment and purification

By using the unique features of nanoparticles, nanochemistry acts as a cornerstone in modernizing water treatment approaches. Several properties of nanochemistry, such as surface area-to-volume ratio, adsorption capacity, catalytic activity, membrane characteristics, and photocatalytic efficiency, are important in tackling water pollution issues. Let's look at these elements in more detail with some instances that demonstrate their practical applications.

3.1 Catalytic properties aiding breakdown, and oxidation of pollutants.

Nanoparticle catalytic qualities entail reaction kinetics, which is characterized by rate equations such as the Langmuir-Hinshelwood model and regulates adsorption and surface reactions during catalysis. Because of their high surface areas and active sites, nanoparticles operate as catalysts in water, speeding oxidation, disinfection, and pollutant breakdown while also allowing electron transport and encouraging certain chemical transformations. Titanium dioxide (TiO_2) nanoparticles, for example, successfully accelerate the breakdown of organic contaminants like methyl orange in water via photocatalysis when triggered by UV light, demonstrating its promise in environmental remediation. Furthermore, silver nanoparticles (AgNPs) have significant catalytic characteristics toward heavy metal pollutants like lead ions (Pb^{2+}), allowing them to be reduced into non-toxic forms and contributing to the removal of dangerous contaminants from water sources. These catalytic techniques exhibit nanoparticle efficiency in tackling various pollutant types and emphasize their involvement in effective water purification methodologies.

3.2 Adsorption properties in removing heavy metals

Because nanoparticles have excellent adsorption characteristics, they can efficiently target heavy metal pollutants in water. Iron oxide nanoparticles (Fe_3O_4 NPs), for example, have a strong affinity for heavy metal ions like lead (Pb) ions in contaminated water sources. The surface functionalization of these nanoparticles boosts their binding sites and surface reactivity, which improves their adsorption efficacy. When lead ions are present in water, Fe_3O4 nanoparticles bind and trap them onto their surfaces via electrostatic interactions or chemical affinity, removing them from the aqueous phase. Similarly, silica nanoparticles functionalized with certain ligands or coatings exhibit considerable cadmium (Cd) ion adsorption in water.

When these modified silica nanoparticles are put in Cd-contaminated water, the tailored surface chemistry adsorbs the heavy metal ions preferentially. Furthermore, carbon-based nanoparticles such as graphene oxide (GO) nanosheets have excellent adsorption characteristics for heavy metal removal from water systems. The two-dimensional structure and large surface area of GO nanosheets enable excellent binding and adsorption of heavy metal ions such as mercury (Hg). GO nanosheets improve their adsorption ability by surface functionalization or modification with certain functional groups, attracting and collecting Hg ions in water effectively. Furthermore, gold nanoparticles (AuNPs) functionalized with different agents, such as thiol-based ligands, show good adsorption capacities for removing chromium (Cr) ions from aqueous solutions. Due to strong ligand-metal interactions, these functionalized AuNPs efficiently adsorb and immobilize Cr ions, providing a viable strategy for addressing chromium contamination in water. Overall, these exemplary instances demonstrate nanoparticles' broad and powerful adsorption capabilities.

3.3 Nanoparticle-incorporated membrane filter systems

Nanoparticle-enhanced membrane filtration is a potential method for improving separation efficiency in water treatment. One example is the incorporation of carbon nanotubes (CNTs) into polymeric membranes to improve their filtering capacities. Because of their high aspect ratio and customizable surface qualities, CNTs strengthen the membrane structure, resulting in greater mechanical strength and decreased pore size. This alteration improves the membrane's permeability and selectivity, allowing for more effective removal of contaminants and smaller particles from water. Another use is the use of graphene oxide (GO) nanosheets in thin-film composite membranes. The incorporation of GO nanosheets onto the membrane surface improves water permeability while retaining selectivity due to the nanosheets' two-dimensional shape and hydrophilic nature. This alteration improves the membrane's pollutant rejection characteristics, allowing for increased water flow and improved separation efficiency in water treatment procedures.

Additionally, silver nanoparticles (AgNPs) embedded into membranes provide another example of improving separation efficiency in water treatment. The inclusion of AgNPs into membranes confers antibacterial characteristics while enhancing filtering performance. Because of their inherent antibacterial action, AgNPs immobilized inside the membrane matrix efficiently inhibit bacterial growth, reducing biofouling and preserving filtering effectiveness over extended operational durations. Another notable use is the use of titanium dioxide nanoparticles (TiO_2 NPs) in ceramic membranes. TiO_2 NPs facilitate self-cleaning processes inside membranes when exposed to UV irradiation due to their photocatalytic characteristics.

This photocatalytic activity accelerates the breakdown of organic fouling agents and improves membrane lifetime and performance by minimizing fouling, guaranteeing sustained separation efficiency in water treatment systems. These examples demonstrate the wide range of applications for nanoparticles.

3.4 Nanoparticle for sensing the ions

Sensing and monitoring contaminants using nanoparticle-based sensors is an innovative technique for environmental monitoring. One example is the use of quantum dots (QDs) in sensor devices to detect heavy metal pollutants such as mercury (Hg) ions in water. Quantum dots, which are semiconductor nanoparticles with unique optical characteristics, allow for the sensitive and selective detection of Hg ions. When functionalized with appropriate receptors, these QDs display fluorescence changes upon contact with Hg ions, enabling precise and quick detection even at trace levels in water samples. Another example is the use of magnetic nanoparticles (MNPs) in sensor systems for organic pollution monitoring. MNPs that have been functionalized with target-specific receptors or antibodies allow for the collection and detection of chemical molecules in water such as polycyclic aromatic hydrocarbons (PAHs). When exposed to PAHs, the magnetic properties of the functionalized MNPs change, allowing for the measurement and real-time monitoring of organic contaminants in water systems.

AuNPs are an exemplary example of nanoparticle-based sensors for detecting different pollutants such as heavy metals and organic chemicals. Functionalized AuNPs with DNA- or aptamer-based probes show excellent selectivity in detecting heavy metal ions in water samples such as lead (Pb) or cadmium (Cd). The binding of the target ions to the modified AuNPs causes changes in their optical or electrical characteristics, enabling accurate and ultrasensitive contamination detection. Furthermore, graphene-based nanomaterials like graphene oxide (GO) or reduced graphene oxide (rGO) provide novel sensing platforms for monitoring volatile organic compounds (VOCs) in water. When exposed to VOCs, GO or rGO-based sensors alter electrical conductivity or optical characteristics, allowing for the quick and sensitive detection of these contaminants.

4. Challenges and Advancements in Nanoparticle-Based Water Treatment

Initially, challenges relating to sensitivity, selectivity, cost, and operational limits hampered nanoparticle-based water treatment. Sensitivity issues occurred as a result of the necessity for higher detection levels for pollutants, particularly at trace quantities, necessitating further advancement of sensor technology. Selectivity issues entailed distinguishing between target pollutants and interfering compounds present in complicated water matrices, necessitating developments in nanoparticle-specific binding capabilities towards intended contaminants. Furthermore, the high initial cost of synthesizing and deploying nanoparticle-based systems has hampered their wider acceptance in water treatment infrastructure. Furthermore, operational limits regarding the scalability and practicability of incorporating nanoparticles into current water treatment processes surfaced, necessitating significant adjustments for smooth integration and successful large-scale application.

Recent research efforts have accelerated breakthroughs in nanoparticle-based water treatment, solving previous hurdles and pushing the development of cost-effective and user-friendly purification equipment. Nanomaterial synthesis procedures and surface functionalization techniques have decreased manufacturing costs dramatically, making nanoparticle-based therapy more economically viable. Furthermore, advancements in nanoparticle design have increased sensitivity and selectivity, allowing for more exact targeting and removal of pollutants while limiting interference from other compounds. Furthermore, researchers have concentrated on developing user-friendly purifying equipment, as well as simplifying operation and maintenance routines, to offer greater accessibility and usage in a variety of situations. These developments demonstrate how nanoparticle-based water treatment has progressed from initial obstacles to achievable solutions, opening the path for more accessible and effective purification methods.

5. Future Prospects of Nanoparticles for water treatment

Nanoparticles have a bright future in the advancement of water treatment technologies, with the possibility for personalized solutions in pollution removal. Their distinct qualities, such as large surface area and multifunctionality, allow for the targeted removal of various contaminants from water sources, integrating into membrane filtration, adsorption processes, and sensor technologies for increased efficiency and cost-effectiveness. These nanoparticles also promise environmentally beneficial solutions, to reduce energy consumption, trash creation, and environmental effects in water treatment procedures. The current study focuses on enhancing nanoparticle functions to enable universal access to safe drinking water in the long term. Using nanoparticles' revolutionary powers promises a fundamental move toward more sustainable, efficient, and adaptive water treatment technologies to tackle the world's mounting water concerns.

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Photocatalysis Method for Air purification

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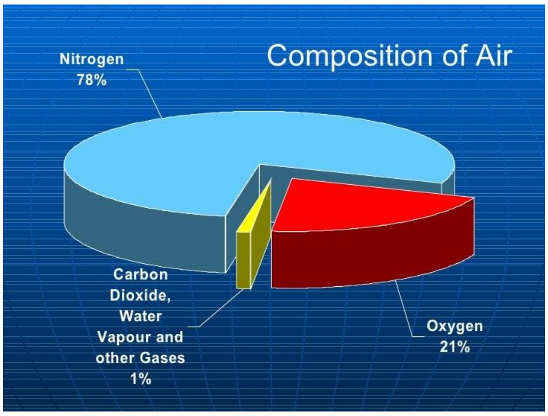
Air, mixture of gases comprising the Earth's atmosphere. The mixture contains a group of gases of nearly constant concentrations and a group with concentrations that are variable in both space and time. The atmospheric gases of steady concentration (and their proportions in percentage by volume) are as follows:



The uniformity of composition is maintained by mixing associated with atmospheric motions; but, above a height of about 90 km (55 miles), diffusional processes become more important than mixing, and the lighter gases (hydrogen and helium, in particular) are more abundant above that level.

water vapour (H_2O)	0 to 7
carbon dioxide (CO_2)	0.01 to 0.1 (average about 0.032)
ozone (O_3)	0 to 0.01
sulfur dioxide (SO_2)	0 to 0.0001
nitrogen dioxide (NO_2)	0 to 0.000002

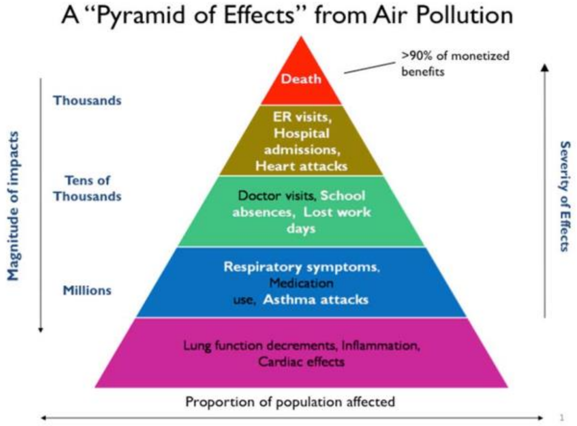
Although present in relatively small amounts, these variable constituents may be very important for maintaining life on Earth's surface. Water vapour is the source for all forms of precipitation and is an important absorber and emitter of infrared radiation. Carbon dioxide, besides being involved in the process of photosynthesis, is also an important absorber and emitter of infrared radiation. Ozone, which is present mainly in the atmospheric region 10 to 50 km (6 to 30 miles) above the Earth's surface, is an effective absorber of ultraviolet radiation from the Sun and effectively shields the Earth from all radiation of wavelengths less than 3,000 angstroms.

Air Pollution

Air pollution is a mixture of hazardous substances from both human-made and natural sources. Vehicle emissions, fuel oils and natural gas to heat homes, by-products of manufacturing and power generation, particularly coal-fueled power plants, and fumes from chemical production are the primary sources of human-made air pollution. Nature releases hazardous substances into the air, such as smoke from wildfires, which are often caused by people; ash and gases from volcanic eruptions; and gases, like methane, which are emitted from decomposing organic matter in soils.

Consequence of air pollution

Air pollution has a disastrous effect on children. Worldwide, up to 14% of children aged 5 – 18 years have asthma relating to factors including air pollution. Every year, 543 000 children* younger than 5 years die of respiratory disease linked to air pollution. Air pollution is also linked to childhood cancers. Pregnant women are exposed to air pollution, it can affect fetal brain growth. Air pollution is also linked to cognitive impairment in human beings.



Photocatalysis for air purification

It is a fascinating technology that uses light energy to activate catalysts, typically titanium dioxide (TiO2), to break down pollutants in the air into harmless substances. Here's how it works:

Photocatalyst: Titanium dioxide is applied as a thin coating onto a surface, such as filters, walls, or building materials.

Activation by Light: When exposed to ultraviolet (UV) light, TiO2 generates electron-hole pairs, creating highly reactive free radicals.

Pollutant Breakdown: These free radicals then oxidize and decompose organic compounds, such as volatile organic compounds (VOCs), bacteria, viruses, and other airborne pollutants.

Harmless Byproducts: The pollutants are broken down into simpler, less harmful substances like carbon dioxide and water.

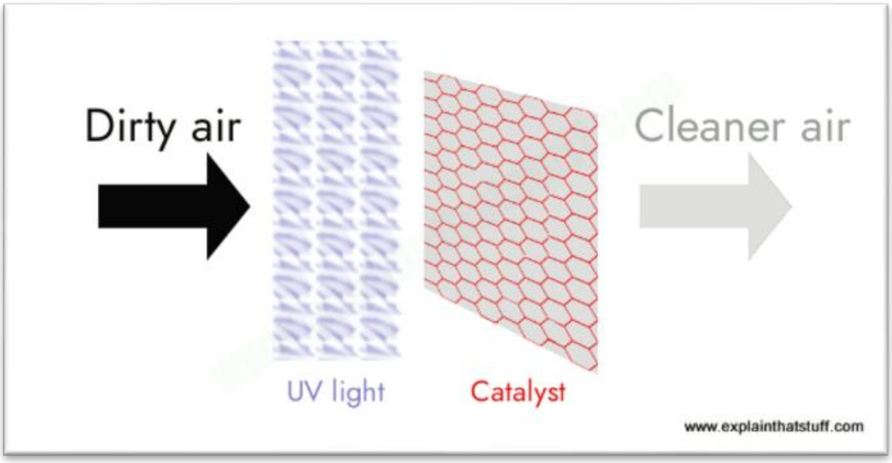
Photocatalysis is known for its ability to continuously break down pollutants and pathogens without being consumed itself, making it a promising solution for indoor air quality improvement. However, there are some considerations:

Light Source: It requires UV light for activation, which can be provided by sunlight or artificial UV lamps.

Effectiveness: The effectiveness can vary based on factors like the intensity of UV light, surface area coated with the catalyst, and the types of pollutants present.

Maintenance: Over time, the catalyst might degrade or get contaminated, affecting its efficiency. Regular cleaning or replacement might be necessary.

This technology has been applied in various settings, from indoor air purification systems in buildings to self-cleaning surfaces in hospitals, reducing the presence of harmful microbes and pollutants in the environment. It's an area of ongoing research and development aimed at improving efficiency and practical applications.



Light is an amazing source of energy—the power behind virtually everything that happens on Earth. Light from the Sun brightens the dark depths of space, makes plants leap to life, and (indirectly) powers our bodies. In air purifiers that work using a method called photocatalysis, light energy kick-starts a process that zaps all kinds of nasty air pollutants and turns them into harmless substances instead. For people who suffer from asthma and allergies, light-powered air purifiers like these are another weapon in the fight for cleaner air and better health. The activation of photocatalysts and corresponding reactions on the photocatalyst surface can be described by the following 5 steps.

1. Adsorption of photons with an energy that matches or is greater than its band gap energy of the semiconductor.
2. Promotion of an electron from the VB to the CB, with concomitant generation of a hole in the valance band
3. Electron and hole diffusion and migration to the surface where they can react .Recombination of electron–hole pairs.
4. Stabilization of electro and hole at the surface to form a trapped electron and a trapped hole, respectively.
5. Reduction of a suitable electron accepter and oxidation of a suitable electron donor.

The photocatalytic purifier includes filter structures coated with a catalytic material. One or more UV lamps are interposed between the filter structures. The catalytic layer reacts with airborne VOCs and bioaerosols when activated by the UV lamps to thereby oxidize the VOCs and destroy the bioaerosols. The photocatalytic air purifier does not need to be replaced or regenerated after a period of continuous usage. The photocatalytic purifier of the present invention substantially eliminates odors, VOCs, and bioaerosols from air directed through the fan coil. The photocatalytic air purifier includes a control system that optimizes operating costs. Because of these features, service, maintenance, and filter replacement are reduced to a minimum. At the same time, the wellbeing of persons living in the space conditioned by the photocatalytic air purifier is improved.

Despite many advantages, photocatalytic air purification has serious limitations, such as a slow rate of treatment. The combination of photocatalysis with other technologies, such as adsorption-photocatalysis, photothermal catalysis, and plasma photocatalysis, has been proposed as a promising method to provide synergistic advantages. Hybridization of an adsorbent and a photocatalyst should increase the treatment capacity by rapidly capturing incoming target compounds on the catalyst/adsorbent surface, especially when the photocatalytic degradation capacity cannot match the rapid influx of target compounds onto the surface in real time. The adsorbed target molecules can be gradually degraded on the photocatalytic active sites by regenerating the adsorbent surface. Photothermal catalysis combines the high efficiency and durability of thermocatalytic oxidation with the low energy consumption of photocatalytic oxidation. Plasma promotes the degradation of air pollutants, and photocatalysis reduces the formation of undesired by-products (e.g., NO_x and O_3) that are often produced in plasma-driven catalysis.

Air purification would be considered one of the most promising technologies to prolong storage life, increase food safety, and protect the environment from pollutants .As in both developed and developing countries, outdoor and indoor air pollution is a primary health issue that needs to be purified by air purification techniques. There is a need for air purification and understanding the concept of controlling common indoor pollution, reducing indoor air health problems.

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Toxic Trespass: The Stealthy Invasion of PFAS in Our Environment

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1. Introduction

In recent years, per- and polyfluorinated alkyl compounds (PFAS) have drawn more attention from the scientific community and the political arena. Numerous items and technical processes employ thousands of commercially manufactured chemicals. People and all other living forms are thus exposed to these compounds on a constant basis because of their remarkable endurance in the environment.

Polyfluoroalkyl substances (PFAS) are a group of human-made chemicals used in various industrial and consumer products for their water- and grease-resistant properties. PFAS include perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), among others. These are a large class of thousands of synthetic chemicals that are used throughout society . Structurally they cotain a chain of carbon atoms bonded to fluorine atoms. Some also have a functional group at the end of the chain. These structures are the basis for different chemical properties and different chemical names.

In perfluoroalkyl substances all carbons except the last one is attached to fluorines. two subtypes, completely fluorinated aliphatic molecules (perfluoroalkyl substances) are those in which all hydrogen atoms linked to the carbon backbone are replaced with fluorine and the second subtype, are partially fluorinated compounds in which all hydrogen atoms connected to at least one carbon (but not all) in the aliphatic backbone have been replaced by fluorine. These compounds accumulate in animals and biomagnify in food webs, posing a threat to aquatic wildlife, insects, and amphibians at concentrations of a few µg/L or less. As the last in many food chains, humans are mainly exposed to PFAS absorption through food and drinking water.

2. Major Sources of PFAS contamination

Per-and polyfluoroalkyl substances (PFAS) can be found in various sources, including industrial discharges, firefighting foam, water-resistant fabrics, and certain consumer products. They may also enter the environment through air and water pollution. It's crucial to monitor and regulate these sources to mitigate potential health and environmental risks.

- **Industrial Discharges**: PFAs are released into the environment through industrial processes, particularly those associated with the production of certain chemicals and consumer products.
- **Firefighting Foam**: PFAs are commonly present in firefighting foams, especially those used at airports and military sites. This can lead to contamination of soil and water in surrounding areas.
- **Non-Stick Cookware**:PFAs are used in the production of non-stick cookware. Overheating or scratching such cookware can release PFAs into food.
- **Waterproofing Agents:** PFAs are used in the manufacturing of waterproofing agents for fabrics, leading to their presence in some outdoor gear, clothing, and even in carpets.
- **Food Packaging**: PFAs can be present in food packaging materials, such as microwave popcorn bags and fast-food wrappers.
- **Landfills:** Disposal of products containing PFAs in landfills can result in the leaching of these substances into the surrounding soil and water.
- **Wastewater Treatment Plants**: PFAs may enter water systems through the discharge of treated wastewater from industrial facilities and households.
- **Atmospheric Deposition:** PFAS can be transported over long distances through the air. They may be released into the atmosphere during manufacturing or product use, eventually settling onto soil and water surfaces through precipitation or atmospheric deposition.
- **Biosolids:** The use of biosolids (treated sewage sludge) as fertilizer on agricultural fields can introduce PFAS into the soil, leading to potential uptake by crops.

The combination of these sources results in the ubiquitous presence of PFAS in air, water, soil, and various ecosystems. Efforts to mitigate environmental exposure involve regulatory measures, responsible waste management practices, and research aimed at developing alternative, less persistent substances

3. Environmental Impacts of PFAS

They are increasingly detected as environmental pollutants and some are linked to negative effects on human health. Several PFAS have numerous harmful effects, with the liver, kidney, thyroid, and immune system being the main targets.These substances have raised environmental concerns due to their persistence, bioaccumulation, and potential adverse effects

- **Persistence:** PFAS known as forever chemicals are highly persistent in the environment, resisting degradation over time. This characteristic leads to their accumulation in soil, water, and living organisms.
- **Bioaccumulation:** PFAS can bioaccumulate in the tissues of organisms, posing risks to the food chain. This bioaccumulation has been observed in fish and other aquatic organisms, potentially affecting humans who consume contaminated seafood.
- **Health Concerns:** Some PFAS are associated with adverse health effects, including developmental and reproductive problems, liver and immune system damage, and an increased risk of certain cancers. Studies have shown that exposure to PFAS can occur through contaminated drinking water, food, and air.
- **Contamination of Drinking Water:** PFAS contamination of drinking water supplies has been a significant issue. Runoff from industrial facilities, firefighting foam, and disposal of PFAS-containing products contribute to water contamination.
- **Regulatory Response:** Many countries have implemented regulations to monitor and limit PFAS use and contamination. Efforts include restricting or phasing out certain PFAS, setting guidelines for acceptable levels in drinking water, and promoting the cleanup of contaminated sites.

The environmental impact of PFAS (polyfluoroalkyl substances) is a growing concern. These chemicals are persistent in the environment, meaning they do not easily break down over time.

Controlling and mitigating the environmental impact of PFAS (polyfluoroalkyl substances) involves a combination of regulatory measures, responsible industrial practices, and remediation efforts. Key control measures include:

4. Regulatory Actions:

Governments around the world are implementing regulations to monitor, restrict, and manage PFAS use. These measures include setting limits on PFAS concentrations in drinking water, regulating industrial discharges, and, in some cases, banning or phasing out specific PFAS compounds.

- **Monitoring and Testing:** Regular monitoring of air, water, soil, and biota helps identify PFAS contamination hotspots. Rigorous testing allows for the assessment of exposure levels and guides the development of appropriate control strategies.

- **Safe Disposal:** Proper disposal of PFAS-containing products, industrial waste, and firefighting foams is crucial. Incineration at high temperatures or specialized treatment methods can reduce the release of PFAS into the environment.
- **Alternative Products and Processes:** Research and development of alternative products and manufacturing processes that do not rely on PFAS help to minimize their use and environmental impact. Identifying safer alternatives is an ongoing focus in industry and research.
- **Wastewater Treatment:** Upgrading and optimizing wastewater treatment plants can help remove or reduce PFAS from effluents before they are discharged into water bodies. Advanced treatment technologies, such as activated carbon filtration, are being explored for their effectiveness in PFAS removal.
- **Containment and Remediation:** Strategies for containing and remediating PFAS-contaminated sites are under development. This includes methods such as soil washing, groundwater extraction, and the use of absorbent materials to reduce PFAS levels in affected areas.
- **Phasing Out Non-Essential Uses:** Some regions are phasing out the non-essential use of certain PFAS, especially those with known environmental and health concerns. This includes restricting the use of PFAS in certain consumer products.
- **International Collaboration:** Given the global nature of PFAS contamination, international collaboration is essential. Sharing information, best practices, and research findings helps create a more comprehensive and coordinated approach to addressing PFAS-related challenges.
- **Educational Initiatives:** Raising awareness and educating industries, communities, and the public about the risks associated with PFAS encourages responsible use and disposal practices.

5. Conclusions

The production and use of PFOA and PFOS are now restricted or banned globally. They are increasingly being replaced by other per- and poly fluoroalkyl substances having similar properties. Effective control measures require a multi-faceted approach that combines regulatory, technological, and behavioural strategies to reduce the environmental impact of PFAS. Ongoing research and collaboration are crucial for refining these measures and developing innovative solutions. The replacement of PFAS involves finding alternative materials that offer similar functionality but with reduced environmental and health concerns. Some potential replacements include bio-based or fluorine-free alternatives, but it's crucial to thoroughly assess the environmental and health impact of these substitutes to ensure a sustainable solution. Ongoing research and collaboration across industries aim to identify safer alternatives to PFAS.

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Development of Sustainable Inhibitors for Corrosion Control

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Corrosion is a natural process which converts a refined metal into a more chemically stable oxide. It is the gradual deterioration of metals by chemical or electrochemical reaction with their environment[1, 2]. This reaction causes damage and disintegration of the metal starting from the portion of the metal exposed to the environment and spreading to the entire bulk of the metal. Corrosion is usually an undesirable phenomenon since it negatively affects the desirable properties of the metal[3, 4]

Corrosion is a spontaneous process playing a vital role in the economics and safety of alloys and metals. Changing the environment by adding corrosion inhibitors is considered as an efficient corrosion management method [5-8]. A corrosion inhibitor is a chemical substance which when added in a small concentration to the corrosive environment results in a significant reduction in the corrosion rate either by reducing the rate of attack or by reducing the probability of its occurrence or by both[9]. An efficient inhibitor should be economical, environment friendly, and inhibit the corrosion process when present in a small concentration. Corrosion prevention using inhibitors has some noticeable advantages such as low cost, simple control and operation, and non-requirement of special instruments[10]. Corrosion inhibition is achieved in two ways. In some cases, the inhibitor interacts with the metal surface and forms an inhibitive surface film at the metal/electrolyte interface. In other cases, the inhibitor can alter the corrosive environment into a less corrosive or noncorrosive environment, e.g. by chemically neutralizing dissolved acidic gases, chemically scavenging dissolved oxygen, etc

The addition of inhibitors containing lone pair and bond pair of electrons prevents the corrosion process by the synergistic interaction between the metal atom and the inhibitor molecule[11, 12]. Many organic and inorganic inhibitors are environmentally harmful and toxic. So, in the context of environmental pollution, the inhibitor should be environment friendly rather than application efficiency.

Green inhibitors for corrosion prevention

The search for green corrosion inhibitors was triggered by the environmental toxicity of organic corrosion inhibitors; these inhibitors are biodegradable and do not include heavy metals or other harmful substances[13]. Green inhibitors refer to the use of eco-friendly or sustainable corrosion inhibitors. These inhibitors are derived from natural sources or are biodegradable and are less toxic to the environment and human health compared to traditional inhibitors [34]. Green inhibitors have gained attention in recent years as there is a growing concern about the environmental impact of chemical inhibitors.

Examples of green inhibitors include plant extracts, Ionic liquids, surfactants, essential oils, chitosan, starch, cellulose, and other biopolymers. These inhibitors have been found to have good inhibitive properties and can be used as an alternative to traditional inhibitors. However, their effectiveness can be affected by factors such as the type of metal, environmental conditions, and inhibitor concentration.

Most of the green inhibitors adsorb on the metal surface by means of physical as well as chemical interactions. They contain heteroatom in their molecules. The free electrons on the heteroatom bond with the metal surface[14]. Some atoms in water ionize to release a proton; thus, the now negatively charged heteroatom helps to free an electron on the heteroatom and forms a stronger bond with the metallic electrons. These properties confer them good inhibition properties.

Research is ongoing to develop and optimize the use of green inhibitors as corrosion inhibitors in various applications, including in the oil and gas industry, marine industry, and construction industry.

It is abundantly clear from various methods like weight loss, electrochemical impedance, and potentio dynamic polarisation approaches that green inhibitors are highly effective at inhibiting steel corrosion.[15]

Plant extracts as green inhibitor

An extract is a solution composed by the active principles of a plant or its parts and a certain medium acting as solvent. The extraction yields depend on the polarity of the solvent used, in the techniques or methods (Soxhlet and maceration), among others. Most commonly, these extracts are recognised for their anti-inflammatory, antiviral, antioxidant, or antibacterial properties. Their corrosion inhibitory qualities can also be thought of as having synergic effects. Most often, extracts are made from the entire plant or the sections with the highest concentrations of active ingredients, or phytochemicals[16]. Plant products are cheap, accessible, and renewable in addition to being environmentally friendly and ecologically acceptable. Studies into the anti-corrosion properties of tannins, alkaloids, organic amino acids, and organic dyes derived from plants are interesting[17-19].

Many plant extracts could prevent the corrosion process as it contains complex mixtures of phytochemicals in their composition[20, 21]. However, researchers working in the corrosion area are dedicated to recognizing the active inhibitors in the plant extract by extraction and isolation of active inhibitors[22]. The current corrosion inhibition study of plant extracts is therefore focused on the isolation of the active compounds accountable for the corrosion inhibition performance of plant extracts.

Ionic liquids as corrosion inhibitors

Ionic liquids possess several captivating characteristics that render them excellent candidates for replacing traditional corrosion inhibitors, which often pose adverse effects on the environment and living organisms[23]. They stand out as the most promising and favorable category of environmentally friendly steel corrosion inhibitors when compared to alternatives. This is attributed to their numerous advantages, including a straightforward and cost-effective preparation process, an appealing array of physical-chemical properties, and their high thermal, chemical, and electrochemical stability. Furthermore, their green and sustainable nature adds to their appeal. Additionally, the tunable properties of ionic liquids contribute to the development of tailored solutions for specific tasks and materials. For instance, the anti-corrosion properties of ionic liquids can be designed at the molecular level to safeguard materials with specific compositions, thereby enhancing inhibition efficiency [24]].

Surfactants as corrosion inhibitors

The potential application of surfactants as corrosion inhibitors has garnered extensive attention in recent years. It is widely acknowledged that surfactants exhibit a propensity to associate with each other at interfaces and in solutions, forming aggregates [25]. The process of adsorption plays a crucial role in corrosion inhibition, with the primary function of the surfactant functional group being to adsorb onto the metal surface. The observed adsorption of surfactant molecules onto the metal surface has been identified as the key factor responsible for the corrosion inhibition of the metal[26]. This phenomenon is generally directly linked to the surfactant's ability to aggregate and form micelles. Consequently, gaining a deeper understanding of the relationship between the adsorption of surfactant molecules onto the metal surface and corrosion inhibition holds great significance for both theoretical and experimental purposes.

Addition of surfactants to acidic media is an efficient and quite cheap method for rust protection of metal surfaces. In past 20 years, research has focused on the scheming electrochemical reactions with surfactants as well as aggregate description through electrochemical methods. Surfactants were introducing in this research field to give a novel and useful dimension to these investigations. Very few investigations were found on the role of surfactants in surface modification of electrodes. Very recently, researchers were engaged in field of surfactants adsorbed from micellar solutions have paid attention on elucidating or utilizing, aggregate structures formed on the electrode. Surfactant molecules usually adsorb at the interface between two bulk phases such as air and water, oil and water or electrode and solution [27].

Amino acids as corrosion inhibitors

Amino acids offer a cost-effective and readily available alternative to conventionally used organic corrosion inhibitors. Their direct application as inhibitors streamlines the process, reducing the time and labor typically associated with preparing organic compound-based corrosion inhibitors[28]. Despite their abundance and biodegradability, the straightforward chemical structures of amino acids may limit their effectiveness as corrosion inhibitors for industrial purposes. To enhance inhibition efficiencies, a viable approach involves utilizing amino acid derivatives. These derivatives can feature varying carbon chain lengths, attached heteroatoms, heterocycles, phenyl rings, polar functional groups, and more, providing a method to optimize their potency for effective corrosion inhibition[29, 30].

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Hybrid Foams Featuring Ultra-High Zeolite Content for Selective Carbon Dioxide Capture: Bio-Based Micro/Meso/Macroporous Materials

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Abstract

Zeolite molecular sieves exhibit higher accessibility and remarkably high selectivity and diffusability resulting from their narrow pore aperture distribution. The current approach toward enhancing the CO_2 adsorption capacity of zeolites is considered. The study presents a novel approach to overcome the limitations of conventional zeolite powders in gas filtration industrial systems. Preparing hybrid foams using mesoporous/macroporous gelatin/nanocellulose can support ultrahigh loadings of silicalite-1, offering an environmentally friendly, low-cost, and highly low-density alternative for sorbent nanomaterials.

Introduction

Anthropogenic emissions have forced the scientific community to develop efficient carbon dioxide (CO_2) capture technologies. CO_2 gas, mainly a byproduct of fossil fuel combustion, accounts for most of greenhouse gas emissions to the atmosphere. These CO_2 emissions contribute to global warming by the greenhouse effect. It is essential to separate CO_2 from fuel or exhaust gas from combustion plants to reduce greenhouse emissions. The widely utilized industrial technology for CO_2 capture is absorption-based, wherein amines are used. However, this process has many disadvantages, such as the high -energy requirement for amine solution regeneration and the fact that amines are highly corrosive. On the other hand, adsorption has much compensation, i.e., low- energy requirements, low cost, and more applicable operating conditions. The choice of adsorbents represents a critical factor in effective CO_2 capture.

Zeolites are natural and synthetic aluminosilicates characterized by microporous crystalline structures commonly used as commercial adsorbents and catalysts. The zeolite framework is built on two structural units of aluminium or silicon atoms bonded to four oxygen atoms, producing tetrahedral shapes. An oxygen atom is attached to the two tetrahedral atoms. These tetrahedra are connected and forming rings comprised of 4 to12 tetrahedra. These combinations of rings form more complex composite building units like molecular cages; the periodic arrangements of these building units form the framework with cavities consisting of channels, pockets, and cages linked by rings that act as windows between the cavities. These cavities are connected by channels that generate the microporous structure, which adequately small molecules can penetrate. Thus, zeolite displays the significant molecular sieving phenomena essential for separation technologies.

There are nearly 50 different types of zeolites (clinoptilolite, chabazite, phillipsite, mordenite, etc.) with varying physical and chemical properties. In 1948, Richard Barrer first synthesized a zeolite that did not have natural counterparts. There are numerous naturally occurring synthetic zeolites, each with a unique structure. The pore size of commercially available zeolites ranges from approximately 3 A° to 8 A°. Some commercially available zeolites are zeolite A, Beta, zeolite Y, and ZSM-5.

The dimensionality of zeolite includes one-dimensional, two-dimensional, and three-dimensional pore structures, depending on the channel arrangements. Moreover, Zeolites also have been classified as low silica (Si/Al atomic ratio ~1), intermediate silica ($1.5<$Si/Al atomic ratio<10), or high silica (Si/Al ratio>10). Low silica zeolites are hydrophilic due to the low content of protons and highly negatively charged frameworks. In contrast, high silica zeolites are hydrophobic because of predominant covalent Si-O-Si bridges.

Due to their high surface area, hydrothermal stability, and structure-selective characteristics, zeolites and other molecular sieves are used for many purposes, including adsorption, membranes, ion exchange, and catalysis. Their applications mainly depend on the framework compositions, such as the Si/Al ratio, associated hydrophilicity/hydrophobicity, and crystalline morphologies. The preparation procedure plays a vital role in the tailoring and fabricating of zeolites for specific use. Different preparative zeolite methods are hydrothermal, sol–gel, precipitation, flame hydrolysis, and impregnation. Controlling the particle size and morphology is incredibly significant in preparing zeolite nanocrystals. Aluminosilicate zeolites are usually synthesized from reactive gels in alkaline media under hydrothermal conditions. The primary approach of synthesizing zeolites, compositions of preparative mixture, preparation method, structural directing agents (SDA), preparation time, temperature, and pH predominately control the zeolite morphology. The synthetic techniques involve a template molecule, such as tetra-propyl ammonium hydroxide (TPAOH) for silicalite and ZSM-5 and tetramethyl ammonium hydroxide (TMAOH) for zeolite Y. The template molecule acts as an organic structure-directing agent (SDA) and can be removed post-synthesis by high-temperature calcination in air or oxygen. The crystallization conditions are carefully controlled, so nucleation occurs more readily than crystal growth. The current approach directed towards enhancing the CO_2 adsorption capacity of zeolites is considered.

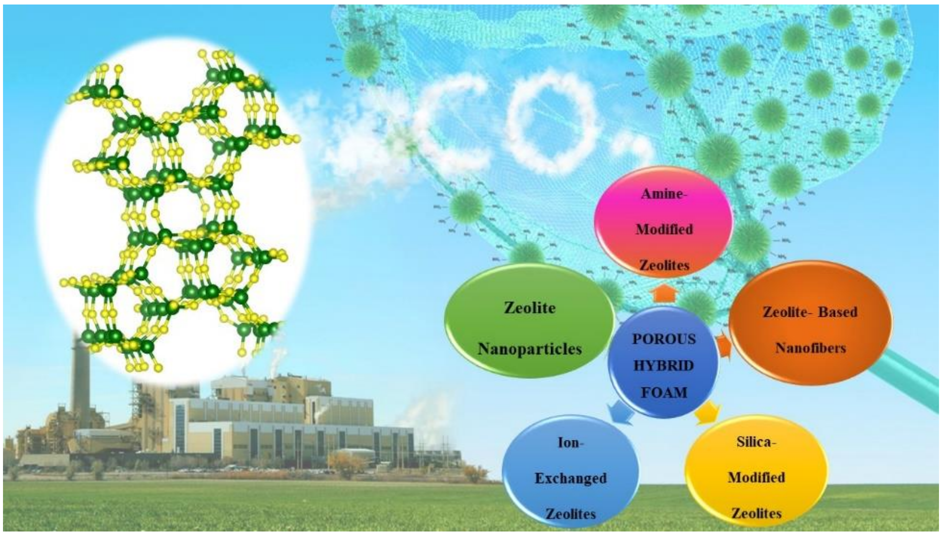

Figure 1. Primary materials used for the preparation of porous Hybrid foam.

History of zeolites

The history of zeolites began in 1756 when the Swedish mineralogist Cronsted discovered the first zeolite mineral, stilbite. He recognized zeolites as a new class of minerals consisting of hydrated alkali and alkaline earth aluminosilicates. Reviews by Morey and co-workers cover developments in hydrothermal chemistry from 1845 to 1937, while the general evolution of the hydrothermal preparative method from the nineteenth century to the mid-1980s is described by Rabenau. The first claim to have made a named zeolite (levynite) in the laboratory was that of St. Claire Deville in 1862.

Richard M. Barrer began his pioneering work in zeolite adsorption and synthesis from mid-1930 to 1940. He reported the first definitive synthesis of zeolites, including the synthetic analog of the zeolite mineral mordenite and the novel synthetic zeolite, much later identified as the MFI framework. Barrer's work inspired Robert M. Milton of the Linde division of Union Carbide Corporation to initiate studies in zeolite synthesis to research new air separation and purification approaches.

Zeolite for CO_2 Capture

Zeolites are crystalline aluminosilicates implemented universally as highly efficient catalysts and sorbents. These are commonly used as molecular sieves in CO_2 adsorption due to their tailor-able cavities and pore size. The mechanism of the CO_2 adsorption process on zeolites has confirmed the physical adsorption of CO_2 molecules induced by firmly bound carbonate molecules by pi- pi-coordination or ion-dipole interactions. Because of the strong interaction between the zeolitic cation and the more potent quadruple moment of N_2 compared with O_2, zeolites are applied in air separation applications. Compared with other adsorbents, zeolites display characteristic performance, especially in the low–pressure regime, along with superior CO_2 / N_2 Selectivity. The adsorption characteristics of zeolites and the pore size can be tuned by varying the outer surface and modifying their crystal structure. The several strategies utilized to functionalize zeolites chemically will be addressed in the following section.

Chemical modification of zeolites

Gas separation technologies that need a resolution in molecular size difference of 0.1 A° represent the main challenge in emerging renewable energy technologies. This concept includes CO_2 capture from flue gases and methane (CH_4) upgrading from biogas by separating hydrogen sulfide (H_2S) and CO_2. CO_2 and biogas upgrading can be accomplished effectively through temperature swing adsorption (TSA) or pressure swing adsorption (PSA) processes. Lately, great attention has been given to designing novel adsorbents with high adsorption capacity and selectivity for CO_2 /N_2 and CO_2 /CH_4 separations. At the heart of this concept, amine-grafted zeolites, mesoporous silica, amine-grafted silica, cation-exchanged zeolites activated carbon, and metal-organic frameworks were employed.

- **Amine- Modified Zeolites**

Amongst different zeolites, zeolite 13X has been studied most because of its high CO_2 adsorption capacity. Zeolites are recognized to be less effective at high temperatures and more effective at ambient temperatures. Amine-impregnated adsorbents have attracted the researcher's interest because of the simple chemistry between the acidic CO_2 molecules and essential amine molecules incorporated onto the adsorbent external surface. The electron density and basicity of the nitrogen atom play a critical role in selecting an amine appropriate for CO_2 capture. Therefore, 1° and 2° amines interact with CO_2 to produce ammonium carbamate. Diffusion hindrance of impregnated amine molecules into the zeolite pores and pore blockage restricts achieving high CO_2 adsorption capacity. This behavior is more critical for zeolites containing tiny pores (i.e., zeolite 4A). Hence, large pores containing zeolites such as NaY, 13X, and β are commonly applied in preparing amine-modified zeolites. Various amines have been used in the preparation of amine-impregnated zeolites, including tetraethylenepentamine (TEPA), polyethyleneimine (PEI), and monoethanolamine (MEA). The CO_2 adsorption capacity in the temperature range of 30–120 °C was measured for MEA-impregnated zeolite 13X, showing CO_2 capture efficiency was enhanced by a factor of 1.6 at 30 °C and 3.5 at 120 °C. Recently, PEI of high molecular weight was impregnated on zeolite

13X by Karka et al. It was observed that the highest adsorption capacity was achieved at 75 °C with 60 wt% PEI content, but the effect of PEI molecular weight and type (branched or linear) on the CO_2 capture efficiency. They reported that increasing PEI molecular weight reduced the CO_2 adsorption capacity, and linear PEI exhibited lower adsorption capacity than the branched one because of the restricted mobility of chains.

- **Silica- Modified Zeolites**

The surface modification of zeolite alters the pore entrance size without influencing the internal morphology. In this context, an ultrathin alumina porous film was deposited on the surface of zeolite 5A particles using the molecular layer deposition (MLD) process. Moreover, the chemical vapor deposition (CVD) technique was applied to deposit a silica layer on mordenite to reduce the pore entrance sizes at 0.1 nm. Dehumidification is essential before CO_2 adsorption, dramatically increasing the total energy consumption, the difficulty of operation, and the investment cost. For instance, Liu et al. used sol-gel coating and PEI impregnation procedures to design core-shell zeolite 5A@mesoporous silica-supported amine (5A@MSA) hybrid adsorbents for advanced CO_2 adsorption from flue gas in the presence of water. The amino groups in the shell can react with CO_2 and H_2O molecules forming carbamate molecules, which will then be converted to bicarbonates or carbonates, efficiently retarding water diffusion and allowing CO_2 molecules to reach the zeolite core easily.

- **Ion- Exchanged Zeolites**

Encompassing silicon and aluminum oxides, zeolites are recognized as microporous crystals exhibiting adsorptive and ion-exchange characteristics that tailor the interactions between adsorbents and adsorbates. The impregnation of electropositive cations can improve the adsorption of acidic gases, and the introduction of alkali metal ions causes a remarkable improvement in the CO_2 adsorption performance. Ammonium ion is often used due to its fundamental nature and affinity toward CO_2 molecules. Diaz et al. modified parent NaX zeolites using Na and Cs aqueous carbonate and hydroxide solutions as precursors.

- **Zeolite Nanoparticles**

Designing promising solid adsorbents with high CO_2 selectivity, high adsorption efficiency, and high thermal and mechanical stability are the foremost challenges in developing CO_2 separation by adsorption processes. Decreasing the particle size reduces the diffusion pathways of adsorbate molecules and, consequently, improves the adsorption capacity. Many concepts have been designed to prepare zeolite nanocrystals with and without using morphology-directing materials. Zeolite NaA nanocrystals with high CO_2 adsorption capacity were synthesized by template-free hydrothermal preparation in thermo-reversible methylcellulose gels. The thermo-gelation of methylcellulose in the alkaline Na_2O-SiO_2-Al_2O_3-H_2O system was vital in determining the particle size.

- **Zeolite- Based Nanofibers**

Nanofibers with desired characteristics such as high surface area, porosity, and diameters ranging from tens of nanometers to a few micrometers can be designed using electro-spinning. For instance, they enhanced the gas separation performance of acrylonitrile butadiene styrene fibers by incorporating ten wt% of natural zeolite. Few researchers discussed structuring zeolite nanofibers with a polymeric carrier and modifying the morphology by post-processing separations.

Conclusions

The processability of conventional zeolite powders is poor, limiting their implementation in many applications, such as gas filtration industrial systems. Moreover, employing adhesives and inorganic binders to prepare zeolite-based materials typically leads to pore blockage and reduced gas adsorption capacity. In this work, this issue can be overcome through the preparation of hybrid foams using mesoporous/macroporous supporting materials based on the solid network properties of gelatin/ nanocellulose, which can support ultrahigh loadings of silicalite-1, used as a model sorbent nanomaterial. Bio-based foams represent an attractive alternative as supporting materials of sorbent nanomaterial from an environmental point of view, not only because of their biodegradability but also because of their low cost and extremely low densities.

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Electric Vehicles: Driving Towards Environmental Sustainability

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1.Introduction

The automotive industry stands at the cusp of a transformative shift with the widespread adoption of electric vehicles (EVs). In this chapter, we explore the environmental implications of EVs and how they contribute to the broader goals of sustainability and climate action.

1.1 Evolution of Electric Mobility

Following a brief appearance and subsequent decline in the late 19th and early 20th century, the enthusiasm for battery electric vehicles (BEVs) experienced a resurgence in the 1960s and 1970s in the United States. This renewed interest was largely driven by growing concerns about air pollution and escalating oil prices. The implementation of the Clean Air Act in 1965 prompted various research institutes and companies to explore electric cars. However, during this period, the outcomes fell short in terms of both technological performance and cost-effectiveness compared to their gasoline counterparts.

After a period of relatively low activity, public interest in BEVs experienced a revival in the latter half of the 1980s and the early 1990s. This resurgence reignited hopes among environmentalists that BEVs might finally gain traction in the mass market.

1.2 Environmental Rationale

The transportation sector is integral to modern society, playing a crucial role in global economic development. As societies progress and living standards improve, the challenges associated with transportation, such as excessive oil consumption, air pollution, and greenhouse gas emissions, are anticipated to intensify. To address these issues, there is a growing emphasis on the advancement of fuel-efficient and alternative-fuel vehicles, with a particular focus on battery electric vehicles (BEVs). This has emerged as a primary objective in the automotive industry across various countries.

BEVs operate solely on electricity, devoid of internal-combustion engines, thus eliminating gas emissions. This attribute holds significant importance in environmental protection and efforts to mitigate climate change. Additionally, BEVs demonstrate higher energy transition efficiency compared to traditional automobiles, and the electricity needed to charge them can be sourced from renewable and clean energy such as wind, solar, and hydropower. Consequently, promoting the adoption of BEVs contributes to a reduction in our reliance on fossil fuels. Moreover, BEVs are well-suited for the low-speed states and stop-and-go traffic patterns commonly encountered in urban driving scenarios

2. Environmental Impact Comparison

2.1 Greenhouse Gas Emissions

The carbon footprint of traditional internal combustion engine vehicles (ICEVs) differs significantly from that of electric vehicles (EVs) when considering the entire life cycle, encompassing manufacturing, operation, and end-of-life disposal. Related with the manufacturing phase, The production of traditional vehicles involves resource-intensive processes, such as extracting and refining raw materials (e.g., steel, aluminium, and plastics), leading to a substantial carbon footprint. While the manufacturing of EVs also requires energy and materials, studies suggest that the overall carbon footprint during this phase is often comparable to or slightly higher than that of ICEVs due to the production of batteries.

While considering operation phase, Internal combustion engines burn fossil fuels, releasing carbon dioxide (CO_2) and other pollutants during operation, contributing significantly to the vehicle's carbon footprint throughout its lifespan. In the case of EVs, electricity production is a crucial factor. If the electricity used to charge EVs comes from renewable sources (wind, solar, hydropower), their operational carbon footprint can be substantially lower compared to ICEVs. However, if the electricity is derived from fossil fuels, the advantage diminishes.

Regarding end-of-life phase, disposing of traditional vehicles involves challenges related to recycling and the environmental impact of materials like lead-acid batteries and various metals. While EV batteries raise concerns about recycling, advancements in technology and recycling infrastructure are addressing these issues. Additionally, the recycling of EV batteries can contribute to reducing their environmental impact. The production of batteries for EVs, particularly lithium-ion batteries, has environmental implications. However, ongoing research aims to improve battery technology, enhance recyclability, and minimize environmental impacts. The carbon footprint of both ICEVs and EVs is influenced by the energy mix of the region. In areas with a high percentage of renewable energy, EVs tend to have a more favourable overall environmental impact.

2.2 Air Quality Improvement

The adoption of electric vehicles (EVs) can make a substantial contribution to improving air quality in urban areas, thereby mitigating the adverse health impacts associated with vehicle emissions. Unlike traditional internal combustion engine vehicles (ICEVs) that emit pollutants such as nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs), EVs operate on electric power without emitting any pollutants directly from the vehicle's tailpipe. The absence of tailpipe emissions from EVs results in a reduction in airborne particulate matter, contributing to cleaner air. Particulate matter is known to have adverse effects on respiratory health and can lead to cardiovascular problems.

EVs contribute to reducing nitrogen oxide (NOx) emissions, which are major contributors to air pollution and ground-level ozone formation. High concentrations of NOx can exacerbate respiratory diseases and impact overall air quality. By promoting EV adoption, there is a potential decrease in the incidence of respiratory diseases, cardiovascular issues, and other health problems associated with exposure to air pollutants. This can lead to an overall improvement in public health outcomes, particularly in densely populated urban areas. Electric vehicles are generally quieter than traditional vehicles, which can contribute to a reduction in noise pollution in urban environments. Lower noise levels have been linked to improved mental well-being and a better quality of life for urban residents. The adoption of EVs can be part of a broader strategy to encourage the use of sustainable transportation modes.

3. Sustainable Manufacturing

Sustainable practices in the manufacturing of electric vehicles involve a holistic approach, addressing material sourcing, energy efficiency, recycling, waste reduction, and accountability throughout the entire supply chain. By incorporating these practices, the EV industry can contribute to a more sustainable and environmentally responsible future for transportation

3.1 Materials and Resource Management

Sustainable practices in the manufacturing of electric vehicles (EVs) are crucial for minimizing environmental impacts and promoting an eco-friendlier transportation. EVs manufacturers are increasingly emphasizing the responsible sourcing of materials such as lithium, cobalt, and nickel used in battery production. This involves ensuring that mining practices are ethical, environmentally responsible, and socially sustainable. Integrating recycled materials into the manufacturing process reduces the demand for new raw materials and lessens the environmental impact of mining and extraction.

Employing renewable energy sources, such as solar or wind power, in manufacturing facilities helps reduce the carbon footprint associated with the production of EVs implementing energy-efficient technologies and practices during manufacturing, such as advanced robotics and optimized production layouts, contributes to overall sustainability. Establishing closed-loop systems for recycling batteries ensures that the materials used in batteries, such as lithium, cobalt, and nickel, are recovered and reused. This reduces the environmental impact of resource extraction and minimizes waste. Investing in recycling infrastructure and technologies specifically tailored to handle EV batteries is essential for creating a circular economy and ensuring the responsible disposal and recycling of end-of-life batteries.

Implementing lean manufacturing principles helps minimize waste by optimizing production processes, reducing excess inventory, and eliminating unnecessary steps. Encouraging the reuse and repurposing of manufacturing by-products and waste materials can further reduce the overall environmental impact of EV production. Conducting thorough lifecycle assessments helps identify areas of improvement in the manufacturing process. This includes evaluating the environmental impact from raw material extraction to manufacturing, vehicle operation, and end-of-life disposal. EVs manufacturers regularly assess and refine their manufacturing processes based on ongoing research and technological advancements, aiming to enhance sustainability throughout the entire lifecycle of their vehicles.

3.2 Transition to Renewable Energy

Powering electric vehicle production facilities with renewable energy sources not only aligns with environmental and sustainability goals but also brings about economic, social, and regulatory benefits. This is achieved by reduction in carbon footprint, advancement of a green energy transition, reduced reliance on finite resources, preservation of ecosystems, community and stakeholder relations and cost savings and energy independence. This transition plays a pivotal role in minimizing the overall environmental impact of EV manufacturing processes and contributes to a more sustainable and resilient industrial landscape.

5. Government Incentives and Policies

Governments can incentivize EV adoption through policies such as subsidies, tax credits, and the development of EV charging infrastructure. These measures play a crucial role in accelerating the transition to cleaner transportation options

5. Future Outlook and Challenges

The future outlook for electric vehicles involves continuous technological innovation and a commitment to addressing environmental concerns. Advancements in battery technologies, materials sourcing, recycling practices, and end-of-life strategies are integral to enhancing the overall environmental sustainability of electric vehicles. Ongoing research and development efforts in these areas pave the way for a cleaner and more sustainable future for the automotive industry.

6. Conclusion

The adoption of electric vehicles represents a pivotal step towards achieving environmental sustainability in the transportation sector. As technology continues to evolve and as societies embrace cleaner energy solutions, electric vehicles stand as a symbol of innovation and a key player in the global effort to combat climate change. While challenges such as battery production environmental impacts and charging infrastructure development persist, the collective efforts of governments, industries, and consumers are paving the way for a more sustainable and resilient future in the realm of transportation.

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Recent Developments in Chitosan-Silica Hybrids: Syntheses, Properties and Applications

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Introduction

Composite materials made of biopolymers and silica are known as biopolymer-silica hybrids. When silica and biopolymers are combined, it gains the advantageous properties of both components. Due to their distinctive characteristics, wide range of uses, and promise for eco-friendly and sustainable solutions, these hybrids have attracted much attention in several disciplines. Biopolymers are polymers derived from natural sources, such as plants, animals, or microorganisms. They are environmentally friendly substitutes for synthetic polymers since they are renewable and biodegradable. Cellulose, chitosan, cyclodextrin, starch, alginate, and proteins like gelatin and collagen are typical examples of biopolymers. Incorporating silica into biopolymers may substantially enhance their mechanical strength and stability, making them appropriate for biodegradable packaging and coating and medicinal implants. The composite is more thermally stable and reduces the risk of thermal degradation. They are highly biocompatible and hence used as biological scaffolds for the regeneration of tissues and cell growth. These hybrids can be used as sustainable adsorbent material with high selectivity and versatility due to the combination of the porous structure of silica and different functional groups of biopolymers. They are important materials in environmental remediation and water purification. Some applications of biopolymer-silica hybrids are given in Fig.1.

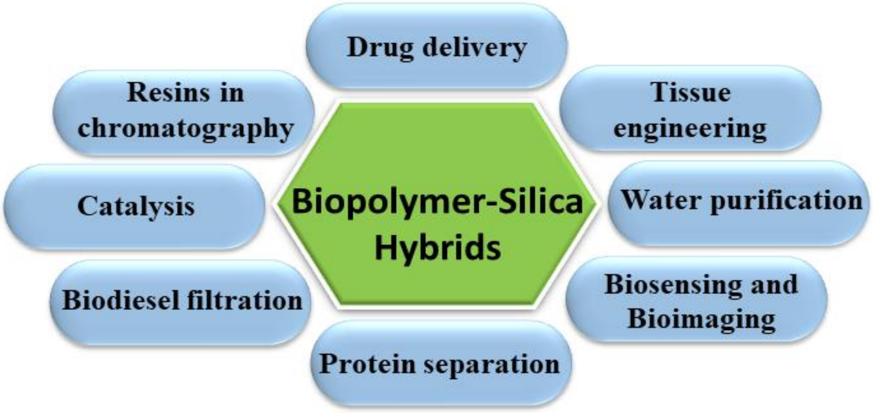

Fig.1. Applications of biopolymer-silica hybrids.

Chitosan

The biopolymer employed in the biopolymer-silica hybrid is determined by the desired application and required qualities of the resulting hybrid. Chitosan is a linear biopolymer which contains (1–4) linked D-glucosamine and N-acetyl-D-glucosamine monomers and derived by alkaline deacetylation of chitin. Chitin is a naturally abundant organic material obtained mainly from the exoskeleton of crustaceans like lobsters, shrimps etc, algae, and fungi. Chitosan is the second most abundant biopolymer after cellulose. It is a cationic polysaccharide with -OH and $-NH_2$ groups, which are easy to functionalize. As a degradation product of natural materials, the characteristics of chitosan are influenced by different parameters such as degree of deacetylation and molecular weight. Hydrophilicity and biocompatibility of chitosan depend on the degree of deacetylation, while the molecular weight mainly affects the degradation rate and the mechanical properties. The possibility of mechanochemical modifications provides novel physicochemical and structural properties to chitosan. It has several advantages such as non-toxicity, biodegradability, biocompatibility, and non-antigenicity.

Chitosan has many applications in wastewater treatment, food industry, packaging material, preservative and food additive, agriculture, pulp and paper industry, cosmetics, tissue engineering, wound healing, drug delivery and gene delivery. This biopolymer is readily processed into gels, membranes, nanofibers, beads, microparticles, nanoparticles, scaffolds, and sponges. Even though chitosan possesses many exceptional features, some essential properties for a specific application can be incorporated by modifying the chitosan backbone.

Silica

Silica is an inorganic substance made of silicon and oxygen atoms. They have superior mechanical, thermal, and chemical qualities and frequently employed in a variety of industrial applications such as molecular sieves, catalysts, and in electrical and biomedical applications. Ultrafine silica powders have many technological applications, such as thixotropic agents, thermal insulators, composite fillers, etc. Silica is characterized by advanced surface stability in the acidic medium, highly developed surface, acceptable kinetics, thermal stability, resistance to microbial attack, and low cost. It can be obtained from a variety of natural and synthetic origins. Sand, quartz, diatomaceous earth, rice husk, Tetraethyl ortho silicate (TEOS), sodium silicates, and colloidal silicates are commonly used silica precursors in industry and research. Silica can be combined with a variety of functional species or molecules since they have large surface area to volume ratio, good physical and chemical stability, low toxicity, and straightforward surface chemistry.

CHITOSAN-SILICA HYBRIDS

The development of chitosan-silica hybrid materials opens the possibility of combining both the advantageous properties of silica and the attractive features of chitosan in one material. Nowadays, much attention is paid to chitosan-silica hybrid materials. Such hybrids are in the form of hydrogel, aerogel, xerogel, membrane, fiber, microsphere, etc. Chitosan-silica hybrids can be synthesized through various methods, including sol-gel, in-situ, and surface modification techniques. The sol-gel method involves the hydrolysis and condensation of silica precursors in the presence of chitosan. In-situ synthesis involves the addition of chitosan to a silica precursor solution, followed by the formation of silica nanoparticles within the chitosan matrix. Surface modification techniques involve the functionalization of silica nanoparticles with chitosan molecules. This review is focused on the recent development in chitosan-silica hybrids.

A chitosan-silica hybrid was synthesized by a simple solution processing method by adding 3-glycidoxypropyltrimethoxysilane (GPTMS) as an in situ cross linking agent. The obtained product is more thermally stable and has less degree of swelling in water. The hydrophilicity of chitosan membrane persisted after cross linking reaction. Another chitosan/silica hybrid was prepared using a sol-gel process, ranging from 0% to 100% in situ silica content. The hybrids can chelate Cu (II) and Fe (III) in acid and alkaline solutions, and are biodegradable through lysozyme treatment. These chitosan/silica hybrids offer potential as environmental biomaterials and adsorbents. A chitosan-silica hybrid hydrogel employing GPTMS was synthesised by sol-gel process. The hydrogels exhibited unique degradation and mechanical characteristics that supported cell development, and they might be employed in applications such as tissue engineering. The hybrid hydrogels displayed good protein loading efficiencies and carried various molecular weight proteins, indicating their potential utility as delivery vehicles for a wide variety of molecular weight proteins/molecules. They can be used as support for cell growth since they do not produce cytotoxic effects. Hydrogels also exhibited antimicrobial activity against P. aeruginosa and E. faecalis. They are promising materials in bone tissue engineering and drug delivery systems.

Chitosan-silica porous hybrid membranes were prepared using a novel strategy to enhance chitosan's mechanical properties in hydrogel state. Inorganic silica phase was introduced through sol-gel reactions, with genipin cross-linking. TEOS and GPTMS were used as silica precursors. GPTMS acts as a coupling agent of chitosan amino groups with a silica network. By immersing in water, the hybrid exhibits increased elastic modulus.

Chitosan-silica hybrid aerogel was prepared using an acidic chitosan solution to catalyse the condensation and hydrolysis of TEOS.3:1 HCl/HF was the preferred catalyst in the reaction. This composite can be used in drug delivery, wastewater treatment, synthesis of carbon-silica composite, etc. Porous chitosan/silica hybrid microspheres were synthesized by a simple and controlled microfluidic method with TEOS as silica precursor. These microspheres have a large specific surface area, good mechanical properties, and good adsorption properties. The adsorption rate and mechanical intensity of the porous hybrid microspheres are two times larger and 1.5 times faster than porous chitosan microspheres, respectively. They exhibited good adsorption performance of heavy metal ions such as Cu (II). A homogeneous chitosan–silica xerogel hybrid nanocomposite was prepared at room temperature by sol-gel process. The hybrid membrane exhibited enhanced mechanical properties, excellent apatite forming ability, good cellular responses, and a significantly higher rate of new bone regeneration than the pure chitosan membrane. The improved properties of the hybrid membrane were attributed to the incorporation of the rigid and bioactive silica xerogel into the chitosan on the nanoscale. Chitosan–silica hybrid aerogel was synthesized using sol-gel and ambient drying methods. Silica was isolated from bamboo leaves and hexamethyldisiloxane was applied for hydrophobicity. They have high surface area due to the presence of many holes and canals on the hybrid. SEM images of different chitosan-silica hybrids are given in Fig. 2.

A chitosan/rice husk-based silica composite membrane with a porous structure synthesised via phase inversion. The membrane is used for biodiesel filtration. The flat sheet could adsorb the impurities in biodiesel and can be used repeatedly. This is an excellent alternative to conventional dry washing method.

Chitosan–silica hybrid adsorbents were synthesized and modified with ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA). The procedure involved hybridizing chitosan and silica in sol-gel method, followed by the addition of anhydrides to graft EDTA- and DTPA-ligands on the amine groups of the chitosan moieties in the hybrid particles. These materials can be used as resins in ion exchange chromatography for the separation of rare earths. A magnetic nano sorbent composed of Fe3O4 nanoparticles encapsulated with chitosan hybrid siliceous thin shells prepared by one step sol-gel method. This magnetic biohybrid material is an efficient sorbent for oil uptake from water using magnetic separation technology. This sorbent is easily separated from water in a magnetic field gradient.

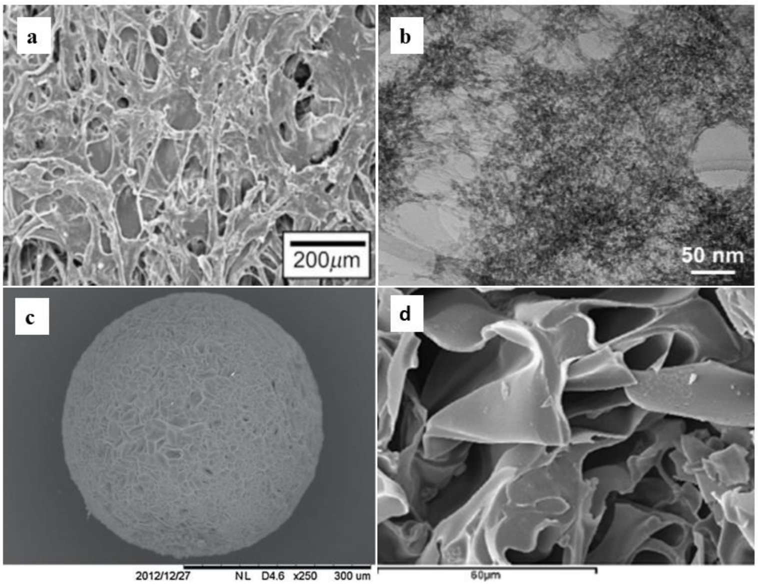

Fig. 2. SEM images of chitosan-silica (a) xerogel, (b) aerogel, (c) microsphere and (d) membrane.

A novel *N*-guanidinium chitosan/silica micro hybrid was prepared via a sol-gel method using GPTMS as silica precursor. N-guanidinium chitosan acetate was synthesised via direct guanylation of chitosan by cyanamide in the presence of scandium (III) triflate. The micro hybrid had high degree of homogeneity with many adsorption sites. They are low-cost and biodegradable. The *N*-guanidinium chitosan/silica micro hybrids display excellent adsorption properties for anionic dyes such as methyl orange. Another nanohybrid fiber with chitosan containing polyethylene oxide and silica was prepared by sol-gel process. Silica sol was prepared by hydrolyzing TEOS and 3-glycidyloxypropyltriethoxysilane. This provides a stable solution for gelation and promotes covalent interaction with chitosan. The fibers utilise biocompatible polymer template silicate components to generate a self-assembled core-shell structure of the polymer chitosan/polyethylene glycol encapsulated by silica. They can be used as active biomaterials in bone repair and regeneration. An EDTA modified chitosan-silica hybrid was synthesized using chitosan, TEOS, and EDTA. The developed adsorbents effectively combined the advantageous qualities of chitosan and silica gel. The material exhibited the porosity and rigidity of silica gel and the wide functionality of chitosan. This material could be used as effective adsorbents for Co (II), Ni (II), Cd (II), and Pb (II). Chitosan-oxidized starch-silica membranes were prepared using oxidized dialdehyde starch and 3-aminopropyltriethoxysilane (APTES) as cross-linking agents by means of a casting method. The hybrid membrane exhibited improved thermal stability and low degree of swelling in water. They have large surface area and can be used as biosorbents for the removal of Direct Blue 71 and Direct Red 3.

Conclusion

Chitosan-silica hybrid is a promising material with unusual features. The synergistic actions between the hybrid components are the main reason that chitosan-silica hybrids are finding wide applications. Here, recent developments in the chitosan-silica hybrids, their syntheses, properties, and potential applications in different fields are briefly reviewed. Different treatments for chitosan and silica precursors, as well as various crosslinking agents used have been explored. This hybrid is an exceptional material that will be regarded as one of the most significant advances in the history of materials chemistry.

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Chitosan- a Promising Biomaterial for Multitudinous Applications

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Introduction

Over the last decade, biopolymer based sustainable technologies have become one of the most swiftly growing research fields in chemistry. Natural polymers like cellulose, chitin, chitosan, gelatine, and alginate have promising applications in various forms. Most of the naturally occurring polysaccharides, e.g., cellulose, dextrin, pectin, alginic acid, agar, agarose, and carrageenans, are neural or acidic in nature, whereas chitin and chitosan are examples of highly basic polysaccharides. Chitosan is a biopolymer derived from chitin, the most abundant biopolymer ranking next to cellulose. It is obtained economically from crab and shrimp canning industries. This book chapter embarks on a journey into the multifaceted world of chitosan, disclosing its unique biological properties.

Chitin

Chitin $(C_8H_{13}O_5N)_n$, is a white, hard, inelastic, nitrogenous biopolymer and is the most abundant biopolymer ranking next to cellulose. Henry Braconnot (1780–1855) was the first to isolate chitin from mushrooms in 1811. Chitin comes about as structured crystalline microfibrils that outline structural components in the exoskeleton of arthropods, endoskeletons of mollusks, or in the cell walls of fungi and yeast. In the chemical structure of chitin, the monomeric units of 2- acetamido-2-deoxy- D-glucopyranose attached to each other through β-(1-4) linkages (Figure 1). Derivatives of chitin are obtained by the alkaline deacetylation reactions using preferably 40–50% NaOH. Chitin has been of significant interest in material science and is identified as an obstinate polymer due to its insoluble nature in various common solvents.

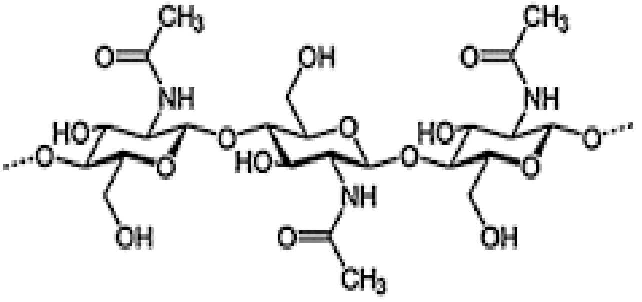

Figure 1. Structure of Chitin

Chitosan

Chitosan is composed of repeating units of β-(1-4)-linked D-glucosamine (deacetylated unit) and N-acetyl-D-glucosamine (acetylated unit). The presence of these two links within the chain is random in nature. Among all chitin derivatives, Chitosan is identified as the most widely used one since it can be functionalized further to be tailored for a wide variety of applications. The growing popularity of chitosan among researchers can be attributed to its versatile properties such as stability, solubility, porosity, permeability, biocompatibility, biodegradability, antimicrobial activity, non-toxicity, controlled release, biomimetics, and the ability to chemically and structurally modify it to improve its chelating and absorption properties. These exemptional properties of chitosan make it an ideal material for a multitude of applications, including biomedical science, material science, bioengineering, and pharmaceuticals.

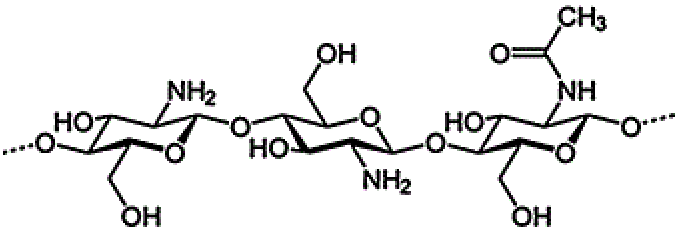

Figure 2. Structure of Chitosan.

Processing of Chitosan

Chitin and chitosan are natural resources waiting for a market. They are waste products of the crabbing and shrimp canning industry. Commercially, chitin and chitosan are of great importance owing to their relatively high percentage of nitrogen (6.89 percent) compared to synthetically substituted cellulose. Figure 3 shows the steps involved in processing chitosan from crabbing and shrimp canning industries.

The following four steps in chronological order are needed to produce chitosan from crustacean shells. In crab and prawn shells, calcium carbonate is dissolved using dilute aqueous HCl (Decalciferation), after which proteins are removed using dilute aqueous NaOH (Deproteination). The chitin is further deacetylated in 40% sodium hydroxide for 1-3 hours at 120°C to form 70% deacetylated chitosan.

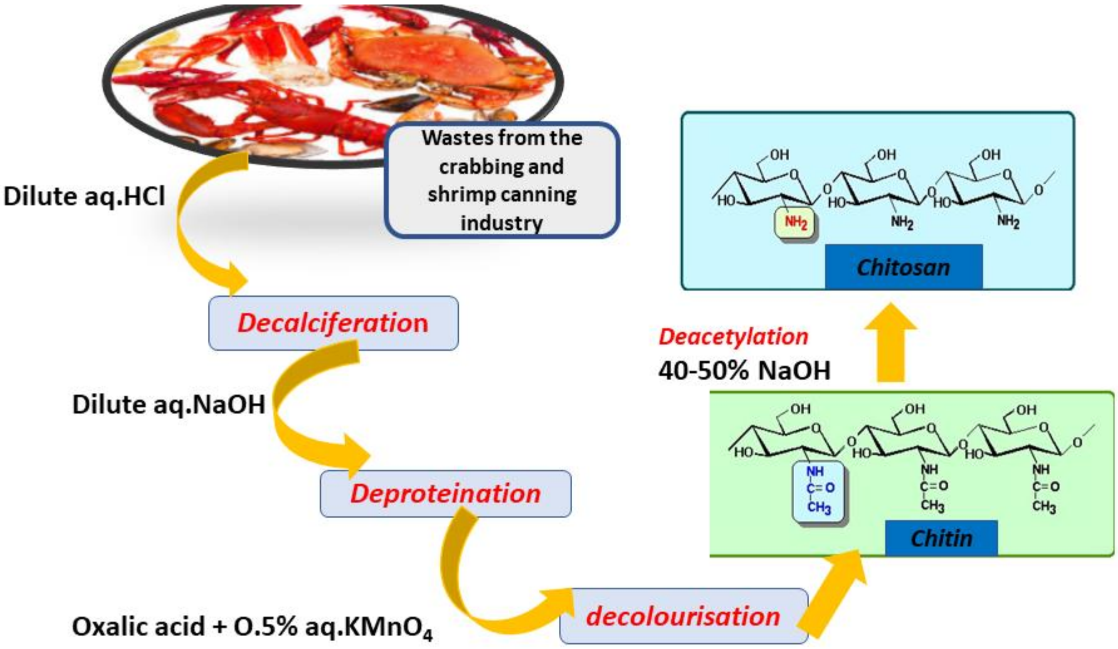

Figure 2. The processing of chitosan from the industry.

Chemical Properties of Chitosan

Due to the presence of amino groups, chitosan is positively charged in acidic conditions. As a result of this feature, it is an ideal candidate for interacting with negatively charged molecules such as heavy metals and certain organic compounds. Although the β (1→4)-anhydroglycosidic bond of chitin is also present in cellulose, the characteristic properties of chitin/chitosan are not analogous to cellulose. It is soluble in dilute acids such as acetic acid and formic acid. Nitrogen is typically found in the chitosan chain as the primary aliphatic amino group, which undergoes amine-based reactions such as N-acetylation and Schiff's reaction. Chitosan can be fabricated in many forms, like film, fiber, sponges, and powder, with different degrees of deacetylation and molecular weights. Chitosan can chelate or bind to heavy metals and certain organic compounds, making it useful for water treatment, detoxification, and metal ion removal from industrial processes.

The molecular weight (Mw) and the degree of Deacetylation (DD) are the two key characteristics that prominently affect the chemical as well as physiological properties. The approximate molecular weight of chitosan in the market lies in the 3800 to 20,000 Daltons range. It is typically categorized into low (3800 to 6000 Daltons), medium (6000 to 10,000 Daltons), and high (10,000 to 20,000 Daltons) molecular weight chitosan based on the range of molecular weights associated with each class. The choice of chitosan with a specific molecular weight depends on the intended application. Low molecular weight chitosan is favored in pharmaceutical and biomedical applications due to its enhanced solubility and bioactivity. Medium molecular weight chitosan finds use in food and cosmetics, offering a balance between solubility and film-forming properties. High molecular weight chitosan is often preferred in industrial and environmental applications, where water solubility is not a critical factor and its larger molecular weight aids in purification processes.

The degree of deacetylation (DD) represents the percentage of acetyl groups removed from chitin to create chitosan (the proportion of glucosamine to N-acetylglucosamine units). A higher DD indicates a higher level of deacetylation. The degree of deacetylation can vary, leading to different chitosan types with distinct properties. Higher DD chitosan has a more open and amorphous structure, making it more soluble in water and more suitable for various applications, such as drug delivery, wound healing, and antimicrobial agents. On the other hand, chitosan with a lower DD may be less soluble and is often used in applications where its structural integrity and film-forming properties are more critical, such as in the food and cosmetic industries.

Biological Properties of Chitosan

The diverse set of biological properties makes chitosan a valuable and adaptable material with applications in fields ranging from healthcare and biotechnology to agriculture and environmental science. Biodegradability, biocompatibility, cytocompatibility, hemocompatibility, antimicrobial activity, etc., are some critical characteristics of chitosan that furnish it as a versatile biopolymer with extraordinary potential for diverse applications.

Biodegradability

The biodegradation of chitosan could be the splitting of the polymer substance into smaller portions, and also as monomers, i.e., D-glucosamine, N-acetyl-glucosamine, they will be catalyzed by enzymes or chemicals in vitro or possibly in vivo. The biodegradation rate is a requirement for the usage of chitosan in tissue engineering and drug-delivery systems. The degree of deacetylation (DD) and molecular weight (MW) will be the factors managing the biodegradation rates of chitosan. Chemical modifications to chitosan also influence the biodegradation rate. The process of biodegradation commonly involves the chemical and enzymatic activity that makes the material into fragments.

Biocompatibility

Biocompatibility could be compatible with living tissue or an income system by not being toxic, harmful, or physiologically reactive rather than leading to immunological rejection. Facts associated with undesirable reactions among the biomaterials and living systems happen to be acquired from retrospective research in humans, and presently, biomaterial-tissue interactions have been discovered by using bioassays in vitro plus in vivo. Chitosan is polycationic at a pH of 6 and merely interacts with a wide variety of negatively charged biomolecules, such as anionic polysaccharides, proteins, essential fatty acids, bile acids, and many others.

Cytocompatibility

The in vitro cytocompatibility of chitosan and its derivatives can be evaluated in two stages. During the first stage, cytotoxicity tests are performed to screen the materials to be employed for external use or implantation. As a basic principle, cytotoxicity tests assess the morphological changes in cells after exposure to the material in question to determine whether they have died or have undergone regressive phenomena. In the second stage, cell viability tests are performed to assess the effects of chitosan and its derivatives on cell proliferation and viability. Cell viability tests measure the number of cells alive after exposure to the material and can help assess the safety of the material.

Hemocompatibility

Hemocompatibility refers to the compatibility of a material with blood, specifically in terms of its interaction with blood components, such as red blood cells, platelets, and plasma proteins. Chitosan is generally considered to have good hemocompatibility for many biomedical applications. However, its interaction with blood components, especially platelets, may require careful consideration and optimization in specific applications. Surface modification of chitosan can be used to tailor its hemocompatibility for specific medical devices or drug delivery systems. It is generally considered hemocompatible with respect to red blood cells. It does not induce significant hemolysis (rupture of RBCs) when in contact with blood. However, the degree of hemolysis can depend on factors like chitosan concentration, molecular weight, and surface modification. Generally, low-molecular-weight chitosan is less likely to cause hemolysis.

Chitosan has been found to interact with platelets to some extent. The specific effects can vary based on chitosan properties. Some studies suggest that chitosan can activate platelets and cause them to adhere to the material's surface. This adhesion can lead to platelet activation and potentially contribute to thrombus formation. Surface modification of chitosan can be used to reduce platelet adhesion and activation.

Chitosan can also adsorb various plasma proteins, such as fibrinogen and albumin, when in contact with blood. Protein adsorption can influence the surface properties of the material and its interactions with blood components. Factors like chitosan surface charge, hydrophilicity, and other surface modifications can influence the extent of protein adsorption. Some studies suggest that chitosan can inhibit blood coagulation to some extent by interfering with the coagulation cascade. This property can be helpful in certain medical applications, such as developing antithrombotic materials.

Non-toxicity

Chitosan is a non-toxic, biologically suitable polymer that has been approved for use in injury dressings by the FDA. The composition of chitosan along with a drug may replace the pharmacokinetic and biodistribution profiles. The path of administration determines the uptake, concentration, and contact time cell kinds influenced.

Antimicrobial activity

Chitosan has gained attention for its antimicrobial properties. The antimicrobial activity is due to chitosan being a cationic polyelectrolyte polymer. Low-molecular-weight chitosan may migrate through microbial cellular areas, bind with DNA, and inhibit DNA interpretation and mRNA functions; instead, high-molecular-weight chitosan can combine with the negatively charged components in the microbial cellular areas. This layer forms an impermeable barrier around the cell, changes cell permeability, and blocks transport into the cell. Microbes are capable of hooking to the exterior of chitosan drastically in a small instance of just 30 minutes.

The quantity of chitosan binding to the bacterial cell wall was reliant on the surrounding pH value, molecular weight, and degree of acetylation of chitosan. Low environmental pH increases the positive charge in the chitosan polymer, which draws towards the bacterial cell wall more often. Generally, chitosan with higher molecular weight and higher degree of deacetylation tends to exhibit more potent antimicrobial effects.

Chitosan has the ability to chelate metal ions, and some studies suggest that this property may contribute to its antimicrobial activity. Chitosan can bind to essential metal ions required for microbial growth, making them unavailable to microorganisms. It is also important to note that enzyme inhibition contributes to antimicrobial activity. Chitosan has been shown to inhibit certain enzymes crucial for microbial survival. For example, it may inhibit the activity of enzymes involved in synthesizing microbial cell walls.

The antimicrobial properties of chitosan make it a promising material for various applications, including wound dressings, food packaging, and water treatment. Researchers continue to explore and optimize the use of chitosan and its derivatives for controlling microbial growth in different environments. It is worth noting that the effectiveness of chitosan can vary depending on the specific microorganisms involved and the conditions of use.

Conclusion

Chitosan has been garnering immense attention and become a center of comprehensive research owing to its vast structural possibilities for physiochemical alterations to produce novel characteristics, functions, and utilization. Chitosan is endowed with numerous properties, such as biodegradability, biocompatibility, cytocompatibility, hemocompatibility, non-toxicity, antimicrobial activity, and adjustable physical strength. They possess multiple extraordinary properties that can be considered a boon to the human race.

The biocompatibility of chitosan has paved the way for groundbreaking innovations in medicine, facilitating its use in drug delivery systems, wound healing, and tissue engineering. Its antimicrobial characteristics contribute to enhanced safety in medical devices and wound dressings, preventing infections and promoting healing. Meanwhile, the biodegradability of chitosan aligns with the growing demand for sustainable materials in both biomedical and environmental contexts.

Figure 4. Broadened application of chitosan-based composites.

In agriculture, chitosan has proven invaluable as a biopesticide and growth promoter, offering eco-friendly solutions for crop protection. Its adsorption and absorption abilities find application in water treatment, where chitosan plays a pivotal role in removing pollutants and heavy metals from water sources. The biotechnological realm benefits from chitosan's contribution to the production of biodegradable materials, films, and scaffolds, furthering advancements in tissue engineering and regenerative medicine. Moreover, the material's versatility extends to environmental science, which aids soil and water remediation efforts.

As research continues to unravel the full potential of chitosan, its significance is poised to grow even further, offering sustainable and practical solutions to some of the most pressing challenges in healthcare, agriculture, and environmental sustainability. The exploration of chitosan's applications underscores its pivotal role in shaping the future of various industries, driving innovation, and fostering a more sustainable and technologically advanced world.

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Green Chemistry in Organic Synthesis

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Abstract

Green chemistry, also known as sustainable chemistry, centers on the creation of products and processes that reduce the generation or utilization of harmful substances. While green chemistry isn't a novel field, its significance has surged due to growing environmental apprehensions. This chapter delves into the evolution of "Green Chemistry" concepts and its fundamental principles. It also features illustrative applications of these principles across various realms of chemistry, along with a comprehensive description of frequently employed alternative solvents in preparative organic chemistry.

Introduction

The concept of green chemistry (sustainable chemistry) emerged in the 1990s, thanks to the groundbreaking efforts of prominent figures like Warner, Trost, Anastas, Sheldon, Clarke, and others. The term "green chemistry" was coined by Anastas, in a programme organized by US Environmental Protection Agency (EPA) in 1991.[1] Green Chemistry is to stimulate a substantial development in chemistry and chemical technology, describing it as "the design of chemical processes and products with the aim of eliminating or reducing the generation or use of hazardous substances".[1] It is a novel paradigm to revolutionize synthetic procedures, methodologies, and chemical processes within the realm of chemistry and chemical technology, making them both environmentally friendly and cost-effective. This transformation can be accomplished through a variety of methods and strategies, including ultrasound-assisted protocols, environmentally friendly solvents, solvent-free drug synthesis, ionic liquids, microwave-assisted techniques, green reduction processes, oxidation catalysts, solid acid-base catalysts, and heterogeneous metal catalysis, among others.[2] Anastas and Warner formulated a set of 12 principles that serve as the foundational criteria for green chemistry.

These principles can be categorized into two main groups: "Risk Reduction" and "Environmental Footprint Minimization".

1. Waste Prevention: The green synthesis of ibuprofen serves as an excellent example, as it yields only 1% waste compared to the traditional synthesis, which generates 60% waste.

2. Atom Economy: Maximizing the incorporation of all reactants into the final products on an atomic level is a fundamental principle. For instance, the addition of chlorine to ethene to produce 1,2-dichloroethane boasts a 100% atom economy.

3. Safer Chemical Synthesis: Utilizing chemical reactants and creating final products with minimal or no toxicity. For instance, in the synthesis of polycarbonate, hazardous phosgene ($COCl_2$) is replaced with solid-state polymerization under green chemistry.

4. Designing Safer Chemicals and Products: The goal is to develop effective chemicals with reduced toxicity.

5. Safer Solvents and Auxiliaries: Minimize the use of auxiliary substances such as solvents and separating agents whenever possible.

6. Design for Energy Efficiency: Recognize and minimize energy requirements to conduct synthetic procedures at ambient temperature and pressure. For instance, replacing bromine with cyanide under conventional conditions occurs at 100 °C with approximately 75% conversion in 72 hours. In contrast, microwave-assisted synthesis achieves 100% conversion in only 10 minutes at 200 °C.

7. Renewable Feedstock: Whenever feasible, opt for renewable raw materials or feedstocks instead of depleting ones.

8. Reduce Derivatives: Minimize the use of derivatives as reactants, protecting groups, or temporary modifications wherever possible.

9. Catalysis: Prefer catalytic reagents over stoichiometric ones to enhance product formation reduce temperature and pressure requirements, and minimize waste generation.

10. Design for Degradation: Chemical products should be designed to break down into harmless degradation products at the end of their function, preventing their persistence in the environment.

11. Real-time Analysis for Pollution Prevention: Develop analytical methods for real-time, in-process monitoring and control to prevent the formation of hazardous substances.

12. Safety: Prioritize substances and processes that minimize the potential for chemical accidents, explosions, fires, and other hazards.

Green Approaches in Organic Synthesis

The concept of green chemistry has introduced environmentally friendly synthetic protocols for synthesizing various organic molecules, which have significantly impacted various fields. These impacts include the utilization of eco-friendly solvents, solvent-free synthesis methods, sustainable catalytic materials, and reduced energy consumption improved atom economy, optimized reaction yields, the use of alternative energy sources, the introduction of multicomponent reactions (MCRs), ionic liquids and the design of high-efficiency and time-saving reactions that work at ambient temperatures.[3] The green methods like solvent-free approach, grinding approach, ball milling approach, solid–wet approach, ultrasonic-assisted approach, microwave-assisted approach, electrochemical green catalytic synthetic approach etc. are adopting frequently.[4]

Green Catalysts in Organic Synthetic

Environmentally friendly synthetic strategies rely significantly on the pivotal role of catalysts in reducing activation energy. This reduction allows reactions to occur at lower temperatures, even at room temperature, resulting in high yields of products with minimal co-products, by-products, and waste generation. Catalysis stands as the cornerstone of green chemistry, and catalysts employed in green organic synthesis should possess attributes such as safety, ease of handling, reusability, biodegradability, cost-effectiveness, recyclability, efficient recovery, and the ability to facilitate high reaction rates for achieving maximum yields within shorter timeframes. The table illustrates various types of green catalysts available for use.[5] Green catalyst such as lewis acids catalysts in water, zeolites as green catalysts, enzyme catalysis, heteropoly acid-based (HPAs) catalysts, natural materials and foods as catalysts, nano particles

(NPs)/materials as catalysts, transition metals as green catalysts, ionic liquids as catalysts, photocatalyst (PC), phase transfer catalyst (PTC) are using by synthetic chemists.[6]

Green Solvents in Organic Synthetic Approaches

Green chemistry primarily centers on the reduction or replacement of solvents in chemical processes and organic synthesis, with a strong emphasis on adopting environmentally friendly alternatives. The necessity for such focus in green chemistry stems from the extensive use of solvents in various industries, including drug manufacturing, paints, textiles, polymers, solvent extractions, purification in final products, and other industrial applications. These solvents have been a major contributor to environmental degradation and harm to living organisms, making it imperative to minimize, substitute, or completely eliminate them in Favor of greener processes and eco-friendly solvents. Green solvents such as aqueous and super critical carbon dioxide, fluorous solvents, organic carbonates, lactates and general solvents, natural and bio solvents archetypal green solvents, ionic liquids as solvents, deep eutectic solvents (DESs) can be used.[7]

Conclusions

Green Chemistry isn't a recent scientific field but rather a fresh philosophical perspective. By embracing and extending its principles, it has the potential to spark significant advancements in chemistry, the chemical industry, and environmental preservation. This approach is poised to address multiple ecological challenges effectively. Educating future generations of chemists in Green Chemistry will play a vital role in resolving numerous ecological issues on national, regional, and global levels, empowering our trained specialists to compete effectively in the global economy. The primary hurdle facing Green Chemistry lies in the practical implementation of its principles.

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Tiny Trouble: Microplastic Pollution's Impact on Environmental Sustainability

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Introduction

Microplastics are tiny plastic particles that measure less than 5 mm in size. They are found in various environments, including terrestrial, aquatic, and even atmospheric. These particles can be classified into two main categories based on their source and size:

Primary Microplastics: These are intentionally manufactured small plastic particles used in various products. They include: Microbeads, Nurdles, Plastic microfibers etc.

Secondary Microplastics: These are the result of the breakdown of larger plastic items over time. Secondary microplastics are typically formed through processes like weathering, fragmentation, and degradation. They include: Fragmented Plastics, Tire Wear Particles, Paint and Coating Particles etc.

Environmental Impact of Microplastics

The environmental impact of microplastics is a growing concern due to the widespread presence of these tiny plastic particles in various ecosystems. Microplastics can have far-reaching effects on the environment and its components.

1. Ecosystem Disruption

Microplastics can disrupt aquatic and terrestrial ecosystems by interfering with natural processes and species interactions. Their presence can have cascading effects throughout food webs.

In aquatic ecosystems, microplastics can interfere with the growth and development of phytoplankton and zooplankton, which form the base of the marine food chain. This can disrupt the entire ecosystem, affecting higher trophic levels, including fish and marine mammals.

In terrestrial ecosystems, microplastics can contaminate soil, potentially affecting nutrient cycling and soil health. The impact on plant growth and soil-dwelling organisms remains an area of active research.

2. Food Web Disturbance:

Microplastics can enter the food chain at various levels. Small organisms, such as zooplankton and filter-feeding animals, often ingest microplastics directly.

As these microplastics move up the food chain, larger predators, including fish and marine mammals, may consume contaminated prey, leading to biomagnification. This can result in higher concentrations of microplastics in top predators, which can have negative health effects.

3. Biodiversity and Habitat Impacts:

Microplastics can accumulate in natural habitats, potentially leading to long-term harm. They can affect the distribution and abundance of native species by favouring species that can tolerate or use microplastics.

In marine environments, microplastics can attach to and damage coral reefs, affecting these critical ecosystems.

In terrestrial ecosystems, microplastic pollution can contaminate soil and harm soil-dwelling organisms, potentially affecting soil health and fertility.

4. Wildlife and Human Health Implications:

Microplastics can be ingested by a wide range of organisms, including zooplankton, filter feeders, fish, birds, and mammals. Ingestion can lead to physical harm, malnutrition, and decreased reproductive success among wildlife.

There are concerns about the potential transfer of microplastics in the food chain to humans. While the extent of human health risks is still under study, it's important to minimize exposure.

5. Water Quality and Aesthetic Concerns:

The presence of microplastics in water bodies can degrade water quality and affect the aesthetics of natural environments. This can have economic implications, particularly for tourism and recreation-based industries.

The Interplay with Environmental Sustainability

The interplay between microplastic pollution and environmental sustainability is a critical aspect to consider when addressing this complex issue.

- Linking Microplastic Pollution to Sustainability Goals:

Environmental Health: Discuss how microplastic pollution threatens the health and resilience of ecosystems. Emphasize the importance of maintaining healthy ecosystems as a fundamental aspect of sustainability.

Biodiversity: Highlight the impact of microplastic pollution on wildlife and biodiversity. Explain that the loss of species and ecosystem diversity can disrupt the balance of nature and compromise long-term sustainability.

Resource Conservation: Address the role of microplastic pollution in the unsustainable use of resources. Emphasize the need to reduce plastic consumption and promote circular economy principles.

- The Role of Sustainable Business Practices:

Corporate Responsibility: Discuss the importance of businesses adopting sustainable practices, including reducing the use of plastics and incorporating responsible product design.

Eco-friendly Alternatives: Highlight the adoption of alternative materials, such as biodegradable plastics and natural fibres, which can reduce the environmental impact of products.

Product Life Cycles: Examine how considering the entire life cycle of products, from production to disposal, can lead to more sustainable choices and reduce microplastic pollution.

- Policy Recommendations for Environmental Sustainability:

Regulation and Legislation: Discuss the need for government regulations to control and monitor microplastic pollution. Highlight examples of countries and regions that have implemented successful policies.

Extended Producer Responsibility (EPR): Explain the concept of EPR, where producers take responsibility for their products throughout their life cycles. EPR can promote sustainable design and waste reduction.

Promoting Sustainability Education: Emphasize the importance of sustainability education and awareness campaigns to encourage responsible consumption and waste reduction.

- The United Nations Sustainable Development Goals (SDGs):

Alignment with SDGs: Illustrate how addressing microplastic pollution aligns with several United Nations Sustainable Development Goals, including those related to life below water, life on land, and responsible consumption and production.

- The Bigger Picture:

The Interconnectedness of Environmental Issues: Emphasize that microplastic pollution is just one part of a larger network of environmental issues. Highlight how addressing this problem contributes to overall sustainability and the achievement of broader environmental goals

Conclusion

In conclusion, the issue of microplastic pollution is not just a concern for the present but a defining challenge for the future of our planet. As we have explored throughout this chapter, microplastics, whether originating from primary sources like microbeads or secondary sources due to plastic degradation, have infiltrated our terrestrial and aquatic ecosystems at an alarming rate.

The environmental impact of these minute plastic particles is profound, disrupting ecosystems, threatening biodiversity, and potentially affecting human health. However, as we have seen, the interplay between microplastic pollution and environmental sustainability offers a ray of hope.

Recognizing the interconnectedness of environmental issues and the importance of sustainable practices, we can take meaningful action to mitigate the prevalence of microplastics. Governments and businesses must adopt responsible policies and practices, and individuals play a pivotal role through informed consumer choices and everyday habits.

By addressing microplastic pollution, we align ourselves with the United Nations Sustainable Development Goals and the broader quest for a sustainable, resilient, and harmonious world. Our collective efforts, both large and small, hold the promise of a cleaner, healthier environment for generations to come. As we move forward, let us keep in mind that the power to enact change lies within our choices and our commitment to preserving our planet's precious ecosystems and the well-being of all its inhabitants.

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Advancing Sustainability in Polymer Technology

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Abstract

This chapter explores the pivotal role of oil and gas companies, positioned at the forefront of the energy value chain, in addressing climate change and sustainability concerns. By leveraging expertise in molecular biology and material science, these companies possess a unique opportunity to drive meaningful conversations about advancements in plastics, composites, and renewables, with the potential for significant environmental impact.

1. Introduction

1.1 Context

In the face of escalating climate change and sustainability challenges, the critical role of oil and gas companies in the energy value chain cannot be overstated. This section underscores their potential to contribute valuable insights, particularly in the domains of molecular biology and material science, while emphasizing the need for sustainable solutions in areas like plastics, composites, and renewables.

1.2 Scope and Objectives

This chapter aims to dissect the evolving landscape of sustainable polymer development. By delving into bio-based polymers, green chemistry principles, and innovative processing techniques, the chapter endeavors to shed light on the current state-of-the-art methodologies. The ultimate goal is to foster a more sustainable and environmentally-conscious future within the polymer industry.

2. Transforming Raw Materials: The Bio- Based Frontier

2.1 Harnessing Renewable Resources

Bio-based polymers, sourced from renewable reservoirs, hold immense promise in sustainable polymer development. This section meticulously scrutinizes various plant-derived feedstocks, including cellulose, lignin, starch, protein, and modified biopolymers, emphasizing their potential applications in bioplastics and composites.

2.2 Biodegradable Marvels

Biodegradable polymers stand as a beacon of hope for sustainable materials. This section provides a comprehensive overview of biodegradable polymers such as PLA and PHAs, exploring their applications and avenues for enhancing performance. Additionally, considerations for biodegradability and their positive impact on the environment are discussed.

2.3 Algae-Derived Potentials

Algae-based polymers, characterized by their rapid growth rates, have emerged as a promising feedstock. This section investigates the extraction and conversion of algae-derived components into biopolymers, highlighting their environmental benefits and potential applications.

3. Green Chemistry in Polymer Synthesis

3.1 Maximizing Atom Efficiency

Green chemistry principles play a pivotal role in sustainable polymer synthesis. This section delves into the concept of atom efficiency, emphasizing the importance of minimizing waste and optimizing resource utilization in polymerization reactions.

3.2 Solvent Selection for Sustainability

The choice of solvents in polymer synthesis significantly impacts environmental sustainability. This section expounds on solvent selection criteria, considering factors such as toxicity, volatility, and recyclability. Additionally, innovative approaches for solvent-free polymerization techniques are explored.

3.3 Catalytic Advances

Catalytic processes offer opportunities for efficient and selective polymer synthesis. This section examines catalytic systems for various polymerization methods, highlighting their potential for sustainable polymer production.

4. Sustainable Processing Techniques

4.1 Pioneering Energy-Efficient Processes

Efficient energy utilization in polymer processing is paramount for sustainability. This section provides an in-depth analysis of energy-saving techniques in key processing methods, including extrusion, injection molding, and others. Strategies for optimizing energy consumption and incorporating renewable sources are discussed.

4.2 Water-Based Revolution

Transitioning to water-based processing methods represents a significant step towards sustainability. This section explores the advantages of water-based techniques, including reduced VOC emissions and diminished environmental impact. Best practices and case studies for implementing water-based processing are presented.

5. Circular Economy and End of Life Management

5.1 Designing for Recyclability

Designing polymers with end-of-life considerations is essential for a circular economy. This section focuses on strategies for creating products that are easily recyclable or biodegradable, emphasizing design principles and material selection.

5.2 Innovations in Recycling Technologies

Efficient recycling technologies are instrumental in closing the loop for polymer materials. This section explores mechanical, chemical, and advanced recycling techniques, providing insights into their environmental benefits and potential applications.

5.3 Upcycling for Sustainability

Upcycling offers innovative approaches to extend the lifespan of polymer materials. This section highlights creative strategies for transforming waste polymers into higher-value products, contributing to a more sustainable economy.

6. Conclusion: Pioneering a sustainable Polymer Future

In the pursuit of a sustainable and environmentally-conscious future, the development of eco-friendly polymers stands as a critical frontier. This chapter has provided a comprehensive exploration of techniques and methodologies, spanning bio-based polymers, green chemistry principles, sustainable processing, and end-of-life management. By embracing these approaches, the polymer industry can usher in a new era of responsible and sustainable practices.

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Novel Trends in Plastic Waste Management

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Introduction

The contemporary era faces a widespread challenge in the effective management of municipal solid wastes (MSW). The accumulation of these waste materials has led to various environmental issues, ranging from the regular release of greenhouse gases to the scarcity of available space for waste disposal. The adverse environmental impacts have sparked growing concerns among the public, prompting political measures and legislation aimed at minimizing the introduction of waste into the environment. In response to these challenges, efforts have been directed towards implementing solutions that promote sustainable waste management. Central to these initiatives is the encouragement of municipal solid waste (MSW) recycling and the efficient conversion of waste materials into energy and other valuable chemicals. The objective is to not only reduce the environmental footprint associated with waste but also to harness the potential energy and resources embedded in these materials.

Conventional methods of plastic waste management

Conventional methods of plastic waste management have been integral in addressing the persistent environmental challenges posed by the increasing accumulation of plastic waste. Some of the conventional methods include

A) Landfills are one of the most common conventional methods for plastic waste disposal. Plastic waste is transported to designated landfill sites, where it is deposited and compacted. Landfill disposal poses environmental risks, including soil and groundwater contamination. Plastics can take hundreds of years to decompose, contributing to long-term environmental impact.

B) Incineration involves burning plastic waste at high temperatures, converting it into ash, heat, and gases. The heat generated can be used for energy production. Incineration releases greenhouse gases and pollutants, contributing to air pollution. It also raises concerns about the potential release of toxic substances from burning plastics.

C) Mechanical recycling is a process where collected plastic waste is sorted, cleaned, melted, and reprocessed into new products. Mechanical recycling is limited by the need for strict separation of plastic types, contamination issues, and the degradation of plastic quality with each recycling cycle.

D) Encouraging the reduction of single-use plastics at the source and implementing plastic bags are strategies aimed at minimizing the generation of plastic waste. Implementation challenges, resistance from industries, and the need for viable alternatives can hinder the effectiveness of source reduction and bans

. E) Collection and Manual sorting involve collecting plastic waste, manually sorting it based on types and recyclability, and then sending it to recycling facilities. Labor-intensive sorting processes can be time-consuming and may not be entirely effective, leading to the inclusion of contaminants in recycling streams.

While these conventional methods play a role in managing plastic waste, the limitations and environmental impacts associated with some of these approaches highlight the need for continuous innovation and the adoption of more sustainable and advanced methods in plastic waste management.

Advanced Non-biodegradable Plastic Waste (NPW) Technologies

The technologies are introduced based on basic classification into two strategies: recycling and degradation. Recycling technologies are further categorized into three subtypes: physical recycling, energy recovery, and resource recovery. Degradation technologies are further categorized into two subtypes: biodegradation and oxo-biodegradation. Oxo-biodegradation is divided into abiotic degradation and biotic degradation. Abiotic degradation includes photodegradation, thermos degradation, mechanochemical degradation and other degradation techniques.

Recycling Technologies:

Recycling disposal methods can be further classified into various subtypes according to technical characteristics. The American Society for Testing and Materials (ASTM) standard D5033-(2000) divides recycling into four categories: primary recycling (mechanical reprocessing of scrap materials with properties similar to those of virgin plastics, named ASTM I), secondary recycling (mechanical reprocessing of used materials into products with fewer performance requirements, named ASTM II), tertiary recycling (recovery of valuable chemical intermediates in the form of gases, liquids, and even solids, named ASTM III) and quaternary recycling (recovery of the energy content of plastics by incineration, named ASTM IV) (Okan et al., 2019).

Primary recycling and secondary recycling involve mechanical reprocessing of used materials into products with little or no effects on their physical properties, which can also be considered physical recycling. Tertiary recycling involves valuable chemical intermediate recovery, while quaternary recycling involves energy recovery, which can be seen as resource recovery and energy recovery, respectively.

A) Physical recycling of NPW

This includes direct reuse, extrusion, segregation and so on. Resource recovery includes thermolysis (pyrolysis, gasification, hydrocracking) and chemolysis. Energy recovery usually refers to incineration. Due to the growing environmental problems associated with NPW, recycling methods have received widespread attention due to their environmental friendliness and economic benefits.

B) Energy recovery of NPW

More importantly, recycling methods can recover abundant valuable products such as fuels and oil. This is consistent with the theme of sustainable development advocated by countries worldwide. According to a previous report, recycling 1 ton of plastic waste will save up to ~130 million kJ of energy. The annual energy savings from recycling all global plastic waste is equivalent to 3.5 billion barrels of oil, valued at approximately $176 billion. The calorific values of PE, PP and PS are very similar to those of conventional fuels illustrating that polyolefin plastic is the most effective plastic for energy recovery from a calorific point of view. The main incineration product of carbon dioxide and water further makes it possible to replace conventional fuels. The calorific values of PVC, PET, and PA are much lower, and thus, these materials are not suitable for incineration. PVC can even generate toxic gases such as HCl that corrode equipment.

C) Resource recovery of NPW

In addition to energy recovery and mechanical recycling, obtaining valuable petrochemicals or monomers from NPW is attracting increasing attention. This is deemed resource recovery. NPW can be treated to generate a mixture containing a variety of hydrocarbon components for use as fuel. For example, polyethylene (PE) has been considered a promising feedstock for fuel (gasoline) and value-added products such as synthetic lubricants.

Resource recovery from NPW is mainly realized via thermolysis. During thermolysis, polymers, which are the major component of plastic, undergo chain scission to produce low-molecular-weight compounds and monomers. Pyrolysis, hydrocracking, gasification are different types of thermolysis technology.

In addition to thermolysis, chemolysis is another resource recycling technology. Chemolysis is also referred as solvolysis or depolymerization. Chemolysis of plastic is a process in which individual plastics can be chemically treated or depolymerized into monomers. The chemolysis reaction routes mainly include glycolysis, hydrolysis, methanolysis, and alcoholysis.

Degradation:

The technologies designed for resource and energy recovery exhibit characteristics of high energy consumption and extensive equipment requirements. Additionally, a significant drawback is that many of these technologies generate additional byproducts that are either toxic or nonrecyclable, persisting in the environment for extended periods. These challenges have prompted the exploration of alternative technologies for the degradation of non-recyclable plastic waste (NPW), each showcasing distinct advantages.

Ideally, the ultimate goal is to achieve degradation products of plastics in the form of carbon dioxide (CO2) and water (H2O). In contrast to traditional recycling methods, the degradation of plastics doesn't necessitate harsh conditions such as elevated temperatures and pressures. This deviation makes the degradation of NPW a more environmentally friendly and non-hazardous approach to waste management.

Degradation, as the name implies, in this strategy where NPW undergo a series of degradation processes eventually converted to carbon dioxide and water, which are released into the environment. The microbial degradation of plastic has attracted much attention due to its advantages of low energy consumption, complete degradation, and environmentally friendliness However, plastics people used are non-biodegradable in most cases.

To reverse this adverse situation, a large number of advanced technologies have been applied to pretreat nonbiodegradable plastics to increase their degradability by microorganisms. Mainstream pretreatment technologies can be classified into four categories: photodegradation, thermodegradation, mechanochemical degradation, and other degradation. These pretreatment technologies are combined with subsequent biodegradation treatment to achieve oxo-biodegradation.

Classifying degradation technologies into two types, biotic and abiotic, reveals distinct characteristics. Biotic technology exhibits a slow degradation rate, whereas abiotic technology operates at a faster pace. However, relying solely on abiotic technology for plastic degradation is hindered by its high energy consumption, making it unsuitable for addressing plastic pollution. Consequently, there has been substantial research interest in combining these two technologies, aiming to leverage their respective advantages and address the challenges associated with plastic waste management.

The predominant focus of research on abiotic technology lies in its impact on the physical and chemical properties of plastics rather than the mineralization rate. This emphasis aims to enhance the biodegradability of plastics by altering their inherent characteristics. In this review, degradation technology is categorized into biodegradation technology and oxo-biodegradation technology. The former utilizes microorganisms or other organisms to break down plastics into carbon dioxide and water. In the latter, the polymer undergoes various abiotic predegradation processes, such as photodegradation and thermal degradation, before being broken down into small-molecule substances. These substances can be easily degraded by microorganisms or other organisms, ultimately converting them into carbon dioxide and water. The latest trends in degradation technology include:

A) Biodegradation of plastics

The biodegradation of plastic is an environmentally friendly treatment that does not generate any by-products. Biodegradation of plastic is a process in which plastics or polymers are broken down by living organisms or microorganisms, e.g., invertebrates, bacteria, fungi and even algae . The end products of this process are CO2, H2O or another non-hazardous biomass.

B) Oxo-biodegradation

The degradation of plastic by microorganisms or invertebrates is challenged by the polymer's structure, long chains, and the presence of additives like antioxidants. Achieving complete degradation in a short time is difficult due to these factors. Consequently, plastic requires pretreatment to predecompose the polymer into forms more accessible for microorganisms. Oxo-biodegradation, extensively researched, employs a two-stage process: abiotic oxidation and biotic degradation. The initial stage utilizes techniques like photodegradation and thermal degradation to oxidize the plastic. In the subsequent stage, microorganisms biodegrade the plastic products generated in the first stage. Studies indicate that the efficiency of the abiotic degradation stage significantly impacts the overall efficiency of oxo-biodegradation. The unique property of the oxo-biodegradation process, combining abiotic and biotic technology, not only significantly reduces the time required for plastic microbial degradation but also facilitates the transformation of plastics into harmless products. This makes oxo-biodegradation a crucial and contemporary NPW treatment technology.

C) Photodegradation

Photodegradation is a process where polymers decompose by absorbing energy from light, generating free radicals, and in the presence of oxygen, it is known as photooxidative degradation. The primary light source for photodegradation is near-UV-range light (290-400 nm). Near-UV-range light, with its high energy, can cleave the C-C bond of the polymer chain. Photodegradation stands out among degradation technologies due to its unique advantage — the ability to spatiotemporally localize and control light in a facile, green, and independent manner This technique not only utilizes sunlight to degrade plastics in nature but also reduces the subsequent biodegradation time, offering the potential for complete plastic degradation.

D) Thermo degradation of plastic

It is important to highlight that thermos degradation should not be confused with pyrolysis. The primary distinction between these two methods lies in their distinct purposes: pyrolysis is geared towards fuel recovery, such as gasoline, while thermos degradation is intended to enhance subsequent microbial degradation by breaking down macromolecular polymers into small-molecule products. Unlike pyrolysis, thermos degradation typically takes place in the presence of oxygen, and the reaction temperature is lower than that required for pyrolysis.

E) Mechanochemical degradation of plastic

Mechanochemical degradation of polymers entails degradation induced by mechanical stress under strong ultrasonic irradiation. In this unique process, the polymer undergoes high vibrations, essentially experiencing a mechanical force. As ultrasonic waves traverse the solution, polymer chains undergo breakdown through sheer and mechanical forces. Chemical reactions induced by radicals further contribute to the process, ultimately leading to a reduction in molecular weight.

Other techniques for NPW treatment involve the generation of reactive oxygen species (ROS). These methods utilize reagents like ozone, the Fenton reagent, and other potent oxidant agents, such as persulfate. Consequently, the easy production of ROS is a key aspect of these degradation techniques

Conclusion

The management of plastic waste is undergoing a transformative phase, with novel trends offering promising solutions to the global challenge. From circular economy strategies to advanced technologies and changes in consumer behavior, a multi-faceted approach is essential. Collaborative efforts between governments, industries, and individuals are crucial to realizing a sustainable and effective plastic waste management ecosystem. Adopting these new trends in plastic waste management can lead to a more sustainable and environmentally friendly approach to the production, use, and disposal of plastics. These initiatives contribute to reducing plastic pollution, conserving resources, and promoting a more circular and responsible approach to plastic use in various industries.

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Shaping a new era for our globe: Sustainable Development Goals (sdgs) of United Nations

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The United Nations, founded in 1945, is currently made up of 193 Member States, and its work is guided by the purposes and principles contained in its founding Charter.[1] The UN's evolution has mirrored the rapid changes in our world over time. The present worldwide scenario of sluggish economic expansion, social disparities, and environmental deterioration poses unparalleled challenges for the international community. We stand amidst an era of transformation: persisting with past patterns of production, energy, and consumption is no longer feasible.[2] To meet these challenges, in 2015, Seventeen interconnected goals, Sustainable Development Goals (SDGs) were formulated by the United Nations General Assembly (UNGA) as an integral component of the Post-2015 Development Agenda to act as a mutual strategy guiding peace and prosperity for both humanity and the planet, spanning the present and the future (Figure 1).[3]

Figure1. Sustainable Development Goals (SDGs) of United Nations[4]

This agenda aimed to craft a new global development framework, supplanting the Millennium Development Goals, which completed in 2015. These goals were officially outlined and embraced in a UNGA resolution recognized as the 2030 Agenda (Agenda 2030). The UNGA resolution made more operationalized the SDGs by outlining precise targets for every goal and establishing indicators for tracking progress. While the majority of these targets aim for fulfillment by 2030. The core of the SDGs lies in prioritizing sustainability, highlighting the interconnectedness of environmental, social, and economic dimensions within sustainable development (Figure 2).[5]

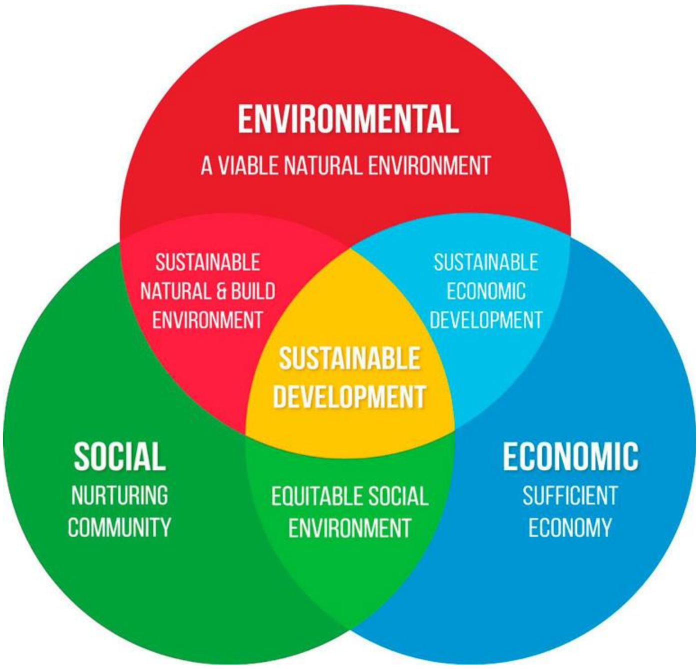

Figure 2. Representation of the balance our economic, environmental and social needs by sustainable developments[6]

The list of 17 SDGs with their targets[7]

Goal 1: End poverty in all its forms everywhere-This goal has five targets, which are eradicating extreme poverty, halving overall poverty rates, establishing social protection systems, guaranteeing equitable rights to ownership, basic services, technology, and economic resources, as well as fostering resilience against environmental, economic, and social disasters by 2030.

Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture- The five objective targets encompass: terminating hunger and enhancing food accessibility; eradicating all types of malnutrition; bolstering agricultural productivity; establishing sustainable food production systems and robust agricultural practices; and promoting the genetic diversity of seeds, cultivated plants, farmed, and domesticated animals through investments, research, and technology.

Goal 3: Ensure healthy lives and promote well-being for all at all ages- The nine targets of goal 3 are Lowering maternal mortality rates, eliminating all avoidable deaths in children under five years old, combatting communicable diseases, decreasing mortality linked to non-communicable diseases and advocating mental health, preventing and addressing substance abuse, diminishing injuries and fatalities from road accidents, ensuring widespread access to sexual and reproductive healthcare, family planning, and education, attaining comprehensive health coverage for all, reducing diseases and fatalities caused by hazardous chemicals and pollution, executing the WHO framework convention on tobacco control, backing research, development, and global access to affordable vaccines and medications, amplifying health financing and supporting healthcare workers in developing nations and enhancing early warning systems for global health threats

Goal 4: Ensure inclusive and quality education for all and promote lifelong learning- The seven objectives encompass: accessible primary and secondary education without cost barriers; equitable access to high-quality pre-primary education; affordable technical, vocational, and higher education; a rise in individuals equipped with pertinent skills for financial prosperity; eradication of all forms of discrimination in education; universal attainment of literacy and numeracy; and education geared towards sustainable development and fostering global citizenship.

Goal 5: Achieve gender equality and empower all women and girls- The different targets include eradicating all types of discrimination against women and girls globally, putting an end to violence and exploitation faced by women and girls, eliminating harmful practices including child, early, and forced marriages, as well as female genital mutilation, elevating the recognition of unpaid care work and encouraging shared domestic responsibilities, guaranteeing complete involvement of women in leadership roles and decision-making processes, ensuring universal access to reproductive rights and healthcare for all.

Goal 6: Ensure access to water and sanitation for all- The six objectives encompass: Ensuring safe and cost-effective drinking water, eradicating open defecation and ensuring access to sanitation and hygiene, enhancing water quality, wastewater treatment, and safe reuse practices, boosting water-use efficiency and guaranteeing freshwater resources, enacting Integrated

Water Resources Management (IWRM), and safeguarding and rejuvenating water-related ecosystems.

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all- There are five targets set for achievement by 2030 within this goal.[53] Monitoring progress toward these targets involves assessing six indicators.[53] Among these targets, three are outcome-oriented: Ensuring universal access to modern energy, elevating the global proportion of renewable energy sources, and doubling the advancement in energy efficiency.

Goal 8: Promote inclusive and sustainable economic growth, employment and decent work for all- Thedifferent targets for SDG 8 are: sustainable economic growth; diversification, innovation, and enhancement of economic productivity, advocacy for policies fostering job creation and expanding enterprises, enhancement of resource efficiency in consumption and production, achieving full employment and securing equitable wages, fostering youth employment, education, and training, eradication of modern slavery, trafficking, and child labor, upholding labor rights and ensuring safe work environments, encouraging beneficial and sustainable tourism and ensuring universal access to banking, insurance, and financial services.

Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation- The five targets serve as outcome objectives, which are fostering the development of sustainable, resilient, and inclusive infrastructures; advocating for inclusive and sustainable industrialization; expanding access to financial services and markets; modernizing all industries and infrastructures to prioritize sustainability; and advancing research while enhancing industrial technologies.

Goal 10: Reduce inequality within and among countries- The seven targets represent outcome objectives: diminishing income inequalities; advocating for universal social, economic, and political inclusion; guaranteeing equal opportunities and eliminating discrimination; embracing fiscal and social policies that advance equality; refining the regulation of global financial markets and institutions; amplifying representation for developing countries in financial institutions; and establishing responsible, well-managed migration policies.

Goal 11: Make cities inclusive, safe, resilient and sustainable- The seven outlined outcome targets encompass ensuring safe and affordable housing, establishing affordable and sustainable transportation systems, promoting inclusive and sustainable urban development,[64] safeguarding the world's cultural and natural heritage, mitigating the adverse effects of natural disasters, curbing the environmental impacts of cities, and facilitating access to safe and inclusive green and public spaces.

Goal 12: Ensure sustainable consumption and production patterns- The eight targets serve as outcome objectives, aiming to: implement the 10-Year Framework of Programs on Sustainable Consumption and Production Patterns; attain sustainable management and efficient utilization of natural resources; halve per capita global food waste at retail and consumer levels, alongside reductions in food losses throughout production and supply chains, including post-harvest losses; achieve environmentally sound management of chemicals and wastes across their life cycles; curtail waste generation through prevention, reduction, recycling, and reuse; encourage businesses to adopt sustainable practices; advocate for sustainable public procurement practices; and ensure widespread access to relevant information and awareness for sustainable development.

Goal 13: Take urgent action to combat climate change and its impacts- SDG 13 has three main targets set for attainment by 2030, addressing diverse facets of climate action. They are focusing on: reinforcing resilience and adaptability to climate-related disasters; integrating climate change measures into policies and planning frameworks; and fostering knowledge and capacity to effectively address climate change.

Goal 14: Conserve and sustainably use the oceans, seas and marine resources- The initial seven targets serve as outcome objectives: lessening marine pollution; safeguarding and rehabilitating ecosystems; mitigating ocean acidification; promoting sustainable fishing practices; preserving coastal and marine areas; discontinuing subsidies that exacerbate overfishing; and amplifying the economic advantages derived from the sustainable utilization of marine resources.

Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss- The nine outcome targets encompass: Preserving and rejuvenating terrestrial and freshwater ecosystems; halting deforestation and reviving degraded forests; halting desertification and restoring degraded land; guaranteeing the conservation of mountain ecosystems and safeguarding biodiversity and natural habitats; safeguarding access to genetic resources and ensuring equitable sharing of benefits; eradicating poaching and trafficking of protected species; preventing the spread of invasive alien species in terrestrial and aquatic ecosystems; and incorporating ecosystem and biodiversity considerations into governmental planning.

Goal 16: Promote just, peaceful and inclusive societies- SDG 16 consists of ten outcome targets aimed at: diminishing violence; shielding children from abuse, exploitation, trafficking, and violence; advocating for the rule of law and guaranteeing equitable access to justice; combating organized crime and curbing illicit financial and arms flows, notably reducing corruption and bribery; establishing effective, accountable, and transparent institutions; fostering responsive, inclusive, and representative decision-making; reinforcing engagement in global governance; facilitating universal legal identity; ensuring public access to information and safeguarding fundamental freedoms.

Goal 17: Revitalize the global partnership for sustainable development- The Goal comprises 17 targets slated for achievement by 2030, categorized into five sections: finance, technology, capacity building, trade, and systemic issues.

In conclusion, This Agenda encapsulates the anticipations, ambitions, and foremost concerns of the global community for the next 15 years. It stands as a transformative Agenda, spotlighting equality and dignity as paramount, and advocates for an evolution in our developmental approach while upholding environmental integrity.

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