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Review Paper

A Comprehensive Review On: Effect of Green Chemistry on Industry

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ABSTRACT

The integration of green chemistry principles into industrial processes has transformed the way businesses approach sustainability, environmental stewardship, and economic growth. This comprehensive review examines the far-reaching impacts of green chemistry on various industries, highlighting environmental, economic, and social benefits. A thorough analysis of existing literature reveals significant reductions in greenhouse gas emissions, water conservation, and waste minimization, alongside improved resource efficiency, cost savings, and enhanced product quality. The review also explores industry-specific applications, including chemical, pharmaceutical, textile, and energy sectors. Furthermore, it identifies challenges, opportunities, and future directions for green chemistry adoption, emphasizing the need for scalability, regulatory frameworks, and public awareness. This review provides valuable insights for policymakers, industry leaders, and researchers seeking to harness the potential of green chemistry for a more sustainable and responsible industrial future.

INTRODUCTION

Green chemistry, also known as sustainable chemistry, is a field of chemistry that focuses on designing products and processes that minimize the use and generation of hazardous substances. The overarching goal of green chemistry is to reduce the negative impact of chemical processes on human health and the environment. The aim is to promote the development of products and processes that are economically viable, environmentally friendly, and socially responsible. One key aspect of green chemistry is the consideration of the entire life cycle of a chemical product.[1] The key target of green or sustainable chemistry is making available to mankind useful compounds and materials, while causing no harm to the environment.[2]

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Figure No. 1[3]

It is a field of chemistry and chemical engineering concerned with designing products and processes that reduce the use and production of dangerous materials. While environmental chemistry is concerned with the effects of chemical pollutants on nature, green chemistry focuses on technological approaches to preventing pollution and reducing the consumption of non-renewable resources (Sanderson, 2011). Therefore, in this review we have summarized the emergence, principles and future directions of green chemistry that would be future of industrial sectors for combating emissions and environmental pollution.[4] In general, green chemistry relates to matters in minimizing waste at the source, the use of catalysts in reactions, the use of harmless reagents, the use of renewable base materials, increased economic efficiency, solvents that are environmentally friendly and can be recycled.[5]

History Of Green Chemistry

The term green chemistry was first given by Poul T. Anastas in 1991 in special program launched by the US environmental Protection Agency (EPA) to implement sustainable development in chemistry ,chemical technology by industry ,academia and government. In 1995 the annual US presidential green chemistry challenge was announced. The first book and journals on the subject of green chemistry were introduced in 1990 by the royal society of chemistry. Green chemistry includes a new approach to the synthesis, processing and application of chemical substances in such a manner to reduce scourge to health and environment like :

- Clean Chemistry
- Atom economy
- Environmentaly benign chemistry.[2]

Salient Features Of Green Chemistry

Green chemistry considered sustainable due to seversl important respects:

- When compared to other traditional synthesis methods, green chemistry typically has lower costs at a high level of sophistication. than chemistry as it is generally practised (not to mention environmental expenses).
- By effectively utilising materials, maximising recycling, and utilising minimal amounts of new raw materials, green chemistry is also sustainable in terms of materials.
- In terms of wastes, green chemistry is sustainable by minimising or even completely eliminating their generation.

Prior to gaining their current importance, environmental, health, and safety issues were less important from an economic standpoint than they are today. Costs of feedstock, energy requirements, and product marketability were among the economic considerations at play. However, expenses now have to take liability, end-of-pipe waste treatment, compliance with regulations, and disposal costs into account.[6]

Benefits of Green Chemistry

- **Benefits for Human Health**

✓ Cleaner air- less release of hazardous chemicals to air leading to less damage to lungs.

✓ Cleaner water-less release of hazardous chemical wastes to water leading to cleaner drinking.

✓ Increase safety for worker in chemical industry, less use of toxic materials, less potential for accident.

- **Benefits for environment**

- ✓ Plant & Animals suffer less harm from toxic chemicals in environment.
- ✓ Lower potential for global warming, ozone depletion and smog formation.
- ✓ Fewer use of landfills, with a special focus on dangerous waste landfills.
- **Economy and Business**
- ✓ Better performance so that less product is needed to achieve the same function.
- ✓ Decrease steps of production in factories.
- ✓ Increase competition of chemical producers and their customers.[7,8]

Principles of Green chemistry

Twelve principles of green chemistry have been developed by Poul Anastas, speaks about the reduction of dangerous or harmful substances from the synthesis, production and application of chemical products. When designing a green chemistry process it is impossible to meet the requirements of all twelve principles of the process at the same time, but it attempts to apply as many principles during certain stages of synthesis.

1. Prevent waste: It is more effective not to produce waste than to treat or clean it up after it has been produced.

2. Atom economy: Synthetic procedures should be planned to optimize the incorporation of all substances used in the process into the final product.

3. Design less dangerous chemical syntheses: Wherever pragmatic, synthetic procedures should be figured to use and manufacture materials that cause little or zero toxicity to people or the environment.

4. Produce safer chemicals and products: Chemical products should be produced to conduct their coveted function while minimizing their perniciousness.

5. Safer solvents and auxiliaries' substances: The use of auxiliary substances (e.g., solvents or separation agents) should be made unnecessary whenever possible and innocuous when used.

6. Increase energy efficiency: Energy requirements of chemical procedures should be distinguished for their environmental and economic effects and should be minimized. If possible, synthetic procedures should be carried out at environmental temperature and pressure.

7. Use renewable feedstocks: A raw material or feedstock should be renewable rather than consumed whenever technically and economically pragmatic.

8. Avoid chemical derivatives: Not needed derivatization (use of blocking groups, protection protection, and not permanent alteration of physical chemical procedures) should be minimized or refrained, if possible, because such steps need extra reagents and can produce waste.

9. Use catalysts, not stoichiometric reagents: Catalytic reagents (as optional as possible) are high to stoichiometric reagents.

10. Produce chemical substances and products to be reduced after use: Chemical products should be produced so that after their function they decay into harmless degradation products and do not last for long time in the environment.

11. Analyse in real time to prevent contamination: Analytical methodologies are necessary to be further advanced to enable for real-time, in-process tracking and control prior to the formation of harmful substances.

12. Minimize the potential for accidents: Substances and the form of a substance used in a chemical procedure should be selected to minimize the risk of chemical accidents, including releases, explosions, and fires.[7]

Figure No. 2 Depiction of Green Chemistry principle given by Anastas & Warner.[9]

Effects of Green chemistry on industry

Green chemistry has many effects on industry, including:

- Reduced use of hazardous substance
- Safer chemicals & products
- Increased efficiency
- Reduced waste
- Improved sustainability
- Increased competitiveness
- Reduced energy use

Figure No. 3[3]

Reduced use of hazardous substance

One of the primary goals of green chemistry is to minimize the production of hazardous waste during chemical processes. Traditional manufacturing processes often generate significant quantities of toxic by-products that require complex and costly disposal methods. Green chemistry offers solutions by redesigning processes to reduce or eliminate hazardous waste at the source. This waste minimization is achieved through innovations such as atom economy, where chemical reactions are designed to maximize the incorporation of all materials into the final product. Atom economy ensures that fewer harmful by-products are generated, making the process both more efficient and environmentally friendly. Another key approach to minimizing hazardous waste is the use of benign solvents and reagents. In conventional chemical processes, toxic organic solvents are commonly used, contributing to environmental pollution and health risks. Green chemistry promotes the replacement of these hazardous solvents with safer alternatives such as water, supercritical carbon dioxide, and ionic liquids. These solvents are non-toxic, more environmentally benign, and often recyclable, significantly reducing the environmental impact of chemical processes. Additionally, the development of catalysis has played a critical role in waste reduction. Catalysts increase the efficiency of chemical reactions, allowing processes to proceed with fewer reagents and under milder conditions. This not only reduces energy consumption but also limits the formation of unwanted by-products. Catalysis has been successfully implemented across various industries, including pharmaceuticals and petrochemicals, to enhance atom economy and reduce hazardous waste generation. By promoting more selective reactions, catalysis enables industries to minimize waste while optimizing resource use.[10]

Safer chemicals & products

Chemical products should be designed to achieve their desired function with at the same time minimizing their toxicity. New products can be designed that are inherently safer, while highly effective for the target application. For example, the direct incorporation of radioactive spent liquid scintillation waste into cement combined with clay materials is considered an added value in the immobilization of the hazardous organic wastes in very cheap materials and natural clay to produce a safe stabilized product easy for handling, transformation, and disposal.[11]

Diverse applications of green chemistry

- **Pharmaceuticals:** Designing environmentally friendly synthesis routes for pharmaceutical compounds. Reducing the use of toxic solvents and reagents in drug manufacturing. Developing greener methods for waste disposal in pharmaceutical production.
- **Agrochemicals:** Creating environmentally benign pesticides and fertilizers. Designing crop protection chemicals with reduced ecological impact. Developing sustainable practices in agriculture to minimize chemical inputs.
- **Materials Science:** Innovations in the production of polymers, plastics, and composites with reduced environmental impact. Recycling and upcycling strategies for materials to minimize waste.
- **Energy Production:** Developing green technologies for renewable energy sources, such as solar cells and batteries. Designing catalysts for cleaner and more efficient energy conversion processes.
- **Textile Industry:** Implementing sustainable practices in dyeing and finishing processes. Developing eco-friendly alternatives to traditional textile treatments.
- **Food Industry:** Designing green processes for food preservation and packaging. Developing sustainable practices for agriculture and food processing.
- **Waste Management**: Implementing green chemistry principles in the treatment and disposal of hazardous waste. Designing processes to minimize waste generation recycling.[1]

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