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Green Chemistry in Organic Synthesis

Dr. Thasnim. P

Department of Chemistry, KAHM Unity Women's College, Manjeri,
Narukara (PO), Malappuram (Dt), Kerala, Pin: 676122
E-mail: thasnim6390@gmail.com

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.

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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.

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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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