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REVIEW ARTICLE

An Over view of Green Chemistry

Sharmila M*[1], Gayathri Devi N B S[2], Sharmila N[2], Sai Teja P B S N[2]

[1] *Asst. Professor, Sri Vasavi Institute of Pharmaceutical Sciences, Tadepalligudem, Andhra Pradesh, India*
[2] *Student, B. Pharmacy, Sri Vasavi Institute of Pharmaceutical Sciences, Tadepalligudem, Andhra Pradesh, India*

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Abstract: Over the past decade, green chemistry principles have demonstrated the potential to protect human health and the environment while reducing costs through the design of chemical products and processes. Products and methods designed according to principles that support life-cycle sustainability could form the basis of an environmentally benign chemical enterprise. While the Pollution Prevention Act of 1990 established a regulatory framework supporting green chemistry's development, its origins can be traced to earlier scientific efforts to minimize waste and hazards. Effective implementation of green chemistry principles requires overcoming challenges in systematically redesigning chemical synthesis routes. This review explores the historical context of green chemistry's growth, current applications across sub-disciplines like organic synthesis, and strategies to advance education and further innovation through alternative solvents and other design approaches. It examines progress in applying green chemistry concepts, remaining barriers, and promising future directions for more sustainable chemical technology.

Keywords: Green chemistry; Organic solvents; Environment; Sustainability; Pollution; Eco-friendly

1. Introduction

Green chemistry aims to reduce or eliminate the use of potentially hazardous substances in chemical products and their production processes. [1-3] It considers the full life cycle of a chemical product from its design, manufacture, use, and final disposal or recycling. The term 'green chemistry' emerged in the early 1990s to describe the design of chemical syntheses and technologies that are environmentally benign. [4-6] Significant early initiatives driving the development of green chemistry principles included the US Presidential Green Chemistry Initiative, launched in 1995, the formation of the Green Chemistry Institute in 1997, and the inaugural publication of the Royal Society of Chemistry's journal Green Chemistry in 1999. [7-9]

In the 1990s, Paul Anastas and John Warner proposed the 12 principles of green chemistry that provide a framework for synthesizing chemicals and designing production processes through safer, non-waste generating methods. This built upon earlier regulatory actions like the 1990 Pollution Prevention Act that established a foundation for reducing environmental impacts from the chemical industry. [10] Paul Anastas is widely recognized for pioneering the field of green chemistry through his research and promotion of its concepts. Nobel prizes in Chemistry have also recognized research advancing green chemistry goals, such as the awards to Knowles, Noyori, and Sharpless in 2001 for developments in asymmetric catalysis and to Chauvin, Grubbs, and Schrock in 2005 for advancements in metal-catalyzed olefin metathesis. [11]

2. Principles of Green Chemistry

The 12 main ideas of Green Chemistry are:

2.1. Prevent waste

Chemical syntheses should be designed to prevent the generation of byproducts and waste materials. This maximizes atom efficiency and mass yield. [12]

2.2. Design safer chemicals & products

The design of chemical products should reduce their potential to cause harm to living organisms and the environment. Toxicity concerns should be evaluated early in the design process through tools like quantitative structure-activity relationship modeling. [13]

* Corresponding author: Sharmila M

2.3. Design less hazardous chemicals synthesis

Synthetic methodologies should be selected or designed to minimize the use and generation of hazardous substances during chemical production. This involves considerations like choosing starting materials and reagents with low inherent hazards. [9,10]

2.4. Use safer solvents/Reactions conditions

Where possible, synthetic processes should be designed to use and generate substances with little or no toxicity to humans and the environment. This involves preferring safer solvents, separation agents, and auxiliary substances over more hazardous alternatives. Water is generally the most suitable solvent. [14]

2.5. Increase energy efficiency

Chemical syntheses should be performed at ambient temperature and pressure conditions whenever feasible. Doing so reduces energy input and avoids energetic side reactions that may generate hazardous byproducts. [12-14]

2.6. Use renewable feedstocks

The source materials or feedstocks used in chemical processes should ideally be renewable rather than depleting finite resources like fossil fuels. Agricultural products and biomass offer attractive renewable raw material alternatives. [12]

2.7. Design for degradation

Chemical products should be designed so that at the end of their function, they break down into innocuous degradation products and do not persist in the environment. Biodegradability is an important design consideration. [12]

2.8. Minimize chemical accidents

The forms and conditions under which chemicals are synthesized and handled should be selected so as to prevent explosions, fires, and unintended releases. Safer processes minimize risks to human health and the community. [14]

2.9. Use real time analysis

Incorporating analytical measurements at each step of a chemical process enables pollutants and hazards to be detected and controlled before they form, allowing problems to be corrected at the source. [14]

2.10. Catalyze rather than stoichiometrically generate reagents

Using catalytic reagents is preferred as it requires smaller quantities, generates less waste, and is more atom efficient than equimolar reagent systems. Catalysts can perform multiple turnover cycles. [14]

2.11. Maximize atoms economy

Synthetic designs should maximize incorporation of all starting material atoms into the desired product structure. Intermediates and byproducts containing unused starting material atoms represent wasted resources and ineffective atom utilization. [14]

2.12. Avoid chemical derivatives

Derivatization leads to additional steps and waste byproducts. Reactions should be designed to minimize temporary protecting/blocking groups and functionality changes, simplifying synthesis and reducing effort and potential waste. [14]

3. Green Chemistry methods

Examples of Green Chemistry methods are:

- Green solvents
- Synthetic techniques
- Carbon dioxide as a blowing agent
- Hydrazine
- 1,3 propanediol
- Lactide
- Carpet tile backings
- Bio-succinic acid
- Transesterification of fats

Green solvents are widely used in paints and coatings applications due to their role as carriers and diluents in these formulations. Other common uses of solvents that could potentially employ green alternatives include chemical synthesis, degreasing, cleaning, and adhesive formulations.[12-15]

Traditional organic solvents are often derived from non-renewable fossil fuels and can pose environmental and health hazards. Chlorinated solvents like dichloromethane are widely used but pose toxicity concerns. Green solvents aim to provide more sustainable alternatives with lower hazards. However, the life cycle environmental impacts of producing some green solvents from biomass must also be considered to avoid simply shifting impacts.[16]

An ideal green solvent exhibits low toxicity during use, can be manufactured from renewable resources, and breaks down harmlessly after use. Supercritical carbon dioxide has received attention as an nontoxic, nonflammable alternative for organic reactions and extractions. Advancements in asymmetric catalysis and its application in enantioselective organic synthesis have also helped develop new greener reaction methods.[17-18]

In polymer science, carbon dioxide has proven useful as an environmentally preferable blowing agent for producing polystyrene foam, replacing more hazardous hydrocarbon blowing agents. Dow Chemical developed a purely carbon dioxide blowing process for insulation foam manufacture, earning an award for this innovative green technology.[19-21]

Hydrazine synthesis conventionally generates sodium chloride as a stoichiometric byproduct via the Olin Raschig process. Researchers developed an alternative peroxide method that avoids salt coproduction, fulfilling green chemistry principles of preventing waste. [22,23]

$$NaOCl + 2NH_3 \longrightarrow H_2N\text{-}NH_2 + NaCl + H_2O$$

The production of 1,3-propanediol from renewable feedstocks like corn sugar via fermentation is an example of a green biochemical transformation. This diol is then used to synthesize new polyesters for carpets. Cargill Dow also received recognition for work on producing polylactic acid biomaterials, though technical challenges remained.[24]

Show Industries developed a polyolefin resin backing for commercial carpet tiles that provides robust performance while featuring renewable raw materials and recyclability, meeting several green chemistry metrics. BioAmber received an award for commercial scale biomanufacturing of bio-based succinic acid building block chemicals from fermentation. [25-27]

Enzymatic interesterification allows food manufacturers to modify plant-derived oils in a mild, specific manner to control fat compositions for health and structured without generating trans fats. This earned Novozymes and ADM recognition for developing a greener chemical process [28]

4. Reported methods on Green Synthesis

4.1. Synthesis of 2-Acetylnaphthalene chalcone derivatives by Arora et al.

Arora et al. reported the synthesis of chalcone derivatives 1a–g by the Claisen–Schmidt condensation of 2-acetylnaphthalene with benzaldehyde or substituted benzaldehydes in methanol using potassium hydroxide as the base catalyst. The chalcone products were evaluated for their antibacterial and antifungal properties, with some demonstrating activity.[32] This reaction meets several green chemistry principles by executing a carbon-carbon bond forming reaction under mild conditions without the need for stoichiometric reagents or solvents.[29-32]

4.2. Synthesis of acetamido chalcone derivatives by P.S.G. et al.

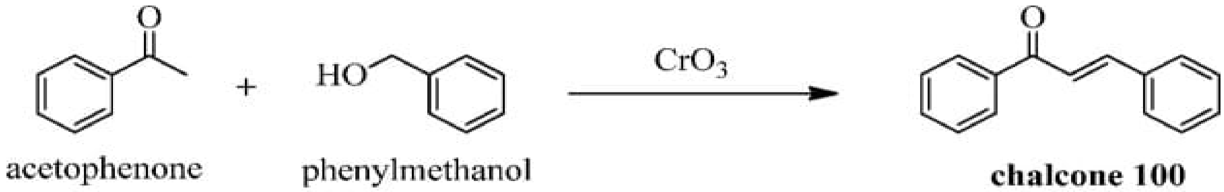
P.S.G. Patil et al. described the synthesis of chalcone derivatives by treating 4-acetamidoacetophenone (9) with substituted aldehydes in ethanol using potassium hydroxide as the base catalyst. The reaction mixtures were sonicated for 10-15 minutes using an ultrasonic water bath. This methodology provides a facile, solvent-free pathway to chalcone products under mild conditions.[33,34]

4.3. Chalcone derivatives from 1,3- and 1,4-diacetylbenzene

Several reports detail the synthesis and biological evaluation of chalcone derivatives prepared from 1,3,5-triacetylbenzene, 1,3- and/or 1,4-diacetylbenzene, and 4-hydroxy-3-methoxybenzaldehyde using acid catalysts such as sulfuric acid, phosphoric acid, hydrochloric acid and acetic acid.[35] The highest yields were attained using concentrated sulfuric acid in ethanol. However, these reaction conditions employ non-green acids and potential safety issues.

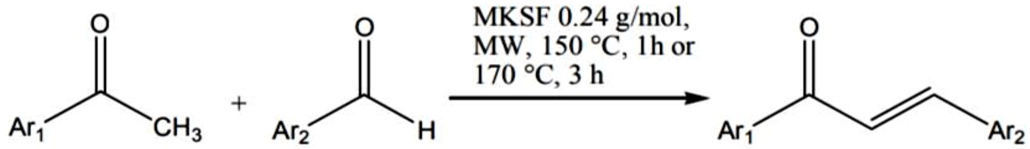
4.4. One-pot microwave-assisted synthesis of chalcones by Mahapatra et al.

Mahapatra et al. demonstrated a solvent-free, one-pot synthesis of chalcone 100 by treating phenylmethanol 105 and acetophenone with CrO_3 under microwave irradiation.[36] This green protocol achieved the transformation using non-toxic oxidizing and heating agents.



4.5. Green synthesis of chalcones under microwave irradiation

Myriad reports detail the green synthesis of chalcones via Claisen–Schmidt condensations under microwave heating conditions. This approach reduces reaction times and improves atom efficiency relative to thermal heating methods. [37]



5. Conclusion

The field of green chemistry research is not a new one. It's a fresh conceptual approach that, if implemented and expanded upon, might result in significant advances in chemistry, the chemical industry, and environmental preservation. Green chemistry principles and practical knowledge and practices should be imparted to chemists of the future. Currently, it is simple to locate several really intriguing instances of the application of Green Chemistry laws in the literature. These concepts apply not just to the synthesis of chemicals but also to their processing and usage. There are now a number of cutting-edge analytical methods that adhere to Green Chemistry guidelines. When it comes to performing chemical reactions and determining their environmental impact, these methods are especially useful. Green chemistry is going to be useful and appealing for many decades to come. Numerous environmental issues are to be addressed by this strategy. The widespread adoption of environmentally friendly and waste-free technology developed during the research phase is not assured. More flexible laws, new programs to expedite technical transfer between governments and universities, and tax breaks for companies utilizing greener technologies are just a few ways to ensure the adoption of such technologies in industry. Through our use of the conveniences of modern civilization, we all harm the ecosystem and owe Mother Nature a debt. Green Chemistry education will enable future generations of chemists handle a range of environmental concerns on a national, regional, and global scale and will also increase their competitiveness in the global economy. We will be well on our way to achieving our goal and reaping the rewards of our labors for upcoming generations of chemists and other experts if we start teaching Green chemistry now.

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Author’s short biography

Sharmila M:

Sharmila M holds a Master's degree in Pharmaceutical Chemistry and serves as an Associate Professor at Sri Vasavi Institute of Pharmaceutical Sciences, bringing 15 years of teaching experience to her role

Gayatrhi Devi N B S:

Gayatrhi Devi N B S is currently in her final year, 8th semester, pursuing a Bachelor of Pharmacy degree at Sri Vasavi Institute of Pharmaceutical Sciences, with a keen interest in pharmaceutical chemistry

Sharmila N:

Sharmila N is currently in her final year, 8th semester, pursuing a Bachelor of Pharmacy degree at Sri Vasavi Institute of Pharmaceutical Sciences, with a passion for organic chemistry

Sai Teja P B S N:

Sai Teja P B S N is currently in his final year, 8th semester, pursuing a Bachelor of Pharmacy degree at Sri Vasavi Institute of Pharmaceutical Sciences, with a strong interest in acquiring practical knowledge of chemistry