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Green Chemistry Approaches in Medicinal Chemistry

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Abstract

One area of study that has gained global interest in analytical chemistry is "green chemistry." Green analytical innovations have been put forward to reduce toxicity without compromising analytical performance. This could be shown at every stage of the analysis by reducing operational risk and contamination of the environment via reduced chemical use and waste production. In this article, review the various researcher's study on green chemistry approaches in medicinal chemistry. The article concluded that green nanotechnology plays a crucial role in therapeutic advancements, including antidiabetic and anticancer treatments, by facilitating targeted drug delivery with reduced toxicity to healthy tissues. The development of green analytical methodologies, assessed through tools like GAPI and Eco-Scale, further supports sustainable pharmaceutical practices. green chemistry offers a sustainable approach to pharmaceutical R&D, reducing environmental impact while maintaining high efficacy in drug design. With continued innovation and investment, green chemistry is set to transform medicinal chemistry, ensuring safer and more sustainable drug development for the future.

Keywords; Green chemistry approaches, Medicinal chemistry, Drug design, Green solvents, Nanoparticles, Pharmaceutical chemistry, Green nanotechnology, etc.

1 Introduction

To increase environmental protection and the economics of chemical manufacture, new chemistry is needed. For creative chemistry research and applications, chemists, researchers, and industry leaders find the green chemistry notion to be an alluring technology. First and foremost, green

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chemistry is defined as minimising environmental harm when producing materials and minimising and appropriately disposing of waste produced during various chemical processes [1]. A other definition of green chemistry is a novel approach to the synthesis, processing, and use of chemical resources in a way that reduces risks to the environment and people [2]. The concept of green chemistry has given rise to a number of new terms, including eco-efficiency, sustainable chemistry, atom economy or efficiency, process intensification and integration, inherent safety, product life cycle analysis, ionic liquids, alternative feedstocks, and renewable energy sources [3]. Therefore, there is a pressing need to advance synthetic and engineering chemistry, either by employing environmentally benign starting materials or by carefully planning innovative synthesis pathways that leverage contemporary energy sources to produce less harmful compounds [4], [5].

A. Green chemistry

An field of chemical engineering and chemistry known as "green chemistry," or "sustainable chemistry," is concerned with creating goods and procedures that utilise and produce fewer or no hazardous materials. A number of pre-existing concepts and research initiatives (such as atom economy and catalysis) gave rise to green chemistry in the years before the 1990s, when concerns about resource depletion and chemical pollution gained more attention [6]. Green chemistry's rise in both Europe and the US was associated with a change in how environmental issues were approached: from command-and-control regulation and the requirement to cut industrial emissions at the "end of the pipe," to actively preventing pollution by innovatively designing production technologies [7]. In the middle to late 1990s, the group of ideas that are today known as "green chemistry" came together, and the phrase itself gained popularity, defeating rival names like "clean" and "sustainable" chemistry [8]. Through its financing, professional coordination, and pollution control initiatives, the Environmental Protection Agency spearheaded the development of green chemistry in the United States. University of York academics helped launch the journal Green Chemistry and create the Green Chemistry Network inside the Royal Society of Chemistry in the United Kingdom at the same time [4].

B. The impact of green chemistry on the environment and population

By lowering the amount of resources required to perform analytical procedures, including solvents, solutions, water, and organic compounds, as well as their storage, green chemistry makes a significant contribution to the economy. The use of GAC in pharmaceutical analysis makes it possible to replace hazardous compounds with safe and sustainable substitutes, resulting in the transition from waste to clean waste [9]. A significant impact on environmental samples and undesired environmental elements has been seen as a result of the current surge in analytical activity. Pharmaceutical analysis residues must be recycled and pre-treated in order to be released back into the environment with the fewest possible negative consequences. However, these procedures are costly, which raises additional financial concerns that scientists should be mindful of [10]. Thus, it is necessary to recycle both online and offline, with the added advantage of recovering expensive and hazardous chemicals. Recycling shouldn't, however, lower the sample throughput or compromise the techniques' accuracy and precision. However, the population is affected by pharmaceutical activity in a variety of ways and across a range of fronts. Various analytical methods, reagents, solvents, operators, and strategies that affect the patient are used to make medication [11].

C. Importance of sustainable synthesis of biologically active compounds

Green synthesis uses renewable energy sources to generate electricity while maximising consumption and minimising energy waste. Pharmaceutical companies generate 1.27 trillion dollars a year, making them the top contributors to the world economy. However, they also contribute significantly to the carbon footprint, generating more than 1.9 million tonnes of CO_2 yearly. Ten years ago, the concept of environmental preservation was originally put out, but due to a lack of industrial participation, many of the programs failed. Controlling production and identifying processes to reduce their environmental effect have always been goals of the industrial nations, but these industries were never satisfied with the earlier ideas [12].

D. Relevance of Green Chemistry in Medicinal Chemistry

Green chemistry plays a crucial role in medicinal chemistry by promoting environmentally friendly practices in the synthesis, design, and production of pharmaceutical compounds. By using renewable feedstocks and atom economy, the environmental impact of drug production is reduced and efficiency is raised. Additionally, cleaner chemicals and solvents lead to fewer hazardous drugs, improving environmental outcomes and patient safety. Green chemistry helps medicinal chemists create more sanitary synthetic routes for active pharmaceutical agents (APIs). The industry decreases unwanted byproducts by replacing more hazardous chemicals with safer ones and using catalysis to boost reaction efficiency [13].

E. Reduction of hazardous waste in pharmaceutical production

The use of more environmentally friendly synthesis techniques greatly lowers the amount of hazardous waste generated during the manufacturing of pharmaceuticals. For instance, it has been shown that using flow chemistry and microwave-assisted synthesis improves reaction efficiency and reduces waste production. Compared to conventional batch procedures, flow chemistry allows for exact control over reaction conditions, which results in greater yields and fewer byproducts. Furthermore, since enzymes may be extremely selective and usually function in moderate environments, biocatalysis often produces less harmful byproducts, improving atom economy and reducing environmental impact [12].

2 Literature Review

(Gavanaroudi, 2024) [14] To address this significant flaw, the creation of nanoparticles from microbes or plants may be helpful in creating biocompatible nanoparticles. Utilising plant extracts to create nanoparticles simplifies and expedites the synthesis process. In actuality, the production of nanoparticles may be accomplished without the requirement to grow and preserve cells thanks to extracellular synthesis. To date, the production of metal nanoparticles, particularly gold, has been accomplished by the use of plant extracts. Examples of these plants include cinnamon, eucalyptus black tea, and sweet root.

(KHAN A et al., 2024) [8] As environmental safety becomes more of a concern, green chemistry is growing rapidly, and chemists are finding it more and more challenging to create new goods, processes, and services that satisfy the social, financial, and environmental requirements. Current green chemistry and its use in illness treatments are briefly discussed in this article, along with green chemistry in nanotechnology. The elements influencing the environmentally friendly production of nanoparticles are also covered. An overview of the present state of green chemistry and its application to pharmaceutical chemistry, toxicology, and pharmacology is provided in this study.

(Onagun & Gbenga, 2024) [12] investigates innovative green chemistry techniques, with a focus on waste minimisation, atom economy, and the use of renewable feedstocks to create biologically active chemicals. Safer solvent substitutes, flow chemistry, and biocatalysis are important developments that show the way to effective, less harmful medication manufacturing. These sustainable approaches have a great deal of promise to lessen the environmental toxicity and carbon footprint of pharmaceuticals, while being hindered by industrial and governmental limitations. The industry may enhance public health, solve urgent ecological issues, and promote a paradigm change towards sustainable pharmaceutical manufacture by using green approaches.

(Parvez et al., 2023) [15] Green chemistry has gained traction and been embraced by the organic and pharmaceutical industries. In order to reduce waste, use renewable resources, create biodegradable materials, and use less energy, Green Chemistry was established. Green chemistry examined the different chemical-related catastrophes brought on by toxicity (whether they were cancerous or explosive), physical hazards (whether they were flammable or explosive), and worldwide threats. (Depletion of stratospheric ozone or climate change). Green chemistry's guiding principles fall into two categories: "Reducing Risk" and "Minimising the Environmental Footprint." This particular study offers a succinct overview of current developments and applications of green chemistry concepts to daily tasks, chemical reactions, economics, pharmacy procedures, and analytical chemistry to produce new drug molecules.

(Rubab et al., 2022) [16] By creating environmentally friendly catalysts, green solvents, using microwave and ultrasonic radiation, solvent-free, grinding, and chemo-mechanical techniques, synthetic chemists can overcome the challenges of conventional synthesis, including slow reaction rates, unhealthy solvents and catalysts, and lengthy reaction completion times. A preferred structural motif with a variety of pharmacological and medical uses, 1,2,4-thiadiazole is a member of the class of heterocycles combining nitrogen and sulphur. In order to build various 1,2,4-thiadiazole scaffolds, this thorough review systematises the types of green solvents, green catalysts, ideal green organic synthesis characteristics, and green synthetic approaches like microwave irradiation, ultrasound, ionic liquids, solvent-free, metal-free conditions, green solvents, and heterogeneous catalysis.

(de Marco et al., 2019) [17] An important turning point in the global economic history was the expanding industrialisation process. The development of analytical techniques is one of the most active areas of research and development in green chemistry, leading to the creation of so-called green analytical chemistry. This paper describes the multifaceted effects of green chemistry on pharmaceutical analysts, the environment, the public, analysts, and companies. Every decision and critical mindset has an impact on the finished product as well as everything around it. This study also considers the future of green chemistry, our future, and the environment.

(Gupta & Mahajan, 2015) [18] The rapidly evolving discipline of "green chemistry" offers a path towards the sustainable advancement of science and technology in the future. It may be used to create synthetic delivery systems that are safe for the environment and can save lives while delivering life-saving medications. Chemical engineers and chemists are anticipated to develop more sustainable and environmentally friendly chemical methods for medication design, and this trend is probably going to keep expanding over the next decades. This study outlines environmentally friendly procedures for using the concepts of green chemistry to synthesise certain FDA (Food and Drug Administration)-approved medications that are in high demand and have stringent chemical and optical purity standards.

3 Conclusion

Green chemistry has revolutionized medicinal chemistry by enabling environmentally friendly synthetic processes with minimal toxic byproducts. The green synthesis of nanoparticles using biological sources such as bacteria, fungi, and plant extracts has demonstrated promising applications in disease diagnosis, drug delivery, medical imaging, and environmental remediation. Green nanotechnology plays a crucial role in therapeutic advancements, including antidiabetic and anticancer treatments, by facilitating targeted drug delivery with reduced toxicity to healthy tissues. The development of green analytical methodologies, assessed through tools like GAPI and Eco-Scale, further supports sustainable pharmaceutical practices. Despite its growing acceptance, the full potential of green chemistry in drug manufacturing requires greater investment in education and research. Additionally, a deeper understanding of technical aspects, such as acoustic power and reactor geometry in ultrasound-assisted synthesis, is needed to optimize reaction mechanisms and enhance efficiency. While challenges remain, green chemistry offers a sustainable approach to pharmaceutical R&D, reducing environmental impact while maintaining high efficacy in drug design. With continued innovation and investment, green chemistry is set to transform medicinal chemistry, ensuring safer and more sustainable drug development for the future.

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