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Environmentally Friendly Compound Preparation with Green Chemistry Principles from Past to Present

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ABSTRACT

Many syntheses can be made by physical, chemical or biological methods. However, these methods have many disadvantages such as the use of toxic chemicals harmful to humans, animals, plants and the environment during the synthesis phase, high energy requirement and cost. Researchers have started to work on reducing or eliminating these negative effects in recent years. For this purpose, the concept of Green Chemistry emerged. Green chemistry, also called sustainable chemistry, is a field of chemical and chemical engineering that focuses on the design of products and processes that will minimize or eliminate the use and production of hazardous substances. It play an important roles in biomedicine, nanomedicine, regenerative medicine, pharmaceutics, environmental remediation, catalysis, etc. Over the course of the past decade, green chemistry has demonstrated how fundamental scientific methodologies can protect human health and the environment in an economically beneficial manner. This review explains the importance of Green Chemistry with a series of illustrative examples.

Keywords: Green chemistry, Environmental impact, Sustainable, Synthesis

1. INTRODUCTION

Green chemistry, also known as sustainable chemistry, is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Its definition by the Environmental Protection Organization (EPA) is; "To promote innovative technologies that eliminate or reduce contamination during and after the design, manufacture and use of chemicals." Also, P. T. Anastas and J. C. Warner in their book Green Chemistry-Theory and Practice; "It is the use of a dozen principles that eliminate or reduce the use and emergence of materials that pose a hazard to human and environmental health in the design, manufacture and use of chemical products." have been defined as [1]. It focuses on the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal [2]. Green chemistry emerged in the early 1990s as a science-based, non-regulatory, economically driven approach to achieving environmental goals [3-5].

Green chemistry offers opportunities for innovation via product substitution, new compounds and catalysis production, utilization of microwaves, and scope for alternative or natural solvents [6-11]. Mostly, synthetic chemists think organic syntheses as yield, selectivity and reaction steps. However, Paul Anastas and John Warner proposed 12 criteria in 1990, which include waste generation, use of reagents and solvents, use of hazardous chemicals, energy density and general safety criteria (in Figure 1) [12]. The most important challenge to the future of this discipline is to reach a compromise between the increasing quality of the results and the improving environmental friendliness. In the last two decades, both academia and industry focused attention on the pressing need for pollution prevention recognizing that chemistry is the solution rather than the problem.

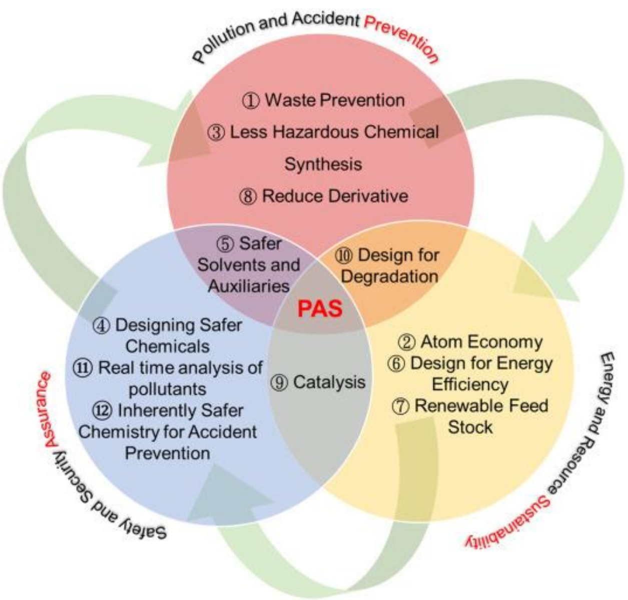

Figure 1. Principles of green chemistry [13]

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Thus, aspiring chemists also learned how to do chemistry in a more environmentally friendly benign manner.

2. GENERAL REQUIREMENTS

Principles of Green Chemistry

Waste Prevention

Waste is known as any substance that is formed as a result of an activity, thrown into the environment or released into the environment and that has no value, is not used, and causes energy loss. By designing waste-free reactions; the need for separation, purification, disposal of hazardous materials can be eliminated. In green chemistry; Rather than treating or cleaning waste after it is generated, it is preferred to prevent waste generation at the beginning. Since the beginning of the industry, the paper and pulp industry has used chlorine-based oxidizers (ClO_2) as bleaching agents which cause the formation of toxic organic chlorine-containing by-products To prevent this, Collins developed a new iron catalyst/hydrogen peroxide system developed by ensures waste prevention and also allows chlorine-free bleaching of paper. It was designed to maximize the incorporation of all materials used in the final product (in Figure 2) [14].

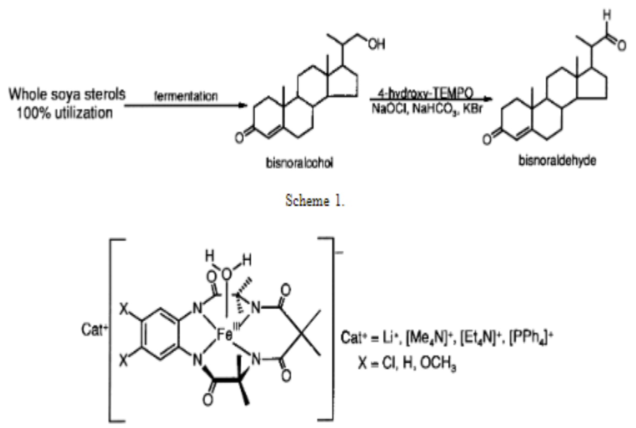

Figure 2. The new iron catalyst/hydrogen peroxide system

Atom Economy

In 1990, Barry Trost introduced the concept that "An ideal reaction should include all atoms of the reactants" [15]. Atom economy provides more efficient use of raw materials, fewer by-products and waste savings. The Diels–Alder reaction is the best example that can be given to illustrate the concept of atom economy because it is 100% atom efficient; all of the atoms in the diene and dienophile are included in the final product [16,17]. Ibuprofen, is a widely used analgesic, is one of the examples in which atomic economical synthesis has begun and has been very successful in this regard. While its synthesis has design in 7 steps at the beginning, it started to be designed in only 3 steps with the development of green chemistry [18].

Less Hazardous Chemical Synthesis

Green Chemistry promotes that, whenever possible, the substances used and created in the manufacturing process present little or no toxicity to human health and the environment. The best example of this is cumene production. Cumene, which has a production of approximately 7 million metric tons per year in the world, had synthesized as a result of alkylation of propylene and benzene over a solid phosphoric acid or aluminum chloride catalyst which is classified as dangerous. In the newly developed design, it is synthesised in high efficiency using an environmentally inert zeolite catalyst [19].

Designing Safer Chemicals

Chemicals are used in many places in our daily lives, so it is one of the goals of green chemistry to design processes that both maintain the functional effectiveness of chemicals and reduce their toxic effects. A better understanding of reaction mechanisms and toxicology allows chemists to better predict which compounds/functional groups may pose an environmental hazard. This information aids in the design of safer chemicals while maintaining the intended purpose of the product. Cascade reactions, C–H activation, metathesis, and enzymatic reactions, etc. are illustrated strong examples of cleaner, more efficient synthetic tools available to organic chemists [20-23].

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Safe Solvents and Auxiliary Agents

Solvents are perhaps the most active area of Green Chemistry research. They represent a significant challenge for Green Chemistry because they often make up the vast majority of wasted mass in syntheses and processes [24]. The environmental health and safety score for some common solvents is given in Figure 3. As environmental requirements increase, synthesis with non-toxic solvents or solvent-free has become widespread [25-27].

Water is the most abundant molecule on the planet and is sometimes referred to as a benign "universal solvent". It can be a useful solvent for synthesis chemistry. The properties of water have even led to improved reaction rates through the hydrophobic effect [29]. Also, recently there has been a great deal of attention focused on the development of Barbier-Grignard type reactions in water [30]. Another example is an improved Diels-Alder reaction in water [31].

Another example of greener solvents would be ionic liquids [32]. Ionic liquids or high-temperature ionic liquids or room temperature ionic liquids, are liquids that are composed entirely of ions. The charge of the cation as well as the charge of the anion is distributed over a larger volume of the molecule by resonance. Furthermore, they have almost no vapor pressure and very low flammability [33, 34].

Some university laboratories have developed web-based tools in this context. For example, Massachusetts Institute of Technology (MIT) has a terrific web-based tool called "The Green Chemical Alternatives Purchasing Wizard". The wizard is a guided process that allows the user to search from a select list of solvents commonly used in the laboratory, and the associated process. The Wizard identifies less hazardous and more environmentally benign chemicals or processes that may be substituted [35].

Design for Energy Efficiency

The environmental and economic effects of the energy required by chemical processes should be identified and minimized. If possible, synthetic methods should be applied at the appropriate temperature and pressure. In this way, less energy will

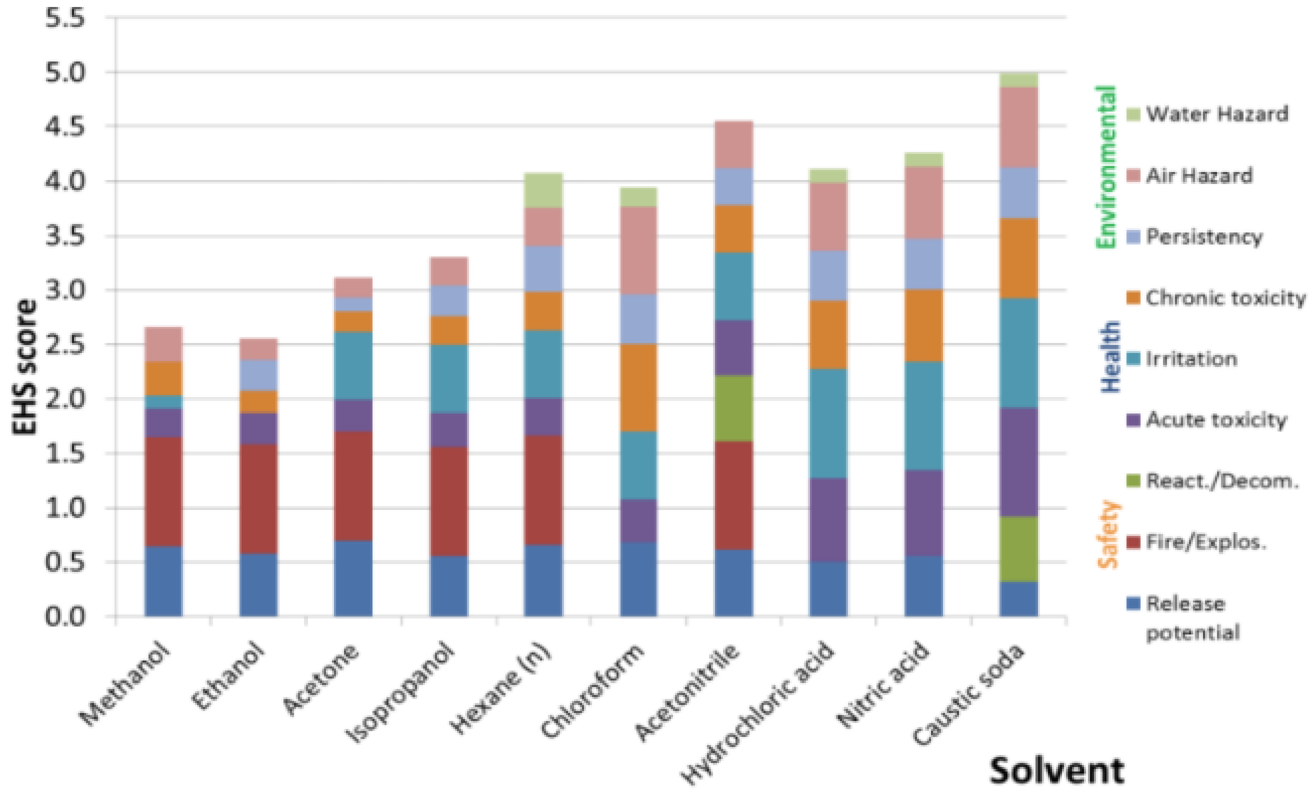

Figure 3. Environmental health and safety score for some common solvents [28]

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be spent during production. Room temperature, and atmospheric pressure reactions, sonication, microwave are examples of synthetic methods design for energy efficiency [36]. Especially, in many instances, microwave heating has been shown to dramatically reduce processing times, increase product yields and to enhance product purities or material properties compared to conventionally processed experiments [37-40].

Use of Renewable Feed Stocks

All products to be produced should be designed to be non-toxic, energy-efficient, renewable feedstocks (carbohydrates, vegetable oils, terpenes and lignocellulosic materials) or biodegradable throughout their use. Because petroleum is the principle for the vast majority of organic chemicals in use, but the supply of fossil fuels is limited, increasing research efforts have been directed toward the development of renewable feedstocks. The increase in the use of renewable feedstocks and their recyclability and reproducibility significantly reduces production costs. Also, recycling of all kinds of waste materials gains vital importance for nature such as paper, glass, plastic, metal. It should be tried to produce the most products with as few and renewable raw materials as possible, by developing methods that will prevent the generation of waste material as a result of production [41].

3. CONCLUSION

Green Chemistry provides a unique forum for the publication of innovative research on the development of alternative green and sustainable technologies. It is reported to be used in many areas such as the use of alternative solvents in the execution of some reactions in chemistry, white goods technology, use of harmless solvents or carrying out the reactions without solvent, purification reactions, organic syntheses, and to prevent the environmental pollution [42-47]. It is very important that the processes made by utilizing the field of chemistry are carried out with simpler steps with less harmful or harmless, low cost, high efficiency, time-saving, low-risk and reliable, nature-friendly natural inputs, and environmentally friendly results. With the correct application of Green Chemistry methods, it seems that environmental pollution and energy loss can be prevented in many ways. In terms of human health, environment and safety, the greening of chemical methods should be an inevitable end and preferred for the whole world. Green chemistry and its principles form an excellent roadmap for the world. It can be seen that green chemistry could be integrated into chemistry curriculum.

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Authors' Contribution

Under this heading, "The authors contributed equally to the study" or "The first author contributed 60%, the second author 40%." expressions such as should be included.

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