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Green Chemistry: Solution to sustainable environment

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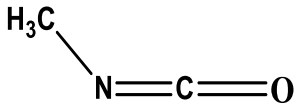
Introduction

In recent years, awareness of clean and green environment is emerging to sustain healthy and pollution free lifestyle. In view of this Green Chemistry is gaining a remarkable attention and there is an exponential increase in advancement of this field. Green chemistry as defined by the Environmental Protection Agency (EPA) is ‘‘the design of chemical products that reduce or eliminate the use of hazardous substances’’ [1]. It is a subset for designing scientific solutions to the environmental problems. Many chemical pollutants are introduced in biosphere by numerous ways resulting in hazardous environmental problems. So Green chemistry focusses on preventing environment from pollution by redesigning more efficient processes that minimize waste, invention of more environmental friendly chemical processes which reduce or even eliminate the generation of hazardous substances, thus making chemicals safe for our health. This concept is embodied in comprehensive set of 12 principles of Green chemistry [2].

There are several major accidents reported in laboratories and chemical industries such as releases, explosions, and fires. These incidents should be abolished and safer working environment is needed. The worst industrial accident reported in history is Bhopal gas tragedy on December 3, 1984. 40 tons of methyl isocyanate were accidentally released when a holding tank overheated at a Union Carbide pesticide plant, taking life toll of several thousand instantly and several others suffer from ailments caused by exposure to gas.



Methyl Isocyanate

The severe consequences of all these accidents can be avoided by working with less hazardous chemicals and avoiding chemical process that have potential of such tragedy. This concern is also pointed in set of 12 principles of Green chemistry [2].

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The objective is to achieve sustainable development without affecting environment. In Green chemistry, risk is defined as function of hazard and exposure and risk factor can be reduced by minimizing either of two or both. Hazard can be reduced by using alternative chemicals that are not hazardous and exposure can be reduced efficiently by taking several preventive measures.

Several research groups over the decades have been focusing on designing more cleaner and sustainable techniques and success in future will be achieved when yield of product will be improved, wastage disposal cost will cut down [3] and pollution level is decreased. For example in any chemical reaction, A and B are the reactants which give Product (P) and waste (w). So Green chemistry focusses on depleting yield of w. Percentage yield can be calculated as:

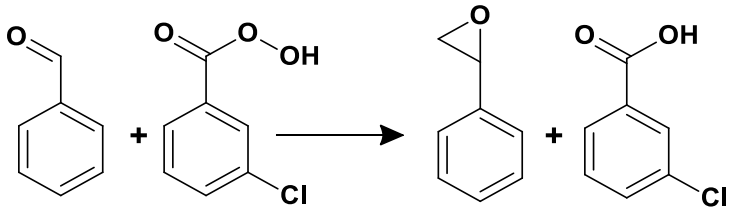
$$\textbf{Percent yield} = \frac{\textbf{Actual Yield}}{\textbf{Theoretical Yield}} \times 100$$

In this equation, yield of by-products is missing which is major concern in green chemistry. In order to achieve objectives of green chemistry the things to be kept in mind are what co-products are formed, how much is their yield, are co-products useable, what solvents are involved in carrying out the reaction and are they benign, how much energy is required, are there any purification steps involved and so on.

Atom economy [4] is defined as

$$\textbf{Atom economy} = \frac{\textbf{Molecular weight of the desired product}}{\textbf{Molecular weight of all product}} \times 100$$

Consider the following styrene epoxidation reaction



Epoxidation of Styrene

Assume 100% yield of desired epoxide product and 100% of co-product formed. Then Atom economy of this reaction will be 23% and yield of waste product is 77%. Nowadays researchers are focusing on to cut down waste product yield to minimal to achieve concept of atom economy. The other metrics which measure the environmental goodness of any chemical product is E-factor [5-7] proposed by Sheldon in 1992, defined as mass ratio of waste over product. Large E-factor implies waste product yield is high which is not environmental friendly. In order to have sustainable chemical process E- factor should be less and zero E-factor implies an ideal case. E-factor calculations are done by excluding water used in the process because if water is included it will results in very high E-factor which will make comparisons intractable. There are several other measurement techniques proposed to identify benign environmental chemical processes such as Process Mass Intensity (PMI), Green Motion [8].

12 Principles of green chemistry [2] are as follows:

1. **Waste prevention**: Better is to prevent waste rather than to clean or treat it after it is formed.
2. **Atom economy**: Synthetic method should be developed for complete conversion of reactant to final product.
3. **Less hazardous chemical synthesis**: Methodologies should be designed that generate substances which are little or not toxic to human health and environment.
4. **Designing safer chemicals**: Chemical products should be designed to achieve desired reaction while reducing toxicity.
5. **Safer Solvents and Auxiliaries:** Auxiliary substances (solvents, separating agents) should be avoided whenever possible and when used, innocuous.
6. **Design for energy efficiency**: Reactions to be carried out at ambient temperature and pressure and energy requirement should be minimal.
7. **Renewable raw materials preferably**: Application of renewable raw material is preferred over non- renewable whenever it is economically practical.
8. **Derivatization should be minimal or avoided**: Shorter syntheses procedures should be followed and unnecessary derivatization (blocking groups, protection/ deprotection) should be avoided.

9. **Catalysis over stoichiometric reagents:** Catalytic reagents should be used instead of stoichiometric reagents.
10. **Products are designed for degradation**: Chemical products should be designed so that they do not persist after completion of their purpose and they don't pollute environment, instead break down into safer products
11. **Analytical methodologies for controlling pollution:** Methodologies need to be further explored allow real-time in-process monitoring prior to formation of substances which are not safe.

12. **Inherently Safer Processes for avoiding accidents:** Chemical related accidents such as explosions, fire can be averted by choosing substances that can be minimize the risk.

These comprehensive set of principle play significant role in reducing health and environmental impacts of chemical synthesis.

Pharmaceutical applications of green chemistry

In pharmaceutical industries, manufacturing of drugs lead to production of several hazardous side products or waste which are not sustainable and thus synthetic process need to be improved. Several research have been done in this field to overcome this difficulty.

Chemical drug **Simvastatin** used for treating high cholesterol is manufactured traditionally involving multistep process and high amount of hazardous substances. A new method for drug synthesis was given by Prof Tang [9] and optimized by Codexis, a biocatalysis company. It was then synthesized by engineered enzymes and low cost feedstock which results in exponential decrease in hazard and waste.

BASF chemical company recognized by the EPA's green chemistry awards succeeded in producing **ibuprofen** a painkiller medicine by just three steps which initially was six step process and thus successful in reducing waste.

Green synthesis of **Sertraline hydrochloride**, a pharmaceutical medicine for treating depression, pain attacks and other stress disorder was reported by Juan C. Colberg [11]. They are successful in achieving greener route for synthesis of Sertraline hydrochloride by eliminating use of titanium tetrachloride TiCl4 used as

dehydrating agents, a hazardous material, number of intermediate isolation is reduced and product yield is enhanced commercially also.

Pregabalin marketed by Lyrica**,** is a medicine used for the treatment of epilepsy, fibromyalgia, neuropathic pain and anxiety disorder. This was commercially first developed by Parke-Davis company but when its E-factor calculations were done it comes out to be very high. High E-factor inspire search for more efficient methodology to have sustainable synthesis and Pfizer very successfully designed new synthesis which had not only enhanced product yield bud had also produced significantly less waste and improved E-factor value [12].This was then manufactured commercially.

Conclusion

Over the last two decades, the term Green chemistry has surfaced importance.

It was coined by Paul Anastas who was then member of US Environmental Protection Agency (EPA). After that this field is emerging importance significantly and many researchers are focusing to achieve the objectives of it since society strives the sustainable environment. Several chemical process involve use of toxic reagents, harsh reaction conditions, use of harmful solvents, high energy consumption and huge waste production. All these factors necessitates the emerging need for more environmental friendly chemical processes that focusses on more superior environmental and economic performances. Though challenges that lie in designing such processes are numerous such as use of greener solvents, but extraordinary work is done by many research groups to achieve the goal of sustainability. Researchers are focusing on utilizing green solvents such as acetone, methanol, ethanol, isopropanol, ethyl acetate, tetrahydrofuran that can be produced from renewable sources and finding more greener solvents which have low toxicity, low vapor pressure and environment friendly. Presidential Green Chemistry challenge award have recognized and awarded many groups which have successfully accomplished the goal of designing chemical processes which focusses on improving chemical yield, minimizing hazard portion of the reaction, using innocuous solvents, and minimizing the potential of chemical accidents. Green chemistry discipline is an emerging field and exponentially increasing advancements in this field will have an greater impact in the coming decades.

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