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GREEN CHEMISTRY – SAFE AND SUSTAINABLE APPROACH TOWARDS PRESERVING ENVIRONMENT: A REVIEW

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ABSTRACT

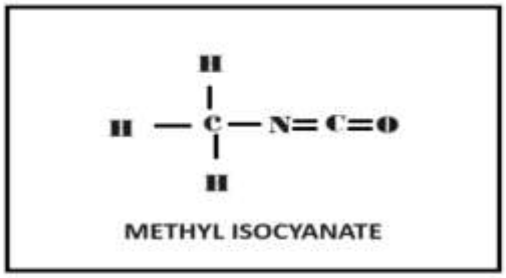
Green chemistry involves in the designing and preparation of chemical processes and products by avoiding the usage and production of harmful, toxic and hazardous substances by the application of 12 principles which includes designing of safer chemicals, use of biodegradable feedstock etc. The goal of green chemistry is to overcome global warming and anthropogenic hazards which come with the industrial waste production. The review article explores on to create awareness about the implementation of the 12 principles of green chemistry to produce chemical products and procedures that are environmentally friendly and pose fewer risk to workers.

INDEX TERMS- green chemistry, hazardous substances, global warming, biodegradable feedstock, anthropogenic hazards

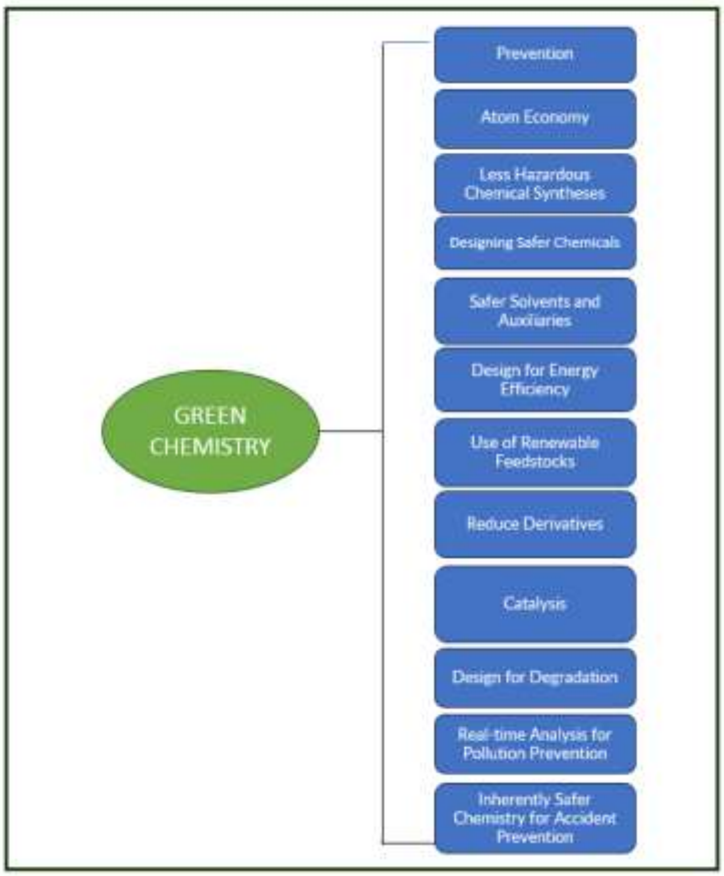
INTRODUCTION

Chemistry deals with science of which the matter is composed. It is profound to say that chemistry is unavoidable as all the living organisms are made up of chemicals [1]. Human body comprises of numerous chemical processes being carried out every day which exceeds in complexity and diverse than those occur in chemical manufacturing units. It is an undeniable fact that in the past years and even today, chemistry is fraudulently used. Such as the air and water pollution, soil contamination, greenhouse gas emission, depletion of natural resources and production of nonbiodegradable materials, resulting in harming the environment and the living organisms. Now the time has come to turn away the ultimate usage of toxic chemical pollutants and it is more emphasised on the usage of more environment friendly chemicals and sustainable resources without causing any harm towards earth ecosystem. The practice of chemistry in a manner that improves its advantages while eliminating or at least greatly minimizing its adverse impacts is known as green chemistry.

The emergence of green chemistry [2,3] has to do with the disasters that occurred over the time, one such disaster is the Bhopal gas tragedy, 1984 in India that arguably illustrates most vividly the potential of chemical substance to kill numerous people was the accidental release of methyl isocyanate from Union Carbide factory. About 40 tons of this chemical was released during the incident exposing thousands of residents in the surrounding area. Of those exposed, more than 3000 died, primarily from pulmonary edema (fluid accumulation in the lung). Immunological, neurological, ophthalmic (eye), and hematological effects were also observed. Because of its high vapor pressure and toxicity to multiple organs, methyl isocyanate is the most toxic of the isocyanates. An interesting aspect of methyl isocyanate toxicity is its ability to cross cell membranes and reach organs far from the site of exposure, despite its very high reactivity.



There are 12 principles of green chemistry which were introduced by Paul Anastas and John Warner in the year 1998. They act as a guiding framework in the production of chemical products without generating waste and unwanted substances by reducing toxicity, right from the start of the reaction to the end of the reaction. The following are the 12 principles of green chemistry [4].



1. **Prevention:** one of the first principles of green chemistry is the prevention of waste. As it is necessary to avoid the generation of waste than to clean up after its formation. Waste can be harmful to the environment [5] in many ways based on the level of toxicity, quantity, and the way it is released. E- factor (environment factor) and process mass intensity (PMI) are valuable tools for practicing green chemistry and minimizing the waste production.

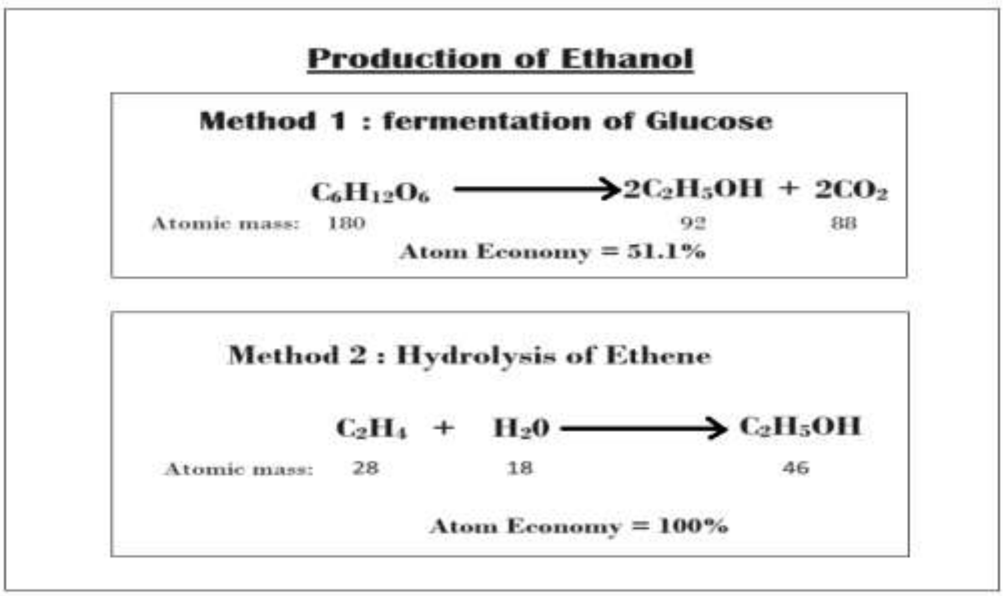
   E factor (environmental factor) is a simple metric which measures the waste production and calculates how much green the reaction is during the manufacturing operation. It is defined as the ratio of mass of total waste per mass of product [30].

$$\text{E factor} = \frac{mass\ of\ total\ waste}{mass\ of\ product}$$

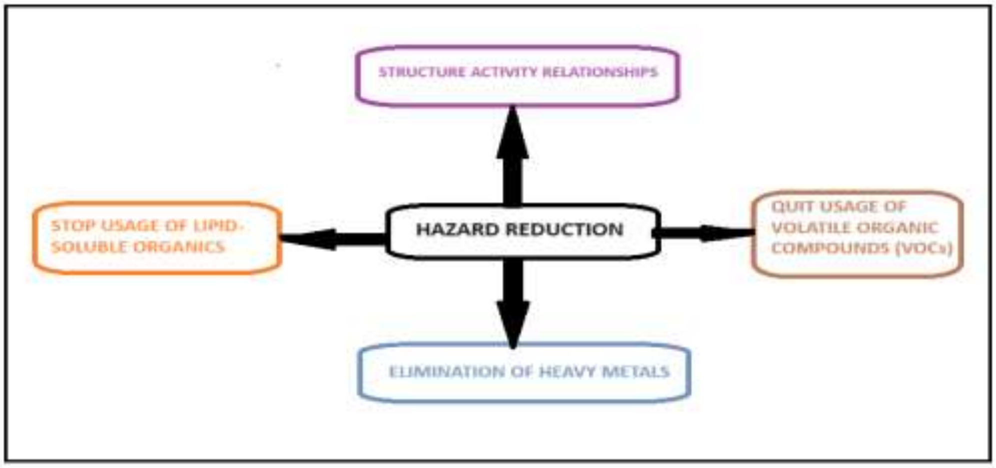
Whereas Process mass intensity (PMI) calculator serves as a criterion to obtain greener reaction at a manufacturing unit with the help of PMI value. Convergent PMI calculator and PMI prediction calculator are introduced beyond the simple PMI calculator. These tools are employed to focus on the total mass of materials used to produce a given mass of product in the pharmaceutical process such as reactants, reagents, catalyst, and solvents to increase the efficiency of pharmaceutical reactions by optimizing the use of these resources. Allowing for the development of sustainable and cost-effective processes [29].

2. **Atom Economy:** Barry Trost, an American chemist developed a concept of Atom economy. It is a synthetic method designed to maximize the incorporation of all materials in the production of final product. Conventionally [6,7], the efficiency of a reaction is calculated by the percentage yield. Atom Economy is a method of expressing how efficiently a particular reaction makes use of the reactant atoms and this method do not take yield into account.

$$\text{Atom Economy} = \frac{Atomic\ mass\ of\ desired\ Product}{Atomic\ mass\ of\ reagent}\ x\ 100$$



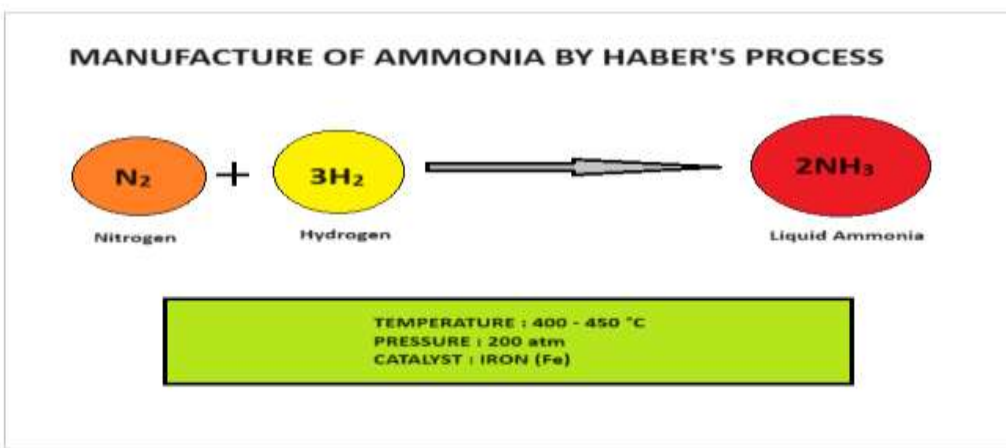
3. **Less Hazardous Chemical Synthesis:** Hazards in chemical industry arise from many sources such as the raw materials, solvents, catalyst and the end products that are produced during a chemical reaction. Green chemistry deals with the usage of less hazardous chemicals and hence the toxic compounds are avoided chemically by **Structure Activity Relationships**. There are three groups of toxic compounds used in the industrial units that are to be avoided such as first group is the usage of **heavy metals** like lead (Pb), Arsenic (As) and mercury (Hg). second group that is avoided is the usage of **lipid-soluble organics** that are not readily degraded in the environment. The third group is the aborting the usage of **Volatile organic compounds (VOCs)** which are basically Hydrocarbons such as benzene, tetrachloroethylene, formaldehyde etc., that are harmful for the human health and are hazardous in nature [8].
Certain combustible or explosive compounds also contribute towards the hazards of the individual working in an industry. Although, one cannot avoid the usage of oxidizers or reactive agents completely in the chemical industry but at least the preventive measures should be taken to avoid the complete exposure to these substances to avoid uncertainties [28].



4. **Designing Safer chemicals:** It is the responsibility of a chemist to apply the applications of toxicology and design the chemicals that are less toxic and are more efficient. The usage of toxic compounds is avoided during the designing and should be replaced with non-toxic substances. For example, during the manufacturing of Polystyrene, Chlorofluoro Carbons (CFC's) which contribute to ozone depletion and global warming are replaced by carbon dioxide [9].

5. **Safer Solvents and Auxiliaries:** The auxiliary substances that are used in the form of solvents and separating agents should not be hazardous [10], explosive and cancerous but should be innocuous in nature to environment and human health when exposed.

6. **Design for Energy Efficiency:** Green chemistry also helps a chemist in designing energy efficient modal of a chemical process. As the usage of high energy chemical reactions are not favourable as it impacts the economy and environment in an unhealthy manner. Hence, it is important to choose the less energy utilization chemical process to produce the by-product which uses ambient temperature and pressure in the presence of a suitable catalyst [11,12].

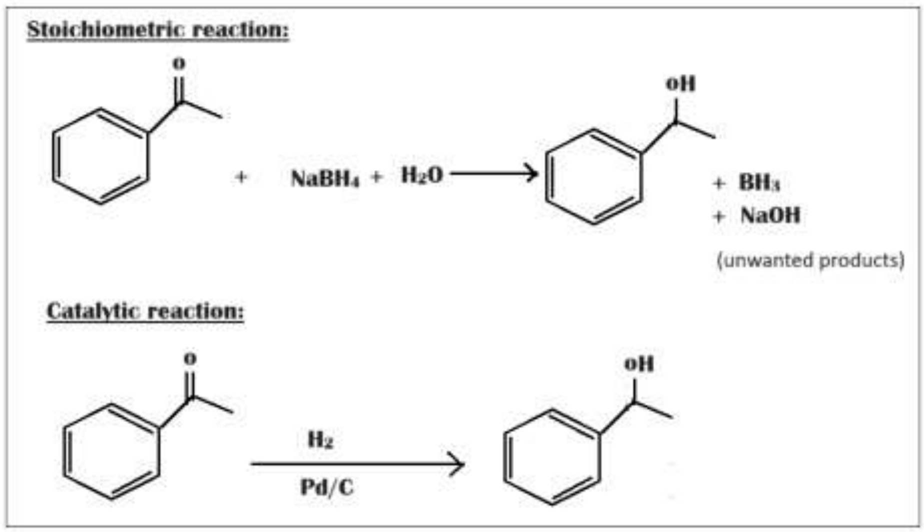


7. **Use of Renewable Feedstock:** The raw material or feedstock that is used during a chemical reaction should be sustainable and non-depleting [13]. Hence, the usage of renewable source of energy which is often a waste product of agricultural by-products is preferred upon non-renewable sources such as coal, petrol, natural gas etc., that are depleting and unsustainable.

8. **Reduce Derivatives:** To produce a by-product during a chemical process there are certain unnecessary derivatization i.e., use of blocking groups, protection/de-protection, temporary modification of physical/chemical processes [24] should be lessened or avoided as it results in usage of additional reagents and can generate waste

material. Overall yield and Atom economy will be decreased. To overcome this, more selective and better alternative synthetic sequences that eliminate the need for functional group protection should be adopted. There are numerous reagents that are green as well and designed to be less impactful to the environment [14].

9. **Catalysis:** Catalysis is the process of adding a catalyst to facilitate the rate of reaction by lowering the activation energy. Catalytic reagents are selective because of which they can increase the amount of desired product and decreases the production of unwanted waste by-products [15]. Thus, catalysis reaction is more superior to stoichiometric reaction. It can be illustrated with an example of a catalytic reaction is the hydrogenation of ketones employing palladium on carbon as catalyst, the ketone can react directly with hydrogen gas to generate the desired product without any waste as shown in the below picture. Whereas the stoichiometric reaction involves the addition of Sodium borohydride followed by addition of water the resultant product is formed along with borane (BH_3) and Sodium Hydroxide (NaOH) are generated as unwanted/waste products [26,27].



10. **Design for Degradation:** Chemical products that are manufactured should be designed in such a way that at the end of their function they do not persist in the environment and are completely break down into innocuous degradation product [16]. As the exposure to persistent chemicals can be significant which results in global dispersion enabled by properties such as volatility or sorption to particles and partitioning into organisms based on properties such as fat solubility. Thus, the concept of half-lives in water, soil and air that define persistence within frameworks used to identify chemicals as PBT (Persistent, Bio accumulative, Toxic) [25]. Green chemistry emphasis on the usage of biodegradable polymers that can be either natural or synthetic in origin. Natural biodegradable polymers include chitosan, Collagen, chitin, alginate, and gelatine [17]. The synthetic biodegradable polymers are Poly Lactic Acid (PLA), Ploy Glycolic Acid (PGA), Polyurethanes etc.,

11. **Real-time Analysis of Pollution Prevention:** Real-time analysis is a process of checking the progress of chemical reactions as it happens as this will prevent a lot of waste formation [18], time and energy. Green Analytical chemistry further allows to help the chemist to allow the real-time in-process monitoring and control to the prior to the formation of hazardous or unwanted substances.

12. **Inherently safer chemistry for Accident prevention:** The chemicals used in the chemical reactions should be safe and not explosive, hazardous and toxic in nature. All the necessary protocols should be taken to ensure the safety of the personnel and develop procedures to handle new chemicals/substances, processes and equipment [19]. Assess changes in safety training and education needs.

ADVANTAGES OF GREEN CHEMISTRY

Green chemistry refers to the sustainable, safe, and non-polluting practice of chemical science and manufacturing. It aims to minimize material and energy consumption while producing little to no waste. This approach starts with acknowledging that the improper production, processing, use, and disposal of chemical products can cause harm [20,21]. Green chemistry and green chemical engineering seek to reduce waste and avoid particularly hazardous substances by modifying or completely redesigning chemical products and processes.

Essentially, green chemistry leverages extensive chemical knowledge to minimize the use of materials, reduce exposure to toxic substances for living organisms, including humans, and limit environmental damage during the production, use, and disposal of chemicals. It achieves these goals in an economically viable and cost-effective manner. In essence, green chemistry represents the most efficient and least costly way to practice chemistry, considering all associated costs, including potential hazards and environmental impacts [22].

CONCLUSION: Green chemistry and its 12 principles in the design of chemical processes and product help us to achieve sustainable growth and development with an energy efficient biodegradable cycle with reduction in waste production. It is basically a sustainable chemistry which makes our planet pollution free from toxic and hazardous substances. The co-founder of Green Chemistry, John Warner has rightly said “Green Chemistry is a revolutionary approach to the way that products are made; it is a science that aims to reduce or eliminate the use and/or generation of hazardous substances in the design phase of materials development.”

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