Green Chemistry - The Way Forward

Sangeeta Kaul

Associate Professor
Department of Chemistry,
Sri Aurobindo College, University of Delhi, Delhi

***Abstract*: The goal of green chemistry is to create safer, better chemicals using safe efficient ways of synthesis and to reduce waste. Intrinsic hazards of chemicals or chemical processes can also be reduced to a great extent at almost all levels of a process. Reduction in damages can be applied to toxicity, explosion, flammability and also global hazards like ozone layer depletion. Green chemistry is an upcoming filed and by following its twelve basic principles, chemical hazards can be reduced and economic profitability attained.**

***Keywords*: Green chemistry, waster, atom economy, energy efficiency, catalyst, feed stock.**

Introduction:

Green Chemistry is an application in chemical sciences wherein renewable raw materials are used, waste products are eliminated. Further use of toxic and hazardous reagents and solvents used in manufacturing and application of chemical products are totally by passed. Science of green chemistry works at the molecular level and aims to achieve sustainability. This is an emerging field and has received wide interest because of its ability to harness innovative chemical methods to attain environmental and economic goals. Work in this field started almost three decades back. There are twelve key principles formulated which ought to be implemented by all chemists at all levels towards attaining the goal of good human health and clean environment.
The twelve key principles formulated by P T Anastas and J C Warner and are discussed herein under:-

1. Waste Prevention: Rather than treating the waste produced at a later stage, the principle advocates that it is better to prevent waste formation at the very onset of the process. Waste is production of any by-product or material that has no use or value, even energy that cannot be harnessed or remains unutilized. The waste so generated in the process affects the environment adversely, both in short term as well as long term and its hazard depends on the nature, quantity, toxicity and the way the waste is released into the environment. Roger Sheldon has introduced a concept of E-factor also called the Environmental Impact Factor. The concept of E-factor is now widely accepted as a bench mark. E-factor is used to quantify the waste produced per kilogram of the final product. This is used as a measuring value for grading environmental acceptability of any manufacturing process. Many innovative and new process methods have been developed/being developed so as to get a lower value of E-factor. Wastes can be used as a new raw material for another chemical process for e.g. production of bio fuels from organic wastes so as to reduce the adverse impact of unutilized waste to the environment.

2. Atom Economy: This refers to designing a process wherein raw materials are used to the maximum in such a way that the final product has the maximum number of atoms from the reactant. The ideal reaction or the process so adopted would utilize all the atoms of the reactants. Chemists measure atom economy as a ratio of molecular weight of the desired product to the molecular weight of all the reactants of the reaction. This theoretical value is used to quickly assess the efficiency of the reaction.

3. Less Hazardous Synthesis: Synthetic methods wherever possible should be employed wherein reactants used and products generated have low human toxicity and also are environment friendly. Chemical reactions using toxic substances are in use because these reactive chemicals make the reaction kinetically and thermos- dynamically more favourable. Although a challenging task but calls for further research and applicability so as to replace the use of these toxic chemicals.

4&5. Designing Safer Chemicals, Safer Solvents and Auxiliaries: Products need to be designed in a way that toxicity is reduced whereas efficacy and function remains preserved. The American Chemical Society acknowledges that designing safe chemicals is one of the major challenges for the scientific community. Designing new chemicals that work optimally and at the same time are non-toxic is a major challenge facing chemists across the globe. This requires the know-how of toxicology, biology, environmental sciences and chemistry. The guiding principles is mankind's desire for the future generations to live in a healthy, safer and environmental friendly world. It is worth mentioning that many manufacturers did not understand / realize the harmful affect the chemicals would have on the people working in their vicinity. Some of these are hazardous and at times workers become sick and can even die because of its usage. Therefore to design novel solvents and chemicals becomes imperative i.e. designing is to be undertaken such that functions performed are more efficient at the same time reduce toxicity.

6. Energy efficiency: By conducting synthesis at ambient temperature and pressure, energy requirement of the synthesis can be minimized. Gone is the era when chemists followed a protocol to lead a reaction to completion and then to separate the product at a yield as high as possible. Energy perspective was not considered relevant at that point of time, whether it was electrical energy or fuel used of any other kind and source. In the 21st century, energy saving has emerged as a key issue, as much as possible renewable energy is used and loss of energy conversion and transmission is also minimized. Design parameters are considered better when synthesis is completed in fewer number of steps and use is made of low cost reactants. It is interesting to note that

nature mostly works with change in entropy and weak forces of inter-action. One does not visualize a tree undergoing photosynthesis at reflux using a solvent or a cell membrane or cell wall is not extruded at the melt temperature of something like polystyrene.

7. Use of Renewable Feedstock: Whenever and wherever possible feed stock or raw material should be renewable. The above is an interesting concept which initially appeared impractical. Human remove, fossil fuels, coal, petroleum, natural gas from oceans and ground and conduct extractions to retrieve minerals for gain until they are exhausted. In the process fossil fuels for gain of carbon based compounds are depleting and more so with rise in global population and extension in energy economies across the globe. The carbon in air in form of various gases is used up for photosynthetic process in presence of sunlight to form trees, plants, algae, crops which collectively is known as Biomass. Nature produces about 170 billion tons of plant biomass per year. To generate a bio-based economy, mankind needs to use more and more of this bio-mass to produce a bio based economy. The challenge is to use renewable feed stock by non-toxic pathway and convert the bio-mass into useful chemicals such that it generates less carbon then is being removed from "thin air". The difference between $C_{(in)}$ from air and $C_{(out)}$ from energy used is termed as the carbon foot print. Designing of synthesis should be in a way that $C_{(in)} >> C_{(out)}$, so that the value is positive. This is a natural way of reducing global warming. It also needs to be ensured that new materials and chemicals derived from renewable sources are non-toxic and not injurious to mankind and to biosphere.

8. Reduce Derivatives: One of the key points of green chemistry is to reduce the use of derivatives and protecting groups in the synthesis of target molecules. One of the ways to achieve this is by use of enzymes. Enzymes are known to be specific so much so that they can react with one site of molecules, therefore protecting groups in synthesis of ampicillin and amoxicillin.

9. Catalysis: A catalyst is a substance that changes the rate of reaction without itself being changed in the process. It works by lowering the activation energy of the reaction, but itself does not get consumed. It implies that it can be used in minute quantities and can be recycled indefinitely. It also does not produce any waste. Catalysis has found wide application in pharmaceutical industry by minimizing large quantities of waste produce by use of stoichiometry. Full use of catalysis is made in chemical industry by use of homogenous, heterogeneous, organo-catalysts and enzymes.

10. Design for Degradation: Designing of chemical product is done in a way that they break down into innocuous degradation product in the end, which does not remain in the environment for long. Degradation can remove exposure thereby eliminating risk, irrespective of the hazard of the chemical involved. Sometimes properties like volatility, absorption or adsorption of particles result in persistent exposure. Regulators have classified chemicals as PBT (Persistent, Bio-accumulative and Toxic) to define persistence within the used framework. Mechanism of degradation are designed by the processes like bio-degradation, hydrolysis, photolysis which will eliminate persistence. Models are developed and researched which evaluate the bio-degradability and PBT characteristics.

11. Real time Analysis for Pollution Prevention: Analytical method need to be updated for real time in-process monitoring and control before the formation of polluting substance starts. For proper functioning of chemical processes real time feedback is needed. Analysis can be performed in-line, on-line or at time in a chemical plant. This sub-discipline is known as Process Analytical Chemistry. This kind of analysis can detect changes in the process, pH, temperature or pressure prior to any reaction getting out of control. Such events when detected timely can avoid major incidence and accidents.

12. Inherently safer chemistry for accident prevention: Form of substance used in any chemical process should always be chosen in a way to minimize the chemical accidents due to its release, explosion or fires. The primary aim of green chemistry is to focus on making the environment safe. Processes undertaken and materials used that are safe for environment are also mostly safe for general public. The workers engaged in such processes/manufacturing units and laboratory workers too, also benefit from these practices.

Use of these key principles of the green chemistry will result in safe conditions for the workers, for public at large and safe environment and safe planet for mankind.

References:

[1] P.T. Anastas, J.C. Warner – Green Chemistry, Frontier 1988 ccc.chem. pitt.edu

[2] M.B. Smith and J. March, in *March's Advance Organic Chemistry : Reactions Mechanisms and Structure*, John Wiley & Sons, Inc. New York, 5th edn, 2001, pp.1231-1237.

[3] D.R. Stuart & K. Fagnou, *Science*, 2007, 3016, 1172.

[4] J.C. Dearden, *J. Comput. Aided Mol. Des.*, 2003, 17,119.

[5] A.M. Voutchkova, L.A. Ferris, J.B. Zimmerman & P.T. Anastas, Toward Molecular Design for Hazard Reduction – Fundamental Relationship Between Chemical Properties and Toxicity, *Tetrahedron*, 2009, in press.