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4. Green Chemistry for Sustainable Development

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Abstract:

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal. For sustainable development green chemistry plays an important role. Through green chemistry, scientists attempt to create more efficient systems that require fewer hazardous chemicals and fewer emissions of air and water pollutants. One example of green technology is the use of biocatalysis, which is the use of catalysts that are found naturally in the environment. Environmental chemistry is used in the method of protecting groundwater from contamination by soil, dust, and waste particles. It is useful for the protection of surface water against sedimentation, microbial and radioactive contaminants. In this chapter I discuss the introduction and twelve principles of green chemistry.

Keywords:

Principles, Green solvents, Sustainable development, less hazardous substance.

4.1 What is Green Chemistry?

Green Chemistry is defined as the design of chemical products and processes which reduce or eliminate the use and generation of hazardous and harmful substances.

- Green chemistry can also be described as Sustainable chemistry.
- Chemistry that is benign by design.
- Pollution prevention at the molecular level.
- Focus on processes and products that reduce or eliminate the use of polluting substances
- Any synthesis, whether performed in teaching, laboratories or industries should create none or minimum by-products which pollute the nature.

4.2 The Benefits of Green Chemistry:

- Economical
- Energy efficient

- Lowers cost of production and regulation
- Less wastes
- Fewer accidents
- Safer products
- Healthier workplaces and communities
- Protects human health and the environment

4.3 Why Do We Need Green Chemistry?

- Chemistry is undoubtly a very well-known part of our daily lives.
- Chemical developments bring new environmental problems and harmful unexpected side effects, which result in the need for 'greener' chemical products.
- Use of CFC as refrigerant and in air conditioner and refrigerator. CFC can deplete ozone layer and can cause skin cancer etc.
- It looks at pollution prevention on the molecular level. It is an extremely important area of chemistry due to the importance of chemistry in our world today and the implications it can show on our nature.
- The Green chemistry program supports the invention of more environment friendly chemical processes which reduce or even eliminate the generation of hazardous and harmful substances.

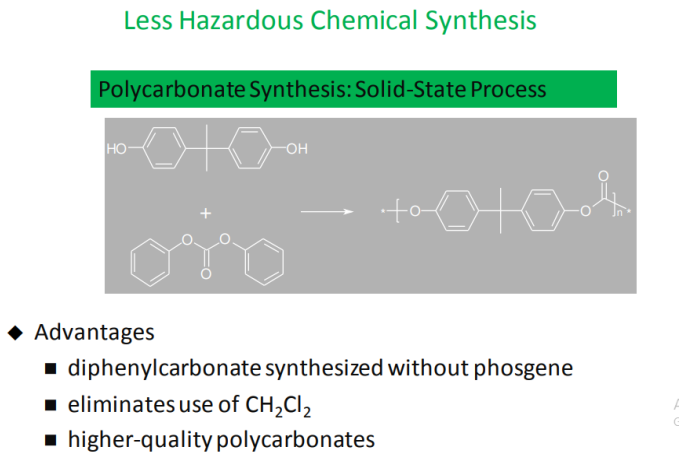
4.4 Goals of Green Chemistry:

1. Protection of environment from pollution
2. Minimization of waste and byproducts formation
3. Synthesis of less hazard's chemicals
4. Synthesis of ecofriendly or biodegradable products. **Example:** synthesis of new pesticides which is only toxic to the target species and it readily degrades into safer products.
5. Replacement of hazardous organic solvents. For these green solvents like water, super critical CO2 (SC- CO2), ionic liquids, fluorous solvent, polyethylene glycol etc. should be used.
6. Use of renewable raw materials or feedstocks. **Example:** use of biomass as raw material rather than petrochemical feedstocks.
7. Consumption of minimum energy.
8. To minimize release of obnoxious and inflammable chemicals, explosion and fires.
9. The principles of **4R's** of IWM (Integrated waste Management)
10. These are 4 pillars of IWM. Green Chemistry aims to use the **4R's** to enhance the movement of Green Chemistry. **4R: R**eduction, **R**e-Use, **R**ecovery, **R**ecycling.

4.5 Twelve Principles of Green Chemistry:

In 1998, **Dr. Paul Anastas** and **Dr. John C. Warner** postulated 12 Principles of Green Chemistry

1. **Pollution Prevention:** It is better to prevent waste than to treat or clean up waste after it is formed.
   Explanation: It is most appropriate to carry out a chemical synthesis by following a technique that produces minimum waste. One type of waste product common and often avoidable is the starting material or reagent that remains unreacted. It follows the principle **"Prevention is better than cure."**
2. **Atom Economy:** Designing of synthetic methods for the maximum incorporation of all materials used in the process into the final product.
   Explanation: Synthetic methods should be designed to maximize the incorporation of all materials (Starting materials and reagents) used in the process into the final product. Chemists globally consider that if the yield of a reaction is above 90%, the reaction is good.
   % atom economy = Formula weight of the desired products/Sum of Formula weight of all the reactants x 100
   <u>Hydrogenation reaction:</u>
   $CH_3\text{-}CH{=}CH_2 + H_2 + \text{Ni-catalyst} \longrightarrow CH_3\text{-}CH_2\text{-}CH_3$
   This reaction is 100% economical.
3. **Less Hazardous Chemical Synthesis:** Synthetic methodologies should be designed to use and produce substances that possess little or no toxicity to human health and the nature.



4. **Designing Safer Chemicals:** Chemical products should be designed to preserve efficacy of the function while reducing toxicity.
   Explanation: During chemical synthesis, the energy requirements should be kept to a minimum.

- If the starting material and the reagents in reaction mixture has to be heated or reflux for a required time, time required has to be kept minimum for the minimum usage of energy.
- Use of a catalyst has the great advantage of lowering the energy requirement of a reaction.
- In case the reaction is exothermic, sometimes extensive cooling is required.
- If the final product is impure, it has to be purified by distillation, recrystallisation or ultrafiltration. All these steps involve energy.
- By designing the process such that there is no need for separation or purification, the final energy requirements can be kept at minimum.
- Energy to a reaction can be supplied by photochemical means, microwave or ultrasonication

5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances (solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous (harmless).

Green Methods:

Explanation: Solvent selected not cause any environmental pollution and health hazard.

- The reaction should be carried out in aqueous phase
- The reaction should be carried out without the use of solvent (solvent less reactions). The use of liquid or supercritical liquid CO2 should be explored.
- The reaction should be carried out in the solid phase

6. **Design for Energy Efficiency:** Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

Explanation: To save energy, the synthetic methods should be carried out with the expense of minimum energy. The use of more moderate conditions and normal temperature and pressure are the good choice for a green synthesis.

The energy requirement for a reaction can be reduced by a suitable catalyst. Biocatalyst like enzyme can work at normal temperature and pressure. It can also be done by using microwave heating, ultra-sonification or photochemical activation.

7. **Use of Renewable Feedstocks:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.

Explanation: The continuous use of non-renewable feed stocks such as petroleum product, fossil fuel etc. can deplete the conventional resource and future generation can be deprived.

On the other hand, agricultural or biological products (e.g. potato, corn,`biomass etc.) can be used as renewable starting materials or feedstocks.

8. **Reduce Derivatives or minimization of steps:** Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

Explanation: During synthesis of a chemical compound the number of steps should be reduced as far as possible because extra steps require extra reagents that can generate excess waste material. So, if possible, the steps like blocking groups, protection/deprotection, temporary modification of physical/chemical processes etc. should be avoided. Thus, the number of steps should be minimum to synthesize a desired chemical compound.

9. **Catalysis. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents:**

Explanation: Catalysts performs transformation without consumed in the reaction and without being incorporated in the final product hence is preferred whenever possible. **Advantages:**

- Better yield
- Reaction becomes feasible
- Selectivity
- Advantage in energy requirement
- Better utilisation of starting materials and minimum waste product formation.

10. **Design for Degradation:** Chemical products should be designed so that at the end of their function they do not persist in the nature and instead break down into innocuous degradation products.

Explanation: In the green chemistry, the chemical product should be designed in such a way that at the end of their function, the chemical products (e.g. plastics, pesticides, detegents etc.) should degrade easily to harmless products and they should not persist in the nature. The waste product should degrade automatically to clean the nature. It can be done by the introduction of suitable groups and other features in the starting materials. The groups should be such that which are susceptible to hydrolysis, photolysis etc.

11. **Real-time Analysis for Pollution Prevention:** Analytical methodologies need to be further developed to allow for realtime in-process monitoring and control prior to the formation of hazardous substances.

Explanation:

- Analytical methodologies should be so designed so that they require minimum usage chemical like recyling of some unreacted chemicals, for the completion of the reaction.
- Placement of sensors to monitor the generation of hazardous products during chemical reaction is also advantageous.

12. **Inherently Safer Chemistry for Accident Prevention:** Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

Explanation: The substance used in a chemical reaction should be selected in such a way that the occurrence of accidents, explosions and fires can be minimized or avoided.

4.6 References:

1. A text book of green chemistry: Sankar P Dey, Nayim Sepay.
2. www.unep.org
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