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Green chemistry: The fundamental approach to preventing pollution in sustainable development

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Abstract
The Green Chemistry revolution is providing an enormous number of challenges to those who practice chemistry in industry in education and research. With these challenges however, there are an equal number of opportunities to discover and apply new chemistry, to improve the economics of chemical manufacturing. Green chemistry is the philosophy and study of design of product or substances that will not involve materials harmful to the environment. It is a modern science of chemistry that deals with the application of environmentally friendly chemical compounds in the various areas of our life such as industrial uses and many other. This area of chemistry had been developed by the need to avoid chemical hazards that organic and inorganic compounds had on the body of humans and animals. Chemistry play a pivotal role in determining the quality of modern life. The chemicals industry and other related industries supply us with huge variety of essential products, from plastics to pharmaceuticals. However, these industries have the potential to seriously damage our environment. Green chemistry therefore serves to promote the design and efficient use of environmentally benign chemicals and chemical processes.

Keywords: Green chemistry, fundamental approach, preventing pollution, sustainable development

Introduction

Green Chemistry is defined as invention, design, development and application of chemical products and processes to reduce or to eliminate the use and generation of substances hazardous to human health and environment. The green chemistry revolution is providing an enormous number of challenges to those who practice chemistry in industry, education and research. With these challenges however, there are an equal number of opportunities to discover and apply new chemistry to improve the economics of chemical manufacturing and to enhance much tarnish image of chemistry. Green chemistry is a philosophy and study of the design of products or substances that will not involve materials harmful to the environment. The ideal scenario is to virtually stop pollution before it can even begin through the use of non-pollutants. Green chemistry is a relatively new area of chemistry that emerged by the need to reduce the hazardous effect of chemicals and to reduce the amount of environmental pollution that chemicals have. All these will be discussed in this article.

History of Green Chemistry

In 1990 the Pollution Prevention Act was passed in the United States. This act helped create a modus operandi for dealing with pollution in an original and innovative way. This paved the way to the green chemistry concept. Paul Anastas and Warner coined the two letter word “green chemistry” and developed the twelve principles in 2000 Ryoji Noyori identified three key developments in green chemistry: use of supercritical carbon dioxide as green solvent, aqueous hydrogen peroxide for clean oxidations and the use of hydrogen in asymmetric synthesis.

The origins of green chemistry

It is a modern science of chemistry that deals with the application of environmentally friendly chemical compound in the various areas of our life such as industrial uses and many others. This area of chemistry had been developed by the need to avoid chemical hazards that organic and inorganic compounds had on the body of humans and animals. Most chemical compounds whether they are naturally made or are synthesized in the laboratory have negative effects on the human body although they are beneficial on a commercial basis. Especially notable are organic compounds which can easily penetrate the hydrophobic skin layer and enter the body.

There it can exert an effect by binding to macromolecules in the body and alter their structure or interfere with their normal metabolism.

Concepts of Green Chemistry
The concept of green chemistry incorporates a new approach to the synthesis, processing and application of chemical substances in such manner as to reduce threats to health and environment. This new approach is also known as:

- Environmentally benign chemistry
- Clean chemistry
- Atom economy
- Benign-by-design chemistry

Green Chemistry or environmentally benign chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Green chemistry was developed by virtue of the need to overcome this hazardous effect that toxic compounds exert on the body. This relatively new area of chemistry uses water as the medium of chemical reactions that are done in the laboratory. Chemical reactions are usually done in a medium that is called solvent. An exception is reactions that take place in the gas phase where there is no need for medium there. Sometimes chemical reactions are done in a neat fashion. Namely, the reacting compounds are mixed and reacted together with the need for a solvent. This is one of the methods that are used in green chemistry to avoid pollution and the hazardous effect of the volatile solvent. As a chemical philosophy, green chemistry applies to organic chemistry, inorganic chemistry, biochemistry, analytical chemistry and physical chemistry to minimize west, utilize renewable resources.

The challenges to chemists: Designing Safer Chemicals
Sustainable development is now accepted by governments, industry and the public as a necessary goal for achieving societal, economic and environmental objectives. Within this, chemistry has a key role to play in maintaining and improving our quality of life, the competitiveness of the chemical industry and the natural environment. This role for chemistry is not generally recognized by government or the public. In fact chemicals, chemistry and chemists are actually seen by many as causes of the problems. So chemists should be designed chemical products to preserve efficacy of the function while reducing toxicity. Chemists are molecular designers; they design new molecules and new materials. Green Chemists make sure that the things that we make not only do what they're supposed to do, but they do it safely. This means that it's not only important how chemists make something, it's also important that what they make isn't harmful. In Chemistry: Function is NOT related to hazard. Making safe, non-toxic products is the goal.

Green Chemistry and Sustainable Development
Green chemistry focuses on how to achieve sustainability through science and technology

- To better understand and solve the issue of environmental pollution, many approaches and models have been developed for environmental impact assessments.
- Some of these approaches and models have been successful in predicting impacts for selected chemicals in selected environmental settings.
- These models have joined air and water quality aspects to point and nonpoint sources and have been very useful for the development of emission control and compliance strategies.
- However, some of the approaches and models were aimed primarily at evaluating the quantity of pollutants that could be discharged into the environment with acceptable impact, but failed to focus on pollution prevention.

The concept of end-of-pipe approaches to waste management decreased, and strategies such as environmentally conscious manufacturing, eco efficient production or pollution prevention gained recognition.

The Twelve Principles of Green Chemistry
Green Chemistry is commonly presented as a set of twelve principles proposed by Anastas and Warner. The principles comprise instructions for professional chemists to implement new chemical compound, and new synthesis and technological processes.

Prevention: It is better to prevent waste than to treat or clean up waste after it is formed. It is advantageous to carry out synthesis in such a way that the formation of waste product is minimum or absent. The waste if discharged in atmosphere, sea and causes not only pollution but also require expenditure for clean-up.

Atom economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product. A synthesis is perfectly efficient or atom economical if it generates significant amount of waste which is not visible in percentage yield calculation.

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoratical yield}} \text{X } 100$$

Rearrangement and addition reaction are 100%atom economical reaction since all the reactants are changes into product.

Less hazardous chemical syntheses: Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment. On the other way we must choose safer route for example polycarbonate synthesise by two routes one in which phosphagens are taken are highly toxic and other are solid state process is environment friendly.

Designing safer chemicals: Chemical products should be designed to preserve efficacy of function while reducing toxicity. Synthetic methodology should be design to generate substances that posses less harmful or toxic product.

Safer Solvents and Auxiliaries: The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used. solvent like ionic liquid, super critical fluid etc which maintain the solvency of material and are also non-volatile in nature.

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 pressures.

Use of renewable feedstock: A raw material or feedstock should be renewable rather than depleting wherever technically and economically practicable. Renewable feedstock is often made from agricultural product or are the wastes of other processes.

Reduce derivatives: Unnecessary derivatization (blocking group, protection/ de protection, temporary modification) should be avoided whenever possible. Such steps require additional reagents and may generate additional waste.

Catalysis: Catalytic reagents that can be used in small quantity to repeat a reaction (as selective as possible) are superior to stoichiometric reagents. Some advantages of catalyst are

1. It gives the better yield of product.
2. The reaction becomes feasible in those cases where no reaction is normally possible.
3. Better utilization of starting material and minimum waste product are formed.

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

Real time analysis for pollution prevention: Analytical methodologies need to be further developed to allow for real time, in-process monitoring and control prior to the formation of hazardous substances. Real time analysis for a chemist is the process of checking the progress of chemical reaction as it happens knowing when your product is done we can save a lot of time and energy.

Inherently safer chemistry for accident prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize potential for chemical accidents, including releases, explosions, and fires.

Synthesis of some industrial compound involving basic principle of green chemistry

Synthesis of acetaldehyde: Commercially acetaldehyde was obtained by catalytic oxidation of ethyl alcohol or by hydration of acetylene. The reaction occur at a very high temperature but in the green synthesis acetaldehyde are obtained by oxidation of ethylene in the presence of catalysts solution.

Free radical bromination: The usual bromination of toluene with N-bromosuccinimide gives benzyl bromide. This process requires a solvent that is carbon tetrachloride. It has been found that free radical bromination of toluene with NBS in supercritical carbondioxide gave 100 percent yield of benzyl bromide.

Synthesis of Adipic acid: Adipic acid is required in large quantities for synthesis of nylon and lubricant but adipic acid is obtained from benzene which cause environmental and health problem. Also nitrous oxide is generated as a by-product which cause greenhouse effect. In green synthesis D-glucose (renewable source) is used as a starting material and also the synthesis is conducted in water instead of organic solvent.

Disinfection of water: Disinfection of water is usually carried out by chlorination. In this reaction chlorine oxidise the pathogen thereby killing them but at the same time it forms harmful chlorinated compound. A remedy of this comes from green chemistry is to use another oxidant such as ozone or supercritical water.

Production of allyl alcohol: In the traditional method, for the production of allyl alcohol hydrolysis of allyl chloride was done which generates the product and hydrochloric acid as a by-product but in green synthesis to avoid chlorine the two-step process are taken using propylene, acetic acid and oxygen.

Production of styrene: The traditional method is two step method starting with benzene (which is carcinogenic) and ethylene to form ethyl benzene followed by dehydrogenation to obtain styrene but in another way in green synthesis to avoid benzene the reaction is started with xylene which is cheapest source of aromatics and environmentally safer than benzene.

Synthesis of ibuprofen: Ibuprofen is one of the products used in large quantities for making pharmaceutical drugs in particular various kinds of analgesic (pain killer). The traditional commercial synthesis was developed by the Boots Company of England in 1960s. It is a six-step process which result in large quantity of by-product. There is only 40% atom economy in this synthesis. The BHC Company developed a new greener synthesis of ibuprofen that consists of only three steps which result in small amount of unwanted products and has very good atom economy i.e. 77%.

Progress in Green Chemistry

Over the past decade, green chemistry has convincingly demonstrated how fundamental scientific methodologies can be devised and applied to protect human health and the environment in an economically beneficial manner. Significant progress has been made in key research areas, such as atom economy, alternative synthetic route for feed stocks and starting materials, bio-catalysis, green solvent, biosorption, designing safer chemicals, energy and waste management.

Atom Economy (Synthesis of Ibuprofen)

Atom economy is one of the fundamental principles of green chemistry. Atom economy looks at the number of atoms in the reactants that end up in the final product and by- product or waste. % Atom economy = 100 x (FW of product /FW of reactants)

Alternative Synthetic Route for Feedstock & Starting Materials

Production of dimethylcarbonate (DMC) production DMC is a versatile and environmentally innocuous material for the chemical industry. Owing to its high oxygen content and blending properties, it is used as a component of fuel. Traditional method for the production of DMC This method involves the use of phosgene ($COCl_2$) and methanol (CH_3OH) as shown below:

$$COCl_2 + 2CH_3OH \rightarrow CH_3OCOOCH_3 \text{ (DMC)} + 2HCl$$

Alternative route for the production of DMC

This involves the use of copper chloride (CuCl), methanol (CH_3OH), oxygen (O_2) and carbon monoxide.

$$2CuCl + 2CH_3OH + 1/2O_2 \rightarrow 2Cu(OCH_3)\,Cl + H_2O$$
$$2Cu(OCH_3)\,Cl + CO \rightarrow 2CuCl + CH_3OCOOCH_3$$

Bio-catalysis

Bioleaching is the extraction of specific metals from their ores through the use of microorganisms such as bacteria. This is much cleaner than the traditional heap leaching using cyanide in the case of gold extraction.

Extraction of gold

This can involve numerous ferrous and sulphur oxidizing bacteria, such as *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* (also referred to as *Thiobacillus*). For example, bacteria catalyse the breakdown of the mineral arsenopyrite (FeAsS) by oxidising the sulphur and metal (in this case arsenic ions) to higher oxidation states whilst reducing dioxygen by H2 and Fe3+. This allows the soluble products to dissolve.

$$FeAsS(s) \rightarrow Fe^{2+} (aq) + As^{3+} (aq) + S^{6+} (aq)$$

This process occurs at the cell membrane of the bacteria. The electrons pass into the cells and are used in biochemical processes to produce energy for the bacteria to reduce oxygen molecules to water. In stage 2, bacteria oxidise Fe^{2+} to Fe^{3+} (whilst reducing O_2).

$$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

They then oxidise the metal to a higher positive oxidation state. With the electrons gained, they reduce Fe^{3+} to Fe^{2+} to continue the cycle. The gold is now separated from the ore and in solution.

Green Solvent

One of the green solvents is supercritical carbon dioxide ($scCO_2$). Supercritical carbon dioxide refers to carbon dioxide that is in a fluid state while also being at or above both its critical temperature and pressure (Tc = 31.3 oC, Pc = 1071 psi (72.9 atm) yielding rather uncommon properties. Supercritical carbon dioxide has been used as a processing solvent in polymer applications such as polymer modification, formation of polymer composites, polymer blending, microcellular foaming, particle production, and polymerization.

Reaction of amines with CO2

$RNH_2 + CO_2 \rightarrow RNHCOOH\ RNH_3 + RNHCOO-$
$RNH_2 + 2H_2C\,(O)CH_2$ ----> $RN(CH_2CH_2OH)_2$
$H_2\,C\text{-}O\text{-}CH_2 + CO_2$ ----→ [COO-CR-C-O-] (polycarbonates)

Bio sorption

Bio sorption is one such important phenomenon, which is based on one of the twelve principles of Green Chemistry, i.e., “Use of renewable resources.” It has gathered a great deal of attention in recent years due to a rise in environmental awareness and the consequent severity of legislation regarding the removal of toxic metal ions from wastewaters. In recent years, a number of agricultural materials such as the following have been used to remove toxic metals from wastewater:

Energy

Fossil fuel is dogged with many environmental pollution problems. There is, therefore, a growing need for alternative energy sources to replace fossil fuels. Renewable energy resources that are currently receiving attention include, solar energy, wind energy, hydro energy (Anastas and Williamson, 1998) [2]. Environmentally benign petrol can be obtained by the removal of Pb from petrol; by addition of ethanol produced from biomaterials to the petrol pool; by addition of methyl t-butyl ether (MTBE) to the petrol pool. MTBE has high octane and by use of electric vehicles powered by fuel cells.

Conclusion

The challenges in resource and environmental sustainability require more efficient and benign scientific technologies for chemical processes and manufacture of products. Green chemistry addresses such challenges by opening a wide and multifaceted research scope thus allowing the invention of novel reactions that can maximize the desired products and minimize the waste and by products, as well as the design of new synthetic schemes that are inherently, environmentally, and ecologically benign. Therefore, combining the principles of the sustainability concept as broadly promoted by the green chemistry principles with established cost and performance standards will be the continual endeavour for economies for the chemical industry. It is, therefore, essential to direct research and development efforts towards a goal that will constitute a powerful tool for fostering sustainable innovation. Green chemistry can solve the pressing environmental concerns and impacts to our modern era, applying the twelve principles of green chemistry into practice will eventually help to pave the way to a world where the grass is greener. Green chemistry is the fundamental approach to preventing pollution.

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