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Review Article

APPLICATIONS OF GREEN CHEMISTRY IN SUSTAINABLE DEVELOPMENT

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ABSTRACT

Chemistry is really very helpful to us as its applications are used worldwide for several purposes. We cannot really imagine a world without chemistry and its applications such as medicines. However, we should now concentrate on green chemistry or sustainable chemistry, which refers to reducing or stopping the damage done to the environment around us. Hence, green chemistry could include anything from reducing waste to even disposing of waste in the correct manner. Another way to save the environment through sustainable chemistry is to make use of renewable food stocks. Yet another good move is to make use of catalysts in experiments rather than using stoichiometric reagents. Chemical derivatives must be avoided as far as possible in any type of application as they often prove to be harmful. All chemical wastes should be disposed of in the best possible manner without causing any damage to the environment and living beings. We have to develop materials that will aid in the infusion of green chemistry into the curriculum such as green chemistry laboratory experiments and short courses on green chemistry. This article presents a brief description on green chemistry principles and its developments.

Keywords: Green chemistry, designing safer solvents, designing safer chemicals, sustainable development.

INTRODUCTION

The term Green Chemistry was coined[1] in 1991 by Paul T. Anastas. The purpose is to design chemicals and chemical processes that will be less harmful to human health and environment. Green chemistry protects the environment, not by cleaning up, but by inventing new chemical processes that do not pollute.

Green chemistry and Sustainable Development

"Green chemistry" and "sustainability" are not just sound bites, but a new paradigm that promises to have a deep and lasting impact on the science of chemistry. Green chemistry and sustainability essentially go hand in hand. Sustainable development is meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. We need greener chemistry- chemistry that efficiently utilizes renewable raw materials, eliminates waste and avoids the use of toxic and or hazardous solvents and reagents in both products and processes-in order to achieve this noble goal. Green chemistry embodies two main components. First, it addresses the problem of efficient utilization of raw materials and the concomitant elimination of waste. Second, it deals with the health, safety and environmental issues associated with the manufacture, use and disposal or re-use of chemicals. Green chemistry is one of the most fundamental and powerful tools touse on the path to sustainability. In fact, without green chemistry and green engineering, there is no path to sustainability. The 12 principles of Green chemistry and their applications to basic and applied research are briefly described below:

1. Prevention

It is better to prevent waste than to treat or clean up waste after it is formed. The ability of chemists to redesign chemical transformations to minimize the generation of hazardous waste is an important first step in pollution prevention. It goes back to the old saying "prevention is better than cure". It is better to prevent waste than clean it up after the fact[2].

2. Atom economy

This principle gets into the actual chemistry of how products are made. This principle states that it is best to use all the atoms in a process. And, those atoms that are not used end up as waste. Choosing transformations that incorporate most of the starting materials into the product are more efficient and minimize waste.

3. Less hazardous chemical synthesis

The goal is to reduce the hazard of the chemicals that are used to make a product. Chemists have traditionally used whatever means necessary. Today we are finding that less hazardous reagents and chemicals can be used in a process to make products.[3] Synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and environment. Some toxic chemicals are replaced by safer ones for a green technology. For example, in the manufacture of polystyrene foam sheet packing material, chlorofluorocarbons which contribute to O_3 depletion and global warming, have now been replaced by CO_2.

4. Designing safer chemicals

Everyone wants safe products. This principle is aimed at designing products that are safe and non-toxic. Pharmaceutical products often consist of chiral molecules and the difference between the two forms can be a matter of life and death- for example, racemic Thalidomide when administered during pregnancy, leads to horrible birth defects in many new borns. Evidence indicates that only one of the enantiomers has the curing effect while the other isomer is the cause of severe defects.[4]

5. Safer solvents

We use solvents regularly in our daily lives (cleaning products, nail polish, cosmetics, etc.) and in the chemistry laboratory. Many chemical reactions are done in a solvent. And, traditionally organic solvents have been used that pose hazards and many are highly toxic. Solvents are extensively used in most of the syntheses.[5] Widely used solvents in syntheses are toxic and volatile-alcohol, benzene (known carcinogenic), CCl_4, $CHCl_3$, perchloroethylene, CH_2Cl_2. Purification also utilize large amounts of solvents (e.g. Chromatography) which add to pollution and can be highly hazardous to human health. The development of Green Chemistry redefines the role of a solvent: An ideal desirable green solvent should be natural, nontoxic, cheap and readily available. This principle focuses on creating products in such a way that they use less hazardous solvents. It is obvious that water is the most inexpensive and environmentally benign solvent.

6. Design for energy efficiency

Today there is a focus on renewable energy and energy conservation. We use energy for transportation purposes and to provide electricity to our homes and businesses. Traditional methods for generating energy have been found to contribute to global environmental problems such as Global Warming and the energy used can also be a significant cost[6]. This principle focuses on creating products and materials in a highly efficient manner and reducing associated pollution and cost.

7. Use of renewable feed stocks

90-95% of the products we use in our everyday lives are made from petroleum. Our society not only depends on petroleum for transportation and energy, but also for making products. This principle seeks to shift our dependence on petroleum and to make products from renewable materials. Biodiesel is one example of this where researchers are trying to find alternative fuels that can be used for transportation[7]. Another example is bio-based plastics. Polylactic acid (PLA) is one plastic that is being made from renewable feed stocks such as corn and potato waste. Benzene used in the commercial synthesis of adipic acid which is required in the manufacture of nylon, plasticizers and lubricants, has been replaced to some extent by the renewable and nontoxic glucose and the reaction is carried out in water.

8. Reduce derivatives

Unnecessary derivatization (blocking group, protection/deprotection) should be avoided whenever possible, because such steps require additional reagents and can generate more waste[8].

9. Catalysis

In a chemical process catalysts are used in order to reduce energy requirements and to make reactions happen more efficiently[9]. Another benefit of using a catalyst is that generally small amounts are required to have an effect. And, if the catalyst is truly a "green" catalyst it will have no toxicity in the process. Enzymes are wonderful examples of catalysts. Biocatalysed reactions are advantageous as they are performed in aqueous medium.

10. Design for degradation

Not only do we want materials and products to come from renewable resources, but we would also like them not to persist in the environment. There is no question that many products we use in our daily lives are persistent. Plastics do not degrade in our landfills and pharmaceutical drugs such as antibiotics build up in our water streams[10]. This principle seeks to design products in such a way that they perform their intended function.

11. Pollution prevention

Everyone known that prevention is better than cure from this pollution is better than pollution control. Pollution prevention is using materials, process or practices that reduces or eliminate pollution or wastes at the source.

12. Safer Chemistry for Accident Prevention

This principle focuses on safety for the worker and the surrounding community where an industry resides. It is better to use materials and chemicals that will not explode, light on fire, ignite in air, etc. when making a product. There are many examples where safe chemicals[11] were not used and the result was disaster. The most widely known and perhaps one of the most devastating disaster was that of Bhopal, India in 1984 where a chemical plant had an accidental release that resulted in thousands of lives lost and many more injuries. When creating products, it is best to avoid highly reactive chemicals that have potential to result in accidents. When explosions and fires happen in industry, the result is often devastating.

Green Chemistry Skills

Chemists from all over the world are using their creative and innovative skills to develop new processes, synthetic methods, reaction conditions, catalysts etc., under the new Green chemistry concepts. Commercial applications of green chemistry have led to novel academic research to examine alternatives to the existing synthetic methods[12]. Some of these are:

1. The use of phosgene and methylene chloride in the synthesis of polycarbonates has been replaced by diphenylcarbonate.

2. The most polluting reaction in industry is oxidation. Implementation of green chemistry has led to the use of alternative less polluting reagents viz., metal ion contamination is minimized by using molecular O_2 as the primary oxidant and use of extremely high oxidation state transition metal complexes.

3. A convenient green synthesis of acetaldehyde is by Wacker oxidation of ethylene with O_2 in presence of a catalyst, in place of its synthesis by oxidation of ethanol or hydration of acelylene with H_2SO_4.

4. Conventional methylation reactions employing toxic alkyl halides or methylsulfate leading to environmental hazard are replaced by dimethylcarbonate with no deposit of inorganic salts.

5. In 1996, Dow Chemical won 1996 Greener Reaction award for their 100% carbon dioxide blowing agent for polystyrene foam production. Polystyrene foam is a common material used in packing and food transportation. Traditionally, CFC and other ozone depleting chemicals were used in the production process of the foam sheets, presenting a serious environmental hazard. Dow Chemical discovered that supercritical CO_2 works equally as well as a blowing agent, without the need for hazardous substances, allowing the polystyrene to be more easily recycled. The CO_2 used in the process is reused from other industries, so the net carbon released from the process is zero.

6. Propylene oxide (PO) is a chemical building block for a variety of products including detergents, polyurethanes and food additives. Traditional PO production uses chlorohydrin which leads to co products such as t-butyl alcohol, styrene monomer or cumene. Its manufacture creates by-products, including a significant amount of waste. Dow and BASF have jointly developed a new route to make propylene oxide with hydrogen peroxide and propylene that eliminates most of waste. Dow and BASF have jointly developed a new route to make propylene oxide with hydrogen peroxide and propylene that eliminates most of waste.

7. Historically, chlorofluorocarbons (CFCs) have been used as refrigerants in air conditioners and refrigerators. CFCs have the advantages of safe incombustibility, high stability, and low toxicity, but unfortunately they destroy the ozone layer. In the past decade, various hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) have replaced CFCs. HCFCs and HFCs are, indeed, safer for the ozone layer.

8. Chelates are complex that interact with metal ions, often increasing the solubility of the metal ion. They are used in many types of cleaners and industrial processes. Conventional chelates are based on aminocarboxylic acids (e.g., ethylenediaminetetraacetic acid, EDTA) and phosphates (e.g., sodium tripolyphosphate). Unfortunately, because EDTA is not readily biodegradable and because phosphates can cause pollution via eutrophication, these conventional materials are often viewed as environmentally unfriendly. Akzo Nobel has developed a readily biodegradable chelating agent that is manufactured principally from a renewable feed stock. This new chelate, called tetrasodium L-glutamic acid, N, N-diacetic acid (GLDA), will replace phosphates in automatic dishwashing detergents. GLDA is manufactured from the flavor enhancer monosodium glutamate (MSG) in an essentially waste-free synthesis. MSG is made by fermenting readily available corn sugars and is considered a renewable material. The synthesis of GLDA includes classic cyanomethylation of the primary amino nitrogen on the MSG followed by in situ alkaline saponification. In contrast with EDTA whose carbon is fossil-based, but in GLDA is biobased. Because GLDA is highly soluble, it will be offered at a significantly higher concentration (approximately 30 percent higher molar aqueous concentration) than EDTA, reducing transport and packaging costs as well as packaging waste. Most significantly, GLDA is readily biodegradable and will reduce pollution by replacing phosphates in dishwashing detergents.

9. Spinosad is a low-risk pesticide in widespread use on crops. Spinosad adsorbs strongly to soils and organic matter, degrades photochemically at the site of application, and is inherently unstable in water. These characteristics make it excellent for use on land, but had prevented its use in aqueous environments. Spinosad is an environmentally safe pesticide but is not stable in water and so therefore cannot be used to control mosquito larvae. Clarke launched Natular in the U.S. market in December 2008. Natular, a spinosad based mosquito larvicide that provides excellent control in aquatic environments. It is 15 times less toxic than the organophosphate alternative, does not persist in the environment and is not toxic to wildlife.

Teaching of Green Chemistry

Teaching must be in harmony with practice. The question of how to educate the future generation of chemists possessing the skill and knowledge to practice environmentally friendly chemistry lies in the center of educational materials[13] related to green chemistry. Education is especially important in the popularization of green chemistry. Different international institutions, i.e. the American Chemical Society (ACS) and Polish Chemical Society (PTChem), are active in publishing materials that promote the rules and achievements of green chemistry. The green chemistry program should lead to sustainability by designing and using the methods in which natural raw materials will be economically processed, rational usage of energy sources, elimination of hazardous gaseous, liquid and solid wastes and by introduction of safety products for man. The popularization of green chemistry in schools, among the workers at plants of chemical industry and distributors of chemical products is also very important. The broad usage of green chemistry achievements will enable us to balance eco-development profitable for society, economy and the environment. The numerous educational materials, available currently on market[14] and on the Internet, are very useful in everyday teaching of green chemistry principles.

CONCLUSION

Green chemistry is not a new branch of science. It is a new philosophical approach that through application and extension of the principles of green chemistry can contribute to sustainable development. Great efforts are still undertaken to design an ideal process that starts from nonpolluting materials. It is clear that the challenge for the future chemical industry is based on production of safer products and processes designed by utilizing new ideas in fundamental research. Furthermore, the success of green chemistry depends on the training and education of a new generation of chemists. Student at all levels have to be introduced to the practice of green chemistry. Finally, regarding the role of education in green chemistry:

"The Biggest Challenge Of Green Chemistry Is To Use Its Rules In Practice."

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