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Review

Green Chemistry in Syllabi Modules

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ABSTRACT

Pollution has come to be recognized as the biggest danger of our planet. On the global front there are extensive, studies, debates and discourses to reduce the effect of pollution and prepare a safe world to live in. If at the very inception the research scholar desirous of making forays in chemical research is informed about the Principles of Green Chemistry then futuristic research will churn out lesser toxic waste, safer molecules and alternative sources of energy. These efforts will leave a positive ecological impact on the environment and will not deplete the planetary resources of energy. This review article discusses the twelve Principles of Green Chemistry which should be incorporated in the curricular design so that future research is benefited as well as the planet.

Keywords: Pollution, Green chemistry, Alternative sources of energy.

INTRODUCTION

Green chemistry involves the development of chemical products and synthetic procedure, which are environmentally friendly and have reduced health risks with the search for more efficient methods to do chemistry. Its roots stem back ten years from a simple idea to a prominent concept which penetrates all area of modern chemistry (Chemistry for the Environment, Inter University Consortium, Retrieved 2007-02-15). The article presented is an exercise to inform the student and/or researcher about the future aspects of 'Sustainable Chemistry' also called Green Chemistry. We all know the simple equation: Risk = Hazard x Exposure, the pollution of the planet is caused by the production of hazardous compounds and coupled with the exposure to them, our earth may suffer the risk of irreparable damage, which will adversely affect each and every ecological aspect. Both environmentalists and green chemists are involved in the same work of eliminating pollution. The former devise methods of minimizing the effects of pollution while green chemists target pollution by designing safer chemicals through simpler processes that prevent the production of pollutants eliminating the evil even before it is born. The greening of the planet by the chemist is achieved by designing less hazardous materials through processes involving lesser generation of waste material and effective use of our energy resources. The study of pollution and its effect on the environment has been taught, debated and discussed but the damage caused may take another millennium to reverse. Academics advocate the introduction of green chemistry in the curricular design of universities and colleges across the globe this may possibly have a greater impact on reversing the trend than environmentalists could ever envisage. If the curricular design of our courses could incorporate the vision of the 'Presidential Green Chemistry Challenge Awards' instituted in 1995 by the Clinton Administration, the world will be eliminating the evil at the inception stage instead of fighting a formidable and invincible giant. Nominees for the above award must show how their work meets one or more of the following criteria:

1). Greener reaction condition for an old synthesis (for example, replacing an organic solvent with water or no solvent),

2). A greener synthesis for an old chemical (e.g. a synthesis using biomass as fuel in place of petroleum or the use of catalytic rather stoichiometric reagents).

3). The synthesis of a compound which is less toxic but has the same desirable properties of an existing compound (for example, a new pesticide that targets organism and then biodegrades to benign substances). The vision was eloquently delivered by Daryl Busch, the former President of the American Chemical Society in 2000 when he said, "Green chemistry represents the pillars that hold up our sustainable future. It is essential to teach the value of green chemistry to tomorrow's chemists". In keeping with the vision it is only logical to introduce the twelve principles of green -chemistry enumerated in the abstract which were developed by [1]. They will have a more positive impact than all the environmental laws have ever had. Trache *et al*. have reported that Ammonium perchlorate (AP), the essential component of oxidizers in solid rocket and missile propellants, exhibits various environmental issues resulting from the release of perchlorate into ground water, which have been directly linked to thyroid cancer. The advantages and shortcomings of various green oxidizers for specific and potential propellant uses are also discussed together with the attempts made to overcome these problems. As a result, efforts will be made to seek AP alternatives and efficient green oxidizers for solid rocket propulsion in the near future [2].

The Twelve Principles of Green Chemistry

1. Prevention of waste: This principle deals with production of fewer waste products on the principle that, 'prevention is better than cure', meaning thereby that it is better to produce a lesser amount of waste rather than cleaning it later. Roger Sheldon proposed one of the best metrics for green chemistry and called E-factor which is defined as the ratio of the mass of waste per unit of the product

$$\text{E-factor} = \frac{\text{Total waste (kg)}}{\text{Total product (kg)}}$$

Sheldon supported his metric from the table 1.

Table 1. Write the title

Industry sector	Annual product (t)	Annual wastes (t)	E-factor
Oil	$10^6 – 10^8$	$10^5 – 10^7$	0.1
Bulk Chemical	$10^4 – 10^6$	10^4-$5x10^6$	1-5
Fine chemical	$10^2 – 10^4$	$5x10^2$-$5x10^5$	5-10
Pharmaceuticals	$10 – 10^3$	$2.5x10^2$-$5x10^5$	25-100

The table reflects that oil companies produce lesser waste than the companies producing fine chemicals and pharmaceuticals this is because the latter pay greater emphasis on quality and in order to achieve it pays the price of producing a significant amount of waste. The purification technique adopted extensive use of solvents and other hazardous auxiliaries which make a marked increase in the amount of waste. The positive fact, however, is that many pharmaceutical companies have adopted greener chemistry programmers in their designing of drugs.

If the chemist is taught to calculate the E-factor of a designed programme, the strategy will pave way towards the adoption of greener mechanisms.

2. Atom Economy: This principle deals with the actual chemistry involved in the formation of a product. Barry Trot's concept won him a Presidential Green Chemistry Award when he proposed a metric that looks at utilized and wasted atoms in a reaction. If a multistep process is given as: A+B'!CC+D'!EE+F'!G, then

$$\text{Atom Economy} = \frac{\text{m.w. of G}}{\text{m.wt's ABDF}} \times 100$$

or

$$\text{Atom Economy} = \frac{\text{F.Wt. of Product}}{\text{F.Wt. of Reactant}} \times 100$$

The chemist should be aware of the principle of atom economy as it will help him in designing processes which will involve a greater utilization of the reactant atoms and a decreased amount of the unutilized atoms.

3. Less hazardous chemical synthesis: This principle is focused on the methods involved in the production of material and molecules. Glaxo Smith Kline have developed a metric called Reaction Mass Efficiency (RME) which takes into account both atom economy and chemical yield.

For any reaction A+B'!C

$$\text{RME} = \frac{\text{Mass of C}}{\text{Mass of A + Mass of B}} \times 100$$

Many efforts to achieve less harmful product have been incorporated in the industry and some like those mentioned below have won the Presidential Green Chemistry Challenge Awards.

- The use of non-ozone depleting waste CO_2 as blowing agent in place of harmful, Chloro fluoro carbons in the manufacture of polystyrene.
- .The replacement of Ozone depleting Chlorine with H_2O_2 as bleaching agent in the manufacture of paper.

4. Designing Safer Chemicals: Chemical products should be designed to perform their required function and minimize toxicity. Glaxo Smith Kline has developed a metric called Carbon efficiency (CE) which is defined as:

$$\text{CE} = \frac{\text{Amount of Carbon in Product}}{\text{Amount of Carbon in Reactant}} \times 100$$

This metric is of much interest for the pharmaceutical chemist who is busy designing and developing new carbon skeletons in effective drug designing.

Some significant efforts are:

- A new synthesis for ibuprofen with better atom economy.
- Production of target specific insecticide which after eliminating harmful organisms biodegrade into benign substances.
- Polylactic acid plastic from corn and potato waste.

5. Safer solvents and auxiliaries: It is now a known fact that solvents in the manufacture of fine chemicals and various purification techniques have an adverse impact on the environment. Among the worst enemies of the planet are xylene, mercury and formalin. This has led Glaxo Smith Kline and Pfizer to publish 'solvent selection guides' for their drug discovery chemists. The Massachusetts Institute of Technology has created "The green alternatives Wizard" which incorporates safer alternatives as replacements for harmful ones.

6. Designing for energy efficiency: This principle is a study of the processes used in the manufacturing programme. Many of the modern processes have been designed so that energy requirements are reduced. These will be accompanied with a reduction in both pollution and cost.

7. Use of renewable feedstock: This principle is based on the slogan for environmental protection: "The Earth has not been inherited from the ancestors but borrowed from the descendants". This slogan led to a revolution which resulted in effort to find alternative sources of energy. Our society depends on petroleum for 90-95% for all its energy requirements. Studies and researches to locate alternative energy sources have yielded Biodiesel as a fuel for industrial requirements.

8. Reduction in derivatives: This principle aims to simplify processes and design products in a safer manner. It is suggested that processes involving use of blocking groups and temporary modification in physical and chemical processes should be minimal, because these processes use additional reagents and generate greater amount of waste.

9. Catalysis: Catalysts have been defined as the pillars of green chemistry. This is because the use of catalysts reduces energy requirements. Catalysts are retrievable and therefore reusable. They do not contribute to global pollution, further they bring down the cost as a very small quantity is used. Enzymes are being used to catalyze processes. As they are not hazardous to the environment, the enzyme catalyzed reactions give better yields, increased selectivity and use milder conditions which qualify them for green chemical processes.

10. Design for degradation: This principle seeks to design degradable products so that they perform their intended function and then degrade into safer bio-products on disposal. The process for developing new material should not be targeted towards a higher yield rather emphasis should be on lower environmental impact and better sustainability.

11. Real-time analysis for pollution prevention: The eco-scale is a recently developed metric tool for evaluation of the effectiveness of synthetic reaction. The eco-scale gives a score from zero to hundred and takes into account cost, safety, technical setup and energy aspects. It is obtained by assigning a value of 100 to an ideal reaction, (for example, if in a reaction compound A undergoes reaction with compound B to give the product C with minimal risk, minimal Impact on environment and 100% yield at room temperature.) In other words, the eco-scale is a quick assessment of the "greenness" of any reaction.

12. Inherent safer chemistry for accident prevention: The principle focuses on the safety for workers and the surrounding community where an industry resides. It is better to use materials and chemicals that will not explode, ignite in air, etc. There are many reports where safe chemicals were not used and the result was a disaster. The most widely known and perhaps one of the most devastating disaster was that in Bhopal, India in 1984 where a chemical plant had an accidental release that resulted in thousands of lives lost and many injuries. The chemical reaction that takes place was an exothermic reaction that went astray and toxic fumes were released to the surrounding area. When creating products, it is best to avoid highly reactive chemicals that have potential to result in an accident.

RESULTS AND DISCUSSION

In order to take the greening of the chemistry curriculum to its next logical step, people are developing green chemistry modules for insertion of green chemistry into specific chemistry courses. These courses should include among others the following core topics:

1. Study of the environmental laws
2. Study of the three criteria for the Presidential Green Chemistry Challenge Award, 2006
   i. Study of the twelve principles of Green chemistry.
   ii. Study of the list of safe auxiliary substances
   iii. Study of the superiority of catalytic reagents

AWARDS

Many awards have been created to encourage research in green chemistry.

- Australia's Green Chemistry Challenge Awards by the Royal Australian Chemical Institute (RACI).
- The Canadian Green Chemistry Medal [3].
- In Italy, Green Chemistry activities center in the inter-university consortium known as INCA [4].
- In Japan, The Green and Sustainable Chemistry Network through the GSC awards program [5].
- In the United Kingdom, the Green Chemical Technology Awards presented by Crystal Faraday [6].

In the US, the Presidential Green Chemistry Challenge Awards for individuals and businesses [7]. A database designed to benefit the community by minimizing barriers when adopting processes of green chemistry has doubled in size in the last two years, its creator told professional colleagues at the national spring meeting of the American Chemical Society [8]. Settle *et al*. have reported important research methodology for progressing in the Diels–Alder catalysis to target novel, aromatic monomers with chemical functionality that enables new properties compared to monomers that are readily accessible from natural sources [9].

CONCLUSION

It is clear that industries and academic research realize and recognize the significance of green chemistry. However, very little discussion of green chemistry has found its ways into the chemistry curriculum. Although, some isolated attempts to bring green chemistry into the classroom have been made, but a lot is yet to be achieved. The Environment Protection Agency [10] along with The American Chemical Society (ACS) have recognized the need to make a concerted and sustained effort to green the curriculum. The EPA and ACS 'Green Chemistry Education Material Development Project' was begun at a workshop in October 1998, the main thrust of this project is to develop materials that will help in the inclusion of green chemistry into the curriculum.

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