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Sustainable Development and Green Chemistry: A Review

Mominul Sinan, Chemistry, Charuchandra College, India

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Abstract

Chemistry brought revolution till about the middle of 20th century. In this era, drugs and anti-biotics were discovered. The world's food supply also increased enormously due to the discovery of hybrid varieties, improved methods of farming, better seeds and use of insecticides, herbicides and fertilizers. But the advancement started showing its ill-effects. Hazardous wastes are released to the air, water, and land by industries. It is essential to find alternative paths for environmentally sound and sustainable development. This new approach has received extensive attention and goes by many names including Green Chemistry. Green chemistry refers to the life cycle of a product, including its design, manufacture, use, and disposal. Main research on green chemistry aims to minimize or eliminate the formation of bi-products and to maximize the desired products in an environment friendly way. In addition, green engineering can be defined as environmentally conscious manners, values, and principles, combined with science and technology, all directed toward improving environmental quality. In this review some of the recent development has been discussed. It is very important to shift our society in a really sustainable direction.

Key words: *Green Chemistry, Environment, Safer chemicals, Biodegradable, Sustainable development*

1. Introduction

In the last decades, humanity faced huge challenges in the sustainability of our lifestyles and systems. Hundreds of tonnes of hazardous waste are released to the air, water, and land by industry in every second. However, it was not until the 1980s that the environment became a priority for the chemical industry. Global environmental issues including energy sources, water access, land use and ecological damage require urgent and relevant answers. It is essential to find alternative paths for an environmentally sound and sustainable development. In this context, green chemistry (Li, & Trost, 2008) and green engineering are instruments used increasingly more by scientists and engineers to make decisions having positive impact on the environment.
Green chemistry aims to minimise the environmental impact of the chemical industry. Green chemistry also prioritises safety, improving energy efficiency and, most importantly, minimising (and ideally) eliminating toxic waste from the very beginning.

2. Sustainable Development Goals

Our human health and the global environment are threatened by the adverse effects of development in different field of science. Our bodies are contaminated with a large number of synthetic industrial chemicals, many of which are known to be toxic and carcinogenic while others remain untested for their health effects. They come to us from unlabeled products, chemically contaminated food, air, water. The United Nations General Assembly has addressed these challenges in its Sustainable Development Goals (SDGs) (UN Summit, 2015) which have been adopted in 2015. A closer look shows that to meet these goals chemistry will play an important role. Also related to this, the UN Environmental Assembly-2 (UNEA-2) has named sustainable chemistry (UN Environment Assembly, 2016) as an important building block within and beyond sound chemicals management. Contributions of both science and industries are essential to meet the SDGs. In this context, green chemistry and green engineering are instruments used increasingly more by scientists and engineers to make decisions having positive impact on the environment.

3. Green chemistry and sustainability

Environmental chemistry is the chemistry of natural environment and of pollutant chemicals in nature, whereas green chemistry particularly tends to reduce and prevent pollution at source (Anastas, Heine, & Williamson, 2000). Paul Anastas known as the father of green chemistry has given the term green chemistry in 1991. Main emphasis of green chemistry researchers is to design safer chemicals and chemical processes in order to replace the use and generation of hazardous substances (Anastas, & Lankey, 2000). The 12 principles of green chemistry can be roughly organized into two major categories: those related to reducing energy usage and waste materials, and those related to producing or utilizing safer products and processes. While the application of these principles will lead to less energy consumption and the reduction of waste material put into the environment, these principles could also aid in protecting and improving worker safety and health (Hughes, LeGrande, Zimmerman, Wilson, & Beard, 2009).

3.1 Basic Principals of Green Chemistry (Anastas, & Warner, 1998)

3.1.1. Prevention: It is better to prevent the production of waste than to treat or clean up waste after it has been generated.

3.1.2. Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials employed in the process into the final product i.e. Reduce waste at the molecular level.

3.1.3. Less Hazardous chemical synthesis: Wherever possible, synthetic methods should be designed to use and create substance that possesses little or no toxicity to human health and environment.

3.1.4. Designing Safer Chemicals: Chemical products should be designed to perform their desired function while minimizing their toxicity and environmental destiny throughout the design of the process.

3.1.5. Safer Solvents and auxiliaries: The use of auxiliary substances (solvents, separation, agents, etc.) should be minimized whenever possible and should be made innocuous when used.

3.1.6. Design for energy efficiency: Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

3.1.7. Use of renewable feed stocks: Use chemicals which are made from renewable (i.e. Plant based) resources rather than chemicals obtained from depleting resources.

3.1.8. Reduce derivatives: Unnecessary derivatization should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

3.1.9. Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents. Using catalytic reagents creates opportunities for increased selectivity, better yield, and feasibility of non feasible reaction.

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

3.1.11. Real time 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.

3.1.12. Safer chemistry for accident protection: Choose and develop chemical techniques and substances that are safer and minimize the potential for chemical accidents, explosions and fires.

Green Chemistry has changed our life style in many ways. The benefits of Green Chemistry are 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, competitive advantage etc.

4. How to Design Safer Chemicals

The more we know about how a chemical's structure causes a toxic effect, the more options are available to design a safer chemical. To reduce the toxic effects of chemicals Green chemists are assembling various information. Green chemists also take a life cycle approach to reduce the potential risks throughout the production process. They work to ensure that a product will pose minimal threats to human health or the environment during production, use, and at the end of its useful life when it will be recycled, or disposed of.

5. Some Green alternatives to conventional methods

5.1 Ionic liquids: Ionic liquids (ILs) (Vedavathi, & Srinivas, 2017) are organic salts that exist as liquids at low temperature (<100 °C). An important future of ILs is immeasurably low vapour pressure. For this reason they are called green solvents in contrast to traditional Volatile Organic Solvents (VOCs).

5.2 Organic Synthesis in Water: Although water is considered a problem for organic synthesis and the purification process and drying in final products is very cumbersome, yet in recent years, water is considered as good solvent for organic reactions (Li, 2000).

5.3 Supercritical liquids: Supercritical liquids are suitable as a substitute for organic solvents in a range of industrial and laboratory processes. Carbon-Dioxide and Water are the most commonly used super-critical fluids. They are known as "Green Solvents" in many industrial processes, providing high yields in many reactions (Marathe, Mayadevi, Pardhy, Sabne, & Sivasanker, 2002; Tadd, Marteel, Manson, Davis & Abraham, 2003).

5.4 Solvent free reactions: In most organic reactions liquid solvents are used such as hydrocarbons, chlorinated hydrocarbons, esters, alcohols, ethers, ammonia, carbon disulphide, water etc. based upon its physical and chemical properties, its suitability to the chemical reaction. But the attempt to develop environment friendly, synthetic procedures has projected the need to minimize use of volatile organic solvents (VOC) which are the major cause of pollution (Waddell, & Mack, 2009; Tanaka, Kishigami, Toda, 1991). Microwave-irradiation in the solidstate is a technique that is being utilized to affect chemical transformations rapidly in contrast to those that have been classically conducted in liquid solutions. Solvent free reactions also reduce waste discharge (Song, Cho, Park, Kwon, & Jenekhe, 2003).

6. Green Chemistry in Our Stores

The application of Green chemistry concepts is becoming more widespread. The Green Chemistry and Consumer network alerts retailers and consumers around the world to new developments in safer product design.

6.1 Green Plastics: Some plastic products (Kristen Flint, 2014) can now be made from plant sugars from renewable crops, like corn, potatoes and sugar beets instead of non-renewable petroleum. Bio-based polymer from corn that is used in food and beverage packaging, as well as a 100% corn fiber, Ingeo, (NPE, 2018) that is used in blankets and other textiles.

6.2 Green Carpets: EcoWorx (Eco Worx, Shaw Industries, 2003) replaces conventional carpet tile backings that contain bitumen, polyvinyl chloride (PVC), or polyurethane with polyolefin resins which have low toxicity. This product also provides better adhesion, does not shrink, and can be recycled. Carpets made from ecofriendly (Joseph Lewitin, 2018) renewable sources also available in the market.

6.3 Ecofriendly Paint: VOCs such as ethyl acetate, glycol ethers, and acetone are mainly used as solvents for conventional paints. If we inhale they can create a toxic effect on our bodies. The odour emanating from these paints can be quite suffocating. Where as Natural paints (Arushi Prakash, 2014) are made of natural compounds (The Hindu, 2017) such as tree resins, water, plant oil, essential oil and natural dyes. They do not contain any VOCs.

6.4 Green Bleaching agents: Most commercial bleaches are oxidizing agents, such as sodium hypochlorite (NaOCl) or hydrogen peroxide (H_2O_2) which are quite effective in "decolorizing" substances via oxidation but during the process carcinogens are generated which causes health problems. In the presence of some activators such as TAML (Hall, Vuocolo, Suckling, Horwitz, Allison, Wright, & Collins, 1999) which catalyses the fast conversion of H_2O_2 into hydroxyl radicals, thus reducing the reaction time and temp for the bleaching process.

6.5 Fire extinguishing material: The conventionally used chemical firefighting foams used worldwide discharge toxic substances into environment contaminating water and deleting ozone layer. New Foam called pyro cool has now been invented to put out fires effectively without producing toxic substances as in other firefighting materials (Moody, & Field, 2000).

6.6 Green dry cleaning of clothes: Percholoroethylene (perc) is the solvent most commonly used in dry cleaning clothes. Perc is suspected to be carcinogenic and it contaminates ground water on its disposal. A new technology known as micell technology in which liquid carbon dioxide can be used as a safer solvent along with a surfactant to dry clean clothes (Anastas, & Williamson, 1998).

6.7 Turning turbid water clear in green way: Conventionally, municipality and industrial waste water is made clear by the use of Alum. Alum is found to increase toxic ions in treated water which causes Alzheimer's disease. The tamarind seed kernel powder (Srikumar, & Rao, 2015) has been found as effective and economic agent to make waste water clear as alum.

6.8 Biofuels: It can be obtained from biomass which may be obtained from sugar cane, corn, rapeseed, straw, wood, animal and agriculture residues. For example: Bio-diesel which is produced from oil or fat by a process called 'transesterification' when burnt in diesel engine with hydrocarbons is found to reduce the petroleum fuel consumption as well as the generation of toxic gaseous substances (Kulkarni, & Dalai, 2006; Saravanan, Mathimani, Deviram, Rajendran, & Pugazhendhi, 2018).

6.9 Biocatalysis: Through millions of years of evolution and 'sustainability', nature has developed highly efficient and selective means to achieve the desired transformations. The potential usefulness of various catalysts of Nature, such as enzymes (Wong, & Whitesides, 1994), whole cells, and catalytic antibodies (Lerner, Benkovic, & Schultz, 1991) for organic synthesis, has become more and more recognized. Frequently, biocatalysis (Sheldon, & Woodley, 2018) leads to extremely high reaction rates and selectivities such as enantioselectivities that go beyond the reach of chemical catalysts.

6.10 Use of Unleaded petrol: The higher the octane number better is the quality of petrol. Octane number of petrol these days is increased without addition of lead components such as tetra ethyl lead (TEL). Unleaded petrol is obtained by adding methyl tertiary butyl ether (MTBE) which supplies oxygen of petrol and hence reducing the formation of per-oxy compounds (Carter, 1994). Better fuel quality (Department of the Environment and Energy, Australian government, 2016) can help reduce the level of noxious emissions. Fuel quality also directly affects the level of harmful emissions produced by motor vehicles.

6.11 Sawdust ash as partial replacement of cement: Recent research discussed the possibility of using sawdust ash (Obilade, 2014) as a substitution in fine aggregate for a new concrete. Sawdust Ash (SDA) generated from rice mills usually delivered in landfills to disposal.

6.12 Greener Pharmaceuticals: The pharmaceutical industry was among the first to recognize the value of green chemistry (Ritter, 2014). Pharmaceutical companies are selecting less hazardous reagents, reducing reaction steps, and developing better catalysts. Zocor (simvastatin) is a leading drug for treating high cholesterol, traditionally used a multistep method that produced a large amount of toxic waste. A new method for synthesizing the drug uses an engineered enzyme and a low-cost feedstock that was optimized by Codexis, a biocatalysis company (U.S. EPA, 2012). Green chemical synthetic procedures (Chigurupati, Mohammad, Selvarajan, Simansalam, Vijayabalan, & Bhore, 2017), are replacing the conventional procedures of producing pharmaceuticals.

6.13 Molecular Self-assembly: Molecular self-assembly is a process in which molecules or parts of molecules spontaneously form ordered aggregates usually by noncovalent interaction. The process of molecular self-assembly is ubiquitous in chemistry, materials science, and biology (Whitesides, & Boncheva, 2002). For example, glycolipids generated from industrial byproducts such as cashew nut shell liquid can self-assemble to produce soft nanomaterials including lipid nanotubes, twisted/helical nanofibers, low-molecular-weight gels, and liquid crystals (U.S. EPA, 2012).

6.14 Solar Cell: The solar cell (Jean, Brown, Jaffe, Buonassisi, & Bulović, 2015) is most important example of green technology. It directly converts the light energy into electrical energy by the process of photovoltaics. Generation of electricity from solar energy results in less consumption of fossil fuels, reduction of pollution and greenhouse gas emissions. In recent years, clean energy experts have been very excited about the emergence of two new chemistry-driven solar technologies, perovskite solar cells and quantum dots.

7. Green Metrics *Eco-Footprint and E Factor*: Ecological Footprint (EF) (Leseurre, Merea, Duprat de Paule, & Pinchart, 2014; Teng, & Wu, 2014)or Ecological Footprint Analysis (EFA), which defines the ability of the ecosystem to absorb the post-consumer waste and to compensate for all the resources used for production of goods and services in a particular area. The lower the

EF value is, the more environmentally friendly the industrial processes or population's consumption in the area will be.

E-Factor is calculated as a total weight of all waste generated in technological or industrial process (in kilograms) per kilogram of a product. The closer to zero the value of E-Factor (E-Factor ~0) is, the less waste generated and more sustainable and greener the process will be.

Our future challenges in society, environmental, economic and resources demand for efficient and environmental-friendly chemical processes and products**.**

8. Scope of Green Chemistry

Sustainable chemistry attempts to expand conventional chemistry to include environmental, social, and economic aspects. The social aspects should include decent, safe working conditions and respect for human rights and labor rights, including the International Labour Organization Core Labour Standards (UN Economic and Social Council, 2010; Rules of the Game: a brief introduction to International Labour Standards, Revised edition, 2014). In brief it's not only important how chemists make something, it's also important that what they make isn't harmful. In green chemistry making safe, non-toxic products is the major goal. As a part of the search for safer catalysts, and reaction and product design and optimization, enzymes are looked as a future solution for the environmental hazards. UN Environment produces a report by 2022 focused on practical steps for hazard reduction in chemical design and use with a special emphasis on developing and transition countries.

9. Conclusion

Green chemistry and sustainability offer a unique opportunity to improve occupational safety and health issues. Reduce, reuse and recycling, the principles of green chemistry will result in decrease of pollution in environment. Though many exciting green chemical processes are being developed but there are far greater numbers of challenges lies ahead. The greatest challenge is to incorporate the green chemistry in industrial, laboratory and day to day processes in order to control environmental pollution. Nature is the biggest laboratory and by applying the logic of the living systems new chemical reactions and the synthesis of functionalized and useful chemicals may be possible in a greener way.

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