Asian Journal of Applied Science and Technology (AJAST)
(Peer Reviewed Quarterly International Journal) Volume 3, Issue 3, Pages 194-201, July-September 2019

A Review on Green Chemistry and Green Engineering on Environmental Sustainability

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Article Received: 30 January 2019 Article Accepted: 29 May 2019 Article Published: 31 August 2019

ABSTRACT

Environmental sustainability is the rates of renewable resource harvest, pollution creation, and non-renewable resource depletion that can be continued indefinitely. Green chemistry, also called sustainable chemistry, is an area of chemistry and chemical engineering focused on the designing of products and processes that minimize or eliminate the use and generation of hazardous substances. Green chemistry has been credited for decreasing the amount of chemical waste released to the air, water, and land. It has also spawned new areas of research including green solvents, bio-based transformations and materials, alternative energy science, molecular self-assembly, next-generation catalyst design, and molecular design for reduced hazard. Green engineering approaches design from a systematic perspective which integrates numerous professional disciplines. In the present scenario, green technologies are playing significant role in changing the course of nation's economic growth towards sustainability and providing an alternative socio-economic model that will enable present and future generations to live in a clean and healthy environment, in harmony with nature. Green technology, which is also known as clean technology, refers to the development and extension of processes, practices, and applications that improve or replace the existing technologies facilitating society to meet their own needs while substantially decreasing the impact of human on the planet, and reducing environmental risks and ecological scarcities. This review article focused on the principles and practices of green chemistry towards sustainability. It also highlights the importance the green engineering in achieving the environmental sustainability.

Keywords: Green Chemistry, Green Engineering, Green Chemical Technology, Sustainability.

1. INTRODUCTION

Rapid industrialization and population growth is creating environmental pollution and in this era we have to think about sustainability and environmental protection. Green engineering approaches the design of products and processes by applying financially and technolourmom processes and products in a manner that simultaneously decreases the amount of pollution that is generated by a source, minimizes exposures to potential hazards (including reducing toxicity and improved uses of matter and energy throughout the life cycle of the product and processes) as well as protecting human health without relinquishing the economic efficiency and viability (U.S. Environmental Protection Agency, 2014). Green engineering is an overarching engineering framework for all design disciplines.

The chemical and related industries including pharmaceuticals and health, agriculture and food, phosphate and fertilizers, environment, oil and energy production, textile, iron and steel, bitumous, building materials, glass, surfactants, cosmetics and perfume, and electronics, etc., are today in a phase of rapid evolution. This development is due to unprecedented demands and constraints, stemming from public concern over environmental and safety issues. Chemical knowledge is also growing rapidly, and the rate of discovery increases every day. The development of combinatory chemical synthesis with the use of nano-and micro technology is a current example (Jean-Claude Charpentier, 2016).

The rapid development of new chemical technologies and the huge number of innovative chemical products in the last decades forced the attention of environmentalists to remedial actions for the harmful impacts (monitoring environmental pollution, reduction of pollutants, recycling, et. (Dr.Kiran D. Pati, 2014). Design and innovation in the manufacturing processes, taking into account energy, materials, atom economy, use and generation of secondary materials which are hazardous and the (life cycle of the products and their practical recycling into new materials are the most efficient way to lower the negative impacts. Green chemical technology is a route to a more sustainable chemical industry. Environmental drivers will focus the industry's attention on the threat of climate change, and the need to use resources efficiently and to switch to renewable resources. The industry will need to be better at understanding the whole lifecycle impact of products, and developing routes to re-use and recycle materials.

"Green Process Engineering" can be defined as a part of chemical engineering that applies process engineering tools to design sustainable and safe chemical processes. It requires the integration of new environment friendly chemical routes and technical innovation to achieve green process development (Anil Kumar Saroha, 2009).

2. GREEN CHEMISTRY

Green chemistry, also called sustainable chemistry, is an area of chemistry and chemical engineering focused on the designing of products and processes that minimize or eliminate the use and generation of hazardous substances (USEPA, 2006).While environmental chemistry focuses on the effects of polluting chemicals on nature, green chemistry focuses on the environmental impact of chemistry, including technological approaches to preventing pollution and reducing consumption of non-renewable resources (Sheldon, R. A, 2007; Clark, J. H, 2012; Cernansky, R. ,2015; Sanderson, K. ,2011; Poliakoff, M.et al.,2007).

Green chemistry is an interdisciplinary field, drawing on knowledge from chemistry, chemical engineering, toxicology, and ecology. Chemists can design new catalysts that reduce the amount of reagents used and thus reduce the amount of waste generated in reactions. Chemical engineers can design a production line to recycle certain reagents and minimize energy consumption. Toxicologists and ecologists provide information about the toxic characteristics and effects of molecules so that chemists can then work to design new molecules that avoid structures linked to toxicity. Green chemistry researchers develop new catalysts, test new solvents, and experiment with microscale flow processes Some of this research is adopted by the chemical industry, particularly in pharmaceuticals.

2.1 Principles of Green Chemistry

a. Prevention: Preventing waste is better than treating or cleaning up waste after it is created.
b. Atom economy: Synthetic methods should try to maximize the incorporation of all materials used in the process into the final product. This means that less waste will be generated as a result.
c. Less hazardous chemical syntheses: Synthetic methods should avoid using or generating substances toxic to humans and/or the environment.
d. Designing safer chemicals: Chemical products should be designed to achieve their desired function while being as non-toxic as possible.
e. Safer solvents and auxiliaries: Auxiliary substances should be avoided wherever possible, and as non-hazardous as possible when they must be used.

f. Design for energy efficiency: Energy requirements should be minimized, and processes should be conducted at ambient temperature and pressure whenever possible.

g. Use of renewable feedstocks: Whenever it is practical to do so, renewable feedstocks or raw materials are preferable to non-renewable ones.

h. Reduce derivatives: Unnecessary generation of derivatives—such as the use of protecting groups—should be minimized or avoided if possible; such steps require additional reagents and may generate additional waste.

i. Catalysis: Catalytic reagents that can be used in small quantities to repeat a reaction are superior to stoichiometric reagents (ones that are consumed in a reaction).

j. Design for degradation: Chemical products should be designed so that they do not pollute the environment; when their function is complete, they should break down into non-harmful products.

k. Real-time analysis for pollution prevention: Analytical methodologies need to be further developed to permit real-time, in-process monitoring and control before hazardous substances form.

l. Inherently safer chemistry for accident prevention: Whenever possible, the substances in a process, and the forms of those substances, should be chosen to minimize risks such as explosions, fires, and accidental releases.

2.2 Green Chemistry and Sustainability

In 1987, the United Nations World Commission on Environment and Development stated that sustainability is "meeting the needs of the present without compromising the ability of future generations to meet their own needs. "Sustainability is the process of people maintaining change in a balanced environment, in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.

Environmental sustainability is the rates of renewable resource harvest, pollution creation, and non-renewable resource depletion that can be continued indefinitely. If they cannot be continued indefinitely then they are not sustainable. Green chemistry is a tool in achieving sustainability but a solution to all environmental problems .It is a fundamental approach to pollution prevention and chemistry's unique contribution to sustainability.

Green chemistry is an important tool in achieving sustainability. The implementation of green chemistry, the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances, is essential if the expanding global population is to enjoy an increased standard of living without having a negative impact on the health of the planet. Cleaner technologies will allow the chemical enterprise to provide society with the goods and services on which it depends in an environmentally responsible manner.

Green chemistry provides solutions to such global challenges as climate change, sustainable agriculture, energy, toxics in the environment, and the depletion of natural resources. A collaborative effort by industry, academia, and government is needed to promote the adoption of the green chemistry technologies necessary to achieve a sustainable society (Mary M.Kirchhoff, 2005).Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations.

2.3 Green Solvents

Solvents are consumed in large quantities in many chemical syntheses as well as for cleaning and degreasing. Traditional solvents are often toxic or are chlorinated. Green solvents, on the other hand, are generally derived from renewable resources and biodegrade to innocuous, often a naturally occurring product (Prat, 2013; Sherman, 1998).

The researchers from University of Wisconsin had used lignin-derived alkyl phenols as solvents in the conversion of hemicellulose and cellulose biomass into high value platform chemicals and transportation fuels (Kellyn Betts, 2015). Another researcher from Merck Research Laboratories suggests a new way to avoid solvents such as acetonitrile in high-performance liquid chromatography (HPLC) replacing them with distilled alcohol. It serves as low-cost and sustainable alternative eluents for HPLC, and in many cases produce excellent analytical results (Cooney,2015; Welch et al., 2015).Other green solvents seeing increasing use are water, supercritical carbon dioxide, and ionic liquids (Sheldon, 2005).

2.4 Bio-based synthetic routes

Green chemistry has played a key role in the development of a growing number of alternative ways to synthesize chemicals traditionally made from petroleum or other non-renewable resources. Advances in genetics, biotechnology, process chemistry, and engineering are leading to a new manufacturing concept for converting renewable biomass to valuable fuels and products, generally known as the bio refinery concept (Vermula, 2008).

For example, the 2005 Nobel Prize for Chemistry was awarded, to Yves Chauvin, Robert H. Grubbs and Richard R. Schrock, for the development of the metathesis method in organic synthesis, with explicit reference to its contribution to green chemistry and "smarter production."

2.5 Green Catalysts

Green catalysts should have some common characteristics such as high activity, selectivity, and stability, and ease of separation and reuse; they should be based on environmentally benign and widely available raw materials such as abundant metals, organic compounds and enzymes. A recent example is the technologies developed by Elevance, which uses a Nobel-prizewinning catalysis approach to produce high-performing, green specialty chemicals at advantageous costs. The catalyst technology breaks down natural oils and recombines the fragments into novel, high-performance green chemicals. These chemicals combine the benefits of both petrochemicals and bio-based chemicals. The technology consumes significantly less energy and reduces greenhouse gas emissions by 50% compared to petrochemical technologies. Elevance is producing specialty chemicals for many uses, including in personal care products, cleaning products, lubricants, and in candle waxes (Kellyn Betts, 2015).In pharmaceutical and food industries enzymes are used a catalyst.

3. GREEN ENGINEERING

Green engineering is the design, commercialization, and use of processes and products in a way that reduces pollution, promotes sustainability, and minimizes risk to human health and the environment without sacrificing economic viability and efficiency. Green engineering is an overarching engineering framework for all design disciplines. Green engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost-effectiveness when applied early, in the design and development phase of a process or product.

3.1 Principles of Green Engineering

In 2003, The American Chemical Society introduced a new list of twelve principles:

1. Inherent Rather Than Circumstantial – Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.
2. Prevention Instead of Treatment – It is better to prevent waste than to treat or clean up waste after it is formed.
3. Design for Separation – Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Maximize Efficiency – Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Output-Pulled Versus Input-Pushed – Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. Conserve Complexity – Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Durability Rather Than Immortality – Targeted durability, not immortality, should be a design goal.
8. Meet Need, Minimize Excess – Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
9. Minimize Material Diversity – Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. Integrate Material and Energy Flows – Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. Design for Commercial "Afterlife" – Products, processes, and systems should be designed for performance in a commercial "afterlife."
12. Renewable Rather Than Depleting – Material and energy inputs should be renewable rather than depleting (American Chemical Society 2014).

3.2. Green Chemical Technology

Green chemical technology avoids the use of non-renewable resources, reduces energy and material use, reduces waste and lowers environmental and human health impacts. There are eight areas of green chemical technology that can improve the sustainability of the chemical industry and address the issues raised by the STEEP analysis

(Crystal, green chemical technology road map, 2004): They are green product design – minimising environmental impact, feedstocks – substituting renewable for non-renewable, novel reactions, novel catalysis, solvents, process improvement, separation technology, enabling technologies. These technology areas can be used to deliver benefits in nine different areas identified as critical by the chemical industry. They are, to reduce product toxicity, to reduce environmental impact of a product, to reduce materials needed to deliver a specific level of performance, to reduce materials used to manufacture the product, to reduce use of non-renewable resources, to reduce waste and emissions during manufacture, reduce energy used to manufacture the product, to reduce risk and hazard from manufacturing processes and to reduce life-cycle cost of chemical plant.

3.3 Alternative energy sources for reaction

Microwave assisted reactions can be run in water at a small scale, often with accelerated rates due to temperature and pressure effects Reactions to build oxygen-, nitrogen- or sulfur-containing rings common in medicinal chemistry can also be driven using microwaves, though these reactions aren't running on a process scale yet. Alternatively, the energy from grinding reagents together using a mortar and pestle or a ball grinder can be enough to trigger a reaction (Melissae Fellet, 2013; Watson,2012).

Ultrasound sonication is another energy source with useful applications such as deprotecting an amine, protecting hydroxyls on sugars, or reducing an α,β-unsaturated ketone in a steroid. The sound waves create areas of high and low pressure, much like ripples in a pond, as they travel through liquid bubbles form in the low-pressure areas, collapse when they reach high-pressure regions, and send shockwaves through the reaction Surprisingly, ultrasound sonication can influence the products of a reaction. When chemists stirred a suspension of benzyl bromide and alumina-supported potassium cyanide, they retrieved diphenylmethane, which contains two connected benzene rings, as the product of a Friedel-Crafts reaction. But when they sonicated the reaction, the cyanide ion replaced the bromine atom, giving benzylcyanide as the product. The researchers suspect that the bubbles generated during sonication masked the metallic catalytic sites on the solid support (Baig, R B N et al., 2012).

4. CONCLUSION

Green chemical technology is a route to a more sustainable chemical industry. Green chemistry researchers develop new catalysts, test new solvents, and experiment with microscale flow processes Some of this research is adopted by the chemical industry, particularly in pharmaceuticals. To address these challenges to achieve sustainability, green chemistry principles and its application in chemical technologies is essential in this era. These technologies are, therefore, viable, cost effective, environmentally advanced and most appropriate to the climatic, economical, geographical, ecological and social conditions of the country. In addition to all engineering disciplines, green engineering includes land use planning, architecture, landscape architecture, and other design fields, as well as the social sciences (e.g. to determine how various groups of people use products and services. Many researches are reported in many areas, including safer and less-polluting industrial solvents and plant-based substitutes for petrochemical products. So chemist and engineers should be significant contributors to the positive changes that industrial green chemistry is creating and will continue to catalyze in our world.

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