THE ROLE OF GREEN CHEMISTRY IN ENVIRONMENTAL POLLUTION CONTROL IN NIGERIA: A PANACEA FOR NATIONAL DEVELOPMENT

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Abstract

Green chemistry is the use of chemistry for pollution control or prevention. It is the design of chemical products and processes that are more environmentally benign. Chemists can greatly reduce risk to human health and environment by reducing or eliminating the use or generation of hazardous substances with a particular chemical synthesis. Green chemistry encompasses all aspects and types of chemical processes that reduce negative impacts to human health and the environment. The applications of green chemistry principles to environmental pollution control or prevention were highlighted. The adoption of the green chemistry principles into the industrial processes for national development and the incorporation of green chemistry into the chemistry curriculum of the educational institutions were recommended.

Over the past few years, the chemistry community and in particular the chemical industry has made extensive efforts to reduce the risks associated with the manufacture and use of various chemicals. There have been innovative chemistries developed to treat chemical wastes and while these are laudable efforts in the reduction of risk, they are not effective pollution prevention or control.

Green chemistry simply, is the use of chemistry techniques and methodology that reduce or eliminate the use or generation of feedstock, products, by-products, solvents, reagents etc. that are hazardous to human health or the environment (Anastas, Williamson, 1996). Environmental chemistry is the chemistry of the natural environment and of pollutant chemicals in nature whereas green chemistry seeks to reduce and prevent pollution at its source. As a chemical philosophy, Green Chemistry is derived from organic chemistry, inorganic chemistry, biochemistry, analytical chemistry and even physical chemistry (Anastas & Warner, 1998).

History of Green Chemistry

Two of the most prominent and early advocates of Green Chemistry were Kenneth Hancock of the United States National Science Foundation (NSF) and Joe
Breen, who after twenty years of service at the United States Environmental Protection Agency (EPA) became the first director of the Green Chemistry Institute (GCI). Green chemistry is a science-based, non regulatory, economically driven approach towards sustainable development that has grown substantially since the concept fully emerged some decades ago. A key event that generated broad interest in sustainable development was the release of the 1987 United Nations report captioned ‘Our Common Future’. In the report, sustainable development was defined as “development that meets the needs of the present without compromising the ability of the future generations to meet their own needs”.

In the U.S, interest in Green Chemistry began in earnest with the passage of the pollution prevention Act of 1990, which was the first environmental law to focus on preventing pollution at the source rather than dealing with remediation. The new law led the EPA to establish its Green Chemistry programme in 1991. The term “Green Chemistry” was coined and first defined at that time by EPA’s staff, Paul T, Anastas, an organic chemist.

The EPA has since collaborated with the academia, industry and other government agencies to promote the use of chemistry to develop new technologies for pollution prevention. The three important outcomes of these collaborative efforts were (a) The chemistry Awards in 1995 which helps to promote and recognize the development of environmentally benign chemical products and manufacturing processes (b) The development of the twelve principles of Green Chemistry; and (c) The Green Chemistry Institute (GCI) which was originally organized on the internet as a non profit organization in 1997.

The twelve principles of Green Chemistry: Anastas and Warner formulated the twelve principles of Green chemistry in 1998 which helped to explain what the term means in practice (Anastas and Warner, 1998), and they include;

1. **Prevention**: It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom Economy**: Synthetic methods should be designed to maximize the incorporation of all materials used in the process.
3. **Less hazardous chemical synthesis**: Whenever practicable, synthetic methods should be designed to use and generate substances that pose little or no toxicity to human health and the environment.
4. **Design safer chemicals**: Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. **Safer solvent and Auxiliaries**: The use of auxiliary substances e.g solvents, separation agents etc should be, made unnecessary wherever possible and innocuous when used.
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.

7. **Use renewable feedstocks:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. **Reduce Derivatives:** Unnecessary derivatization—use of blocking groups, protection and temporary modification of physical/chemical processes should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents. In other words, catalysis are used in small amounts and can carry out a single reaction many times unlike the stoichiometric reagents which are used in excess and work only once.

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

11. **Real-time analysis for pollution prevention:** In-process real time monitoring and control during syntheses should be included to minimize or eliminate the formation of by-products.

12. **Inherently safer chemistry for accident prevention:** Substances and form of a substance (solid, liquid or gas) used in chemical processes should be chosen to minimize the potential for chemical accidents, including explosives, fires and releases to the environment.

**The Application of Green Chemistry**

Green chemistry, the design, manufacture and use of efficient effective, safe and environmentally friendly chemical products and processes is the integral to the way we do business. During the 1990s, many industries in the United States began to earnestly adopt Green chemistry and they realized that the practice not only leads to environmental benefits, but also economic and social benefits. The combination of these three benefits is known as the ‘triple bottom line’ and provides strong encouragement for business to develop sustainable products and processes (Donohue, Geiger, Kiamoss & Nielson, 1996). When chemists are considering a compound they are concerned with the chemical, biological and physical properties of this compound and the method by which the compound is prepared. For instance, Dichlorodiphenyl trichloroethane (DDT) is one of the most well known insecticides. During the World War II, it saved thousands of Allied lives by killing disease-carrying insects; but during the 1960s, it did a lot of environmental damages.

One approach to producing less environmentally harmful pesticides is to use compounds that destroy only the target organism. Insecticides that mimic a hormone
used only by molting insects have been manufactured and insects that do not molt are not affected, leaving many beneficial insects unharmed.

Furthermore, synthetic polymers or plastics are everywhere. They are used in cars, computers, planes, houses, eye glasses, paints, bags, appliances, medical devices, carpets, tools, clothing, boats, batteries and in pipes. In order to decrease human consumption of petroleum, chemists have investigated methods for producing polymers from renewable resources such as biomass. Polylactic acid (PLA) is a polymer of naturally occurring lactic acid (LA) and LA can be produced from the fermentation of corn. The goal is to eventually manufacture the biodegradable polymer from waste biomass. PLA can also be easily recycled by conversion back into LA. It can replace many petroleum-based polymers in products such as carpets, bags, cups and textile fibers.

In addition, the manufacture of computer chips requires excessive amounts of chemicals, water and energy. The use of supercritical carbon dioxide is one of the steps in chip preparation which has been developed and it significantly reduces the quantities of chemicals, energy and water needed to produce chips. Condensed phase carbon dioxide is also used as solvent for the dry – cleaning of clothes. Although, carbon dioxide alone is not a good solvent for oils, waxes and greases, the use of carbon dioxide in combination with surfactant allows for the replacement of Perchloroethylene (which is the solvent used most often to dry clean clothes although it poses hazards to the environment and is a suspected human carcinogen). A dry-cleaning process called Micare which uses liquid carbon dioxide as a solvent rather than perchloroethylene a ground water contaminant and possible human carcinogen, has been developed (Onuegbu and Ekemezie, 2009). It can recover about 98% of the carbon dioxide used. Many solvents, especially the widely used volatile organic solvents have been known for their toxicity and contributions to air and water pollution. Green chemistry in general has focused on the use of super critical fluids (SCFS) as solvents. Solvents systems such as supercritical carbon dioxide and super critical Carbon dioxide/water mixtures are useful in a wide range of reaction types (Morgenstern, Lelacheur, Morita, Borkowsky, Fern, Brown, Luna, Gross, Burk and Tumas, 1996). Carbon dioxide is the super critical fluid of choice for several reasons. Firstly, in addition to being non-flammable and odourless, it is non corrosive and inert. Secondly the supercritical state is easily reached because carbon dioxide has low critical temperature (31°C); and its critical pressure (7.376Mpa) is within the operating range of conventional spray equipment. Thirdly carbon dioxide is inexpensive and readily available in bulk as a by-product from chemical plants or neutral gas production. Fourthly, it has appreciable solubility in coatings even at low solvent levels (Simmons, 1996).

Another important area in Green Chemistry is catalysis. Catalysts have been applied in improving air quality by NO$_x$, removal and emission control, reducing the
use of volatile organic compounds (VOCS), developing alternative catalytic technology to replace the use of chlorine or chlorine based intermediates in chemical synthesis, and processing with minimization (Simmons, 1996). Catalyzed reactions are important in designing environmentally safer technologies and in the production of safer chemicals. Aromatic amines can be synthesized by using nucleophilic aromatic substitution by hydrogen instead of chlorinated aromatic in the synthetic pathway (Stem, 1994).

Chlorinated aromatic are known to be persistent bio accumulators. Again, benzene has been replaced with glucose in the synthesis of adopic acid, catechol and hydroquinone. Since benzene is known carcinogen a process that removes it from the synthesis of large volume chemicals in a technically and economically possible manner is certainly a goal compatible with that of Green Chemistry.

Phosgene has been used industrially in large scales in the two most important processes for manufacturing polycarbonates and isocyanates all over the world. Phosgene however is notorious for its high toxicity and corrosiveness (Manzer, 1994). Methylene chloride is a toxic chemical and is also one of the seventeen chemicals targeted for emission reduction by EPA. Isocyanates are produced on large scale annually and are generated exclusively through phosgenation technology. The use of carbon dioxide as a phosgene replacement has been explored. One of the goals is to eliminate the use of phosgene in the production of methylene chloride and dimethylsulfate in methylation reactions. Dimethylsulfate is a suspect human carcinogen, besides being extremely toxic.

A new process for spraying paints and other coatings has been developed which reduces atmospheric emissions of environmentally harmful volatile organic compounds (Donohue, Geiger, Kiamsos, Nielson, 1996). Volatile organic compounds are a class of air pollutants that enter the environment from many sources, chemical manufacturing and solvent evaporation during the spray application of coating, paints, adhesives and other materials.

Volatile organic compounds are detrimental to the environment in many ways. For example when released to the atmosphere, they facilitate the production of ozone (O\textsubscript{3}) a compound which is desirable in the stratosphere to block ultraviolet rays but which is toxic at ground level. A short term exposure to ozone contributes to eye, nose and throat irritation. It can also cause acute lung inflammation and pulmonary edema. It can also lead to congenital birth defects (Suess, Greten and Remisch, 1985).

Volatile organic compounds can also migrate from the atmosphere to water systems through precipitation, fallout or absorption into surface waters. Aquatic volatile organic compounds taints seafood, contaminate drinking water and can penetrate into
the soil where they can injure plant life and inhibit microorganisms responsible for soil fertility (National Research Council, 1976).

The new system called the supercritical fluid spray process, uses environmentally-benign supercritical carbon dioxide to replace the fast evaporating solvent used in conventional solvent-borne coatings. Some other examples of Green Chemistry include: taking Chromium and Arsenic which are toxic out of pressure treated wood, using new and less toxic chemicals for bleaching paper; substituting yttrium for lead in auto paint (Onuegbu and Ekemezie, 2009).

**Ozone Layer and Green Chemistry**

The ozone layer chemistry as it affects the global environment is one of the critical areas that professional chemists can adopt the principles of Green Chemistry in the development of our nation. The existence of ozone was unknown until 1838 and it has been characterized as “the single most important chemically active trace gas in the earth’s atmosphere”. Two singular characteristics of this remote, unstable and toxic gas make it so critical to human society (Williams, 2009). First, certain wave length of ultraviolet radiation (UV-R) that can damage DNA and the immune system and can cause cancer in living cells are absorbed by the thin layer of ozone molecules and is thus prevented from reaching the earth’s surface. Secondly, differing quantities of ozone at different altitudes have major implications for global climate. In fact human health, agriculture and livestock, fisheries, biological diversity and many materials would be significantly impacted by damage to the ozone shield. The ozone layer at its historic natural concentration and diffusion is essential to life as it currently exists on earth.

In 1973, two university of Michigan scientists, Richard Stolarksi and Ralph Cicerone, in the cause of examining possible effects chlorine in the stratosphere could unleash, discovered the possibility of a complex chain reaction that would continuously destroy ozone over a period of decades. Fortunately, very little “free chlorine” was thought to exist at that altitude (Williams, 2009). However, a year later, Mario Moluna and Sherwood Rowland at the University of California became intrigued with some peculiar properties of chlorofluoro carbons (CFC). They discovered that, unlike almost all other gases, CFCs were not chemically destroyed or rained out in the lower atmosphere, but rather migrated slowly up into the stratosphere. There they remained for several decades. The two researchers concluded that man-made CFCs, which are not naturally present at this altitude are eventually broken down by radiation and thereby release large quantities of free chlorine. The combined implications of these two hypotheses showed that the protective ozone shield would be seriously compromised. The enhanced levels of ultraviolet radiation that would then penetrate the atmosphere and earth’s surface would have potentially disastrous impacts.
Ozone itself amounts to considerably less than one part per million of the total atmosphere, with 90% of it located above six miles in altitude. The intrinsically unstable ozone molecules are continually being created and destroyed by complex natural forces involving solar radiations and interactions with even more minute quantities of other gases (Williams, 2009). Moreover, stratospheric ozone concentrations can fluctuate on a daily, seasonal and solar cyclical basis and there are significant geographical as well as altitudinal variations. To fully understand the implications of a diminishing ozone layer, scientist had to venture far beyond atmospheric chemistry; they had to examine our planet as a system of inter related physical, chemical and biological processes that are themselves influenced by economic, political and social forces.

Over the years researching the dangers and solutions of ozone layer involved not only chemists and physicists but other inter disciplinary efforts which are compatible with the goal of Green chemistry. In line with the principles of Green Chemistry, the industrialized nations have started phasing out all of the major ozone-depleting substances as well as other toxic chemicals.

Developing nations including Nigeria should also adopt the principles of Green chemistry in all chemical processes to urgently address the problem of climate change due to ozone layer depletion.

**Green Energy and Green Chemistry**

The application of Green chemistry principles to produce energy has given rise to the term called Green energy. According to Nweze-Akpa (2009), energy powers economics, generate jobs and contributes to the overall quality of life. The energy the world needs is enormous and will continue to grow over a long term. This energy can be generated through different means and from various sources. Energy can be both helpful and harmful depending on its sources and use. All energy sources require energy and give rise to some degree of pollution from manufacture of the technology. The quest to generate energy that has minimal relative impact on humanity and the environment led to the discovery of “Green Energy”.

Green energy is perhaps the most urgent issues for green technology and it includes the development of alternative fuels, new means of generating energy and energy efficiency. The term green energy is often used interchangeably with the terms renewable energy, alternative energy or clean technologies. These terms suggest a non-polluting, non-fossil-fuel sources, in fact “Green energy” is the term used to describe sources of energy that are considered to be environmentally friendly and non-polluting, such as wind, geothermal, solar and hydro energy. Green energy sources are often considered “green” because they are perceived to lower carbon emission and create less pollution.
Green Nanotechnology

According to Nweze-Akpa (2009) nanotechnology is the manipulation of matter at the molecular scale, a level of nature at which quantum phenomena take charge over the Newtonian phenomena experience at the macro level. Nanotechnology has the potential to greatly reduce emission from buildings which produce a large percentage of the world’s CO\textsubscript{2} emissions; reduce construction waste which accounts for an appreciable percentage landfill materials, while providing cleaner air and water inside buildings.

Green nanotechnology is the development of clean technologies that are aimed at minimizing potential environmental and human health risks associated with the manufacture and use of nanotechnology products and to encourage replacement of existing products with new nano products that are more environmentally friendly throughout their life cycle. Green nanotechnology uses the existing Green chemistry principles and green engineering to make nanomaterials and nanoproducts without toxic ingredients at low temperature, using less energy and renewable inputs wherever possible and using life cycle thinking in all design and engineering stages (Nweze-Akpa, 2009).

Conclusions

As a chemical philosophy, Green Chemistry derives from all aspects of chemistry especially inorganic, organic, analytical, physical and biochemistry. However, its philosophy tends to focus on the industrial applications i.e. industrial chemistry. And this focus is on minimizing the hazard while maximizing the efficiency of any chemical choice.

Green chemistry reduces toxicity, minimizes waste, saves energy and cuts down on the depletion of natural resources in our environment. It allows for advances in chemistry to occur in a much more environmentally benign way. In future, when Green Chemistry is practiced by all chemists and all chemical related companies all issues related to environmental pollutions emanating from our chemical industries would have been laid to rest.

Recommendations

Since education is a very vital tool in every human endeavor, it should be made as an important component of Green Chemistry incorporating it into the Chemistry curriculum of the educational institutions.

A national centre for Green Chemistry should be established where research work on Green Chemistry are monitored and research finding are communicated to the public and industries for national development. Following the present glut in world oil
price, Nigeria as a developing Nation may be put at a disadvantaged position economically if nothing is done urgently to dis-emphasize Nigeria’s dependence on oil. This is a serious signal that our young scientist should be trained in the area of Green chemistry not only to address our present environmental problems but also to provide the nation a new path way into clean technology or alternative fuel.

Finally the principles of Green Chemistry should be adopted in all our chemical industries in order to control or prevent the environmental pollution in Nigeria.

References


