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RESEARCH ARTICLE

GREEN CHEMISTRY: ITS APPLICATIONS IN EVERYDAY LIFE

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ABSTRACT

Green chemistry is defined as environmentally benign chemical synthesis. It is the design of chemical products and processes that minimize or eliminate the use and generation of hazardous substances, focusing on sustainability across a chemical's entire life cycle. The goal of green chemistry is to design new synthetic methodologies using green solvents, lower reaction temperature, and environmentally friendly catalysts etc., that minimize or eliminate the production of environmentally hazardous materials and provide highest yield of product along with high atom economy. In this article, the principles of green chemistry, its goal and applications in our daily life has been discussed.

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INTRODUCTION

Green chemistry is defined as environmentally benign chemical synthesis (Anastas and Warner, 1998; Anastas and Farris, 1994). It focuses on the chemical process that reduces or eliminates the use and generation of hazardous substances or by-products. The interest in green chemistry was first initiated in the United States after the passage of the Pollution Prevention Act of 1990. Subsequently, the environmental protection agency (EPA), got involved in green chemistry. The term green chemistry was first used in1991 by Poul T. Anastas in a special program launched by the US Environmental Protection Agency (EPA) to implement sustainable development in chemistry and chemical technology by industry, academia and government. The pollution Prevention Act of 1990 dealt with prevention of the formation of pollutants. This act leads the industries to devise technologies and processes that avoided the formation and/or use of hazardous substances. The chemists all over the world were inspired to devise greener reaction conditions even for earlier old synthesis. This was achieved by replacing an organic solvent (Li, C. 1993; Horva´th *et al.*, 1995) with water wherever possible and use of supercritical fluids (Jessop and Leitner, 1999) in the reaction conditions. Alternatively, the reactions were conducted in solid state without the use of solvents (Larhed and Olofsson, 2006; Mason, 1999; Chalmers, 2000). There has been a renewed focus on the age-old pursuit of the organic chemist to design and successfully apply the ideal synthesis in terms of efficiency, with atom economy (Trost 1991; Trost 1995; Trost 2002) and step economy (Wender *et al.*, 2006) being a major goal. New catalytic processes continue to emerge to advance the goals of Green Chemistry, while techniques such as microwave (Bose et al. 2002; Nuchter *et al*. 2004; Larhed, M, 2006) and ultrasonic synthesis (Mason, T. J. 1999) as well as in situ spectroscopic methods (Chalmers, J. M. 2000; Bargon and Kuhn, 2007) have been used extensively, leading to spectacular results. Green synthesis were developed for existing products by using starting materials that use biomass rather than petrochemicals which were derived from non-renewable natural sources. It was advantageous to use catalyst rather than stoichiometric reagents. Special care was taken to see that the products contained were less toxic and biodegradable. It is heartening to know that Noble prize for green chemistry has been awarded for 2005 by the Royal Swedish Academy to Yves Chauvin (France), Robert Grubbs (USA) and Richard Schrock (USA). These chemists shared the Noble prize for their contribution to the development of metathesis, an energetically favoured and less hazardous method in organic synthesis. It is believed that it represents a great step forward for 'green chemistry', reducing potentially hazardous waste through smart chemistry. Metathesis is an example of how important is basic science for the benefit of man, society, and environment, the Noble Prize committee cited. In this article, the principles of Green

Chemistry and its applications in our daily life has been discussed with an aim to solve some of the environmental pollution issues with help of green chemistry.

NEEDS OF GREEN CHEMISTRY

To meet the demands of modern civilization, we need varieties types of chemical products and chemical industries. Chemistry, as we know, has changed the life style of the people. It has brought about medicinal revolution e.g. synthesis of drugs etc. The world's food supply has increased many folds due to discovery of hydride varieties, improved method of farming, better seeds and use of agro-chemicals like fertilizers, insecticides, and herbicides etc. The quality of life has improved due to discovery of dyes, plastics, cosmetics and other materials of our daily use.

All these developments resulted in increasing the average life exception. However, these very often lead to the formation of hazardous substances and sometimes we are also to use hazardous substances. The most important effect is due to release of hazardous by-products of chemical industries and the release of agrochemicals; particularly the pesticides which are non-biodegradable, in the atmosphere, land and water bodies. All these are responsible for the pollution of the environment. To prevent or minimize the formation of and use of such hazardous substances, the chemists are required to develop the novel technologies. This need has inspired the generation of the new branch of chemistry called Green Chemistry which follow the principles, Prevention is better than cure. The main purposes of Green Chemistry are mentioned below:

Eco-friendly chemical technology: Green Chemistry aims to protect the environment and this is why it is also described as Environmentally Benign Chemistry.

Replacement of organic solvent and to minimize the waste product: Green chemistry aims to devise greener reaction conditions for the synthesis of chemicals so that waste product (toxic product) formation can be minimized. It needs the replacement of organic solvent by water or completely elimination of the use of solvent. It also needs to minimize the formation of by-products.

Use of renewable feedstock's: Green Chemistry aims to develop the greener synthesis of the required chemical products by using the renewable resources.

Minimization of energy consumption: Green Chemistry aims to develop the greener conditions for the synthesis of chemical products so that energy consumption can be minimized. For many existing chemical technologies, drastic reaction conditions such as high temperature, high pressure etc. is required. Greener synthesis aims to develop the mild or modest reaction conditions. Ideally, the reactions should be carried out at ambient temperature and pressure.

Use of eco-friendly chemical products: Green chemistry aims design the new chemical products to replace the exciting hazardous chemicals products provided the new chemicals are having the same desirable properties of the exciting one.

Four R's and integrated waste management: These four R's are: Reduction (at source), Recycling, Reuse and Recovery.

PRINCIPLES OF GREEN CHEMISTRY

The term 'Green Chemistry' was coined by Professor Paul T. Anastas, who is most appropriately known as the father of Green Chemistry. It was only in 1991 (after the passage of the Pollution Prevention Act of 1990) that Environmental Protection Agency IEPAP of USA introduced Green Chemistry as a formal area of work with a view to eliminate the use of hazardous substances during the design, manufacture and use of chemical products and processes. Green Chemistry is commonly presented as a set of twelve principles proposed by Anastas and Warner.

Prevention: It is better to prevent waste than to treat or clean up waste after it has been formed. The first principle aims to develop the Zero Waste Technology (ZWT). That is, in a chemical synthesis, waste production should be zero or minimum. In case if in a reaction hazardous waste is generated, it has to be separated, treated and disposed. All these steps add to the cost of the manufacturing process. It is found that the cost of waste disposal may be many times more the cost of starting materials. Another factor is that the waste if generated is discharged into the environment causes pollutions. In universities and colleges, the cost of disposal of waste from chemical laboratories can be reduced by carrying out experiments on a much smaller scale.

Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product. In order to find, if a particular reaction is green, the concept of atom economy was developed by Barry Trost of Stanford University. This concept considers the amount of starting materials incorporated into the desired final product. The percentage of atom economy is calculated by using following formula:

% Atom economy = (FW of atom utilized / FW of all the reactants used in the reaction) x 100. Addition reaction, rearrangement reactions are 100% atom economical. Atom economy is a very important procedure for evaluating a particular reaction to be called a green reaction.

Less Hazardous Chemical Synthesis: Whenever practicable synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment. One of the most important principles of green chemistry is to design a synthesis in such a way so that the formation of hazardous by-products is minimized. Such hazardous by-products are harmful to the environment and human health. One example of such explosion was occurred in Bhopal gas tragedy which was responsible for the death of thousand people.

Designing Safer Chemicals: Chemical products should be designed to affect their desired function while minimizing toxicity.

Safer Solvents and Auxiliary: The use of auxiliary substances (such as solvents, separation agents etc.) should be made unnecessary wherever possible. Among the commonly used solvents are halogenated solvents like methylene chloride, chloroform, perchloroethylene and carbon tetrachloride. These volatile organic solvents have been categorized as suspected human carcinogens. Benzene and other organic hydrocarbons are also used as solvent which are also involved in the promotion of cancer in human and other animals. All these volatile solvents may damage human health and the environment. This problem of solvents has been overcome by using such solvents which do no pollute the environment. Such solvents are known as green solvents. Water is considered as an universal green solvent. Others green solvent used in organic synthesis across the globe includes supercritical carbon dioxide, ionic liquids, 2-methyl tetrahydrofuran etc. Moreover, a large number of organic reactions have been performed in solid state. Such reactions are simple to handle, reduce pollution, comparatively cheaper to operate and are especially important in industry.

Design for Energy Efficiency: Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure. In any chemical synthesis, energy is required for completion of the reaction. In many reactions, the starting mixture has to be heated to reflux to bring the reaction to completion. In such cases, the time required for completion of the reaction should be minimum, so that large amount of energy is not used. A large amount of energy generation has a major environmental effect. For example, coal based power generating units discharge oxides of carbon, nitrogen and sulphur in the environment. All these gases are responsible for acid rain, which are disastrous for the agricultural crops. However, the requirement of energy can be kept to a bare minimum in certain cases by the use of catalyst. A great advantage of catalyst is that it reduced the activation energy of the reaction. Conventionally, researchers have been carrying the reaction by heating on wire gauge, in oil bath, or heating mantles. It is now possible that the energy can be supplied to a reaction by using microwaves, by sonication or photochemically. Microwaves are considered as a more efficient source of heating that conventional steam, since the energy is directly imparted to the reaction mixture rather than through the walls of the reaction vessels. This rapid heating capability of the microwaves leads to considerable saving energy and reduction of time for competition of the reaction. This decreases the overall cost of production and also diminishes the waste disposal problem.

Use of Renewable Feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable. It encourages the use of starting material i.e. raw materials which should be renewable, if technically and economically practicable. In fact, continuous use of the non-renewable feedstock (e.g. petrochemical product, fossil) will deplete the sources. So, these are not regarded as sustainable from of environment point of view. Moreover, their use leads to environmental pollution. On the other hand, use of sustainable or renewable resources e.g. agricultural or biological product ensures the sharing of resources by future generation. Moreover, this practice generally does not put much burden on the environment. The products and wastes are generally biodegradable. This practice of the principle has been illustrate in many cases like bioplastics, biopolymers (PHB, PHV, chitin a unique biopolymer, biodiesel, CO_2 feedstock in the manufacture polycarbonate, greener synthesis of furfural from biomass, greener synthesis adipic acid and catechol, polyacetic acid, a green polymer obtained from biomass.

Reduce Derivatives: If possible, the steps like blocking group, protection/ deprotection of group etc., should be avoided as far as possible during the synthesis of a chemical product. Thus, there should be minimum number of steps to synthesize a target product.

Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

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

Real-time analysis for 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.

Inherently Safer Chemistry for Accident prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions and fires.

These principles can motivate chemistry at all levels: research, education and public perception. The first principle describes the basic idea of green chemistry in protecting the environment from pollution. The remaining principles are focused on atom economy, toxicity, solvent and other media using consumption of energy, application of raw materials from renewable sources and degradation of chemical products to simple nontoxic substances that are friendly for the environment.

GOALS OF GREEN CHEMISTRY

Green chemistry aims to eliminate or at least reduce the pollution by preventing it from happening as far as possible. In fact, the goal of green chemistry is to design synthetic methodologies that reduce or eliminate the use or generation of toxic products, by-products, solvents and all other associated products. The above goals could be achieved by the chemists who design the synthesis of new chemicals and their manufacturing processes. All possible routes for a particular synthesis must be examined and the most appropriate route which uses non-hazardous starting materials should be used. This not only minimizes danger to workers in manufacturing plants when they handle the chemicals but also prevents accidental release of harmful chemicals to the environment in case there is an explosion. This could be well understood by considering the manufacture of adipic acid. About 2 billion kg of adipic acid are required each year for the production of nylon, polyurethane, lubricants and plasticizers. The typical procedure used for the preparation of adipic acid applying benzene as starting material, which can cause cancer in human. In a newly developed process that is aided by biocatalysis (genetically altered bacteria), the simple sugar glucose can be used as the starting material. Thus, the use of harmful chemical can be avoided to make adipic acid in large quantities by using a safer substance like glucose. The green chemistry incorporates pollution prevention practices in the manufacturing of chemicals and promotes pollution prevention.

PROGRESS OF GREEN CHEMISTRY

There have been several novel green innovations that have been implemented by the industry. There are continuous efforts by the researches to developed green methods in a number of other areas to reduce environmental pollution caused by chemical industry. One such example is the use of liquid carbon dioxide as an environmental benign medium for dry cleaning. The use of volatile organic solvents like perchloroethylene has been considerably reduced due to the application of liquid CO_2. Carbon dioxide has also been used as a suitable medium in fluoropolymer manufacture. Due to its cheap cost, non-toxic and non-inflammable nature, it is an excellent alternative medium for several industrial applications. The recent green chemistry mission was originally initiated by the US Environmental Protection Agency (USEPA), there are a number of research networks that works towards the progress of green chemistry. Some of research establishments include The Green Chemistry Research Network (Europe). Green Chemistry Institute (US), Green and Sustainable Chemistry Network (Japan). In 1996 the working party on green chemistry was created, acting within the framework of International Union of Pure and Applied Chemistry. One year later the Green Chemistry Institute (GCI) was formed with chapters in 20 countries to facilitate contact between governmental agencies and industrial corporations with universities and research institutes to design and implement new technologies. The first conference highlighting green chemistry was held in Washington in 1997. Since that time other scientific conferences have been soon held on a regular basis. The first book and journals on the subject of green chemistry were introduced in 1990, including the Journal of Clean Processes and Green Chemistry, sponsored by the Royal Society of Chemistry. The concept of green chemistry incorporates a new approach (Anastas and Hovarsth, 2007; Ravichandran 2010; Sheldon, R. A., 2005; Ahluwalia and Kidwai, 2004) to the synthesis, processing and application of chemical substances in such manner as to reduce threats to health and environment.

Most of the universities around the world have incorporated green chemistry principles into their curriculum. Funding has been increased by Governments and Industry for funding the innovation of green technologies. In India, the Department of Science and Technology (DST) has a funding programme exclusively for green chemistry projects. Various chemical societies have recognised green chemistry as a core research area for their Journal. The Royal Society, UK even has a journal named Green Chemistry, exclusively to cover research in this area. The USEPA has also instituted the Presidential Green Chemistry Challenge Awards for both academic researches and industries that excel in the discovery and practice of environmentally friendly chemistry. The chemical industry has developed at a faster rate and it is now the first priority of the governments and the various chemists working in the academic institutions and industries to follow the concepts of green chemistry. All these efforts will go a long way in curbing the environmental degradation. Some of the environmental issues that effect the society adversely are given below:

Pesticides: These are chemical substances used to kill unwanted insects, fungus, rodents etc. It is well known that these insecticides also pose a health risk to human and damage environment. For example, DDT is a pesticides used against agricultural pests, flies and mosquitoes. In India, it was used on large scale for eradication of malaria. The widespread use of DDT has resulted in pollution of crop lands and a large number of pests have become resistant to it. When it enters the food chain, DDT accumulates in the fatty tissues of animals. Stress is now given on the biological control pests which used harmless substances extracted from plants or friendly insects to get rid of unwanted species.

Chlorofluorocarbons (CFC): These are the group of organic compounds entirely of chlorine, fluorine and carbon. These are extensively used as cleaning agents, blowing agents and as refrigerants. It is also used as solvents in electronic industry and as propellants in Aerosols. These compounds are largely unreactive and stay in the atmosphere for very long period of time. CFCs are reacted with ozone in the upper atmosphere (stratosphere) under the influence of ultraviolet radiation. The large concentrations of CFC in the stratosphere over the Polar Regions have led to the destruction of ozone layer and cause ozone hole. Ozone layer, as we know absorb the harmful ultraviolet radiations from the sun. These harmful solar radiations if not checked may cause skin cancer and other ailments. In view of the harmful effects of CFC's attempts have been made to discover other refrigerants which are biodegradable.

Global warming: The release of greenhouse gases like carbon dioxide, methane, nitrous oxide and CFC's into the atmosphere have far reaching effects on the climate due to increase in average temperature of the earth's atmosphere. It is expected that earth's climate may be modified in the next 50 years or so. This would, in turn, alter the earth's delicate ecological balance.

Bhopal disaster: A most tragic accident in the history of mankind in a pesticide manufacturing factory occurred Bhopal, India on the night of 2^{nd} December, 1984. This accident was responsible for the death of about 25,000 people and serious injuries to more than 2,00,000 people. In this accident, approximately 33 tons of methyl isocyanate (MIC), an extremely poisonous gas used in the manufacture of 'seven'- a pesticide, escaped from a storage tank and spread like mist and cloud over the city of Bhopal. The cause of the accident was due to failure of various controls and was attributed to human error. Other such environmental problems arises from the pollutions are acid rain, havoc created by dioxins, thalidomide scare, Love canal episode, photochemical smog. Some deadly diseases such as minamata diseases (a case of mercury poisoning held in 1950's), Itai-Itai disease-a case of cadmium poisoning, methaemoglobinaemiaetc diseases mostly resulted by the discharge of poisonous pollutants from the industries into water bodies.

On the above, it is clear that most of the environmental and health problems would not have been there, if the industries followed the basic norms. It is in context that green chemistry plays a vital role in keeping the environment clean. The concept of green chemistry addresses environmental issues in an economically profitable manner. Green chemistry makes it more or less mediatory for the industries to see that appropriate starting materials and conditions be used so that there is no hazardous by-product generation. Green chemistry must permeate not only to the chemical industries, but it is necessary to bring changes at the grass root level. This can be achieved by bringing about necessary changes in the chemistry curriculum not only in the colleges and universities but also in the secondary school. Brining green chemistry to the class room and the laboratory will have the desired effect in educating the students at various levels about green chemistry.

GREEN CHEMISTRY IN EVERYDAY LIFE

Green Dry Cleaning of Clothes: Perchloroethylene (PERC), $Cl_2C{=}CCl$ is commonly being used as a solvent for dry cleaning. It is now known that PER contaminates ground water and is a suspected carcinogen. A technology, known as Micell technology developed by Joseph De Simons, Timothy Romark, and James McClain made use of liquid CO_2 and a surfactant for dry cleaning clothes, thereby replacing PERC. Dry cleaning machines have now been developed using this technique. Micell Technology (www.micell.com, accessed Dec. 1999) has also evolved a metal cleaning system that uses CO_2 and a surfactant thereby eliminating the need of halogenated solvents (Anastas and Williamson, 1998).

Versatile Bleaching Agents: It is common knowledge that paper is manufactured from wood (which contains about70% polysaccharides and about 30% lignin). For good quality paper, the lignin must be completely removed. Initially, lignin is removed by placing small chipped pieces wood into a bath of sodium hydroxide (NaOH) and sodiumsulphide (Na_2S). By this process about 80-90% of lignin is decomposed. The remaining lignin was so far removed through reaction with chlorine gas (Cl_2). The use of chlorine removes all the lignin (to give good quality white paper) but causes environmental problems. Chlorine also reacts with aromatic rings of the lignin to produce dioxins, such as 2,3,4-tetrachlorodioxinand chlorinated furans. These compounds are potential carcinogens and cause other health problems.

These halogenated products find their way into the food chain and finally into products, pork, beef and fish. In view of this, use of chlorine has been discouraged. Subsequently, chlorine dioxide was used. Other bleaching agents like hydrogen peroxide (H_2O_2), ozone (O_3) or oxygen (O_2) also did not give this the desired results. A versatile agent has been developed by Terrence Collins of Camegie Mellon University. It involves the use of H_2O_2 as a bleaching agent in the presence of some activators known as TAML activators (Hall *et al.*, 1999) that as catalysts which promote the conversion of H_2O_2 into hydroxyl radicals that are involved in oxidation (bleaching). The catalytic of TAML activators allow H_2O_2 to breakdown more lignin in a shorter time and at much lower temperature. These bleaching agents find use in laundry and results in lesser use of water (Tundo and Anastas, 1998).

Green Solution to Turn Turbid Water Clear: Tamarind seed kernel powder, discarded as agriculture waste, is an effective agent to make municipal and industrial waste water clear. The present practice is to use Al-salt to treat such water. It has been found that alum increases toxic ions in treated water and could cause diseases like Alzheimer's. On the other hand kernel powder is not- toxic and is biodegradable and cost effective. For the study, four flocculants namely tamarind seed kernel powder, mix of the powder and starch, starch ad alum we reemployed. Flocculants with slurries were prepared by mixing measured amount of clay and water. The result showed aggregation of the powder and suspended particles were more porous and allowed water to ooze out and become compact more easily and formed larger volume of clear water. Starch flocks on the other hand were found to be light weight and less porous and therefore didn't allow water to pass through it easily. The study establishes the powder's potential as an economic flocculants with performance close more established flocculants such as $K_2SO_4Al_2(SO_4)_3.24H_2O$ (potash alum).

CONCLUSION

Green Chemistry is new philosophical approach that through application and extension of the principles of green chemistry can contribute to sustainable development. Presently it is easy to find in the literature many interesting examples of the use of green chemistry rules. Great efforts are still undertaken to design an ideal process that start from non-polluting materials. It is clear that the challenge for the future chemical industry is based on 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. Students at all levels have to be introduced to the philosophy and practice of green chemistry.

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