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Brief Description of Principles and Applications of Green Chemistry - An Approach for Sustainable Development

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ABSTARCT-

Green Chemistry is an emerging and demanding branch of Modern Chemistry. The applications of chemistry are used worldwide. One cannot imagine a world without chemistry. In recent times, green chemistry, also referred to as sustainable chemistry, has gained significant importance.The main motivation of green chemistry is to reduce the damage of the environment by man-made substances and the methods used to produce them and maximizing the desired products in an eco-friendly way. Therefore, Green chemistry includes anything that reduces waste and disposes it in correct manner so that minimal damage can be done to the human beings and the environment. Green chemistry is a wide multidisciplinary field that covers areas such as synthesis, solvents, catalysis, efficient processes etc. The 12 principles of green chemistry—such as waste prevention, improved atom efficiency, safer chemical synthesis, development of non-toxic substances, the use of environmentally friendly solvents and conditions, and enhanced energy conservation—provide a comprehensive framework for achieving sustainable development.. These principles motivate chemistry at all levels: research, education and public perception. The 12 principles of green chemistry are designed in such a way in order to provide the framework for sustainable growth.

This review paper majorly focuses on the principles, applications and the advantages of green chemistry and its impact on human health and environment.

The main development of green chemistry includes use of super critical carbon dioxide, water as green solvent and aqueous hydrogen peroxide as an oxidizing agent. It is also helpful in preventing pollution and in pharmaceutical industry.

KEY WORDS – Green Chemistry, Sustainable Environment, Hazardous substances

GRAPHICAL ABSTARCT -

INTRODUCTION

Green Chemistry and sustainable development is based on twelve principles which aims for removing and decreasing chemical materials from their production and application so that there is less damage to human health and the environment. The concept of green chemistry was first given by 1990s. The institute was founded in 1997 [1] and its first volume was well established in green chemistry journal of the royal society of chemistry in 1999 [2,3].

Green chemistry focuses on all parts of chemistry including inorganic, organic, physical, environmental, biochemistry and polymer chemistry.

By adopting key trends in green initiatives—such as catalysis, biocatalysis, and the use of safer alternatives like renewable feedstocks (e.g., biomass), environmentally friendly solvents (like water, supercritical fluids, and ionic liquids), improved reaction conditions (such as microwave-assisted processes), and innovative synthetic methods (like photocatalytic reactions)—it is possible to achieve both environmental protection and economic development. [4]

Green chemistry also broadly related to sustainable environment is related to the manufacture of chemical products and processes in order to decrease or eliminate the use and production of harmful materials. In order to be called "green," each reaction should be having three major green components which includes reagent or catalyst, solvent, and energy consumption.[5]

Green Chemistry is the emerging requirement for the future of science and technology to fulfil the general requirements of the society. It is useful for the healthier living conditions, Economical and Profitable growth of business, encourages creativity to the work, energy efficient and forms safer products with lower costs.

PRINCIPLES OF GREEN CHEMISTRY

In 1989, the 12 principles of Green Chemistry was given by Sir Paul Anastas and John Warner. [6]

1. **Prevention of Waste** –The first principle of green chemistry states that, it is easier to prevent the formation of waste rather than to clean it up once it is formed. The reaction should be done considering that the waste products should be avoided as far as possible. If discharged (or disposed off) in the atmosphere, sea or land not only causes pollution but also requires high expenditure for cleaning-up.

2. **Atom Economy-**It stands for the maximum incorporation of the reactants into the final products. The synthesis process is considered to be green if there is maximum incorporation of the starting materials and reagents in the final product. In other words, we can state that 1 mole of reactant gives one mole of product.

3. Minimization or Preventing Hazardous Products -This principle states that it is better to prevent or at least reduce the formation of hazardous products, which may be toxic or harmful for the environmental. The hazardous substance effect is minimized by providing the use of protective clothing to the workers.

4. Designing Safer Chemicals –With the advanced technology, it is easier for the chemists to design and produce safer chemicals. Chemicals synthesised such as dyes, paints, adhesives, cosmetics, pharmaceuticals etc. should be safe to use. Drug like thalidomide (introduced in 1961) is unsafe drug for lessening the effects of nausea and vomiting during pregnancy (morning sickness). Also, it is found that the children born by women those have taken this drug during pregnancy suffers several birth defects.

5. Energy Requirements for Synthesis –The synthesis of the reaction is done in such a way that it requires the minimum energy. Using a catalyst is crucial as it helps reduce the energy required for a chemical reaction to occur.

6. Selecting Appropriate Solvent and auxiliary for use –The solvent selection for a particular reaction should be done in such a that it should not cause any environmental issue or health hazard of human. The use of liquid or supercritical liquid like CO_2 should be avoided. If possible, the reaction should be done out in aqueous phase. Another major issue is that many solvents are volatile which harms the human health and the environment. The use of auxiliary substances should be made un necessary.

7. Using Reneweable feed stock –Reactions are carried out in a way that raw material should be renewable rather than depleting. We depend upon petroleum for transportation. This principle shifts the use of petrol and make use of renewable material. Biodiesel is one of the example for the same.

8. Reduce the use of Derivatives –The use of chemical derivatives or the blocking groups, protection, deprotection should be avoided because it requires additional steps and generates more waste to the environment.

9. Use of Catalyst – Catalyst is a substance that facilitates transformation without being consumed in the reaction and without being incorporated in the final product. Therefore, catalyst can be used whenever possible. Green catalyst do not cause any toxicity in the process. For Example – Enzymes.

10. Design for Degradation –

Chemical products should be designed in such a way so that at the end of their function they break down into products and do not persist in the environment. Plastics do not degrade in our landfills and pharmaceutical drugs such as antibiotics build up in our water streams. This principle aims to develop products that effectively fulfill their intended purpose.

11. Real-time analysis for pollution prevention-Analytical techniques should be advanced to enable real-time, in-process monitoring and control, helping to prevent the creation of hazardous substances.

12. Minimize potential for accidents-Materials should be chosen in way so as to minimize hazard and risk for chemical accidents, such as explosions, and fires. This principle primarily emphasizes ensuring the safety of both workers and the surrounding community near industrial facilities. It is always better to use materials and chemicals that will not explode, light on fire, ignite in air, etc. when making a product. There are many examples where safe chemicals were not used and the result was disaster. One of the most catastrophic industrial accidents occurred in Bhopal, India, in 1984, when a chemical plant accidentally released toxic gas, leading to thousands of deaths and countless injuries. So, while creating products, it is best to avoid highly reactive chemicals that have potential to result in accidents.

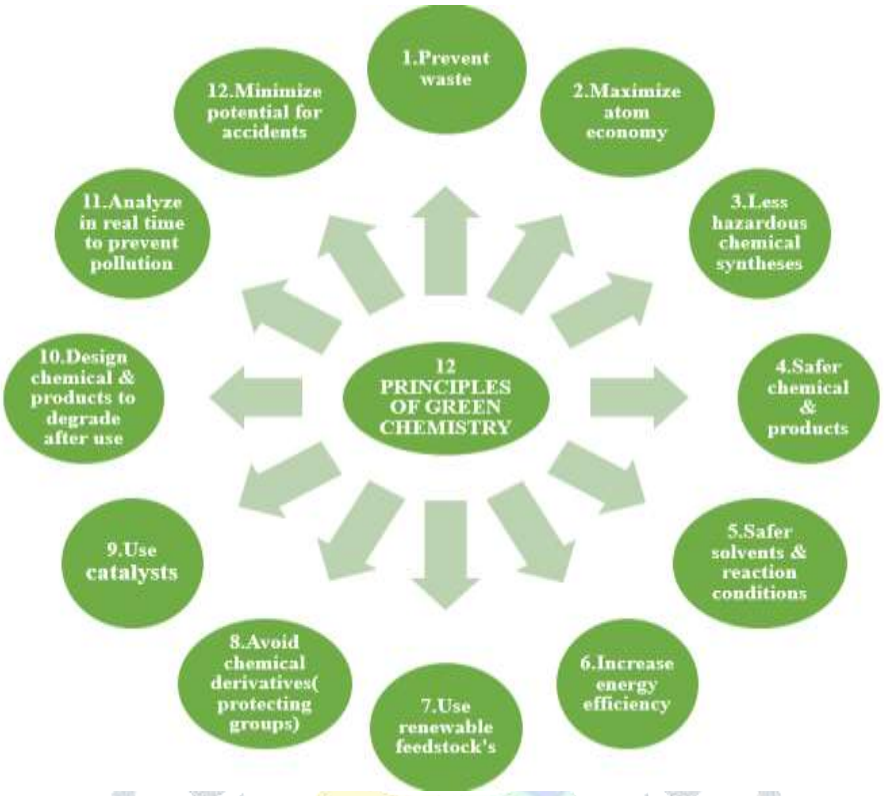

Figure 1: Representing 12 Principles of Green Chemistry

APPLICATIONS OF GREEN CHEMISTRY

1. Green approach for Dry Cleaning of Clothes –Perchloroethylene (PERC), Cl2C═CCl2 is a commonly used reagent as a solvent for dry cleaning of clothes. This reagent is carcinogenic in nature and also contaminates the ground water. Micelle technology uses liquid CO_2 and a surfactant which was developed by Joseph De Simons, Timothy Romark, and James McClain for dry cleaning of clothes which gives the substitute for PERC. Nowadays, Dry cleaning machines have now been developed using this technique. This eco-friendly method avoids the use of halogenated solvents altogether.[8]

2. Greener Bleaching Agents –Manufacturing of paper is done using wood (which contains 70% polysaccharides and 30% lignin approximately). The lignin must be completely removed in order to get good quality paper. It is removed by placing small chipped pieces wood into a bath of sodium hydroxide (NaOH) and sodium sulphide (Na_2S). It decomposes 80-90% of lignin. The remaining amount was removed through reaction with chlorine gas (Cl_2). However, chlorine gas contributes to various environmental issues. It reacts with aromatic rings of the lignin to produce dioxins, such as 2,3,4-tetrachloro- pdioxin and chlorinated furans. These compounds are potential carcinogens in nature. (8)

3. Green Approach to Clear Turbid Water Into Clear Water

Currently, alum salt is commonly employed for the treatment of industrial and municipal wastewater. But alum is not perfect for this purpose because it increasing the hazardous ions in discharged water which may cause Alzheimer's ailments. In contrast, kernel powder is non-toxic, biodegradable, and economical. For this study, four flocculants were used: tamarind seed kernel powder, a mixture of the powder with starch, starch alone, and alum. To prepare the flocculants, a measured quantity of clay was mixed with water to form slurries. The findings

indicated that the combination of kernel powder and suspended particles created more porous flocs, which facilitated easier water separation and compaction, resulting in a greater volume of clear water. Conversely, flocs formed with starch were lighter and less porous, making it difficult for water to pass through efficiently. The study shows that powder's potential as an economic flocculant. [8]

4. Solar Cell

This is a prime example of green technology, as it directly transforms light energy into electrical energy through the photovoltaic process. Solar photovoltaic technology is recognized as one of the few renewable and low-carbon energy sources that offer both scalability and ongoing technological advancement.
. The use of solar photovoltaic has been rising at an average of 43% per year since 2000. Generation of electricity from solar energy results in less consumption of fossil fuels, reduction of pollution and greenhouse gas emissions.

5. In Pollution Prevention

Activated carbon plays a vital role in controlling air pollution. This method uses carbon-based filters to trap and reduce the release of harmful pollutants into the atmosphere. These filters work by absorbing contaminants, thereby helping to purify the air. Another effective air pollution control method is bio-filtration, which relies on microorganisms—typically bacteria and fungi—to break down pollutants. This technique is commonly used in industries such as food processing, pharmaceuticals, waste treatment, and wastewater management. Although bio-filtration is effective, it requires a substantial amount of space for proper operation, making it unsuitable for industries with limited room. Fuel switching is another strategy for reducing air pollution. This approach involves using cleaner fuels to minimize emissions. For instance, electric power plants may opt for low-sulfur fuel instead of high-sulfur variants. However, low-sulfur fuels are generally more costly than their high-sulfur counterparts.[7]

ENVIRONMENTAL ADVANTAGES OF GREEN CHEMISTRY

- Fewer chemical pollutants in nature:

Many substances enter the environment through **intentional use** (such as agricultural chemicals), **accidental leaks** (like emissions from production processes), or **waste disposal**. In contrast, green chemicals are designed to either **break down into non-toxic substances** or be **collected for reuse**. [9]

- Reduced harm to wildlife and vegetation:

The use of safer, environmentally friendly chemicals leads to **less exposure of animals and plants to dangerous toxins**, helping to maintain ecological health.

- Lower contribution to atmospheric issues:

Eco-friendly chemicals help decrease the risk of climate change, reduce ozone layer damage, and limit the formation of air pollutants like smog.

- Minimized disturbance to natural ecosystems:

Green chemistry supports preservation of ecological balance by using substances that interfere less with environmental systems.

- Decreased reliance on hazardous waste disposal sites:

Since these processes generate **less toxic waste**, there is a **reduced need for landfills**, particularly those handling **dangerous or harmful materials**.

HUMAN HEALTH BENEFITS OF GREEN CHEMISTRY

- **Improved air quality:**

Reduced emission of dangerous chemicals into the atmosphere leads to **fewer respiratory issues** and **less lung irritation**.

- **Cleaner water sources:**

Minimized discharge of toxic waste into water bodies results in **safer drinking water** and **cleaner water for recreational activities**.

- **Enhanced workplace safety in chemical industries:**

With **decreased use of harmful substances**, workers face **lower health risks**, **reduced need for heavy protective gear**, and **fewer chances of accidents** such as **fires or explosions**.

- **Healthier and safer consumer products:**

Innovative products made using **eco-friendly methods** will be **safer to use**, including **medications made with less chemical waste** and **greener alternatives** to traditional **pesticides and cleaning supplies**.

- **Safer food systems:**

The **removal of long-lasting toxic chemicals** that can contaminate the food chain leads to **healthier crops and food items**. Eco-designed pesticides are **targeted only at specific pests** and **break down quickly** after application.

- **Lower exposure to harmful compounds:**

Reduced use of hazardous substances, including **endocrine-disrupting chemicals**, results in **less human contact with dangerous toxins**.

CONCLUSION-

Green chemistry is a transformative approach for the environmental protection and economic growth using several ways. It is new philosophical way through its applications and extension of principles of green chemistry can contribute to the sustainable development. Presently, there are various examples for the use of green chemistry. Several initiatives are still taken to design an ideal process that starts from non-hazardous or non-polluting materials. It is clear that the challenges for the future chemical industry is based on safer products and processes designed by using new ideas in fundamental research.

Successful growth of green chemistry depends on the training and knowledge given to the students of new generation. There are various benefits of green chemistry for helping the human health and environment. With the growing environmental challenges, the adoption of green chemistry is essential for building a safer and sustainable future.

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