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Green Chemistry and Catalysis

Adiba Mulla, Suhani Sinha, Sonali Mehetar, Srushti Gholap
Navsahyadri Institute of Pharmacy, Pune

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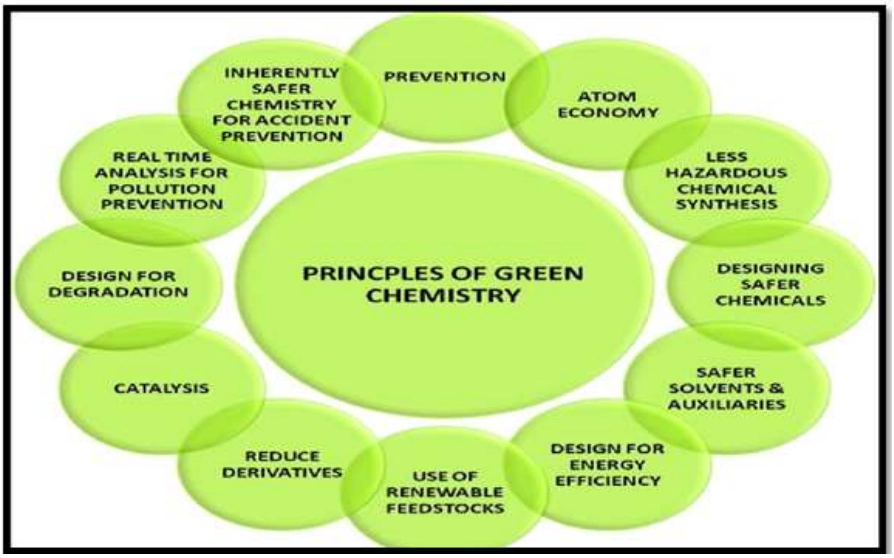
ABSTRACT: Green chemistry and catalysis work together to improve chemical processes while being kinder to the environment. Catalysis helps reactions happen faster and with less waste, which is good for nature. Recent progress focuses on finding new ways to make catalysts, using eco-friendly materials, and creating cleaner methods for making chemicals. Different techniques like using special catalysts, natural enzymes, or light help make these processes greener. Scientists also use computers to find smarter ways to make catalysts and processes. Overall, these advancements show how catalysis plays a crucial role in making chemistry more environmentally friendly.

KEYWORDS: GreenChemistry, Catalysis, Sonochemistry, Ionic liquid, Solvent, Enzyme Technology, Ultrasonography, Nanoparticle

I. INTRODUCTION

Green chemistry, sometimes referred to as sustainable chemistry, is a branch of chemical engineering and research. It encourages the design of product and procedures that minimise the usage of hazardous materials.[1]



Catalysis is an increase in the rate of a chemical reaction due to the addition of a substance called a catalyst. Catalysts are not consumed in the reaction and remain unchanged after the reaction.

Green chemistry is about making chemical processes and products more environmentally friendly, while catalysis is a method that helps speed up these processes.When combined, green chemistry and catalysis work together to develop cleaner and more sustainable ways of producing chemicals.[1]

Green chemistry and catalysis are two interconnected fields that play critical roles in addressing environmental and sustainability challenges in the chemical industry.By integrating catalysis into green chemistry principles, researchers and industries aim to develop innovative processes that are both environmentally benign and economically viable. Catalytic reactions often play a central role in green chemistry strategies by enabling transformations that would otherwise be impractical or environmentally harmful.Overall, the synergy between green chemistry and catalysis holds promise for transforming the chemical industry towards more sustainable practices and fostering a greener and cleaner future.[2]

II. HISTORY OF GREENCHEMISTRY

The term "Father of Green Chemistry" is often attributed to Paul Anastas. Together with John Warner, he played a pivotal role in defining the principles and framework of green chemistry. Anastas and Warner co-authored a book titled "Green Chemistry: Theory and Practice," which outlined the following 12 principles of green chemistry.[3]

1. Prevention

Instead of treating or cleaning up, it is preferable to check or prevent the synthesis of hazardous, poisonous, explosive, bio-accumulative, and waste chemical products.

2. Atom Economy

Plan the chemical reactions so that the end product has the highest possible concentration of the reactant or initial raw materials, with just a small amount of raw material atoms remaining.[6]

3. Less Hazardous Chemical Synthesis

Create chemical processes and products that are designed to prevent environmental degradation and human harm by ensuring that the usage and synthesis of chemical compounds do not beyond the critical limit of toxicity.

Example: (a) Avoid the synthesis of chemicals like organ mercurial’s compounds; which caused Minamata disaster

4. Designing safer chemicals

Chemical goods and processes should be created with the least amount of toxicity, bioaccumulation, and biotransformation possible while yet having a highly selective character that affects their intended activities.

5. Safer solvent and auxiliaries

When utilising auxiliary compounds as solvents, separating agents, or extractive agents, they should not cause cancer, be non-explosive, non-toxic, non-bio accumulative, or induce mutations.

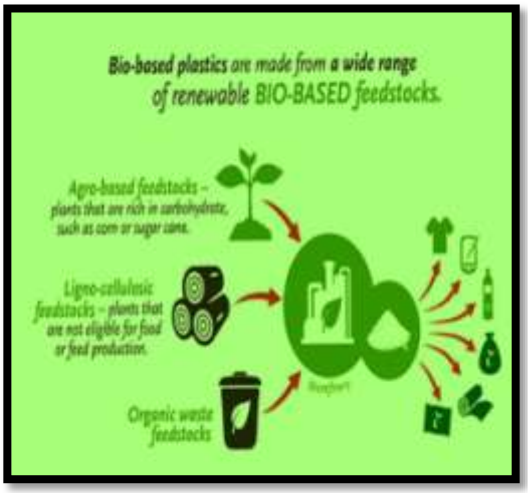
6. Design for energy Efficiency

In order to create the intended outcome, chemical processes and products must be designed to use the least amount of energy possible. This may be achieved by maintaining the processes at room temperature and pressure while using an appropriate catalyst.

7. Use of renewable feedstocks

Avoiding the use of non-renewable natural resources such as coal, oil, and natural gas is preferable for sustainable development.

Example: Biobased plastics made from renewable feedstocks.



8. Reduced derivatives

During a chemical process, waste product are formed or generated if additional chemical reagent are used to block or protect any groups, so avoid such type of blocking, protecting groups or even any modifications, if possible.

9. Catalysis

A catalyst is a chemical that is used in small amounts to speed up reactions by lowering activation energy and self-regenerating after the process is finished.

10. Design for degradation

The design of chemical processes and products should ensure that both the final goods and the waste items they produce can decompose naturally. By using physical, chemical, and biological processes, the intended products disintegrate into innocuous tiny components and disappear into the surrounding environment. The product shouldn't exhibit biomagnifications or be bio accumulative in any way.

11. Real time analysis for pollution prevention.

To regulate the creation of desired products and prevent the production of any hazardous or waste materials as byproducts, it is crucial to understand the events of product formation throughout a chemical process at varying temperature, pressure, and time.

12. Inherent safer chemistry for accident prevention

Chemical accidents, such as explosions, fires, and smoke produced by chemicals released into the environment, can be reduced or completely avoided by designing chemical processes, products, and their physical states, such as solid, liquid, and gaseous.

CATALYSIS

Catalysis is a process where a substance (catalyst) speeds up a chemical reaction without being consumed itself, typically by lowering the activation energy required for the reaction to occur.[4]

HOW IT RELATED TO GREEN CHEMISTRY?

Large volumes of waste are produced daily by chemical activities. Particularly with stoichiometric equivalents, unwanted byproducts such inorganic salts are produced. Scientists are able to conserve energy and resources when more effective catalytic alternatives gradually replace stoichiometric chemical procedures. Greener catalysis is defined as moving away from stoichiometric processes and towards homogeneous and heterogeneous catalytic reactions employing organic, inorganic, organometallic, and biological catalysts.[3]

ROLE OF CATALYST IN GREEN CHEMISTRY

The field of green chemistry is concerned with finding and using ecologically beneficial compounds and methods. One essential element of green chemistry is catalysis. Green chemistry, sometimes referred to as sustainable chemistry or ecologically benign chemistry, reduces toxicity. Its goal is to plan and carry out energy-saving, waste-reduction, and resource-saving pollution avoidance strategies that don't include trash management. Because green chemistry is supposed to lower pollutants and carbon emissions, it is seen as ecologically benign. Catalysis has aided in the reduction of pollution in our environment. By lowering the use of volatile organic compounds (VOCsi), eliminating and controlling NOx emissions, and creating alternative catalytic technology to replace the use of chlorine or chlorine-based intermediate in chemical synthesis and waste minimization, catalysts have been used to improve air quality. Numerous byproducts and other waste substances can be eliminated because catalysis promotes more effective and selective reactions.[15]

SOLID ACIDS AND BASES AS CATALYSTS

Acid- and base-catalysed reactions play a significant role in the petrochemical and oil refining industries, as well as in the synthesis of several specialty chemicals, including flavours, fragrances, agrochemicals, and pharmaceuticals. Numerous operations in liquid-phase homogeneous systems or vapour-phase systems on inorganic substrates call for the employment of Lewis acids ($AlCl_3$, $ZnCl_2$, BF_3) or standard Bronsted acids (H_2SO_4, HF, HCl, p-toluene-Sulfonic acid). In a similar vein, common bases include KO, NaOH, KOH, and NaOMe. The creation of inorganic salts as a result of their ultimate neutralisation, which finally finds its way into water streams.[5]

Using solid acids and bases as catalysts has additional benefits, such as:

- Easier separation and recycling, which leads to a quicker process and cheaper production costs.
- Solid acids are safer and simpler to work with than their liquid counterparts, such as HF, H_2SO_4, and others. Extremely caustic and requires expensive building supplies.
- Neutralised catalyst contamination at trace levels in the final product is frequently avoided. When the latter is a trustworthy one.
- Comparing granular compounds to their liquid equivalents, the former are safer and simpler to use.

ENZYME TECHNOLOGY IN BIOCATALYTIC REDUCTION

The use of natural materials, such as enzymes from biological sources or whole cells, to accelerate chemical processes is known as biocatalysis. The metabolic conversion of compounds to create new chemicals for industrial use is referred to as biocatalysis. The metabolic breakdown of chemicals for the benefit of the environment is referred to as biodegradation. The same enzymes frequently play key roles in biocatalytic and biodegradative processes.[5]

In organic synthesis, reductions are crucial because they provide chiral molecules with novel uses.Enzymes with remarkable stereo-, regio-, and chemo selectivity can catalyse these activities, leading to the creation of shorter and higher-value conventional synthesis routes. Chemicals in bulk as well as compounds are accessible.As the catalysts of nature, enzymes provide almost infinite access to a vast array of chemical processes. Specifically, reductions have the ability to produce numerous chiral centres as well as multiple chiral centres.However, novel functional groups in goods that are highly sought after by the fine chemical and pharmaceutical sectors.[7]

An example of enzyme technology in biocatalytic reduction is the use of alcohol dehydrogenase enzymes to catalyse the reduction of ketones or aldehydes to their respective alcohols. This process is widely used in pharmaceutical and chemical industries for the synthesis of chiral compounds with high selectivity and efficiency.[10]

SONOCHEMISTRY

In chemistry, the study of sonochemistry is concerned with understanding the effect of ultrasound in forming acoustic cavitation in liquids, resulting in the initiation or enhancement of the chemical activity in the solution. Therefore, the chemical effects of ultrasound do not come from a direct interaction of the ultrasonic sound wave with the molecules in the solution.[12]

GREEN SONO CHEMICAL APPROACHES FOR ORGANIC SYNTHESIS.

Sono chemical approaches in organic synthesis involve using ultrasound to promote chemical reactions. They're valued for their efficiency and environmental friendliness. They're particularly useful for promoting reactions in a greener, more sustainable way, often reducing the need for harsh reaction conditions or toxic components.Even though ultrasonography has long been used in both business and academia, environmental and synthetic chemists have only just come to appreciate the "green" value of this non-hazardous acoustic radiation. Ultrasound's chemical and physical impacts are caused by cavitation collapse, which locally creates extreme conditions. This leads to the synthesis of chemical species that are difficult to get under normal circumstances, which in turn drives a specific radical reactivity. This non-mathematical justification foresees the benefits of applying this technology to a range of processes, such as safer reagent substitution, easier creation of reactive species and catalysts, and softer reactions with higher yields and selectivity. Sonication facilitates the quick dispersion of solids, the breakdown of organic materials, including biological components, and the formation of porous materials and nanostructures.[9]

SOLVENT-FREE SONOCHEMICAL PROTOCOL

A solvent-free Sonochemical protocol involves conducting chemical reactions using ultrasound without the use of any organic solvents. This approach aligns with the principles of green chemistry by reducing environmental impact, eliminating or minimizing the need for volatile and often harmful solvents.

1. Heterogeneous Catalysis in Organic

Heterogeneous catalysis is a branch of catalysis in which the catalyst is in a different phase (usually a solid) than the reactants. This approach is widely used in organic synthesis due to its various advantages, including ease of separation and recycling of the catalyst, as well as the ability to perform reactions under milder conditions.Heterogeneous catalysis in organic chemistry involves using solid catalysts to accelerate chemical reactions in which the reactants and catalyst are in different phases (e.g., solid catalyst and liquid or gaseous reactants). It's widely used in industrial processes like hydrogenation, oxidation, and hydrocracking.[10]

2. Heterocyclic Synthesis in Water

Heterocyclic synthesis in water is the process of producing heterocyclic compounds utilizing water as a reaction media. This technique is consistent with green chemistry principles, as water is a safe, abundant, and environmentally beneficial solvent.Heterocyclic synthesis in water, also known as aqueous-phase synthesis, is a green and sustainable approach to forming heterocyclic compounds using water as the solvent. This method offers several advantages, including environmental friendliness, mild reaction conditions, and easier purification. It’s becoming increasingly popular in organic chemistry due to its compatibility with green chemistry principles.[8]

3. Solvent-free Reactions

Solvent-free reactions refer to chemical reactions that are conducted without the use of any liquid solvents. This approach is part of the broader concept of green chemistry, aiming to minimize or eliminate the use of potentially harmful solvents, reduce waste generation, and improve the overall environmental sustainability of chemical processes.Solvent-free reactions, also known as neat reactions or solventless reactions, are chemical reactions that are carried out without the use of any solvent. These reactions offer several advantages, including environmental friendliness, reduced waste generation, and simplified purification processes. They are particularly useful in green chemistry and are becoming increasingly popular in organic synthesis. Examples include solid-state reactions, mechanochemical reactions, and gas-phase reactions

4. Reactions in Organic Solvents

Reactions in organic solvents involve carrying out chemical reactions in liquid organic solvents such as ethanol, acetone, or toluene. Organic solvents serve as reaction media, dissolving reactants and facilitating interactions between them. They can influence reaction rates, selectivity, and yields. Common organic solvents include ethers, alcohols, hydrocarbons, and chlorinated solvents. Choosing the appropriate solvent is crucial for optimizing reaction conditions and achieving desired outcomes in organic synthesis.[7]

SOLVENTS AND IONIC LIQUIDS

1. Solvent

A solvent is a substance that dissolves a solute, resulting in a solution. Although they can also be solids, gases, or supercritical fluids, solvents are typically liquids. All ions and proteins in a cell are dissolved in the water that exists within the cell. Water is a solvent for polar molecules and the most frequent solvent utilised by living organisms.Although they can also be solids, gases, or supercritical fluids, solvents are typically liquids. All ions and proteins in a cell are dissolved in the water that exists within the cell. Water is a solvent for polar molecules and the most frequent solvent utilised by living organisms.[13]

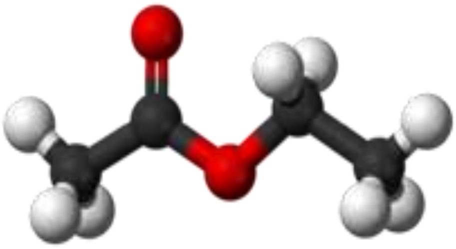


Fig. Ethyl acetate, nail polish solvent.

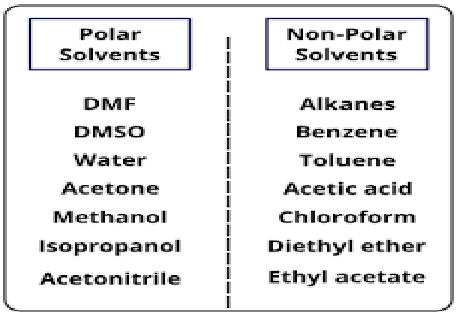
Solvents find extensive use in paints, paint removers, inks, and dry cleaning. Organic solvents have specific applications, such as in dry cleaning (tetrachloroethylene, for example), paint thinners (turpentine, toluene), glue solvents (acetone, methyl acetate, ethyl acetate), spot removers (hexane, petrol ether), detergents (citrus terpenes), and perfumes (ethanol). In the chemical, pharmaceutical, oil, and gas sectors, solvents are used in a variety of processes, such as chemical synthesis and purification.

Polar and non-polar solvents are the two basic categories into which solvents may be divided. A unique instance is elemental mercury, whose solutions are referred to as amalgams; moreover, there are other metal solutions that are liquid at ambient temperature.

In general, a solvent's dielectric constant can be used to approximate its polarity. Water has a high dielectric constant of 88 (at 0 °C), which indicates its strong polarity. Nonpolar solvents are often defined as those with a dielectric constant of less than 15.

The dielectric constant quantifies the solvent's propensity to partially negate the electric field intensity of a submerged charged particle.[15]

Next, a comparison is made between this decrease and the charged particle's field strength in a vacuum.A solvent's heuristic dielectric constant might be conceptualised as its capacity to decrease the effective internal charge of the solute. In general, a solvent's dielectric constant may be used to reasonably estimate how well it would dissolve typical ionic substances, such salts.[13]



Polar Solvents	Non-Polar Solvents
DMF	Alkanes
DMSO	Benzene
Water	Toluene
Acetone	Acetic acid
Methanol	Chloroform
Isopropanol	Diethyl ether
Acetonitrile	Ethyl acetate

2. IONIC LIQUIDS

A salt that is liquid at room temperature is known as an ionic liquid (IL). The phrase has occasionally been limited to salts that melt at or below a particular temperature, such 100 °C (212 °F).Ordinary liquids like petrol and water are mostly composed of molecules that are electrically neutral, whereas ionic liquids are primarily composed of ions. These materials go by a number of names, including fused salts, liquid salts, ionic melts, ionic electrolytes, and ionic glasses.[11]

The term "ionic liquid" in the general sense has been used from the beginning in 1943. The date of discovery of the “first” ionic liquid is still disputed. the identity of its discoverer. Ethanol ammonium nitrate (m.p. 52–55 °C) was reported in 1888 by S. Gabriel and J. Weiner. ILs are typically colourless viscous liquids.[19]

They are usually moderate to poor conductors of electricity and rarely self-ionize. However, there are a very large number of them electrochemical window, allowing electrochemical purification of Difficult minerals.

They exhibit low vapor pressure, which can be as low as 10-10 Pa. Many have low combustibility and are thermally stable. The solubility properties of ILs are diverse. Saturated aliphatic compounds are generally onlysparinglysoluble in ionic liquids,whereas alkenes show somewhat greater solubility, and aldehydes often completely miscible.[14]

ROLE OF VARIOUS TYPES OF SOLVENTS AND IONIC LIQUIDS USED IN GREEN SYNTHESIS

Green synthesis aims to develop environmentally friendly and sustainable methods for the production of chemicals, materials, and pharmaceuticals.[4] The choice of solvents plays a crucial role in determining the overall environmental impact of a synthetic process. Both traditional solvents and ionic liquids can be employed in green synthesis, each offering specific advantages and considerations. Here's a discussion of their roles in green synthesis:[3]

Role of Various Types of Solvents:

1. Water:

Advantages:

- Abundant and inexpensive.
- Non-toxic and environmentally friendly.
- Green extraction solvent for natural products.

Applications:

- Hydrothermal synthesis.
- Reactions involving hydrophilic reactants.
- Biomolecule synthesis.

2. Organic Solvents (Green Solvents):

Advantages:

- Some are derived from bio-based feedstocks.
- Low toxicity compared to traditional solvents.

Applications:

- Organic synthesis reactions.
- Extraction processes.
- Chromatography.

3. Supercritical Fluids (e.g., Supercritical CO2):

Advantages:

- Excellent for extracting natural products.
- Can replace volatile organic solvents.

Applications:

- Extraction of essential oils.
- Green separation processes.

Role of Ionic Liquids:

1. Catalysis:

- Ionic liquids can serve as both solvents and catalysts in various reactions.
- They provide a unique environment for catalysis and can enhance reaction rates and selectivity.

2. Extraction and Separation:

- Ionic liquids are used in extraction processes, particularly for separating polar and nonpolar compounds.

3. Biocatalysis:

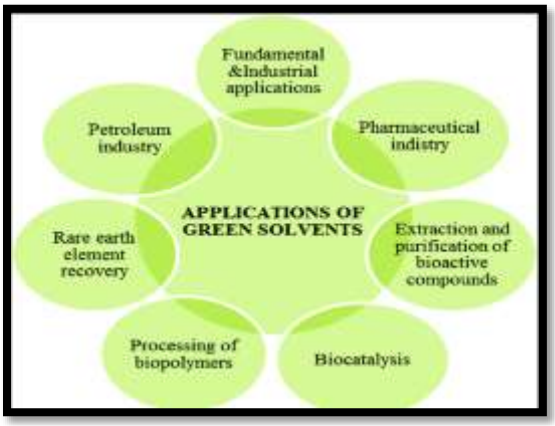
- Ionic liquids provide a stable medium for enzymatic reactions, facilitating the use of biocatalysts in synthesis.

4. Green Synthesis of Nanomaterials:

- Ionic liquids are used in the green synthesis of nanoparticles and nanomaterials.
- They can act as both solvents and stabilizing agents for the nanoparticles.

6. Green Solvents for Biopolymers:

- Ionic liquids are explored as green solvents for the dissolution and processing of biopolymers, contributing to the development of sustainable materials.[14]



III. CONCLUSION

Older methods that harm the environment, involve hazardous solvents, and are not atom-specific in the sense that they defy the principles of green chemistry must be updated or modified. This has the potential to improve environmental sustainability and student safety at the same time. This is the first time a novel strategy has been developed. Non-traditional methods are employed in organic synthesis. The synthesis of chemicals in an ecologically responsible manner depends heavily on catalysis. Numerous byproducts, co-products, potential wastes, and pollutants can be avoided by switching from a typical synthetic method to an ecologically friendly synthetic one. The feasibility of using catalysts for environmentally friendly synthesis is demonstrated by the elimination of many stages that are typically included in the process.

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