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Green chemistry and catalysis: An emerging sustainable approach in synthetic chemistry

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Abstract. This tutorial review summarizes the basic new concepts of green chemistry in relation to education and pharmaceutical industries. The origin and history of Green analytical chemistry is described in detail. Basic twelve principles are well summarized with suitable examples of each principle such as oxidation of alcohol, enzymatic reactions, and non-covalent derivatization. This article also covers the concept of E-factor for waste minimization, detailed various solvent selection guidelines and tools for betterment of synthetic pathways at laboratory and industrial level. The efficiency of green chemistry in organic synthesis for greenness of traditional organic synthesis methods are discussed. Nowadays, there is a constant need to add catalysts for chemical synthesis to minimize or downsize the risks correspondent with chemical manufacture. Catalyst helps to enhance air quality by reducing harmful gas emissions such as NOx. It cuts down on the use of VOCs (volatile organic compounds). It developed an alternative catalytic method which substitutes the usage of chlorine-based intermediates in chemical synthesis and processes. Biocatalysts is a term used to describe compounds that aid in the stimulation of biological reactions. In the fine chemical industry, cleaner biocatalytic alternatives are replacing traditional chemical operations.

1 Introduction

The concept of Green Chemistry was first formulated in the beginning of 1990s, when the growth of industrial activities gave rise to environmental issues. The process of green chemistry becomes a powerful tool for conventional production through synthesis; screening and applications of resulting compounds in one's way that deplete harmful effects to health and environment. Through conferences, political agreements on green chemistry, industries and organizations have reworked their practice of production and product development habits supporting sustainable processes. Education of green chemistry introduces new concepts and strategies across the chemistry curriculum (Paul and Nicolas 2010; Bianca et al. 2019).

The 12 principles of green chemistry were first introduced by Paul Anastas and John Warner, and they are being used till today. The aspiration of these principles is to reduce the use of hazardous solvents in chemical processes and analyzes, as well as reduce waste from these processes. The major purpose is to reduce the environmental and occupational hazards by suggesting environmentally beneficent steps from the point of scheming the product to its synthesis, processing, analysis and its destination after use (Paul 1999; Lenardao et al. 2003; Prado 2003). The progression of new analytical methodologies and strategies which are capable to minimize and eradicate the use and generation of harmful chemical substances in every step of chemical analysis under the area of Research and Development in Green Chemistry is known as Green Analytical Chemistry (Paul 1999; Sanseverino 2000; Nolasco et al. 2006; Guardia et al. 2012).

Green chemistry's key benefit is that it eliminates toxicity, reduces pollution, saves energy, and aids in the conservation of natural resources. It focuses primarily on the development and implementation of pollution avoidance methods. Green chemistry is widely perceived as a means to reduce carbon emissions and pollution in the environment. To reduce the likelihood of negative consequences, careful planning and design are required. The ambition of green chemistry is to achieve molecular-level sustainability. Catalysis also plays remarkable involvement in pollution prevention.

1.1 Substructure of Green Chemistry

- It designs the different nature of molecular products and also helps to minimize their hazards.
- It works on designing different life cycles of chemicals.
- It works on different principles (Paul and Nicolas 2010).

1.2 History

The term Green Chemistry was first initiated as a result of the Pollution Prevention Act 1990. Under this Act, the U.S. national policy should minimize the pollution by improving synthesis and processing of chemical substances instead of treatment and disposal. In 1991, the term Green Chemistry was first used by P. Anastas in a special program launched by the US Environmental Protection Agency (EPA) to execute sustainable development in chemistry and chemical technology by industry, academia and government. The annual US Presidential Green Chemistry Challenge in 1995 was declared and further corresponding awards were established in European Countries. In 1996 the Working Party on Green Chemistry was developed which work within the framework of International Union of Applied and Pure Chemistry. In 1997, the Green Chemistry Institute (GCI) was introduced with chapters in 20 countries to promote new technologies in research institute and universities the result of which the first conference highlighting concept of Green Chemistry held in Washington. Thereafter, many similar conferences were conceived on a regular basis. In 1990s, the first books and journals in the name of green chemistry were introduced including the Journal of Clean Processes and Products (Springer-Verlag) and Green Chemistry, sponsored by the Royal Society of Chemistry (Wardencki et al. 2005).

1.3 Twelve Principles of Green Chemistry

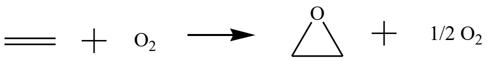
The first manual of Green Chemistry was published by Paul Anastas and John Warner in 1998, in which they described 12 principles for the theme (Anastas and Warner 1998) which are explained in Fig. 1.

Fig.1 Twelve Principles of Green Chemistry

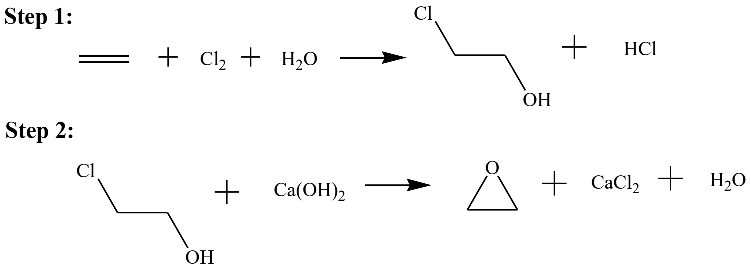
1.4 Waste Prevention

"It is better to prevent waste than to manage or clean up after its formation" (Paul and Nicolas 2010). Any substance that is no longer useful is referred to as waste. When a substantial amount of raw material deviates from the intended plan of the process, waste is produced. Chemical industries use a variety of environmental considerations to eliminate some industrial processes while also coming up with innovative solutions (Paul and Nicolas 2010).

For example, earlier ethylene oxide was synthesized by way of intermediate named as chlorohydrin, the result of which 5kg of waste were disposed for each kilogram of product and wastewater was contaminated by chlorine by- product (Sheldon 2008; Sheldon 2007; McClellan 1950). The modification of this process was done by using molecular oxygen instead of chlorine and the waste was reduced to 0.3kg. The new synthesis procedure creates 16 times less waste than the existing procedure and removes generation of wastewater as well (Kilty and Sachtler 1974).



(a)



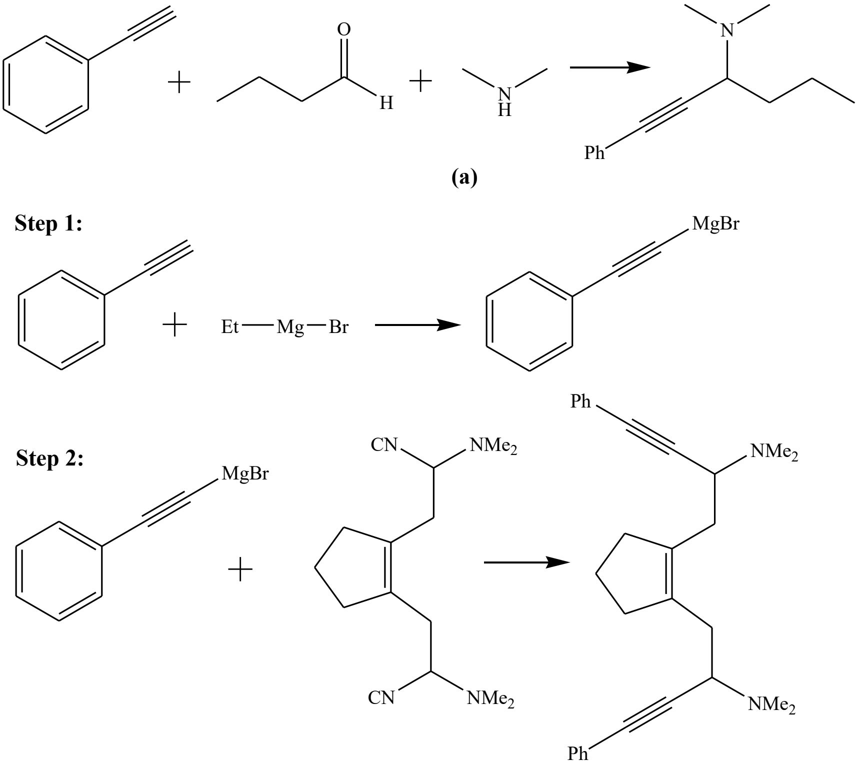
(b)

Fig.2 (a) Substitutive Synthesis of ethylene oxide and (b) Established Synthesis of ethylene oxide

1.5 Atomic Economy

Design such type of synthetic processes which incorporates as much as reagents in the formation of final product. Atom efficiency or atom economy is calculated by dividing the molecular weight of the desired product by the sum of the molecular weights of all chemicals generated by stoichiometric equations. Barry Trost was the first to introduce it (1991). It's one of the most crucial aspects of green chemistry. It's used to determine how green a synthesis is (Trost BM 1995).

In relation to this principle, countable examples such as The Grignard reaction, is unfortunately a poor atom economical reaction due to the use of metal reactant in particular amount during reaction and the separate preparation of Grignard reagent which use to set up the structure of propargylic amine. The values of atom economy are 44 and 56% respectively, which shows the loss of a portion of the raw material. The A3 coupling (Alkyne, Aldehyde and Amine) was proposed by C.-J. Li et al. in 2002 as a solution. This one-step multicomponent coupling reaction conserves 92% atoms than the original and is more efficient (Smith and March 2001; Epsztein and Goff 1985; Wei and Li 2002).



(a)

(b)

Fig.3 (a) Synthesis of propargylic amine using A3 Coupling (b)Synthesis of propargylic amine usingGrignard reagent

1.6 Safer Chemical Synthesis

Synthetic methods should be designed that use solvents with low or no toxicity having no occupational and environmental toxicity. Various new synthetic approaches such as Cascade or tandem reactions, C–H activation, metathesis, and enzymatic reactions are strong examples of cleaner and synthetic tools for organic chemists (Nicolaou et al. 2003; Murai 1999; Grubbs 2004; Silverman 2002; Paul and Crabtree 2009).

One other well-known example is the second generation chemoenzymatic process for the synthesis of Pregabalin, an active ingredient of CNS drug Lyrica described by Pfizer Scientists. By comparing earlier routes for synthesis e.g synthesis of Mannich Bases by Benzimidazole (Sethi et al. 2015), this new synthesis results in dramatic improvement in process efficiency. In this synthesis, the stereocenter was set earlier according to the golden rule of chirotechnology and the wrong enantiomer could be easily racemized and reused (Martinez et al. 2008; Sheldon 1993).

Chemoenzymatic process of Pregabalin:

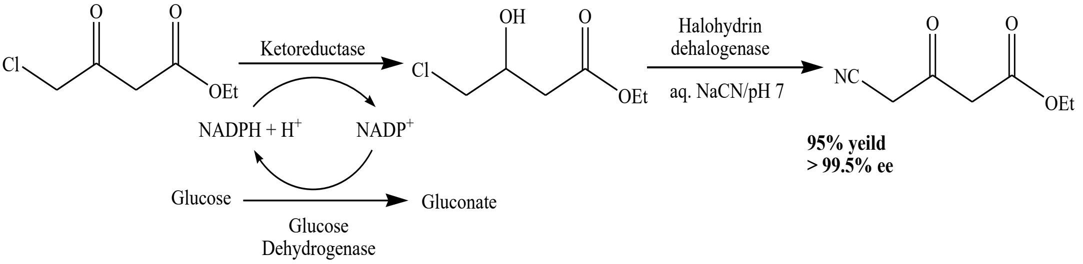


Fig.4 Chemoenzymatic synthesis of Pregabalin

1.7 Safer Chemical Design

Chemical products should be designed to have low toxicity and desired function. While there has been a lot of effort on generating synthetic chemicals for a variety of uses, from prescriptions to materials, there has been an unexpected lack of attention paid to risk during the planning phase. Understanding the qualities of an atom that influences climate and biosphere changes is critical for long-term sustainability. Chemicals will be able to design molecules that are both safe for humans and the environment (Paul and Nicolas 2010).

Free radicals were generated through highly toxic neurotoxic organotin compounds, especially tributyltin hydride. There is possibility that at the completion of reaction and at purification stages, the product contain traces of organotin compounds which is significant hazardous for ingestion by humans. So, new synthetic approach is the replacement of organotin compounds with easily oxidized sulfide which give radical anion by transferring an electron to electrophile. This is in turn giving an organic radical.

1.8 Use of safer solvents and auxiliaries

Unnecessary use of solvents and reagents should be avoided, but when used these solvents are harmless in nature. Solvent research is arguably the highly operative area of Green Chemistry (Anastas 2002). They are an important test for Green Chemistry since they frequently account for most of the mass lost in unions and cycles (Curzons et al., 2001). Many available solvents are flammable, toxic and corrosive which contribute to air, water and land pollution and increased the risk of labourers' openness and resulted in serious mishaps. In an effort for betterment of these solvent selection problems, various Supercritical fluids (SCF), Water, solventless systems and more recently ionic liquids are some examples of safer solutions founded by various chemists. One of the useful examples is Diels-Alder reaction in which water is used as a solvent (Kerton 2009; Breslow 1998; Kerton 2009; Welton 1999).

1.9 Energy Efficiency

The effect of energy requirement of chemical processes on environment and economic sector should be recognized and minimized. If possible, synthetic processes should be carried out at ambient temperature and pressure. Concerns about petroleum feedstock depletion and rising energy demand have prompted the creation of more energy efficient cycles and the survey for non-draining assets in a time frame that is meaningful to people (Laughton 1990).

Solar energy, Wind power, Hydro power are some of the alternatives to petroleum and the fundamental sustainable energy source on earth (Luque and Hegedus 2003; Gunnes et al 2007). The other solution of increasing energy demand is Proton Exchange Membrane (PEM) fuel cells (Vielstich et al. 2003; Gasteiger and Markovic 2009).

2 Green Catalysis

It is better to use catalytic reagents instead the use of stoichiometric reagents. One keyway to improving the effectiveness of the manufactured tool kit is to switch from stoichiometric approaches to synergist metrics. Catalysis can enhance a response's efficiency by minimizing the amount of energy required, avoiding the necessity of stoichiometric reagent measurements, and improving item selectivity. This implies that there will be less energy, feedstock, and waste (Horvath 2003).

A well-established procedure of reduction which uses a significant amount of DIBAL-H (reducing agent) as hydride donor and generate amount of waste. Instead of this procedure, catalytic hydrogenations such as Noyori hydrogenation used which eliminates the use of stoichiometric reagents and reduce the amount of generated waste (Yoon and Gyoung 1985; Noyori et al. 1987).

2.1 Use of renewable raw materials

Renewable raw material should be used instead of non-renewable, whenever it is technically and economically feasible". Various examples of renewable material include cellulose, lignin, suberin and other wood compounds, polyhydroxyalkanoates, lactic acid, chitin, starch, glycerol and oil (Belgace and Gandini 2008).

2.2 Reduction of Derivatives

If possible, avoid or minimize dispensable derivatization processes because such processes necessitate further reagents and therefore, generate waste". Covalent derivatization is worldwide technique used in analytic chemistry and organic synthesis (Knapp 1979). In the early 1990s, non-covalent derivatization concept was introduced which rely on intermolecular interaction rather than covalent bonding (Taylor and Warner 1993). This concept of non-covalent derivatization is explained by controlled diffusion and solubility of hydroquinones used in Polaroid films at elevated pH (Cannon and Warner 2002).

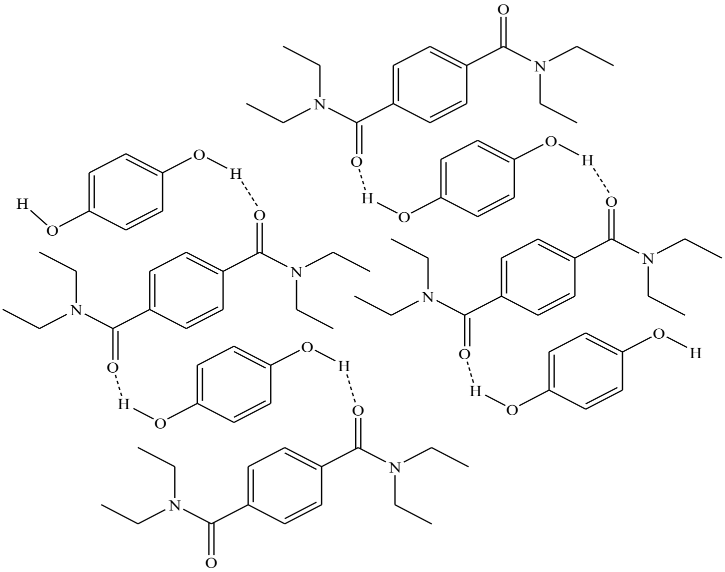


Fig.5 Hydroquinones protected by non-covalent interactions with bis-(N,N-dialkyl) terephthalamides

3 Degradation Product Design

Chemical products should be proposed in that manner so that in the end they result in to innocuous degradation products and do not remain in the atmospheret".Tetrapropylene alkylbenzene sulfonate (TPPS) was used in laundry detergent as a surfactant but due to its incomplete degradation it starts accumulating into the water supply. Then in the solution for this the branched chain of TPPS was replaced by a linear carbon chain which reduces the bio persistence (Boethling et al. 2007; Painter 1992).

3.1 Real time analysis for pollution prevention

Analytical methods should be examined in real time to control or elude the development of threatening substances (Kumar et al. 2014)". The two major issues associated with analytical methods occurred during two steps of a method: a pretreatment of sample including extraction, separation or even sometimes chemical modification of sample, and a signal acquisition step. In the pretreatment step, the greater volume of solvents used, but if use of solvents cannot be escape at extraction step, then Accelerated Solvent Extraction (ASE) or SCF extraction should be considered as alternative (Keith et al. 2007; Afonso and Crespo 2005).

3.2 Accidents prevention

Both the chemical substances and their forms inclined in chemical processes should be selected seeing the decreased risk of probable mishap such as leaks, fires and explosions, focusing at maximizing occupational and environmental safety". According to the ''Chemical accident prevention and the clean air act amendments of 1990,'' preventing accidents starts by identifying and assessing the hazards. All types of hazards such as its toxicity, physical hazards and global hazards should be mentioned in the design and process of chemical (US Environmental Protection Agency).

The UCLA tragedy, which occurred in January 2009 (Kemsley 2009), provided a new and spectacular description of these difficulties and dangers. The customary and extremely combustible butyl lithium reagent was handled incorrectly, resulting in a catastrophic consequence, involving the decease of the examination assistant. This event should serve as a potent remembrance to mainstream researchers that several synthetic compounds we use pose real dangers and should be substituted with healthy choice wherever possible to avoid mishaps (Paul and Nicolas 2010).

3.3 E-Factor Concept

The simplest solution is the best, considering this fact Shaldon has introduced fast and simple criteria for measuring the industrial impact on environment known as E-Factor or Environmental Factor. E-factor is calculated as the total weight of all waste generated through any process (in kilogram) per kilogram of a product. The lower the value of E-factor or closer to the zero is, the less waste is generated and more sustainable and greener the process will be. However, relying on its feasible applications, the value of E-factor can be calculated by including or excluding water used in the process (Sheldon 2011; Sheldon 2000; Constable et al. 2002; Manley 2008; Sheldon 2007).

E factor can be calculated as:

E-factor = R - D.P / P.O
R= rawmaterial in kg.
D.P= desiredproduct in kg.
P.O= product out in kg.
or
E-factor= waste (in kg) / product (in kg)

Therefore, the productobtainedwillbebetter if the E-factor willbelower.

The significant limitation of E-factor as measure of environmental impact of technological processes is that is neither considered environmental risk nor hazards of the generated waste. The two examples of successful approach of E-factor in pharmaceutical industry as evaluation of greenness of technological process are: synthesis of sildenafil citrate (Viagra™) (Quallich et al. 2004) and synthesis of antidepressant sertraline hydrochloride (Zoloft®) (Manley 2008; Quallich 2005).

3.4 Solvent Selection Tools and Guides

In the synthesis process of any new drug substance, solvents play a vital role because it represents at least half of the material used in synthesis (Jimenez-Gonzalez 2011). Therefore, selecting the "greenest" solvent and controlling their amount are the most widely way to reduce the environmental and occupational impact of active pharmaceutical ingredient (Capello et al. 2007). By increasing the interest in concept of Sustainable Chemistry, various industries become a part of ACS Green Chemistry Institute Pharmaceutical Roundtable (GCI-PR), created in 2005 and the Innovative Medicines Initiative (IMI)-CHEM21 public-private partnership was created in Europe in 2012. They all aim to develop sustainable biological and chemical methodologies.

Several pharmaceutical associations and institutions issued elaborated and data rich solvent selection guides for chemists to select more sustainable solvents for synthesis. Pfizer published a simple two-page document in which solvents are classified as preferred, usable and undesirable category (Alfonsi et al. 2008). Astra Zeneca's guide consists of a table of 46 solvents with ten different criteria. Each criterion is scored between 1 and 10, with a 3-color code (green, yellow and red) to encourage analysis. Similarly, Sanofi's published a solvent guide in which solvents are categorized in four classes: Recommended, Substitution advisable, Substitution requested and Banned. This ranking derives from Safety, Health and Environmental hazards, and industrial issues (Prat et al. 2013; Denis et al. 2016; Prat et al. 2013).

3.5 Role of catalysis in green chemistry & synthesis

Catalyst is a defined as substance that enhances the rate of a reaction when it is added to it without being consumed by the process. Catalysis is one of the green chemistry concepts, and catalysed reactions normally operate under softer circumstances than non-catalyzed reactions (Anastas and Warner 1998). They work by lowering the reaction's activation energy, which increases the rate at which the equilibrium is reached, making them intrinsically green. In Green chemistry, catalysis has a number of advantages, including: -

1. There is a lower need for energy.
2. Increased selectivity
3. Reduces the usage of separating and processing agents
4. Allowing for the use of less harmful ingredients.

Three significant elements influence the catalyst's commercial viability and intrinsic greenness:-

1. Selectivity
2. Turnover frequency
3. Turnover number

Types of catalysts used in green chemistry:

1. Homogenous
2. Heterogenous

3.6 Heterogeneous Catalysis

Among various heterogeneous catalysts, Pd, Pt, Ni, or Co are the most prevalent types containing an inorganic or polymeric support which may be inert or have basic or acidic functionality. The overall reaction rate is influenced by both diffusion and adsorption. They make it easy to separate products and catalysts, obviating the requirement for distillation or extraction. There are primarily two types of adsorption processes involved in it, namely, chemical and physical adsorption.

Physisorption originating from Vander waal forces of attraction between the reactant and surface. Physisorption does not show catalytic activity but may be a precursor to chemisorption.

Chemisorption is because of the chemical bond formation between the reactant and the catalyst. Bonds formed during chemisorption should be strong enough to prevent desorption yet not too strong to prevent reaction with other reactant molecules.

3.7 Homogenous catalysis

Homogeneous catalysis is a frequently utilized idea in organic synthesis that allows for a wide range of alterations by lowering activation energies. Organocatalytic reactions are metal-free by definition. However, the catalyst design can have an impact on the comprehensive surroundings of the reaction, especially given the high catalyst loadings required for organocatalytic reactions (Kokel and Schafer 2018). Examples:

- Metal-Based Catalysis
- Oxidation Reactions

One of the significant transformations in chemical synthesis is the conversion of alcohols to carbonyl compounds. Toxic metals (Pd, Ir, Ru, Mo, etc.) and hazardous solvents and/or oxidants are used in traditional catalytic reactions that conduct such oxidation. Some environmentally friendly synthetic routes have been created employing minor harmful catalysts and/or environmentally friendly solvents and oxidants. Aqueous reactions with water-soluble catalysts have a lower potential environmental impact.

Reduction of C=C and C=X Double Bonds

Hydrogenation is a crucial and atom-efficient process in chemical synthesis. The hydrogenation reaction can be carried out by a variety of catalysts. In this sector, transition metal complexes such as palladium, ruthenium, and rhodium, in conjunction with organic solvents, are commonly used. Because of their flammability, toxicity, and volatility, organic solvents should be avoided.

3.7.1 Cross-Coupling Reactions

Many chemical syntheses have been interested in the production of C-C and C-X bonds. The discovery of cross-coupling processes gave scientists a potent tool for forming these types of connections directly. A transition metal catalyst and an organometallic precursor are commonly used in these reactions. Efforts have been made for several years to produce sustainable cross-coupling reactions in order to find procedures that aren't as wasteful and energy-intensive as existing protocols.[82]

3.7.2 Cycloisomerization Reactions

Cycloisomerization is atom efficient because each and every atom from the starting material is involved in the finished product. However, depending on the reaction protocol, waste might come from a variety of places. Solvents and additives make up a significant portion of organic synthesis waste. As a result, it's critical to keep their quantity and toxicity to a minimum. Cycloisomerization allows for the creation of the carbon framework in a single step, whereas conventional transformations would require numerous steps. Exploitation of new, more environmentally friendly cycloisomerization processes is a focus of continuing study.[83]

3.7.3 Organocatalysis

3.7.3.1 Amine-Based Catalysts

In the realm of organocatalysis, amine-based organocatalysts are used in the vast majority of applications. The majority of these catalysts are made up of natural substances. Some chemicals can be utilised as catalysts in their natural state, whereas others must be derivatized first (Kokel and Schafer 2018).

3.7.3.2 N-Heterocyclic-Carbene-Based Catalysts

They have unique features that allow them to be used as ligands in metal catalysis instead of phosphines. However, stable carbenes, particularly N-heterocyclic carbenes (NHCs), are increasingly being used as organocatalysts (Enders et al., 1995).

3.7.3.3 Chiral Phosphoric Acids Catalysts

It is a different type of organocatalysts. Their activation mode generally entrusts on their Bronsted acidity. When chiral constitutents are integrated as substituents in their structures they can be valuable catalysts for carrying off enantion selective reactions (Connon 2006).[84]

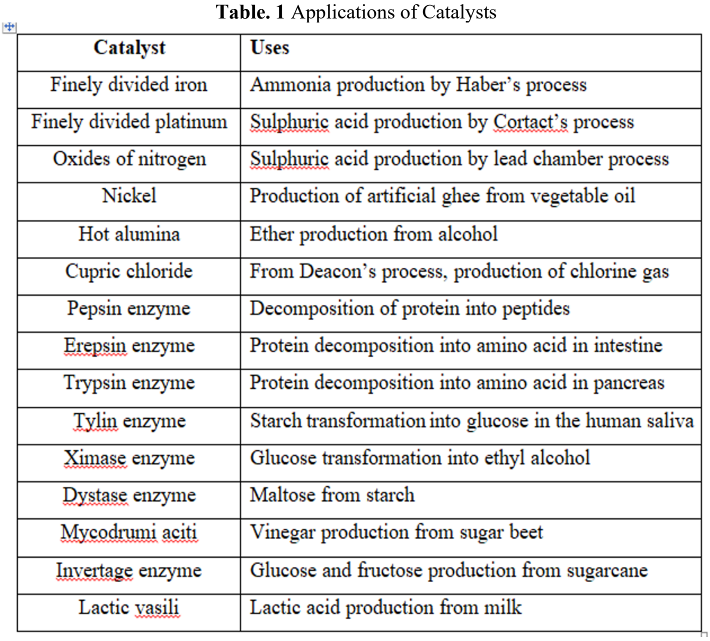
3.7.3.4 Carbohydrate-Based Catalysts

Carbohydrates and closely related molecules are abundant in nature and make up the majority of biomass generated from plants. They have many stereogenic centres that are continuous and normally only appear as one of the diastereomers. They've been used as ligand building blocks in metal-catalyzed reactions because of their features. With the rise of organocatalysis, there has been a surge in interest in using it as a direct catalyst as given in Table-1. They are appealing for application in green chemistry reactions because of their high water solubility (Kokel and Schafer 2018).[85]

4 Applications of Catalysts

Applications of catalysts are given in Table 1:

Table. 1 Applications of Catalysts



Catalyst	Uses
Finely divided iron	Ammonia production by Haber's process
Finely divided platinum	Sulphuric acid production by Cortact's process
Oxides of nitrogen	Sulphuric acid production by lead chamber process
Nickel	Production of artificial ghee from vegetable oil
Hot alumina	Ether production from alcohol
Cupric chloride	From Deacon's process, production of chlorine gas
Pepsin enzyme	Decomposition of protein into peptides
Erepsin enzyme	Protein decomposition into amino acid in intestine
Trypsin enzyme	Protein decomposition into amino acid in pancreas
Tylin enzyme	Starch transformation into glucose in the human saliva
Ximase enzyme	Glucose transformation into ethyl alcohol
Dystase enzyme	Maltose from starch
Mycodrumi aciti	Vinegar production from sugar beet
Invertage enzyme	Glucose and fructose production from sugarcane
Lactic vasili	Lactic acid production from milk

5 Efficiency of Green Chemistry in Organic Synthesis

According to the Brundtland Report, Sustainable development is defined as "Meeting the needs of the present generation without compromising the ability of future generations to meet their own needs" (Sheldon 2012). In the past two decades, the concept of sustainable Green Chemistry and their principles have the greatest impact on the synthesis processes performed in industry and laboratory. With reference to green chemistry, an ideal synthetic process having (i) lower steps involved, (ii) highly selective and (iii) include usage of inexpensive and easily available substrates (Schafer 2011). New compounds are synthesized under influence of green chemistry by modify known synthetic pathway with more environment friendly process by using green solvents, substrates and reaction conditions.[86]

Aims of Green Chemistry related to Green Synthesis

1. Displacement/ elimination of hazardous solvents and reagents
2. Reduction of the amount of waste and end-product generated at each step.
3. Use of catalysts
4. Toxic chemicals are replaced by environmentally friendly solvents such as water, ionic liquids etc.
5. Reduction of energy source during synthesis by replacing existing heating methods with alternative sources such as ultra-sonication, microwave radiation etc.

In 1990s, green organic synthesis comes with new trends relating to development of metric for considering environmental impacts of synthetic process as whole or its individual step. These metrics are also concerned with environmental impacts of certain changes of synthetic process (Constable et al. 2002). There are various metrics which are used for evaluation of greenness of organic synthesis such as Carbon Efficiency (CE), Mass Intensity (MI), Reaction Mass Efficiency (RME), Atom Utilization (AU), and Stoichiometric Factor (SF). Atom Economy is considered as the most important tool as green chemistry metric. Atom Economy parameter estimates the number of reagents that will be incorporated in final product (Banitaba et al. 2013; Loupy 2004; Patel et al. 2013):

Environmental Assessment Tool for Organic Syntheses (EATOS) is another tool developed by Eissen and Metzger for an assessment of the greenness of laboratory scale synthesis. It is a type of software used for comparison of different pathways of same product synthesis in terms of their environmental impact, utilization of resources, etc. (Eissen and Metzger 2002).

6 Conclusion

The concept of Green Chemistry answers the various environmental issues raised by growth of industrial activities. It is a type of new point of view in chemistry curriculum from the last two decades. The 12 principles are well used by various scientists to be developed new synthetic procedures that are safe for the environment and human health. Various concepts such as E factors, waste minimization and atom economy introducing clean or green chemistry in academia and industrial circle worldwide. Using various solvent selection tools and metrics for evaluation of greenness of organic synthesis companies can be environment friendly and economically profitable at the same time. Catalysis is crucial in the environmentally friendly synthesis of compounds. A conventional synthetic pathway is replaced by the environmentally friendly synthetic pathway, which can assist in limiting the number of co-products, bi-products, wastes, and pollutants. The catalyst employed in environmentally friendly synthesis minimizes the number of stages that occur in traditional synthesis. Catalysis decreases the utilization of hazardous chemicals. The amount of active energy used in the reaction is reduced by using a catalyst. Catalysts' main applications in chemical synthesis can aid in the development of environmentally friendly technology and the production of environmentally friendly compounds. In the next decades, for developing sustainable and efficient chemical industry, these green organic synthesis and technologies will be the successful approach.

7 Acknowledgments

Not Applicable

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