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Green Chemistry: Types of Catalysts

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ABSTRACT: One of the core tenets of green chemistry is catalysis. In order to create sustainable manufacturing systems, green chemistry can be applied. This review describes how the use of catalysis may be utilized to create chemical goods and procedures that lessen or completely do away with the usage and production of dangerous compounds. By decreasing the usage of dangerous chemicals, cutting waste, improving efficiency, minimizing pollution, and supporting sustainable development, green chemistry catalysts lessen their negative effects on the environment.
KEYWORDS: green chemistry, catalyst, hazardous, environment.

I. INTRODUCTION

Green chemistry and catalysis are concepts that work to reduce the negative effects that chemical processes have on the environment. A key component of green chemistry is catalysis, which promotes the efficient and waste-free completion of chemical reactions. The introduction of green chemistry and catalysis can be summarized as follows:

- Green chemistry refers to the development of chemical goods and procedures that lessen or do away with the use or production of hazardous compounds (1).
- Chemical reactions can be accelerated by catalysis with the least amount of waste and greatest efficiency (2).
- Utilizing renewable resources, reducing waste, and utilizing non-toxic catalysts are all aspects of "green" catalysis (3).
- Green catalysis includes bio-catalytic approaches as a key component since they can offer ecologically responsible and environmentally sustainable processes for chemical transformations (4).
- In order to generate more environmentally friendly chemical processes, the burgeoning discipline of eco-catalysis blends catalysis with ecological concepts (3).
- The chemical industry may benefit from green chemistry and catalysis by using less resources and energy and operating more profitably (5).

Overall, Catalysis and green chemistry are crucial for fostering environmentally friendly and waste-free chemical processes.

TYPES OF CATALYSIS

Homogeneous or heterogeneous catalysis can be chosen depending on the number of phases in the catalytic reaction that is carried out for a synthesis. While heterogeneous catalysis is a two or multi-phase catalytic reaction, homogeneous catalysis is a single phase catalytic reaction that is typically liquid/liquid. Homogeneous catalysts have a number of benefits, such as decreasing reaction temperatures and preserving energy. Less undesired and undesirable by products are produced at lower temperatures, which tend to offer more specificity. The necessity to separate the catalyst, the cost of recovering the catalyst, and the release of significant quantities of heavier transition metals into the biosphere, which have a negative influence on the environment, are some drawbacks (like diseases and toxicity). Due to the high cost of the metals used to make catalysts, any considerable loss (6). Heterogeneous catalysis involves systems in which the reactions take place in different phases. Mostly the catalyst in the solid phase, while the reactants are in the gaseous or liquid phase(7).The lifespan of heterogeneous catalysts is significantly shortened by disadvantages such hig h operating temperatures; High temperatures hinder catalysts' capacity to produce high yields,speed up deactivation, and diminish their selecti-vity. Some types of catalysts include the followings:

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SURFACE CATALYSTS

In a wide variety of chemical processes, surface catalysts are crucial. Following are some salient details from the search results:

- Atoms are provided for chemical reactions by catalyst surfaces. For instance, in a hydrogen fuel cell, hydrogen atoms from a gas are attracted to a metal surface where they participate in an electrochemical reaction to produce electricity (8).
- Sites that can interact with one another may be present on the catalyst surface. Even when both sites are present, the acid or base behaviour may prevail on some surfaces (9).
- Catalysts that are in a distinct phase from the reactants are said to be heterogeneous catalysts. For instance, the reactants could be gases or liquids and the catalyst could be a solid. These catalysts are crucial in a variety of industrial processes (10).
- Thin films and two-dimensional single- or polycrystalline bulk surfaces are examples of extended surface catalysts. These surfaces are crucial in many catalytic reactions because of their large surface area (11).
- More surface area is exposed by helping to avoid or reduce the agglomeration and sintering of tiny catalyst particles. As a result, catalysts have more specialised activity (12).
- According to Langmuir, the surface of a catalyst should be thought of as a region with a specific number of elementary spaces, some of which are active sites for the reaction (13).

BIOCATALYSTS

Biocatalysis is the process of accelerating chemical reactions by using natural materials like enzymes derived from biological sources or complete cells (14). Almost all types of organisms use enzymes, a flexible bi-ocatalyst, to control their biotransformation reactions (15). In contrast to chemical catalysts, biocatalysts are made from renewable materials, biodegradable, and work in aqueous sol vents in benign conditions (16). Biocatalysis has been used for more than 100 years to perform chemical transformations on synthetic organic compounds that are not naturally occurring, and its use in the production of fine chemicals, particularly for the pharmaceutical industry, has significantly increased (17).

The following significant features of biocatalysis are noteworthy:

- Hundreds of reactions are catalyzed by enzymes, including the creation of alcohols through fermentation and the manufacture of cheese through the breakdown of milk proteins (14).
- Under mild, regulated conditions, biocatalysts are used to selectively carry out the necessary transformations (18).
- Utilizing computational design, guided evolution, and non-canonical amino acids, scientists can optimize biocatalysts to (16).
- Definition of the qualities a biocatalyst must possess in order to successfully carry out a specific reaction under certain industrial conditions is necessary before researchers take on the challenge of developing a good industrial biocatalyst (16).

Overall, biocatalysis is a significant field with many applications in various industries, and enzymes are a flexible biocatalyst that may be used in a variety of biological systems.

ENZYME CATALYSTS

The biological molecule known as an enzyme serves as a catalyst, speeding up chemical reactions within cells. Although RNAs can also catalyze several biological events, proteins are generally responsible for catalyzing them (19).Enzyme characteristics include the following:

- Catalytic activity: Enzymes speed up chemical processes without being consumed or irreparably changed by the process. Without changing the chemical balance between reactants and products, they speed up reactions (19).
- Mechanism: In order to move closer to the transition state, substrates are brought together by enzymes and have their conformations altered. Additionally, a large number of enzymes take part directly in the catalytic process, with the precise side chains of amino acids at the active site playing a critical function (19).
- Types: There are six different categories of enzyme catalysts: ligases, hydrolases, lyases, isomerases, and oxidoreductases (20).
- Efficiency: One enzyme catalyst molecule can convert up to a million molecules of

the reactant every second, making enzyme catalysts very effective (21).

- Optimum temperature: At its ideal temperature, an enzyme catalyst performs at the highest level of efficiency. At either side of the optimal temperature, the activity of the biological catalysts decreases (21).

The same catalyst cannot be employed in more than one reaction since enzymes are specific to some types of reactions (21). The optimization of such catalytic activity is a critical feature of evolution, despite the fact that only the most important enzymes operate at or close to catalytic efficiency limits (22).

ACID-BASE CATALYSTS

Acid-base catalysis is a type of catalysis in which the addition of an acid or a base speeds up a chemical reaction without consuming the acid or bases itself (23). The Brnsted-Lowry idea of acids and bases describes the mechanism of acid- and base-catalyzed reactions as one in which there is an initial transfer of protons from an acidic catalyst to the reactant or from the reactant to a basic catalyst (24, 25). Most organic chemical reactions are catalysed by acids, and a variety of acids can serve as donors of protons in these reactions (25). Many industrial processes use acid catalysis, such as the conversion of petroleum hydrocarbons into petrol and related products (24). Many industrial processes also employ base catalysis, such as the production of polyurethane foams by diisocyanates reacting with polyfunctional alcohols (24).

Depending on the chemical species that acts as the acid or base, acid-base catalysis can be categorized as either specific or universal (25). While in general catalysis the reaction rate depends on all the current acids and bases, in specific catalysis the reaction rate is dependent on the presence of a particular acid or base (26). The most frequent reaction that enzymes carry out is proton transfer, and proton donors and acceptors, such as acids and bases, can do both in order to stabilise growing charges in the transition state (23).

Many industrial processes employ solid acid catalysts, which do not dissolve in the reaction medium (27). Several well-known examples are sulfated zirconia, zeolites, alumina, and silico-alumino-phosphate (25). A variety of techniques can be used to identify and describe acid-base sites in acid-base catalysis, including the use of Hammett's indicators, basic or acidic probes of varying strengths for adsorption measurements in microcalorimetry, and FTIR, ESR, NMR, photoluminescence, Raman, UV-Vis, and XPS (28).

ANTIBODY CATALYSTS

Antibodies with the ability to function as enzymes are referred to as antibody catalysts, catalytic antibodies, or enzymes. Proteins known as antibodies are created by the immune system in reaction to the presence of foreign agents in the body, such as viruses or bacteria. Antibodies frequently bind to particular targets, such antigens, and aid in neutralising or removing them. However, it has been shown that some antibodies have catalytic activity, which means they can quicken chemical processes.

Following are some salient details from the search results:

- There are several ways to produce catalytic antibodies, such as immunising with transition state analogues or transition state substrates (29).
- Various autoimmune illnesses have been linked to both harmful and therapeutic effects of naturally occurring catalytic antibodies (30).
- Catalytic antibodies have been applied in chemistry, biology, and medicine, among other disciplines (31).
- In 1969, it was initially proposed that an antibody that binds to the transition state might be used to catalyse a process (32).

Catalytic antibodies have just recently demonstrated limited catalytic activity, despite their potential. By designing them to employ metal ions and other cofactors, for example, researchers have been attempting to increase their catalytic activity (32).

METAL CATALYSTS

In heterogeneous catalysis, a substance known as a catalyst is added to accelerate the rate of a chemical process (33). Here are some key points from the search results:

1. Single atoms, nanoclusters, and nanoparticles of diverse metal species exhibit various catalytic behaviours for various processes (34).
2. The process of a metal catalyst becoming synterized involves the supported metal atoms migrating to create bigger metal aggregates (35).

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3. Due to their high catalytic activity, noble metal catalysts are frequently employed for the oxidation of water, such as iridium oxide (IrO_2) (36).
4. Due to their incompletely filled d-orbitals, transition metals like iron, silver, iridium, rhodium, palladium, and nickel make good catalysts (37).
5. For research and manufacture of fine chemicals involving synthetic organic chemistry, Strem Chemicals provides over 1,000 metal catalysts (38).

METAL OXIDE CATALYST

In many industrial catalytic processes, metal oxide catalysts play a significant role (39). They function both as supports for catalysts and as catalysts themselves (40). Following are some salient details from the search results:

- Type of metal oxide catalysts: Simple oxides like silica, alumina, and perovskite oxide materials are used as metal oxide catalysts (39, 41). They also consist of metal atoms spread on oxide substrates known as single-atom catalysts (42).
- Uses of metal oxide catalysts: The vast majority of industrial catalytic processes use metal oxide catalysts (39). They serve as catalysts for CO_2 conversion, selective or total oxidation, and redox processes (43, 44).
- Metal support interaction: Unique physicochemical characteristics of metal-oxide-based catalysts make them efficient for the removal of VOCs (41).For metal/oxide and oxide/metal inverse catalysts to function effectively, metal-support interactions and metal-metal interactions are crucial (40).

Metal oxide catalysts are useful and significant for a wide range of chemical processes. Researchers are looking into how to make industrial processes more sustainable by optimizing their use.

METAL COMPLEXES

A chemical compound known as a metal complex is made up of a core metal atom or ion plus multiple other atoms, ions, or molecules known as ligands (45). Ligands are molecules or ions that can exist on their own and are joined to the main metal atom or ion (45, 46). Water, ammonia, and chloride ions are examples of simple ligands, and all ligands serve as Lewis bases (46, 47). One or more additional molecules or ions surround the metal ion at the centre of a complex ion, which can be thought of as being connected to the core ion by coordinate (dative covalent) connections (46). The coordination number refers to the quantity of ligands attached to the transition metal ion (47). Virtually all metal compounds are coordination compounds, also known as metal complexes, and the study of "coordination chemistry" involves the study of "inorganic chemistry" of all transition metals, lanthanides, actinides, and metalloids as well as alkali and alkaline earth metals. A form of coordination complex known as "classical" (or "Werner Complexes") refers to ligands in which the donor atom is joined to the remainder of the molecule by a single atom. If the ligands around the metal are carefully selected, it can help with stoichiometric or catalytic transformations of molecules or be employed as a sensor. These atoms within a ligand are known as donor atoms (48). Computational approaches, such as high-throughput screening and machine learning, can be used to study metal complexes (49). In the field of homogeneous catalysis, luminescent first-row transition metal complexes have recently attracted attention (50).

ZEOLITES

Commercial adsorbents and catalysts frequently use the crystalline, microporous aluminosilicate substance known as zeolites (51). They have the general formula Mn+ and are made up of silicon, aluminium, and oxygen. Zeolites are interconnected tetrahedra of alumina (AlO_4) and silica (SiO_4), which are hydrated aluminosilicate minerals. Water molecules trapped between them and alkali or alkaline-Earth metals like sodium, potassium, and magnesium are what cause them to form. There are roughly 40 zeolites that form in volcanic and sedimentary rocks naturally (52). Zeolites are white solids that are produced industrially on a big scale and have common handling characteristics, like many common aluminosilicate minerals (51). Many different applications use zeolites, including petrochemical cracking, water softening, filtration, separation and removal of gases and solvents, agriculture, animal husbandry, and construction (53). Zeolites are advertised as dietary supplements for autism, diarrhoea, herpes, hangovers, to balance pH and eliminate heavy metals; however they have not been proven to treat cancer or other illnesses in people (54).

BIOMIMETIC CATALYST

Biomimetic catalysts are novel, highly effective, and selective catalysts that closely resemble several essential characteristics of

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enzymes (55, 56). They are employed in chemical catalysis to put together beneficial chemicals and materials to enhance human life (57). Organometallic catalysts, such as metalloporphyrins, which imitate cytochrome, can be used to create biomimetic catalysts (58). Due to the chemical structure of maleic acid being similar to the active site, it can also be used to make them for the pretreatment of lignocelluloses (59). Many types of aerobic life depend on non-heme iron-containing metalloproteins because they bind and transport oxygen (60).

PHASE TRANSFER CATALYSTS

A type of catalyst called a phase-transfer catalyst (PTC) is used in chemistry to speed up the transition of a reactant from one phase into the phase where the reaction takes place (61,62,63). A unique type of catalysis called phase-transfer catalysis can operate using either homogeneous or heterogeneous catalysis techniques. Due to the fact that they permit the use of water and decrease the requirement for organic solvents, PTCs are particularly helpful in green chemistry. A second phase that comprises both reactants is entered by one or more of the reactants (62). PTCs transfer anions of inorganic salts into organic solvents and release them back into the aqueous phase. They are soluble in both solvents (64).

PTCs are not only applicable in systems with hydrophilic and hydrophobic reactants, but also in liquid/solid and liquid/gas processes. Quaternary ammonium salts like benzyl triethyl ammonium chloride, methyl tricapryl ammonium chloride, and methyl tributyl ammonium chloride are frequently used to catalyze anionic reactants. As PTCs, organic phosphonium salts are also employed (62).

Although the PTC's mechanism is still not entirely understood, it is thought that it crosses the phase boundary by forming a complex with one of the reactants (65). PTCs are a potential approach for the synthesis of organic molecules and are employed in a range of organic synthesis procedures (63,66).

ALUMINIUM PHOSPHATE BASED MOLECULAR SIEVES

"ALPOs," also referred to as aluminium phosphate molecular sieves, are a class of molecular sieve that contain framework architectures with tiny cavities (67). They are made of alternating phosphorus tetrahedra and aluminium polyhedra joined by oxygen atoms. These molecular sieves can be used as catalysts, ion-exchangers, and molecular sieves, among other things. They share structural similarities with zeolites and have a wide range of uses, such as adsorbents in the petrochemical sector and the manufacturing of fine chemicals (68).

Aluminium phosphate molecular sieves come in a variety of forms, such as MAPO-5 and AlPO4-34 (69,70). Several techniques are used to create these molecular sieves, including the use of silicon sources, phosphorus sources, and organic formwork agents (71). Recently, scientists have been investigating other kinds of aluminium phosphate molecular sieves, like the 2-dimensional layered SYSU-6 (72).

AUTOCATALYSTS

To reduce hazardous emissions, auto catalysts are a type of catalyst used in car catalytic converters. Following are some salient details from the search results:

- A ceramic or metal cylinder or elliptical cross section that has been shaped into a fine honeycomb and covered with a chemical solution and a mixture of platinum, rhodium, and/or palladium is known as an auto catalyst (73).
- In a chemical reaction known as autocatalysis, one of the byproducts also serves as a catalyst for a related or connected reaction (74).
- Autocatalytic reactions help to convert reactant to product by acting as a catalyst and using the product of the reaction as a catalyst (75).
- Ecological cycles' inherent mutual benefit are referred to as "autocatalytic" in ecology, where it is a concept (76).
- In an autocatalytic reaction, the process's byproducts speed up the rate at which they are produced. Auto catalysts are these goods (77).

Auto catalysts are employed in the context of vehicle catalytic converters to change dangerous pollutants in exhaust gases into less dangerous ones. In order to accelerate the chemical reactions that transform pollutants into less dangerous molecules, the auto catalyst is coated with a chemical solution and a combination of platinum, rhodium, and/or palladium (73).

II. CONCLUSION

Green catalysts, which often entail the use, recovery, and reprocessing of enzymes as biocatalysts, are recognized for their effectiveness in chemical transformations. A key component of green chemistry is catalysis, which may increase the effectiveness of chemical reactions and lessen the need for hazardous stoichiometric procedures. Utilizing enzymes and switching from stoichiometric processes to more effective and ecologically friendly reactions are key components of green catalysts and green catalysis. Green chemistry aims to develop chemical products and procedures that lessen or do away with the usage or production of dangerous materials and stop molecular pollution.

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