RNI No. RAJHIN/2007/26996
ISSN 0976-7452 Raaso
Refreed Journal

रासो

अन्तर्विषयी त्रैमासिक शोध पत्रिका

वर्ष-18, अंक-2, मार्च अप्रैल मई 2025

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त्रैमासिक शोध पत्रिका
2005
॥ स्वस्ति पन्थामनु चरेम ॥

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Refreed Journal

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इतिहास, संस्कृति, साहित्य एवं दर्शन की त्रैमासिक शोध पत्रिका

वर्ष-18 अंक - 2 मार्च-अप्रैल-मई-2025

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सृजन संस्थान,
आचमन, वेद विहार,
लोहाखान, अजमेर-06
दूरभाष : 0145-2426610
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पुष्पा शर्मा
सृजन संस्थान,
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सहयोग दर

* वार्षिक सदस्यता - 500 रु. (चार अंक) संस्थाओं हेतु - 600 रु. (चार अंक)
कृपया चैक/ड्राफ्ट/मनीऑर्डर श्रीमती पुष्पा शर्मा, प्रकाशक, आचमन पब्लिकेशन्स, अजमेर- 305006 के नाम भेजें।

प्रकाशक-श्रीमती पुष्पा शर्मा, 51/1509, वेद विहार, लोहाखान, अजमेर द्वारा मैसर्स सृजन संस्थान, अजमेर की ओर से प्रकाशित एवं मुद्रक-श्रीमती उषा गर्ग द्वारा मैसर्स आर्य प्रिन्टर्स, केसरगंज, अजमेर से मुद्रित।

INDUSTRIAL APPLICATIONS OF CHEMICAL CATALYSTS

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Abstract

Chemical catalysts are the backbone of modern industrial chemistry. They accelerate reaction rates, lower activation energies, and make large-scale chemical manufacturing economically viable and environmentally sustainable. This article explores the concept of catalysis, its types, mechanisms, and the extensive industrial applications across sectors such as petroleum refining, pharmaceuticals, fertilizers, polymers, and environmental protection. The paper also highlights the growing significance of green and heterogeneous catalysts in promoting sustainable industrial development. The future prospects of catalytic technologies, including nanocatalysts and enzyme-based biocatalysts, are also discussed in this Article.

KEYWORD - Catalyst, Industrial Application, Sustainable Development, Nanocatalyst, Enzyme Based Biocatalyst.

Introduction

The rate of chemical reaction may bechanged by presence of small amount of a foreign materi: a reaction. The foreign material remains unchanged at the end of the chemical reaction is known as catalyst. Greek -Keta wholly and lein means process. The catalysis was first introduced by JONS JACOB BERZELIUS IN 1835.

Catalysts are substances that alter the rate of a chemical reaction without being consumed in the process. They enable chemical transformations to occur more efficiently by providing alternative pathways with lower activation energy. Nearly 90% of all chemical manufacturing processes involve catalytic steps, making catalysis one of the most critical pillars of the global chemical industry.

Catalysts are classified broadly into homogeneous (same phase as reactants) and heterogeneous (different phase than reactants). A third category, biocatalysts, involves enzymes derived from living organisms. Each category has its unique advantages, mechanisms, and industrial relevance.

Definition: Any substance which alters the rate chemical reaction and remains unaffec. chemically during that reaction is known catalyst and the phenomenon as catalysis.

Principles of Catalysis

Catalysts function by offering an alternative reaction route with a reduced activation energy barrier.The general mechanism involves theformation of a catalyst-substrate complex, which facilitates bond rearrangements and product formation. The efficiency of a catalyst is measured by:

1 Turnover frequency (TOF) - the number of reactant molecules converted per catalytic site per unit time.

2 Selectivity - the ability to direct the reaction toward a desired product.

3 Stability - resistance to deactivation during repeated use.

Industrial catalysis aims to maximize these parameters while minimizing cost and environmental impact.

Role of catalyst

1. It Initiate the reaction
2. Specific path of reaction
3. To avoids the side products of the reactons

Types of Catalysts Used in Industry

1. Homogeneous Catalysts

Homogeneous catalysts exist in the same phase as the reactants, usually in liquid form. They offer excellent selectivity and are easy to study mechanistically. Examples include:

* Acid-base catalysts such as sulfuric acid in esterification.

* Transition-metal complexes like Wilkinson's catalyst (RhCI (PPh?) ?) used in hydrogenation reactions.

Their limitation lies in the difficulty of separating and recycling the catalyst after the reaction.

2.Heterogeneous Catalysts

These catalysts operate in a different phase, typically solid catalysts interacting with gaseous or liquid reactants. They dominate industrial catalysis due to easy separation and robustness. Common examples include:

Nickel, platinum, or palladium on solid supports for hydrogenation.Vanadium pentoxide (V_2O_5) used in the oxidation of SO? to SO_3 in the Contact Process.

Auto catalyst

In certain reactions, it is observed that one of the pro formed during the reaction acts as a catalyst for that react. Such type of catalyst is called auto catalyst and the phenomenon is known as auto catalysis.

In the oxidation of oxalic acid by potassium permanganate, one of the products $MnSO_4$ acts as a auto-catalyst because it increases the speed of the Reaction

$$5\begin{array}{c}COOH\\ |\\ COOH\end{array} + 2KMnO_4 + 3H_2SO_4 \rightarrow 2MnSO_4 + K_2SO_4 + 10CO_2 + 8H_2O$$

Induced Catalyst

When one reactant influences the rate of o ? reaction, which does not occur under ordina., conditions, the phenomenon is known as induced catalysis.

Sodium arsenite solution is not oxidised by air. If, however, air is passed through a mixture of the solution of sodium arsenite and sodium sulphite, both of them undergo simultaneous oxidation. When one reactant influences the rate of o reaction, which does not occur under ordina., conditions, the phenomenon is known as induced catalyst.

Promoters

The activity of a catalyst can be increased by addi of a small quantity of a second material. A substance which, though itself not a catalyst, promotes the activity of a catalyst is called a promoter. Some examples of the promoters are given below.

• In the Haber's process for the synthesis of ammonia, traces of molybdenum increase the activity of finely divided iron which acts as a catalyst.

$$N_2 + 3H_2 \underset{+MO}{\overset{Fe}{\rightleftharpoons}} 2NH_3$$

Catalytic Poisons A substance which destroys the activity of catalyst is called a poison and the process iscalled catalytic poisoning. Some of the examples are

• The platinum catalyst used in the oxidation of SO_2 in contact process is poisoned byarsenious oxide.

Induced Catalysis: When one reaction influences theof other reaction, which does not occur under or conditions, the phenomenon is known as induced catalysis. Some examples are as follows:

(i) Sodium arsenite solution is not oxidised by however, air is passed through a mixture of the solution of sodium arsenite and sodium sulphite, both of them undergo simultaneous oxidation. The oxidation of sodium sulphite, thus, induces the oxidation of sodium arsenite.

(ii) The reduction of mercuric chloride with oxalic acid is very slow, but potassium permanganate is reduced readily with oxalic acid. If, however, oxalic acid is added to a mixture of potassium permanganate and both are reduced simultaneously. The reduction of potassium permanganate, thus, induces the reduction of mercuric chloride

Biocatalysts

Enzymes serve as highly specific catalysts for biochemical reactions. They operate under mild conditions, making them ideal for green chemistry applications such as pharmaceutical synthesis, food processing, and biofuel production.

Photocatalysts and Electrocatalysts

With growing emphasis on renewable energy, photocatalysts (like TiO?) and electrocatalysts (such as platinum for fuel cells) have become vital for processes like water splitting, CO? reduction, and hydrogen production.

Industrial Applications

1. Petroleum Refining

Catalysis plays a central role in the petroleum industry. Major catalytic processes include:

• **Catalytic cracking:** Converts heavy hydrocarbons into gasoline and diesel using zeolite catalysts.

• **Hydrocracking and hydrotreating:** Employ metal catalysts (Ni, Mo, Pt) to remove sulfur and improve fuel quality.

• **Reforming:** Platinum-based catalysts convert naphthenes to aromatic compounds for high-octane fuels.

These catalytic operations ensure the efficient conversion of crude oil into valuable fuel products while meeting environmental standards.

2 Ammonia and Fertilizer Industry

The Haber-Bosch process is one of the most significant industrial catalytic processes ever developed. It synthesizes ammonia (NH_3) from nitrogen and hydrogen using an ironnitrogen and hydrogen using an iron catalyst at high temperature and pressure.

Mechanisms of Catalyst Deactivation

Industrial catalysts often face deactivation due to:

(1) Poisoning - binding of impurities like sulfur or lead to active sites.

(2) Sintering - agglomeration of catalyst particles at high temperatures.

(3) Fouling - deposition of carbonaceous materials (coke) blocking active sites.

(4) Leaching - dissolution or loss of active metal species.

Economic and Environmental Impact

Catalysts contribute massively to industrial efficiency:

They lower energy consumption by reducing reaction temperatures.

Increase product selectivity, minimizing by-products and waste. Enable continuous processes that enhance productivity.

According to the International Energy Agency, catalytic processes account for over one-third of the world's GDP linked to chemical manufacturing. In addition, catalytic innovations support the transition toward carbon- neutral technologies such as hydrogen fuel cells and CO_2 utilization

Future Trends in Industrial Catalysis

Nanocatalysts - offering higher surface area and reactivity for efficient energy and chemical conversion.

Biocatalysis and Enzyme Engineering - enabling eco-friendly production under mild conditions.

Artificial Intelligence in Catalysis Design using computational modeling to predict catalytic performance.

Photocatalysis for Solar Fuel Production - converting sunlight directly into chemical energy.

Circular Catalysis - integrating catalyst recycling and life-cycle optimization into industrial practice.

These advancements will reshape the industrial landscape by enhancing efficiency and reducing the environmental footprint.

Industrial applications of Catalysts

The applications of catalysis are summarised as follows.

(i) Haber's process for the manufacture of ammonia.

(ii) Ostwald's process for the manufacture of nitric acid.

Lead chamber process for the manufacture of sulphuric acid.

(iv) Contact process for the manufacture of sulphuric acid.

(v) Deacon's process for the manufacture of chlorine.

(vi) Bosch's process for the manufacture of hydrogen.

Conclusion

Catalysts are the invisible drivers of industrial chemistry, transforming raw materials into essential products that sustain modern life. From fuels and fertilizers to plastics and pharmaceuticals, nearly every sector depends on catalytic technology.

With growing emphasis on green chemistry, catalysis is evolving toward sustainability through the development of nanostructured, enzyme-based, and recyclable catalysts. The future of industrial chemistry lies in the intelligent design and application of these catalysts, ensuring a balance between progress and planetary well-being.

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