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

रासो

अन्तर्विषयी त्रैमासिक शोध पत्रिका

वर्ष-16, अंक-3, जून जुलाई अगस्त 2023

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

रासो

इतिहास, संस्कृति, साहित्य एवं दर्शन की त्रैमासिक शोध पत्रिका

वर्ष-16 अंक - 3 जून-जुलाई-अगस्त-2023

☆ सम्पादकीय/सचिव
व्यवस्थापकीय कार्यालय
सृजन संस्थान,
आचमन, वेद विहार,
लोहाखान, अजमेर-06
दूरभाष : 0145-2426610
e-mail : rasoajmjournal@gmail.com

☆ प्रकाशक :
पुष्पा शर्मा
सृजन संस्थान,
द्वारा आचमन पब्लिकेशन्स,
अजमेर

☆ मुद्रक :
मैसर्स आर्य प्रिन्टर्स,
केसरगंज, अजमेर

☆ कम्प्यूटराइज्ड सेटिंग :
श्रीनिवास प्रिन्टोग्राफिक्स
132, पंचवटी कॉलोनी,
अजमेर दूरभाष : 0145-2442701

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।

Air Pollution Control Using Photocatalysis: A Chemistry-Based Sustainable Solution

Kripa Sharma
Asstt. Professor (Department of Science & Technology)
Hukumchand Noble Institute of Science & Technology, Ajmer

1. Introduction

Air pollution remains one of the most critical global environmental problems, driven mainly by industrialization, fossil fuel combustion, urban traffic, and rapid population growth. Pollutants such as nitrogen oxides (NOx), sulfur dioxide (SO?), volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM), and ozone (03) severely impact human health, climate, and ecosystems. Conventional air purification technologies-including adsorption, filtration, thermal oxidation, and chemical scrubbing -often suffer from high energy demand, secondary pollution, and limited long-term efficiency.

Photocatalysis has emerged as a revolutionary green technology for removing air pollutants efficiently and sustainably. It relies on semiconductor materials activated by light to drive chemical reactions that degrade harmful pollutants into harmless products like CO2, H2O, and inorganic salts. Among various photocatalysts, titanium dioxide (TiO?) is the most widely used due to its stability, low toxicity, strong oxidizing power, and affordability.

This article explains the chemistry behind photocatalysis, the mechanisms involved in pollutant degradation, major applications, recent advancements, challenges, and future prospects-with references to recent scientific research.

2. Principles of Photocatalysis

Photocatalysis is a light-driven redox process utilizing semiconductor materials. When a semiconductor photocatalyst absorbs light equal to or greater than its band-gap energy, electrons are excited from the valence band to the conduction band, leaving behind holes.

2.1 Mechanism of Photocatalytic Reaction

Charge Separation:

Electrons (e-) and holes (h+) migrate to the catalyst surface.

Redox Reactions:

Holes oxidize water or hydroxide ions to generate hydroxyl radicals (OH).

शोध-पत्र में उल्लिखित सन्दर्भ एवं विचारों के लिए लेखक स्वयं उत्तरदायी है, सम्पादक नहीं।

Electrons react with oxygen to produce superoxide radicals (02-).

Pollutant Degradation:

These strong radicals convert pollutants into harmless products Hydroxyl radicals have extremely high oxidation potential (2.8 V), enabling photocatalysis to degrade even resistant pollutants at room temperature.

3. Photocatalysts Used for Air Pollution Control

3.1 Titanium Dioxide (TiO_2)

The most widely used photocatalyst. Advantages include:

high photostability, low cost, non-toxicity, strong oxidizing ability

However, TiO? absorbs only UV light (< 387 nm), which limits its efficiency under natural sunlight.

3.2 Zinc Oxide (ZnO)

Offers high electron mobility and strong photocatalytic activity but suffers from photochemical instability.

3.3 Tungsten Trioxide (WO_3)

Effective under visible light; often used for NOx removal.

3.4 Modified Photocatalysts

Recent studies focus on modifying catalysts to overcome limitations.

Popular modifications include: Doping (metal and non-metal dopants like N, C, Fe, Ag) Improves visible-light absorption and electron-hole separation. Composite Photocatalysts Examples: TiO2-graphene, TiO2-ZnO Provide synergistic effects.

Plasmonic Photocatalysts Use nanoparticles like Ag, Au to enhance light absorption.

Carbon-based Catalysts (Graphitic carbon nitride g-C3N4) Metal-free, visible-light responsive, and eco-friendly.

4. Air Pollutants Treated Using Photocatalysis

4.1 Removal of Nitrogen Oxides(NOx)

NOx gases from vehicles and industries contribute to acid rain, smog, and respiratory diseases. Photocatalytic oxidation converts NO and NO_2 into nitrates (NO^{3-}) which can be washed away by rain.

4.2 Degradation of Volatile Organic Compounds (VOCs)

VOCs like benzene, toluene, and formaldehyde are emitted from paints, fuels, and industrial activities. Photocatalysis breaks them into CO_2 and H_2O, preventing toxic by-products.

4.3 Treatment of Carbon Monoxide (CO)

CO oxidation by photocatalysis converts it into CO_2. Doped catalysts like Pt-TiO? show high efficiency even at low light.

4.4 Oxidation of Ozone (03)

Photocatalysts speed up ozone

4.5 Particulate Matter (PM) Control. Although photocatalysis does not directly destroy PM, it captures PM onto catalyst-coated surfaces breaks down organic components, reducing toxicity

5. Photocatalytic Technologies for Air Purification

5.1 Photocatalytic Coatings on Buildings

TiO_2-coated surfaces (walls, tiles, roofs) degrade NOx and VOCs in urban air.

Examples include self-cleaning buildings like:

The Millennium Tower (Japan)

The Jubilee Church (Italy)

5.2 Photocatalytic Pavements and Roads

NOx removal from traffic areas using TiO?-based pavements has shown reductions of up to 40% in some fieldtests.

5.3 Indoor Air Purifiers

Photocatalytic oxidation (PCO) units integrate UV lamps with TiO2-coated filters to remove VOCs and microorganisms.

5.4 Photocatalytic Paints

Commercially available paints containing nano-TiO? are used for both indoor and outdoor air purification.

5.5 Solar Photocatalytic Reactors

Used in remote or rural areas to degrade harmful gases using sunlight.

6. Recent Developments and Research Advances

6.1 Visible-Light Active Photocatalysts

To improve solar efficiency, researchers focus on materials that absorb visible light.

N-doped TiO2

g-C3N4-based composites

Ag-ZnO hybrids

6.2 Photocatalyst Nanostructuring

Nanoparticles, nanotubes, nanosheets, and quantum dots provide higher surface area and reactive sites, improving activity.

6.3 Hybrid Systems

Combination technologies like:

Photocatalysis + Adsorption

Photocatalysis + Plasma

Photocatalysis + Filtration

These enhance pollutant capture and degradation efficiency.

6.4 Self-Cleaning and Anti-Bacterial Applications

Beyond pollution control, photocatalysts prevent microbial growth and keep surfaces clean, reducing maintenance costs.

7. Advantages of Photocatalysis for Air Pollution Control

Operates at room temperature, no external heating needed Uses renewable sunlight for activation Produces no harmful byproducts Low energy consumption Long-lasting photocatalyst materials Wide applicability indoors and outdoors. Environmentally friendly compared to thermal or chemical oxidation

8. Limitations and Challenges

Despite many strengths, photocatalysis faces challenges:

Low efficiency under weak sunlight

Fast recombination of electron-hol pairs

Formation of nitrates that require removal

Limited photocatalyst lifetime due to surface poisoning

High cost of modified or doped catalysts

Large-scale field performance varies with weather and pollution load

Researchers are actively working on next-generation photocatalysts that address these limitations.

9. Future Prospects

The future of photocatalytic air purification is promising, with emerging directions such as:

Smart photocatalytic coatings that dynamically adjust to light intensity. Artificial intelligence-optimized photocatalytic reactors for maximum pollutant degradation. Large-scale urban integration (buildings, roads, public transport systems). Hybrid solar-activated air purification units for sustainable air quality improvement.

Green catalyst synthesis using plant extracts, biopolymers, and waste materials.

As research advances, photocatalysis has the potential to play a major role in global clean-air strategies.

10. Conclusion

Photocatalysis represents a powerful and environmentally sustainable technology for air pollution control. Utilizing semiconductor catalysts that convert harmful pollutants into harmless products under light, it offers a modern approach to improving both outdoor and indoor air quality. Although challenges remain-especially regarding efficiency under visible light and real-world scalability-ongoing innovations in catalyst design, nanotechnology, and hybrid systems continue to enhance performance With widening applications in buildings, transportation, and airpurification systems, photocatalysis stands out as a key green chemistry solution aligning with global efforts toward clean and sustainable environments.

References

1. *Fujishima, A., Zhang, X., & Tryk, D. A. (2008). TiO? Photocatalysis and Related Surface Phenomena. Surface Science Reports, 63(12), 515-582.*
2. *Schneider, J., et al. (2014). Understanding TiO? Photocatalysis: Mechanisms and Materials. Chemical Reviews, 114(19), 9919-9986.*
3. *Ao, C. H., & Lee, S. C. (2005). Indoor VOC Removal by Photocatalysis. Building and Environment, 40(5), 657-664.*
4. *Chen, X., & Mao, S. S. (2007). Titanium Dioxide Nanomaterials: Synthesis and Applications. Chemical Reviews, 107(7), 2891-2959.*
5. *Li, X., et al. (2020). Recent Advances in Visible-Light Photocatalysts. Applied Catalysis B: Environmental, 260, 118-201.*
6. *Yang, H., et al. (2021). Photocatalytic NOx Removal in Urban Environments. Environmental Science & Technology, 55, 1452-1463.*