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Review

A review on photocatalysis for air treatment: From catalyst development to reactor design

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HIGHLIGHTS

- A state of art review of photocatalysis for air purification.
- Provides an in-depth analysis of photocatalyst development.
- Discusses various aspects of photoreactor modelling.
- Presents an overview of possible intensification pathways.

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ABSTRACT

Photocatalysis has been extensively investigated for several decades, motivated by the fascinating applications in pollution remediation, chemical synthesis, and energy innovation. However, the practical/commercial/industrial applications of photocatalysis have been restricted in the field of building materials. The low quantum efficiency in solar energy conversion and limitation of low level of pollutants in photodegradation are very difficult to solve. Air purification by photocatalytic oxidation (PCO) of various pollutants, for example volatile organic compounds (VOCs) or inorganic gaseous (NO_x, SO_x, CO, H_2S and ozone, etc) at reasonably low concentrations, appears to be more feasible for commercialization. This review firstly introduces the removal mechanism of these contaminations by PCO, and then provides detailed survey and discussion on both photocatalysts and reactor design. This paper aims to deliver fundamental and comprehensive information for paving the venue of gas-phase photodegradation to commercialized air purification.

Contents

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Nomenclature

C_i	molar concentration of species i (mol L^{-1})
$e^{a,s}$	local superficial rate of photon absorption (Einstein s^{-1} m^{-2} or moles of photons s^{-1} m^{-2})
E	incident intensity at any point from all the directions (W m^{-2} or Einstein s^{-1} m^{-2} or moles of photons s^{-1} m^{-2})
g	gravitational constant (m s^{-2})
h	axial coordinate of an element on lamp (m)
I	intensity (Wm^{-2} sr^{-1} or Einstein s^{-1} m^{-2} sr^{-1} or moles of photons s^{-1} m^{-2} sr^{-1})
J_i	diffusion flux of species i (kg m^{-2} s^{-1})
k	apparent rate constant (m s^{-1})
K	Langmuir adsorption equilibrium constant (mol m^{-2} s^{-1})
L	half length of lamp (m)
$p(\Omega' \rightarrow \Omega)$	phase function for in scattering of radiation
P	pressure (N m^{-2})
r	radial direction (m)
r_i	reaction rate of destruction for species i (kg m^{-3} s^{-1})
R	lamp radius (m)
s, z	distance (m)
S_M	momentum sink (kg m^{-2} s^{-2})
v	velocity vector (m s^{-1})

Greek letters

θ	angular coordinate
κ	absorption coefficient (m^{-1})
λ	wavelength (nm)
ρ	density (kg m^{-3})
σ	scattering coefficient (m^{-1})
$\boldsymbol{\tau}$	viscous stress tensor (hydrodynamics modelling, N m^{-2})
ϕ	angular coordinate of an element of lamp (lamp emission model)/monolith photon absorption efficiency
η	radius of lamp-element in volume source model (lamp emission model, m)/factor giving the uniformity of irradiation of the front surface a monolith
Ω	solid angle (steradian)
Φ	quantum yield (mol Einstein^{-1} or mol mol of photons^{-1})/photonic efficiency
φ	angle between normal to point of emission and radiation direction (lamp emission model)

Subscripts

P	pollutant
S	catalyst surface
w	water
λ	wavelength dependent

Other symbols

$\langle\ \rangle$	denotes volumetric of wavelength averaged values

1. Introduction

The discovery of photocatalysis in 1972 on hydrogen production by water splitting attracted immediate research interests owing to the following two energy crises, 1973 oil crisis and 1979 energy crisis. In the study carried out by Fujishima and Honda [1], a semiconductor of TiO_2 electrode was used to facilitate hydrogen evolution under irradiations. Once semiconductor particles are employed, provided the different sites of one particle can perform as anodes and cathodes, a myriad of photoelectrochemical cells are then produced [2]. The scope of photocatalysis, based on semiconductor mechanism, was then greatly broadened, with a variety of practical implications, such as photooxidation/photodegradation [3], photocatalytic CO_2 reduction [4], photocatalytic synthesis [5], photocatalytic gas-phase oxidation [6], photocatalytic removal of heavy metals [7], and photoinduced self-cleaning [8].

The extensive experimental and theoretical progresses in photocatalysis had enabled a number of excellent reviews, which paved the fundamentals of photocatalysis varying from activated surface, charge production, surface reactions to applications [9–12]. In earlier studies, most photocatalytic reactions were conducted on wide-band semiconductors, such as TiO_2 and ZnO. The restrictions of photocatalysis were believed to be both thermodynamic and kinetic limitations as a whole. The nature of