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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/com mercial/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, H₂S 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.

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Nomenclature

C_i	molar concentration of species i (mol L ⁻¹)	Greek let	tters
$e^{a,s}$	local superficial rate of photon absorption	θ	angular coordinate
	(Einstein $s^{-1} m^{-2}$ or moles of photons $s^{-1} m^{-2}$)	κ	absorption coefficient (m ⁻¹)
Ε	incident intensity at any point from all the directions	λ	wavelength (nm)
	$(W m^{-2} \text{ or Einstein s}^{-1} m^{-2} \text{ or moles of photons})$	ρ	density (kg m ^{-3})
	$s^{-1} m^{-2}$)	σ	scattering coefficient (m^{-1})
g	gravitational constant (m s ^{-2})	τ	viscous stress tensor (hydrodynamics modelling,
ĥ	axial coordinate of an element on lamp (m)		$N m^{-2}$)
Ι	intensity (Wm $^{-2}$ sr $^{-1}$ or Einstein s $^{-1}$ m $^{-2}$ sr $^{-1}$ or moles	ϕ	angular coordinate of an element of lamp (lamp emis-
	of photons $s^{-1} m^{-2} sr^{-1}$)		sion model)/monolith photon absorption efficiency
Ji	diffusion flux of species i (kg m ⁻² s ⁻¹)	η	radius of lamp-element in volume source model (lamp
k	apparent rate constant (m s^{-1})		emission model, m)/factor giving the uniformity of irra-
Κ	Langmuir adsorption equilibrium constant		diation of the front surface a monolith
	$(\text{mol } \text{m}^{-2} \text{ s}^{-1})$	Ω	solid angle (steradian)
L	half length of lamp (m)	Φ	quantum yield (mol Einstein ⁻¹ or mol mol of pho-
$p(\Omega' ightarrow g)$	Ω) phase function for in scattering of radiation		tons ⁻¹)/photonic efficiency
Р	pressure (N m $^{-2}$)	φ	angle between normal to point of emission and radia-
r	radial direction (m)		tion direction (lamp emission model)
r_i	reaction rate of destruction for species <i>i</i> (kg m ⁻³ s ⁻¹)	Subscrip	ts
R	lamp radius (m)	Р	pollutant
S, Z	distance (m)	S	catalyst surface
S _M	momentum sink (kg m ⁻² s ⁻²)	w	water
v	velocity vector (m s ^{-1})	λ	wavelength dependent
		Other sy	mbols
		$\langle \rangle$	denotes volumetric of wavelength averaged values

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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 TiO₂ 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/photode gradation [3], photocatalytic CO₂ 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

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