Supplementary Information (SI) for RSC Sustainability.

Supplementary Information

for

Polyaniline-based ternary composites for the photocatalytic degradation of organic pollutants in wastewater: Multifunctional properties, synthetic routes, and mechanistic insights

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Table S1 Conduction band (CB), valence band (VB), and energy band gap (E_g) of photocatalysts.

Photocatalyst	**CB (eV)**	**VB (eV)**	**E_g (eV)**
PANI[1]	-1.9	0.8	2.7
gC_3N_4[2]	-1.1	1.6	2.7
GaP[3]	-0.97	1.23	2.2
CdSe[3]	-0.54	1.16	1.7
SiC[3]	-0.46	2.34	2.8
TiO_2[3]	-0.25	2.95	3.2
$FeTiO_3$[3]	0.1	2.9	2.8
ZnO[3]	0.15	3.35	3.2
BiOCl[4]	0.22	3.47	3.25
BiOBr[4]	0.3	3.06	2.76
WO_3[3]	0.71	3.41	2.7
Fe_2O_3[3]	0.73	2.93	2.2
CdO[3]	0.74	2.94	2.2

Table S2 Treatment performance of various photocatalysts for the degradation of dyes.

Dyes											
Contaminant	**Composite**	**Synthesis method**	**C_0**	**Dose**	**pH**	**Time (min)**	**Light source**	**Efficiency (%)**	**K (min^{-1})**	**TOC (%)**	**Reusability**
	PANI@ Er-doped ZnO (PEZ)[5]	Ultrasonic-assisted wet impregnation method	10 mg/L	0.2 g/L	7	90	UV light	89%	0.01753	-	
	PS/PANI/CeO_2 Core-shell[6]	In-situ crystallization			-	480 min		91.1%	0.33×10^{-3}		-
	Chitosan grafted PANI/Cobalt tetraoxide (Co_3O_4) nanocube nanocomposites[7]	Oxidative-radical copolymerisation		0.3 g/L	-	180 min		88%	-	-	3
	Ag/ZnO-ZnS/PANI[8]	In-situ oxidative polymerization		0.05 g/L	6	90 min		95%	0.0295	-	5
	ZnO-ZnS/PANI[8]	Simple coprecipitation method followed by in-situ oxidative polymerization		0.1 g/L				86%	0.0182	-	-
	NiO@PANI/RGO[9]	Microemulsion solvothermal process	30 mL of 10^{-5} M	8 mg	-	11 min	sunlight	98%	0.086	-	10
	PANI–Fe_3O_4@ZnO core–shell microspheres[10]	Pickering emulsion route	10 mg/L	2/3 g/L	-	40 min	Visible light	90.9%	-	-	7

	La/Cd/PANI BNC[11]	Reverse micelles micro-emulsion technique	1.5×10^{-5} M	100 mg/L	-	300 min	Solar light	92.14%	-	-	
	Carbon nitride/polyaniline/ZnO[12]	In-situ polymerization and solvent evaporation induced assembly (EIA) process	60 µL of 0.2% solution	0.5 g/L	-	80 min	Visible light	90%	0.026	-	5
	PANI@Bi_2O_3-BiOCl[13]	Oxidative polymerization	-	-	-	120 min	Solar light	80%	0.012	-	4
	TiO_2 @CS–PANI[14]	Chemical polymerization technique	30mg/L	100mg	11	50 min	Visible light	92.3%	-	-	5
	Ag/PANI/$ZnTiO_3$[15]	Facile sol/gel and ultrasonication	0.02 mM	1 g/L	-	25 min		95.6%	2.31×10^{-4}	-	5
	TiO_2/Polyaniline/Graphene Composites[16]	Hydrothermal technique	10 mg/L	-	-	90 min		97.7%	-	-	
	Ag/$CoFe_2O_4$/Polyaniline (core-shell)[17]	In-situ polymerization	-	0.05 g/L	-	300 min	solar light irradiation	Approx. 85%	0.01085	-	5
	ZnO–MoS_2-PANI[18]	Facile Hydrothermal synthesis	5×10^{-5} M	1 g/L	-	60 min	Natural sunlight irradiation	99.6%	93.03×10^{-3}	-	4

	GO/Fe_3O_4/PANI[19]	Mechanochemical mixing	10 mg/L	0.2 g/L	-	60 min	Natural sunlight (700 × 102 ± 100 lx)	92%	3.9×10^{-2}	-	-
	$ZnFe_2O_4$/TiO_2/PANI[20]	In-Situ Polymerization	-	0.25 g/L	-	4 h	UV light	98%	-	-	4
	PANI-TiO_2/rGO hybrid composites[21]		1×10^{-5} M	0.5 g/L	-	90 min		90.5%	0.025	-	4
	GH/PANI/Ag@AgCl[22]	In situ fabrication and subsequent photo reduction	-	-	-	120 min		93.2%	-	-	5
Rhodamine B	TiO_2/Bi_2O_3/PANI[23]	Mixing/ stirring		0.5 g/L	-	50 min	Visible light	99.6%	10.4×10^{-2}	-	4
	TiO_2/Polyaniline/Graphene Composites[16]	Hydrothermal technique	10 mg/L	5/6 g/L	-	30 min		95%	0.11749	-	5

	PANI/Ag/Ag_3PO_4[24]	Ultrasonication-Assisted In-Situ Formation of Ag_3PO_4 Nanoparticles on PANI		1 g/L	-	5 min		> 95%	-	-	5
	ZnS/CdS/PANI[25]	Successive ionic layer adsorption and reaction	20 mg/L	0.7 g/L	-	135 min	Irradiated with UVA CUBE 400	96.5%	1.7×10^{-2}	-	-
	Polyaniline/BiOCl/GO[26]	Oxidative polymerization method	5 ppm	0.6 g/L	8	120 min	Solar light	96%	0.015	-	6
Congo red	Fe_3O_4/ZnO/PANI Core-shell[27]	Ultrasonic-mediated optimization	30 mg/L	2 g/L	3	90 min	Visible light	86%	5.928×10^{-3}	-	5
	Cu_2O/ZnO-PANI (CZP)[28]	In situ polymerization		1 g/L	6	30 min		100%	0.1		5
	PANI/Fe0 doped Bismuth oxychloride (BiOCl)[29]	Facile chemisorption method	50 mg/L			120 min		79.91%	0.0106		3
	TPU/TiO_2/PANI[30]	Electrospinning combined with ultrasonic-assisted	10 mg/L		7	30 min		99.7%	0.313		10

		nanoparticle deposition and in-situ polymerization									
Rose Bengal	Aluminium-doped zinc oxide-polyaniline (PAZ)[31]	In-situ oxidative polymerization	1×10^{-5} M	0.4 g/L		150 min	Visible light	> 98%	2.61×10^{-2}		
	TiO_2/PAni/GO nanocomposites[32]	In situ-codeposition and oxidation	25 mg/L	1.6 g/L	7	180 min		99%	22.4×10^{-3}		
Methyl orange	$ZnFe_2O_4/TiO_2$/PANI[20]	In situ polymerization		0.25 g/L		4 h	UV light irradiation	98%			4
	CPA/N-SWCNTs-GO-CE/CuO nanocomposites Core-shell[33]	Chemical oxidative copolymerization	10 mg/L	0.05 g/L	6.0	100 min		100%			4
	TiO_2-DPA-PANI[34]	Oxidative Polymerization	50 mg/L	0.2 g/L	6.5	20 min		99.5%	0.133		3
	ZnO/rGO/polyaniline ternary nanocomposite[35]	Hydrothermal followed by in situ chemical oxidation	10 mg/L	0.5 g/L		60 min		99%			3
	polyaniline-coated TiO_2/SiO_2 nanofiber membranes[36]	In situ polymerization	1.5 mg/L			90 min		87%	0.021		5

	TiO_2 @CS–PANI[14]	Chemical polymerization technique	30mg/L	100mg	3	50 min		89.5%			5
	Aluminium-doped zinc oxide-polyaniline (PAZ)[31]	In-situ oxidative polymerization	1×10^{-5} M	0.4 g/L		150 min		> 92.5%	1.77×10^{-2}		
	TiO_2/Polyaniline/Graphene Composites[16]	Hydrothermal technique	10 mg/L			90 min		98.2%			
Acid Blue-29 (AB-29)	CdS-Zinc-PANI (CZP) & CdS-TiO_2 -PANI(CTP)[37]	Chemical precipitation method	0.6mM	1g/L		90 min	Visible light	89.8%	5.84×10^{-4}		5
K-2G dye	Polyaniline/dicarboxyl acid cellulose@ graphene oxide[38]	In situ Polymerization Process	100 mg/L	0.13 g/L	6	190 min	Visible light irradiation	97.9%	0.02071		5
Thymol blue	TiO_2/PAni/GO nanocomposites[32]	In situ-codeposition and oxidation	25 mg/L	1.6 g/L	7	180 min	Visible light	98%	25.2×10^{-3}		3

Safranin-T dye	Heulandite/polyaniline@ nickel oxide[39]	Chemical oxidation and ultrasonic processing	10 mg/L	0.25 g/L	6	30 min	Solar light	100% (100% of 5 mg/l dye was removed after only 1 min)	0.164		5

Table S3 Treatment performance of various photocatalysts for the degradation of pharmaceutically active compounds (PhACs).

PhACs											
Contaminant	**Composite**	**Synthesis method**	C_0	**Dose**	**pH**	**Time**	**Light source**	**Efficiency**	**K (min^{-1})**	**TOC (%)**	**Reusability**

Tetracycline	MIL-88B@COF-200@10%PANI[40]	Self-assembly method	50 mg/L	1/3 g/L		120 min	Visible light	97.2%	0.0303	69.5	5
	PANI@MoO_3@Fe_3O_4[41]	In situ polymerization	5 mg/L	500 mg/L	5	30 min		82.1%	0.037		
	PANI/$CoFe_2O_4$/WO_3[42]	Microwave-assisted ionic liquid	10 mg/L	0.025 g/L		50 min		99.1%	0.0557		6
	ZnO–MoS_2-PANI[18]	Facile Hydrothermal synthesis	1×10^{-5} M	1 g/L		60 min	Natural sunlight irradiation	94.5%			
Tetracycline hydrochloride (TCH)	g-C_3N_4/PANI/α-MnO_2[43]	Chemical polymerization	50 mg/L			60 min	Visible light irradiation	96%	0.253		5
Ibuprofen	PANi@carbon nanotubes/stainless steel[44]	In situ polymerization	10 mg/L		5	35 min		76%	0.0419		5
Clozapine	PANI/$LaFeO_3$/$CoFe_2O_4$[45]	Ultrasonication followed by in-situ polymerization	50 ppm	0.3 g/L	6	120 min		92%	0.0248	37.4	5
Clavulanate potassium	PANI-rGO-ZnO[46]	In situ polymerization		0.1 g		100 min		47%	0.0055		
Thiamphenicol	MIL-100(Fe)/PANI + H_2O_2[47]	In situ electrochemical deposition	20 mg/L			120 min		100%	0.0239		6

Ciprofloxacin	PAN@ZnONPs/MOF[48]	In situ polymerization under ice bath	5 mg/L	0.008 g/L	7	70 min		97.3%	0.0503		10
	$rGO/Ag_3PO_4/PANI$[49]	In-situ precipitation followed by hydrothermal method	10 mg/L	0.4 g/L		15 min		86.2%	0.0639		4
	CN-PANI-CQDs[50]	In situ polymerization		1 g/L	6.12	90 min		87.6%	0.1020	75.1	5
17β-estradiol	C-PANI/BiOBr[51]	Chemical precipitation	3 mg/L	0.5 g/L		40 min	300 W xenon lamp	100%	0.0922		5

Table S4 Treatment performance of various photocatalysts for the degradation of phenolic compounds.

Phenolic compounds

Contaminant	Composite	Synthesis method	C_0	Dose	pH	Time	Light source	Efficiency	K (min-1)	TOC (%)	Reusability
	BiOCl/WO_3@Polyaniline[52]	Co-precipitation followed by heating	25 mg/L	0.5 g/L	5		Natural sunlight illumination	99.7%	0.021		4
2-Chlorophenol	ZnO-ZnS@polyaniline nanohybrid[53]	In-Situ Oxidative Polymerization	50 mg/L	0.5 g/L		240 min	Visible light irradiation	89%	0.0078		3
	WO_3/WS_2/PANI[54]	Hydrothermal method	10 mg/L	0.25 g/L	5			100%	0.012		5
4 Chlorophenol	carbon nitride/polyaniline /ZnO[12]	In-situ polymerization and solvent evaporation induced assembly (EIA) process	120 µL of 0.2% solution	0.5 g/L		120 min	Visible light	50%	0.0049		5
BPA	PANI/TiO_2–graphene hydrogel[55]	Chemical reduction	40 mg/L	0.4 g/L		40 min	UV light	More than 99%			5
Tetrabromobisphenol A	$g\text{-}C_3N_4$- and polyaniline-co-modified TiO_2 nanotube arrays[56]	Electrochemical polycondensation with dip coating	10 mg/L		3 12	120 min	Visible light	94%			10
Bisphenol A	rGH-PANI/TiO_2[57]	hybridization process	10 mg/L			4.5	UV light	61.2%,			5

and 2,4-dichlorophenol		and a water bath approach				and 3.5 h, respectively		56%			
Phenol Nitrophenol	Ag_3PO_4@MWCNTs@PANI[58]	In situ precipitation	25 mg/L; 20 mg/L	0.5 g/L		20 min	Visible light	100% 100%	0.35	83.59	5
Phenol	Ag_3PO_4/PANI/Cr:$SrTiO_3$[59]	In-situ precipitation	25 mg/L	0.5 g/L		18 min	Visible light	100%	0.57	89.60	5
	PANI@g-C_3N_4/$ZnFe_2O_4$[60]	In situ oxidative polymerization method	20 ppm	10 g/L		120 min		85.1%	0.0085		4
	CN-PANI-CQDs[50]	In situ polymerization followed by an ultra-sonication	10 mg/L	1 g/L		70 min		45.6%	0.0356		
	$BiVO_4$-GO-TiO_2-PANI[61]	One-pot hydrothermal reaction	10 mg/L	0.6 g/L		3 h		80%	0.86×10^{-3}		5
	s-PANI@g-C_3N_4/GN1%[62]	In situ oxidative polymerization	50 mg/L	2/3 g/L		7 h	UV light	100%	0.437		
	rGH-PANI/TiO_2[57]	Hybridization	10 mg/L			8 h		42%			5

		process and water bath approach									

Table S5 Treatment performance of various photocatalysts for degradation of other miscellaneous compounds.

Others											
Contaminant	**Composite**	**Synthesis**	**C_0**	**Dose**	**pH**	**Time**	**Light**	**Efficiency**	**K (min-1)**	**(TOC%)**	**Reusability**

		method					**source**				
EDTA (Ethylenediaminetetraacetic acid)	Fe_3O_4@PANI/ TiO_2[63]	in situ chemical oxidative polymerization	20 mg/L	0.6 g/L		135 min	Visible light	94%	1.97×10^{-2}	88.12	6
Diethyl phthalate	PANI/CNT/TiO_2[64]	Sol/gel method and hydrothermal method			5 (sol/gel) 7 (hydrothermal)	120 min	Simulated solar light	59.0%- sol/gel method 67.4%- hydrothermal method	9.0×10^{-3}		5
NO^{3-} to N_2	Cu0 /Cu_2O- PANI-CNTs[65]	Combination of in situ polymerization and liquid phase reduction	20 mg/L	4 g/L	7	180 min	1000-W high pressure mercury lamp	100%			4
Benzene	TiO_2/MWCNT /Pani[66]	In-situ polymerization	700 mg/L	1.5 g/L	6	80 min	Visible light	84.9%	0.00035		4
Cr (VI)	TiO_2-WO_3 nanocube-polyaniline[67]	Hydrothermal followed by coating	15 ppm		5.8		Visible light	79.3%			3
	TPU/TiO_2/PANI[30]	Electrospinning combined with	10 mg/L		3	25 min		99%	0.128		10

		ultrasonic-assisted nanoparticle deposition and in-situ polymerization									
	CeO_2/SnS_2/PANI[68]	Ultrasonication	50 mg/L	1 g/L	5.3	180 min		99%	0.034		4
Monocrotophos (MCP)	Ag_3PO_4/polyaniline@g-C_3N_4[69]	Solvothermal Synthesis	15 mg/L	0.08 g/L	5	50 min	Visible light	99.6%			7
Triclopyr (TC)	TiO_2/Bi_2O_3/PANI[23]	Mixing	10 mg/L	0.5 g/L		120 min		76.1%	1.5×10^{-2}		4
Diazinon	$Co_2TiO_4/CoTiO_3$/Polyaniline[70]	Sol/gel method	20 mg/L	50 mg	6	120 min	Visible light	98.3%			6
Chlorpyrifos	CuO/TiO_2/PANI[71]	In situ polymerization	5 mg/L	0.45 g/L	7	90 min	Visible light	95%			5
Diuron	ZnR@CGR/PANI[72]	Ultrasonic method	10 mg/L	2 g/L	3	40 min	Visible light	100%			5
Glyphosate	PANI/$ZnWO_4/WO_3$[73]	Ionic liquid (IL)-assisted in situ oxidative	10 mg/L	0.025 g/L	7	60 min	Visible light	98.4%	0.0707	90.3	5

		polymerization									

References

1 M. Al Kausor and D. Chakrabortty, *Surfaces and Interfaces*, 2022, **31**, 102079.

2 S. Ye, R. Wang, M.-Z. Wu and Y.-P. Yuan, *Appl. Surf. Sci.*, 2015, **358**, 15–27.

3 V. J. Babu, S. Vempati, T. Uyar and S. Ramakrishna, *Phys. Chem. Chem. Phys.*, 2015, **17**, 2960–2986.

4 C. Zuo, Q. Su and Z. Jiang, *Molecules*, 2023, **28**, 3982.

5 E. Dhanda, A. Nain and S. Dahiya, *Water. Air. Soil Pollut.*, 2024, **235**, 1–16.

6 Y. Chen, T. Wang, J. Pan, M. Wang, A. Chen and Y. Chen, *Bull. Mater. Sci.*, 2022, **45**, 45.

7 S. Shahabuddin, N. M. Sarih, F. H. Ismail, M. M. Shahid and N. M. Huang, *RSC Adv.*, 2015, **5**, 83857–83867.

8 F. Khan, M. Zahid, H. N. Bhatti and Y. Jamil, *Int. J. Environ. Sci. Technol.*, 2023, **20**, 4811–4826.

9 P. Ahuja, S. K. Ujjain, I. Arora and M. Samim, *ACS Omega*, 2018, **3**, 7846–7855.

10 X. Zhang, J. Wu, G. Meng, X. Guo, C. Liu and Z. Liu, *Appl. Surf. Sci.*, 2016, **366**, 486–493.

11 G. Sharma, M. Naushad, A. Kumar, S. Devi and M. R. Khan, *Iran. Polym. J.*, 2015, **24**, 1003–1013.

12 K. Pandiselvi, H. Fang, X. Huang, J. Wang, X. Xu and T. Li, *J. Hazard. Mater.*, 2016, **314**, 67–77.

13 A. Bouziani, M. Yahya, C. L. Bianchi, E. Falletta and G. Celik, *Nanomaterials*, 2023,

13, 713.

14 S. Palliyalil, R. K. V. Chola, S. Vigneshwaran, N. C. Poovathumkuzhi, B. M. Chelaveettil and S. Meenakshi, *Environ. Technol. Innov.*, 2022, **28**, 102586.

15 M. Faisal, M. Jalalah, F. A. Harraz, A. M. El-Toni, J. P. Labis and M. S. Al-Assiri, *Sep. Purif. Technol.*, 2021, **256**, 117847.

16 S. Zhao, Y. Tao, P. Maryum, Q. Wang, Y. Zhang, S. Li, H. Cheng, F. Min and Y. Tai, *Russ. J. Phys. Chem. A*, 2021, **95**, 1745–1755.

17 V. S. S. Mosali, M. Qasim, B. Mullamuri, B. Chandu and D. Das, *J. Nanosci. Nanotechnol.*, 2017, **17**, 8918–8924.

18 V. Sharma, V. Maivizhikannan, V. N. Rao, S. Kumar, A. Kumar, A. Kumar, M. V. Shankar and V. Krishnan, *Ceram. Int.*, 2021, **47**, 10301–10313.

19 M. Asghar Jamal, S. Iqbal, S. Mahmood, S. Chohdry, A. Zidan, M. Tariq Qamar, M. Saeed, H. Asghar and K. M. Alotaibi, *Polyhedron*, 2024, **255**, 117137.

20 J. Li, Q. Xiao, L. Li, J. Shen and D. Hu, *Appl. Surf. Sci.*, 2015, **331**, 108–114.

21 J. Ma, J. Dai, Y. Duan, J. Zhang, L. Qiang and J. Xue, *Renew. Energy*, 2020, **156**, 1008–1018.

22 F. Chen, W. Liang, X. Qin, L. Jiang, Y. Zhang, S. Fang and D. Luo, *ChemistrySelect*, 2021, **6**, 4166–4177.

23 S. Sharma, A. Sharma, N. S. Chauhan, M. Tahir, K. Kumari, A. Mittal and N. Kumar, *Inorg. Chem. Commun.*, 2022, **146**, 110093.

24 Y. Bu and Z. Chen, *ACS Appl. Mater. Interfaces*, 2014, **6**, 17589–17598.

25 H. Ali and E. S. Mansor, *Colloid Interface Sci. Commun.*, 2020, **39**, 100330.

26 P. Hait, R. Mehta and S. Basu, *J. Clean. Prod.*, 2023, **424**, 138851.

27 N. Zare, R. K. Kojoori, S. Abdolmohammadi and S. Sadegh-Samiei, *J. Mol. Struct.*, 2022, **1250**, 131903.

28 A. M. Mohammed, S. S. Mohtar, F. Aziz, M. Aziz and A. Ul-Hamid, *J. Environ. Chem. Eng.*, 2021, **9**, 105065.

29 R. Tanwar, S. Kumar and U. K. Mandal, *J. Photochem. Photobiol. A Chem.*, 2017, **333**, 105–116.

30 Z. Cui, S. Tian, X. Liu, Q. Wang, S. Zeng and J. Si, *Colloids Surfaces A Physicochem. Eng. Asp.*, 2023, **664**, 131111.

31 M. Mitra, A. Ghosh, A. Mondal, K. Kargupta, S. Ganguly and D. Banerjee, *Appl. Surf. Sci.*, 2017, **402**, 418–428.

32 A. Kumar, C. J. Raorane, A. Syed, A. H. Bahkali, A. M. Elgorban, V. Raj and S. C. Kim, *Environ. Res.*, 2023, **216**, 114741.

33 D. F. Katowah, S. M. Saleh, S. A. Alqarni, R. Ali, G. I. Mohammed and M. A. Hussein, *Sci. Rep.*, 2021, **11**, 5056.

34 F. Mousli, A. Chaouchi, S. Hocine, A. Lamouri, M. Rei Vilar, A. Kadri and M. M. Chehimi, *Appl. Surf. Sci.*, 2019, **465**, 1078–1095.

35 H. Wu, S. Lin, C. Chen, W. Liang, X. Liu and H. Yang, *Mater. Res. Bull.*, 2016, **83**, 434–441.

36 Z. Liu, Y. E. Miao, M. Liu, Q. Ding, W. W. Tjiu, X. Cui and T. Liu, *J. Colloid Interface*

Sci., 2014, **424**, 49–55.

37 N. Qutub, P. Singh, S. Sabir, K. Umar, S. Sagadevan and W.-C. Oh, *Nanomaterials*, 2022, **12**, 1355.

38 T. Liu, Z. Wang, X. Wang, G. Yang and Y. Liu, *Int. J. Biol. Macromol.*, 2021, **182**, 492–501.

39 M. R. Abukhadra, M. Shaban and M. A. Abd El Samad, *Ecotoxicol. Environ. Saf.*, 2018, **162**, 261–271.

40 S.-W. Lv, J.-M. Liu, F.-E. Yang, C.-Y. Li and S. Wang, *Chem. Eng. J.*, 2021, **409**, 128269.

41 S. K. Fanourakis, S. Q. Barroga, R. A. Mathew, J. Peña-Bahamonde, S. M. Louie, J. V. D. Perez and D. F. Rodrigues, *J. Environ. Chem. Eng.*, 2022, **10**, 107635.

42 B. Barik, S. J. Sahoo, B. Maji, J. Bag, M. Mishra and P. Dash, *Ind. Eng. Chem. Res.*, 2021, **60**, 15125–15140.

43 N. A. Chopan and H.-T.-N. Chishti, *New J. Chem.*, 2023, **47**, 15487–15505.

44 P. Xu, D. Zheng, Z. Xie, Q. He and J. Yu, *J. Clean. Prod.*, 2020, **265**, 121872.

45 A. Kumar, M. Chandel, A. Sharma, M. Thakur, A. Kumar, D. Pathania and L. Singh, *J. Environ. Chem. Eng.*, 2021, **9**, 106159.

46 E. Girija Shankar, M. Aishwarya, A. Khan, A. B. V. K. Kumar and J. S. Yu, *Ceram. Int.*, 2021, **47**, 23770–23780.

47 J. An, Y. Li, W. Chen, G. Li, J. He and H. Feng, *Environ. Res.*, 2020, **191**, 110067.

48 K. Shoueir, A. R. Wassel, M. K. Ahmed and M. E. El-Naggar, *J. Photochem. Photobiol.*

A Chem., 2020, **400**, 112703.

49 J. Wang, X. Yu, X. Fu, Y. Zhu and Y. Zhang, *Mater. Sci. Semicond. Process.*, 2021, **121**, 105329.

50 V. Balakumar, M. Ramalingam, K. Sekar, C. Chuaicham and K. Sasaki, *Chem. Eng. J.*, 2021, **426**, 131739.

51 Y. Qing, Y. Li, L. Cao, Y. Yang, L. Han, P. Dansawad, H. Gao and W. Li, *Sep. Purif. Technol.*, 2023, **314**, 123545.

52 R. Kumar, M. A. Taleb, M. A. Barakat and B. Al-Mur, *Catalysts*, 2023, **13**, 175.

53 M. Anjum, M. Oves, R. Kumar and M. A. Barakat, *Int. Biodeterior. Biodegrad.*, 2017, **119**, 66–77.

54 M. A. Barakat, R. Kumar, T. Almeelbi, B. A. Al-Mur and J. O. Eniola, *J. Clean. Prod.*, 2022, **330**, 129942.

55 F. Chen, W. An, Y. Li, Y. Liang and W. Cui, *Appl. Surf. Sci.*, 2018, **427**, 123–132.

56 Q. Zhou, D. Zhao, Y. Sun, X. Sheng, J. Zhao, J. Guo and B. Zhou, *Chemosphere*, 2020, **252**, 126468.

57 W. Cui, J. He, H. Wang, J. Hu, L. Liu and Y. Liang, *Appl. Catal. B Environ.*, 2018, **232**, 232–245.

58 Y. Lin, S. Wu, C. Yang, M. Chen and X. Li, *Appl. Catal. B Environ.*, 2019, **245**, 71–86.

59 X. Yu, Y. Lin, H. Liu, C. Yang, Y. Peng, C. Du, S. Wu, X. Li and Y. Zhong, *J. Colloid Interface Sci.*, 2020, **561**, 379–395.

60 S. Patnaik, K. K. Das, A. Mohanty and K. Parida, *Catal. Today*, 2018, **315**, 52–66.

61 J. Zhao, M. R. U. D. Biswas and W.-C. Oh, *Environ. Sci. Pollut. Res.*, 2019, **26**, 11888–11904.

62 A. Jilani, G. U. Rehman, M. O. Ansari, M. H. D. Othman, S. Z. Hussain, M. R. Dustgeer and R. Darwesh, *New J. Chem.*, 2020, **44**, 19570–19580.

63 W. Li, Y. Tian, C. Zhao, Q. Zhang and W. Geng, *Chem. Eng. J.*, 2016, **303**, 282–291.

64 C. H. Hung, C. Yuan and H. W. Li, *J. Hazard. Mater.*, 2017, **322**, 243–253.

65 L. Cai, X. Zhang, Q. Wang and Y. Liu, *Chem. Eng. J.*, 2023, **475**, 146261.

66 M. Karamifar, S. Sabbaghi, M. S. Mohtaram, K. Rasouli, M. Mohsenzadeh, H. Kamyab, A. Derakhshandeh, L. Dolatshah, H. Moradi and S. Chelliapan, *Powder Technol.*, 2024, **432**, 119176.

67 T. Rathna, J. PonnanEttiyappan and D. R. Sudhakar, *Water Environ. J.*, 2023, **37**, 819–827.

68 H. Wei, Y. Zhang, Y. Zhang and Y. Zhang, *Colloid Interface Sci. Commun.*, 2021, **45**, 100550.

69 J. Balasubramanian, S. K. Ponnaiah, P. Periakaruppan and D. Kamaraj, *Environ. Sci. Pollut. Res.*, 2020, **27**, 2328–2339.

70 M. Rahimi-Nasrabadi, A. Ghaderi, H. R. Banafshe, M. Eghbali-Arani, M. Akbari, F. Ahmadi, S. Pourmasoud and A. Sobhani-Nasab, *J. Mater. Sci. Mater. Electron.*, 2019, **30**, 15854–15868.

71 R. Nekooie, T. Shamspur and A. Mostafavi, *J. Photochem. Photobiol. A Chem.*, 2021, **407**, 113038.

72 T. S. Anirudhan, F. Shainy and A. Manasa Mohan, *Sol. Energy*, 2018, **171**, 534–546.

73 B. Barik, M. Mishra and P. Dash, *Environ. Sci. Nano*, 2021, **8**, 2676–2692.