International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Nanoscience for environmental remediation: A Review

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Abstract

A number of nanosized advanced materials have been synthesized for photocatalysis using different techniques. These catalysts find applications in environmental remediation, sterilization, hydrogen production and renewable energy. Nanophotocatalyst has been used successfully for the treatment of hazardous materials such as industrial effluents containing dyes. The study of composition, surface area, shape, size and nanostructure of these photocatalyst may help in current and further development of photocatalysts for environmental remediation.

Key words: Nano materials, Remediation, Nano-photocatalyst, Nanoscience

Full length article Received: 21-06-2012 Revised: 15-07-2012 Accepted: 23-07-2012 Available online: 31-07-2012
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1. Introduction

Polluted waste water plays significant role in environmental pollution. Industrial effluents contain different chemicals especially synthetic dyes which are carcinogenic in nature [1]. Some dyes decompose aerobically and anaerobically resulting in the formation of carcinogenic compounds [2,3]. Classical techniques which are still in use to decontaminate polluted water include adsorption [4,5], chlorination [6,7], coagulation [8,9], ion flotation [10], membrane process [11,12], sedimentation [13] and solvent extraction [14,15]. The end products of these techniques need to be processed further for complete purification. There are newer advanced oxidation processes which can be used to degrade harmless products and into carbon dioxide and water [16]. These include biodegradation [17,18], fenton [19,20], photofenton [21,22], photocatalytic [23,24] radiation [25-27], sonolysis [28-30], ozonation [31] and UV photocatalytic processes [32,33]. These advanced oxidation processes are better than chemical ones however these are much costly. Evolution of a new branch of science known as nano science has completely replaced the previous technologies due to the following reasons

i) Nanomaterials completely mineralize most of organics and are inexpensive [34].
ii) Semiconductors remove completely organic matter from polluted water [35].
iii) Nanophotocatalyst are non-toxic, non-corrosive and stable chemically and thermally [36].
iv) Photocatalyst are easily available, inexpensive and stable to corrosion in the presence of water and chemicals [37].

2. Mechanism of photocatalysis

A nanophotocatalyst when exposed to light valance band electrons absorb energy and transfer to conduction band producing an electron-hole pair [38]. h^+_{vb} reacts with H_2O to give $^{\cdot}OH$ and e^-_{eb} react with dissolved O_2 to give $^{\cdot}O_2$ [39]. These active radicals are responsible to decompose dye. The mechanism of the photocatalytic degradation is as under.

$$\text{Catalyst} + h\nu \longrightarrow e^-_{cb} + H^+_{vb}$$
$$H_2O + h^+_{eb} \longrightarrow {}^{\cdot}OH + H^+$$
$$O_2 + e^-_{cb} \longrightarrow {}^{\cdot}O_2$$
$$O_2^- + H^+ \longrightarrow HO^{\cdot}_2$$
$$2HO_2^{\cdot} \longrightarrow H_2O_2 + O_2$$
$$H_2O_2 \longrightarrow 2\,{}^{\cdot}OH$$
$${}^{\cdot}OH + \text{Dye} \longrightarrow CO_2 + H_2O$$

3. Synthesis techniques

There are several techniques to synthesize nanophotocatalysts.

3.1. Ball-milling or High Energy Ball-milling

Transition metal oxides, borides, carbides and silicides can be synthesized by ball milling which is also known as mechano chemical method. Different alloy composite can also be obtained by mechanical activation in ball mills e.g. metal alumina composites [40]. We can prepare nanosized particles by alloying mechanically in ball mills. High energy ball mills are indispensable in material science and engineering [41]. Nano crystalline powders with new and unusual properties can be prepared by ball milling which is a good state processing method [42]. Powdered particles are broken and welded repeatedly forming nano structured alloys in ball mills [43]. Nanoparticles prepared by this technique are given in Table 1 [44 - 48].

3.2. Hydrothermal technique

Nanoparticles can also be synthesized by this technique which is also known as solvo-thermal technique [49]. The reactions are carried out in an autoclave at a pressure of 2000 pounds per square inch and a temperature of 200°C or higher. Nanoparticles prepared by this method show better crystallinity and grain size [50]. Nanophotocatalyst with specific sizes and morphology can be synthesized by continuous hydrothermal technique [51]. Reaction kinetics can be increased by microwave heating during hydrothermal technique [52]. Microwave hydrothermal technique needs lower temperature as 150°C and shorter time as 25 min as compare to conventional hydrothermal technique. It is also a single step, fast and easy technique for the preparation of nanophotocatalysts some of which are given in Table 2 [53-82].

3.3. Sole-gel technique

This method is one of the most popular processes for producing nanophotocatalyst mentioned in several books [83,84]. Over the years, solution precipitation and sol–gel processing have come to be used interchangeably, mostly by people on the fringes of the technical community. There are distinct differences between the two methods, as will be made clear below. Transition metal precursor is hydrolyzed with water and product is allowed to react to form precipitates, which are washed, dried and calcined at elevated temperatures to form nanocrystals of metal oxides. Smaller particles can be produced by slow and controlled hydrolysis and base catalyzed condensation reaction form denser particles. Nanophotocatalyst prepared by this technique are given in Table 3 [85-116].

3.4. Chemical co-precipitation

A facile and convenient method to prepare nanoparticles is chemical co-precipitation technique. Two or more soluble salts solutions are mixed in a definite ratio and co-precipitated with a base solution under inert atmosphere [117]. Solutions of two or more water soluble salts of metals are dissolved in water, mixed and co-precipitated with alkali very slowly (in approximately 2 hours). Afterwards the resulting solution was stirred for 6 hours. The precipitate thus formed were filtered, washed, dried and sintered at about 400-600°C for 4-6 hours [118].

Composition shape and size of nanophotocatalyst can be controlled by the following factors:

i) Type of the base and mixing rate.
ii) Ionic strength of mixture solution and addition sequence
iii) Bubbling of nitrogen gas
iv) pH of the medium
v) Reaction temperature
vi) Nature of salts used (chlorides, sulphates or nitrates).

An increase in mixing rate decreased the size of nanophotocatalyst [117]. It is a simple method which takes place at lower temperature than hydrothermal or thermal decomposition. Solvent used is environmental friendly and yield is high. Nanophotocatalyst prepared by this technique are given in Table 4 [119-132].

3.5. Reverse Micelle technique

Micro emulsion of oil in water is used to prepare uniform sized nanoparticles [133,134]. This emulsion contains three components oil, water and surfactant which form thermodynamically stable, single phase, isotropic transparent solution. The reacting reagents are present in nano water droplets surrounded by surfactant molecule. These water droplets containing reagents coalesce rapidly allowing mixing and precipitating the nanoparticles. Nano droplets of water solution are spherical and surrounded by surfactant molecular wall which act as a cage of growing particles. The size of precipitated molecule changes with size of water pool in micelle [117]. Mono dispersed nanoparticles of different morphologies and sizes can be synthesized by this technique. This method is costly and have low yield. Nanophotocatalyst prepared by this technique are given in Table 6 [135-138].

3.6. Calcination

This is a high temperature technique. In this method volatile fraction is removed and phase transition as well as thermal decomposition takes place. This reaction is usually performed below the melting points of the reactants. Ores and other materials which need thermal decomposition are used in this method [132]. Calcination can take place at different temperatures depending upon the material to be calcined as Liu et al 2010 synthesized N/Zr-TiO_2 at 300, 400 and 500°C for 2 hr [139]. Some nanophotocatalysts prepared by calcination are given in Table 6. [140-142]

3.7. Other Techniques

Nanophotocatalysts are synthesized by other techniques are given in Table 7 [143- 199].

4. Dye Degradation study techniques

Various qualitative and quantitative techniques are used depending on the nature of pollutant and their degraded products. These are generally the instrumental techniques for example:

i) UV-Vis spectroscopy
ii) HPLC (High Performance Liquid Chromatography)
iii) Ion Chromatography

iv) Capillary electrophoresis
v) FTIR (Fourier Transform Infra-Red Spectroscopy)
vi) NMR (Nuclear Magnetic Resonance Spectroscopy)

Table 1. Nanophotocatalyst synthesized by ball-milling and their applications

Nanocatalyst	Application/Degradation	Reference
$InVO_4$	Organic pollutant	[44]
TiO_2	Organic pollutant	[45]
SiOC/ZnO	Methylene Blue	[46]
$LiFe(WO_4)_2$	Methylene Blue	[47]
$Cs_{0.68+x}Ti_{1.83-x}Fe_xO_4$	Methylene Blue	[48]

Table 2. Nanophotocatalysts synthesized by hydrothermal technique and their applications

Nanocatalyst	Application/Degradation	Reference
$ZnIn_2S_4$	Water reduction	[53]
TiO_2/SiO_2	Methylene Blue	[54]
$La_2Ti_2O_7$	Methyl Orange	[55]
ZnS/MMT	Eosin B	[56]
Sn^{4+}-TiO_2	Malachite Green	[57]
$ZnO/(La,Sr)CoO_3$	Methyl Orange 4-Chlorophenol	[58]
TiO_2	Energy application	[59]
MoS_2 MoS_2/TiO_2	Phenol	[60]
$K_{0.3}Ti_4O_{7.3}(OH)_{1.7}$	Methylene Blue	[61]
$K_4Nb_6O_{17}$	Acid Red G	[62]
Fe^{+3}-TiO_2	Malachite Green	[63]
$Sr_2Ta_2O_7$	Water splitting	[64]
Au/TiO_2, Pd/TiO_2	Methyl Alcohol	[65]
$TiO_2/SiO_2/NiFe_2O_4$	Violet 5B	[66]
ZrO_x/ZnO	Endocrine	[67]
Fe-TiO_2	Phenol	[68]
Ag/ZnO	Organic pollutant	[69]
C-$Zn(OH)_2V_2O_7$	Methylene Blue	[70]
TiO/Sulfanilic acid	Cango Red	[71]
N-TiO_2	Methyl Orange	[72]
CeO_2	Amido Black, Acridine Orange	[73]
ZnO/SnO_2	Methyl Orange	[74]
$BiVO_4/Bi_2O_2CO_3$	Rhodamine B	[75]
W/TiO_2	2-Chlorophenol	[76]
ZnO/Au	Methylene Blue	[77]
Ag/AgCl	Phenol	[78]
CNTs/P-TiO_2	Methyl Orange	[79]
$CdS/La_2Ti_2O_7$	Methyl Orange	[80]
Ce-TiO_2	Glyphosate	[81]
SnS_2	Methyl Orange	[82]

Table 3. Nanophotocatalysts synthesized by sol-gel technique and their applications

Nanocatalyst	Application/Degradation	Reference
WO_x-TiO_2	Methylene Blue	[85]
TiO2/Bentonite	Cationinc Azo dye	[86]
TiO_2/MMT	Phenol	[87]
M/TiO_2	Phenol	[88]
Ag-TiO_2	Reactive yellow 17	[89]
$Cs_xH_{3-x}PW_{12}O_{40}/TiO_2$	Methyl Orange	[90]
RE/TiO_2	Direct Blue	[91]
Zn-Bi_2O_3	Methylene Blue	[92]
WO_x/TiO_2	Phenol	[93]
RE/TiO_2	Direct Blue	[94]
$BiFeO_3$	Rhodamine B	[95]
TiO_2/SiO_2	Cango Red	[96]
Ag/V-TiO_2	Rhodamine B	[97]
TiO_2/ZrO_2	Methyl Orange	[98]
B,Y/TiO_2	Phenol	[99]
N-TiO_2	Alizarin Red S	[100]
TiO_2	Acid Red 27	[101]
V-TiO_2-MMT	Sulpho-Rhodamine B	[102]
TiO_2/C	Reactive Dyes	[103]
$BiFeO_3$/BFO	Water splitting	[104]
TiO_2 MT-150A	Methyl Orange	[105]
Er^{+3}/TiO_2	Orange I & Methylene Blue	[106]
Ag,Pt,Au-TiO_2	Chlorophenol	[107]
$H_3PW_{12}O_{40}/TiO_2$	Rhodamine B	[108]
P-TiO_2	Rhodamine B	[109]
Y^{+3}/TiO_2	Methyl Orange	[110]
$H_3PW_{12}O_{40}$/ZrO	Different dyes	[111]
La or Eu /TiO_2	Methylene Blue	[112]
TiO_2	Methyl Orange	[113]
$H_3PW_{12}O_{40}$-Y-TiO_2	Methyl Orange	[114]
TiO_2/Al-MCM-40	Methyl Orange	[115]
Nd/TiO_2-SiO_2	Methyl Orange	[116]

Table 4. Nanophotocatalyst synthesized by chemical co-precipitation and their applications

Nanocatalyst	Application/Degradation	Reference
TiO_2-$ZnFe_2O_4$	Phenol	[119]
$M(OH)_x/TiO_2$	Methylene Blue	[120]
Fe_2O_3/SnO_2	Acid Blue 62	[121]
NiO-Bi_2O_3	Methylene Blue	[122]
ZnO/Mg-Al-CO_3LDHs	Acid Red I	[123]
ZnO/CuO	Rhodamine B	[124]
Zn_{1-x} Cu_xS	Cango Red	[125]
Zn_{1-x} Ni_x S		
WOx/TiO_2	Acid Orange 7	[126]
Fe_3O_4-HAP	Diazinon	[127]
Mn/ZnO	Cresols	[118]
Zn-Al-In(MMO)	Methylene Blue	[128]
Co/ZnO	Methylene Blue	[129]
BSA/CdS	Methylene Blue	[130]
$CoFe_2O_4$-Cr_2O_3-SiO_2	Methylene Blue	[131]
Fe^{+3}-TiO_2-Zeolite	Methyl orange	[132]

Table 5. Nanophotocatalysts synthesized by Reverse Micelle technique and their applications

Nanocatalyst	Application/Degradation	Reference
CdS/TiO_2	Phenol	[135]
ZnS/TiO_2	Parathion-methyl	[136]
Ag/TiO_2	Phenol	[137]
CdS/TiO_2	Reactive Black 5	[138]

Table 6. Nanophotocatalysts synthesized by calcination technique and their applications

Nanocatalyst	Application/Degradation	Reference
Ag-TiO_2/MMT	Methylene Blue	[140]
S/TiO_2	Nitrite	[141]
$NaTaO_{3-x}$-N_x	Methylene Blue	[142]
$BiFeO_3$	Rhodamine B	[95]
$Zn/SrTiO_2$	Water splitting	[30]
Fe^{+3}-TiO_2-Zeolite	Methyl orange	[132]

Table 7. Nanophotocatalyst synthesize by other techniques and their applications

Nanocatalyst	Synthesis Technique	Application/Degradation	Reference
ZnO/TiO_2	Non-hydrolytic	Metylene Red	[143]
TiO_2	EFISPS method	Acid Red 44/Phenol	[144]
Fe-Lap-RD	Ion exchange	Acid Black 1	[145]
TiO_2	Thermal decomposition	Diuron	[146]
TiO_2/Pt	Microwave irradiation	Methyl Red	[147]
ZnO	Wet-chemical	Methylene Blue	[37]
$Ba_5Ta_4O_{15}$	Ion exchange	Rhodomine B	[148]
TiO_2	Immoblization	Methyl Red	[149]
SiO_2/Bi_2S_3	Chemical	Methyl Blue	[150]
Ag/TiO_2	Liqiuid impregnation	Acid Red 88	[151]
$N\text{-}SiO_2/TiO_2$	Hydrolysis	Orange II	[152]
TiO_2-ZnO	Ultrasonic precipitation	Basic Blue 41	[153]
RE/TiO_2	Wet impregnation	Methylene Blue	[154]
$Ln_2Ti_2O_7$	Citric acid Precurser	Methylene Blue	[155]
TiO_2/ZnS	Chemical Deposition	Mthylene Blue	[156]
TiO_2-pyr / Fe-pyr	Chemizorption	Rhodamine B	[157]
Au/TiO_2	X-ray Radition	Synchrotron	[158]
ZnO-Au	Flame Spery	Methylene Blue	[159]
RE/TiO_2	One step-one part	Orange II	[160]
TiO_2/P-3-HT	Blending	Methyl Orange	[161]
ZnO-TNTs	Chemical Facile	Rhodamine B	[162]
Fe-Co-TiO_2	Steric acid Gel	Rhodamine B	[163]
TiO_2/ZrO_2	Evaporation Induced	Rhodamine B	[164]
Chitosan/CdS	Simulating Bio-Mineralysation	Cango Red	[165]
Au/WO_3	Rf Magnetron Sputtering	Methylene Blue	[166]
ZnO/TiO_2	Nanorods	Methylene Blue	[167]
ZnO	Pyrolysis	Rhodamine B	[168]
ZnO	Flame-Spery Pyrolysis	Methylene lue	[169]
Ag/ZnO	Wet-Chemical	Methylene Blue	[170]
$NiO/Ag/NbO_3$	Wet Impregnation	Methylene Blue	[171]
ZnO/SiO_2	Chemical synthesis	Acid Red	[172]
Cu_xS/TiO_2	Photochemical	Methylene Blue, Methyl Orange	[173]
Ag-TiO_2	Photoreduction	Safdamine-O	[174]
Pt/TiO_2	Photodeposition	Crystale Violet	[175]
Bi_2SiO_5	Dip Coating	Mthyl Orange	[176]
W-TiO_2	Liquid pahse Deposition	Dodecyl Benzene Sulphonic Acid	[177]
Ag-AgI/Fe_3O_4@SiO_2	Deposition-Precipitation	Rhodamine B 4-Chlorophenol	[178]
Ag-ZnO	Microwave	Cyanide	[179]
CeO_2-ZnO	Electrospining	Rhodamine B	[180]
Y_2InSbO_7, Y_2GdSbO_7	Chemical synthesis	Rhodamine B	[181]
WO_3/TiO_2	Template	Methylene Blue	[182]
CdS-Zeolite	Precipitation	Crystal violet	[183]
TiO_2/Ni	Coating	Organic pollutants	[184]
Mn-BiOCl	Hydrolytic	Malachite Green	[185]
CuO-ZnO	Wet-impregnation	Acid Red 88	[186]
WO_3/BiOCl	Hydrolytic	Rhodamine B	[187]
ZnO	Facile precipitation	Methylene Blue	[188]
Zr-I-TiO_2	Hydrolytic	Methyl Orange	[189]
Zr/TiO_2	Gel to Crystalling	Ethidium brimide	[190]
ZnO	Chemical	Mehtyl Orange	[191]
Ag/T-ZnOW	Photodeposition	Methyl Orange	[192]
CuO/T-ZnOW	Photodeposition	Mehtyl Orange	[193]
Fe_3O_4@SiO_2@MS (M = Pb,Zn or Hg)	Wet-chemical	Rhodamine B	[194]
Fe_3O_4/ZnO	Facile two step startegy	Methyl Orange	[195]
Ag/MWNTs	Photoreduction	Rhodamine B	[196]
Ag/ZnO	Liq-Liq two phase	Methyl Orange	[197]
$MgFe_2O_4/TiO_2$	Mixing-annealing	Rhodamine B	[198]
TiO_2/TR	Interclation	Acid Red G	[199]

In the case of dye degradation, solution after irradiation is transferred to cuvette of spectrophotometer for absorption studies and the degree of decolorization can be calculated from the decrease in the absorbance of the dye [200]. A cylindrical glass vessel or glass dish is used as photochemical cell for the degradation of the dye solution [201, 202]. Whereas up flow type membrane based or coated surfaces have been reported for degradation [203, 204].

5. Factors affecting photocatalytic degradation

There are a number of factors which govern the photodegradation of dye [205].

5.1. Photocatalyst concentration

Heterogeneous photocatalysis is influenced by the concentration of photocatalyst [206]. ·OH radicals are increased with the increase in concentration of photocatalyst resulting decolorization of the dye. After a certain limit of time concentration of catalyst solution become opaque and light radiation cannot enter in to activate the catalyst particles. Hence the rate of dye degradation decreased [207].

5.2. Dye Concentration

Photo catalytic degradation of those molecules of dye take place which are adsorbed on the surface of photocatalyst particles, whole of the dye molecule do not degrade [208]. If the dye concentration is increased the number of dye molecule in the solution is increased which affect the degradation rate. Hence for the optimum degradation rate, the concentration of dye should not be increased after certain limit [209].

5.3. pH of the Solution

pH of the solution also affect the rate of photo degradation of the dye by changing the surface charges of the nanophotocatalyst particles. Hence adsorption of charged particle at the surface of catalyst is altered which changes the rate of degradation reaction [208]. Photocatalyst surface may protonate or deprotonate with the change of pH value. Anionic dyes will be degraded more at lower pH [210]. Reductive cleavage may take place in azo dyes at low pH favoring the degradation of azo dyes [211].

5.4. Free Oxygen in solution

O_2 molecule in solution accept the e^- from conduction band and form stabilize $O_2^{\bullet}$ radicals decreasing the e^-/h^+ recombination rate. $O_2^{\bullet}$ radicals oxidize the dye molecule and degrades. O_2 does not adsorb on the surface of catalyst. Free O_2 present in solution stabilize intermediate radicals which are responsible for the mineralization of the dye molecule. It also induces the cleavage mechanism of aromatic bonds in organics which pollute water [212].

5.5. Intensity of light and time of irradiation

Intensity of light and irradiation time both have affect on the rate of photo degradation of pollutants [213]. The degradation reaction rate changes linearly if the intensity of light increases at low intensity values (0-20mW/Cm^2) but the rate of reaction changes with the square root at intermediate intensity (25 mW/cm^2) [214]. At higher light intensity the rate of degradation become independent of light intensity. Rate of degradation initially increase if the intensity is increased [215, 216]. Time of irradiation also affect the degradation rate at longer irradiation time byproducts are accumulated on the active sites of nanoparticles resulting in the deactivation of photocatalyst [217].

6. Conclusion

Scientists around the world have performed very extensive and promising work in this field. But still there is room to work in this field due to the following grounds. Synthesis of visible light induced nanophotocatalyst with enhanced activity in a controlled and large production manner to meet the commercial requirements. There is evidence of eco-toxicity of nanoparticles and free radical formation in troposphere. There should be a method for efficient and complete removal of these nanoparticles from treated waste water on commercial scale.

References

[1] S. Parsons. (2004). Advanced Oxidation Processes for Water and Wastewater, IWA Publishing, London, UK.

[2] M.Z. Alam, S. Ahmad., A. Malik and M. Ahmad. (2010). Mutagenicity and genotoxicity of tannery effluents used for irrigation at Kanpur, India. Ecotoxicology and Environmental Safety. 73: 1620–1628.

[3] C. O. Neill, A. Lopez., S. Esteves., F.R. Hawkes., D.L. Hawkes and S. Wilcox. (1999). Azo-dye degradation in an anaerobic-aerobic treatment system operating on simulated textile effluent. Applied Microbiology and Biotechnology. 53: 249–254.

[4] N. Nasuha, B.H. Hameed and A.T.M. Din. (2010). Rejected tea as a potential low-cost adsorbent for the removal of methylene blue, Journal of Hazardous Materials 175: 126-132.

[5] M. A. Rauf, S.M. Qadri, S. Ashraf and K.M. Al-Mansoori. (2009). Adsorption studies of Toluidine Blue from aqueous solutions onto gypsum. Chemical Engineering Journal. 150: 90–95.

[6] V. K. Sharma, G. A. K. Anquandah, R. A. Yngard, H. Kim, J. Fekete, and K. Bouzek. (2009). Nonylphenol, octylphenol, and bisphenol-A in the aquatic environment: A review on occurrence, fate, and treatment. Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering. 44(5): 423.

[7] F. Ge, L. Zhu, and J. Wang. (2008). Distribution of chlorination products of phenols under various pHs in water disinfection. Desalination. 225(1-3): 156.

[8] T. M. Riera, C. Gutierrez-Bouzán and M. Crespi. (2010). Combination of coagulation– flocculation and nanofiltration techniques for dye removal and water reuse in textile effluents. Desalination. 252: 53–59.

[9] A. L. Ahmad and S.W. Puasa. (2007). Reactive dyes decolourization from an aqueous solution by combined coagulation/micellar-enhanced ultrafiltration process. Chemical Engineering Journal. 132: 257–265.

[10] K. Shakir, A.F. Elkafrawy, H.F. Ghoneimy, S.G. Elrab Beheir and M. Refaat. (2010). Removal of rhodamine B (a basic dye) and thoron (an acidic dye) fromdilute aqueous solutions and wastewater simulants by ion flotation. Water Research. 44: 1449 1461.

[11] M. S. Lee, C. Huang, K. R. Lee, J. R. Pan, and W. K. Chang. (2008). Factors affecting phenol transfer through polydimethylsiloxane composite membrane. Desalination. 234(1-3): 416.

[12] H. Jirankova, J. Mrazek, P. Dolecek and J. Cak. (2010). Organic dye removal by combined adsorption–membrane separation process. Desalination and Water Treatment. 20: 96–101.

[13] S. Zodi, O. Potier, F. Lapicque and J. P. Leclerc. (2010). Treatment of the industrial wastewaters by electrocoagulation: optimization of coupled electrochemical and sedimentation processes. Desalination. 261: 186–190.

[14] V. M. Egorov, S. V. Smirnova, and I. V. Pletnev. (2008). Highly efficient extraction of phenols and aromatic amines into novel ionic liquids incorporating quaternary ammonium cation. Separation and Purification Technology. 63(3): 710-715.

[15] R. S. Juang, W. C. Huang, and Y.H. Hsu. (2008). Treatment of phenol in synthetic saline wastewater by solvent extraction and two-phase membrane biodegradation. Journal of Hazardous Materials. 164(1): 46-52.

[16] M. A. Rauf and S.S. Ashraf. (2009). Application of Advanced Oxidation Processes (AOP) to dye degradation—an overview, in: Arnold R. Lang (Ed.), Dyes and Pigments: New Research, Nova Science Publishers, Inc.

[17] L. Ayed, K. Chaieb, A. Cheref and A. Bakhrouf. (2010). Biodegradation and decolorization of triphenylmethane dyes by Staphylococcus epidermidis. Desalination. 260: 137–146.

[18] O. CInar, S. Yasar, M. Kertmen, K. Demiröz, N.O. Yigit and M. Kitis. (2008). Effect of cycle time on biodegradation of azo dye in sequencing batch reactor. Process Safety and Environmental Protection. 86: 455–460.

[19] C. Bouasla, M.E.H. Samar and F. Ismail. (2010). Degradation of methyl violet 6B dye by the Fenton process. Desalination. 254: 35–41.

[20] A. Masarwa, S. Rachmilovich-Calis, N. Meyerstein and D. Meyerstein. (2005). Oxidation of organic substrates in aerated aqueous solutions by the Fenton reagent. Coordination Chemistry Reviews. 249: 1937–1943.

[21] J. M. Monteagudo, A. Duran, I.S. Martin and M. Aguirre. (2010). Catalytic degradation of Orange II in a ferrioxalate-assisted photo-Fenton process using a combined UVA/ C-solar pilot-plant system. Applied Catalysis B: Environmental. 95: 120–129.

[22] N. Modirshahla, M.A. Behnajady and F. Ghanbary. (2007). Decolorization and mineralization of C.I. Acid Yellow 23 by Fenton and photo-Fenton processes, Dyes and Pigments 73: 305–310.

[23] M. A. Rauf, M.A. Meetani, A. Khaleel and A. Ahmed. (2010). Photocatalytic degradation of Methylene Blue using a mixed catalyst and product analysis by LC/MS. Chemical Engineering Journal. 157: 373–378.

[24] R. Xu, J. Li, J. Wang, X. Wang, B. Liu, B. Wang, X. Luan and X. Zhang. (2010). Photocatalytic degradation of organic dyes under solar light irradiation combined with Er^{3+}: $YAlO_3$/Fe- and Co-doped TiO_2 coated composites, Solar Energy Materials and Solar Cells 94: 1157–1165.

[25] A. Vahdat, S.H. Bahrami, M. Arami and A. Motahari. (2010). Decomposition and decoloration of a direct dye by electron beam radiation. Radiation Physics and Chemistry. 79: 33–35.

[26] K. M. Mohamed, A.A. Basfar and A.A. Al-Shahrani. (2009). Gamma-ray induced degradation of diazinon and atrazine in natural groundwaters. Journal of Hazardous Materials. 166: 810–814.

[27] Y. P. Chen, S. Y. Liu, H. Q. Yu, H. Yin and Q. R. Li. (2008). Radiation-induced degradation of methyl orange in aqueous solutions, Chemosphere. 72: 532–536.

[28] S. Merouani, O. Hamdaoui, F. Saoudi and M. Chiha. (2010). Sonochemical degradation of Rhodamine B in aqueous phase: effects of additives. Chemical Engineering Journal. 158: 550–557.

[29] H. Ghodbane and O. Hamdaoui. (2009). Intensification of sonochemical decolorization of anthraquinonic dye Acid Blue 25 using carbon tetrachloride. Ultrasonics Sonochemistry. 16: 455–461.

[30] G. Wang, Y. Qin, J. Cheng and Y. Wang. (2010). Influence of Zn doping on the photocatalytic property of $SrTiO_3$. Journal of Fuel Chemistry and Technology. 38(4): 502-507.

[31] A.R. Tehrani-Bagha, N.M. Mahmoodi and F.M. Menger. (2010). Degradation of a persistent organic dye from colored textile wastewater by ozonation. Desalination. 260: 34–38.

[32] T. M. Elmorsi, Y.M. Riyad, Z.H. Mohamed and H.M.H. Abd El Bary. (2010). Decolorization of Mordant red 73 azo dye in water using H_2O_2/UV and photo-Fenton treatment. Journal of Hazardous Materials. 174: 352–358.

[33] F. H. Alhamedi, M.A. Rauf and S.S. Ashraf. (2009). Degradation studies of Rhodamine B in the presence of UV/H_2O_2. Desalination. 239: 159–166.

[34] M. Stylidi, D.I. Kondarides and X.E. Verykios. (2003). Pathways of solar light-induced photocatalytic degradation of azo dyes in aqueous TiO2 suspensions. Applied Catalysis B: Environmental. 40: 271–286.

[35] U. Diebold. (2003). The surface science of titanium dioxide. Surface Science Reports. 48: 53–229.

[36] Y. B. Xie and X.Z. Li. (2006). Interactive oxidation of photoelectrocatalysis and electro Fenton for azo dye degradation using TiO_2–Ti mesh and reticulated vitreous carbon electrodes. Materials Chemistry and Physics. 95: 39–50.

[37] R. Ullah and D. J. Dutta. (2006). Photocatalytic activities of ZnO nanoparticles synthesized by wet chemical techniques. 2nd International Conference on Emerging Technologies Peshawar, Pakistan. 13-14 November.

[38] I. K. Konstantinou and T.A. Albanis. (2004). TiO_2-assisted photocatalytic degradation of azo dyes in aqueous solution: kinetic and mechanistic investigations: a review. Applied Catalysis B: Environmental. 49: 1–14.

[39] N. M. Mahmoodi, M. Arami, N.Y. Limaee and N.S. Tabrizi. (2006). Kinetics of heterogeneous photocatalytic degradation of reactive dyes in an immobilized TiO_2 photocatalytic reactor. Journal of Colloid and Interface Science. 295: 159–164.

[40] D. Basset, P. Matteazzi and F. Miani. (1993). Designing a high energy ball-mill for synthesis of nanophase materials in large quantities. Materials Science and Engineering, A. 168:149-152.

[41] J. Qiu, H. Shen and M. Gu. (2005). Microwave absorption of nanosized barium ferrite particles prepared using high-energy ball milling. Powder Technology. 154: 116-119.

[42] H. Dutta, M. Sinha, Y. C. Lee and S. K. Pradhan. (2007). Microstructure characterization and phase transformation kinetics of ball milled prepared nanocrystalline Mg-Zn ferrite by Rietveld's analysis and electron microscopy. Materials Chemistry and Physics. 105(1): 31-37.

[43] M. Sinha, H. Dutta and S.K. Pradhan. (2006). X-Ray characterization and phase transformation kinetics of ball-mill prepared nanocrystalline Mg-Zn Ferrite at elevated temperatures. Physica E. 33: 367-369.

[44] L. Zhang, H. Fu, C. Zhang and Y. Zhu . (2006). Synthesis, characterization, and photocatalytic properties of InVO4 nanoparticles. Journal of Solid State Chemistry. 179(3): 804-811.

[45] V. Brezova, Z. Vreckova, P. Billik, M. Caplovicova and G. Plesch. (2009). Photoactivity of mechanochemically prepared nanoparticulate titanium dioxide investigated by EPR spectroscopy. Journal of Photochemistry and Photobiology A: Chemistry. 206(2-3): 177-187.

[46] M. Hojamberdiev, R. M. Prasad, K. Morita, M. A. Schiavon and R. Riedel. (2012). Polymer-derived mesoporous SiOC/ZnO nanocomposite for water decontamination. Microporous and Mesoporous Materials. 151: 330–338.

[47] F. Ji, C. Li, J. Zhang and L. Deng. (2011). Heterogeneous photo-Fenton decolorization of methylene blue over $LiFe(WO_4)_2$ catalyst. Journal of Hazardous Materials. 186(1-3): 1979-1984.

[48] K. Zhang, B. Lin, Y. Chen, B. Xu, X.T. Pian, J. Kuang and B. Li. (2011). Fe-doped and ZnO-pillared titanates as visible-light-driven photocatalysts. Journal of Colloid and Interface Science. 358(2): 360-368.

[49] J. Wang, F. Ren, R. Yi, A. Yan, G. Qiu and X. Liu. (2009). Solvothermal synthesis and magnetic properties of size-controlled nickel ferrite nanoparticles. Journal of Alloys Compounds. 479: 791-796.

[50] C. Xu and A.S. Teja. (2008). Continuous hydrothermal synthesis of iron oxide and PVA-protected iron oxide nanoparticles. Journal of Supercritical Fluids 44: 85-91.

[51] A. S. Teja, L.J. Holm and Y.P. Sun. (2002). Production of Magnetic Oxide Nanoparticles, Supercritical Fluid Technology in Materials Science and Engineering: Synthesis. Properties and Applications. Elsevier: 327-349.

[52] S. Komarneni and H. Katsuki. (2002). Nanophase materials by a novel microwave hydrothermal Process. Pure and Applied Chemistry. 74:1537-1543.

[53] Z. Lei, W. You, M. Liu, G. Zhou, T. Takata, M. Hara, K. Domen and C. Li. (2003). Photocatalytic water reduction under visible light on a novel $ZnIn_2S_4$ catalyst synthesized by hydrothermal method. Chemical Communication. 2142-2143.

[54] Z. Li, B. Hou, Y. Xu, D. Wu and Y. Sun. (2005). Hydrothermal synthesis, characterization, and photocatalytic performance of silica-modified titanium dioxide nanoparticles. Journal of Colloid and Interface Science. 288(1): 149-154.

[55] Li K. W., Y. Wang, H.Wang, M. Zhu and Hui Yan. (2006). Hydrothermal synthesis andphotocatalytic properties of layered $La_2Ti_2O_7$ nanosheets. Nanotechnology. 17: 4863-4867.

[56] S. Miao, Z. Liu, B. Han, H. Yang, Z. Miao and Z. Sun. (2006). Synthesis and characterization of ZnS-montmorillonite nanocomposites and their application for degrading eosin B. Journal of Colloid and Interface Science. 301(1): 116-122.

[57] F. Sayılkan, M. Asilturk, P. Tatar, N. Kiraz, E. Arpaç and H. Sayılkan. (2007). Photocatalytic performance of Sn-doped TiO_2 nanostructured mono and double layer thin for Malachite Green dye degradation under UV and vis-lights. Journal of Hazardous Materials. 144(1-2): 140-146.

[58] D. Jian, P. Gao, W. Cai, B. S. Allimi, S. P. Alpay, Y. Ding, Z. L. Wang and C. Brooks. (2008). Synthesis, characterization, and photocatalytic properties of ZnO/(La,Sr)CoO_3 composite nanorod arrays. Journal of Materials Chemistry. 19: 970-975.

[59] G. Li, S. Ciston, Z. V. Saponjic, L. Chen, N. M. Dimitrijevic, T. Rajh and K. A. Gray. (2008). Synthesizing mixed-phase TiO_2 nanocomposites using a hydrothermal method for photo-oxidation and photoreduction applications. Journal of Catalysis. 253(1): 105-110.

[60] B. Pourabbas and B. Jamshidi. (2008). Preparation of MoS_2 nanoparticles by a modified hydrothermal method and the photo-catalytic activity of MoS_2/TiO_2 hybrids in photo-oxidation of phenol. Chemical Engineering Journal. 138(1-3): 55-62.

[61] S. Tawkaew, M. Chareonpanich and S. Supothina. (2008). Preparation and photocatalytic study of fibrous $K_{0.3}Ti_4O_{7.3}(OH)_{1.7}$–anatase TiO_2 nanocomposite photocatalyst. Materials Chemistry and Physics. 111(2-3): 232-237.

[62] Zhang G., F. He, X. Zou, J. Gong and H. Zhang. (2008). Hydrothermal preparation and photocatalytic properties of sheet-like nanometer niobate $K_4Nb_6O_{17}$. Journal of Physics and Chemistry of Solids, 69(5-6): 1471-1474.

[63] M. Asilturk, F. Sayılkan and E. Arpaç. (2009). Effect of Fe^{3+} ion doping to TiO_2 on the photocatalytic degradation of Malachite Green dye under UV and vis-irradiation. Journal of Photochemistry and Photobiology A: Chemistry. 203(1): 64-71.

[64] C. Zhou, G. Chen, Y. Li, H. Zhang and J. Pei. (2009). Photocatalytic activities of $Sr_2Ta_2O_7$ nanosheets synthesized by a hydrothermal method. International Journal of Hydrogen Energy. 34: 2113-2120.

[65] A. A. Ismail, T. A. Kandiel and D. W. Bahnemann. (2010). Novel (and better) titania-based photocatalysts: Brookite nanorods and mesoporous structures. Journal of Photochemistry and Photobiology A: Chemistry. 216 (2-3): 15.

[66] Y. Jin, L. Yong-kang, L. Yu and L. Jun-ping. (2010). Synthesis and Characterization of Magnetic $TiO_2/SiO_2/NiFe_2O_4$ Composite Photocatalysts. Chemical Research in Chinese Universities. 26(2): 278-282.

[67] W. Liao, T. Zheng, P. Wang, S. Tu and W. Pan. (2010). Efficient microwave-assisted photocatalytic degradation of endocrine disruptor dimethyl phthalate over composite catalyst ZrO_x/ZnO. Journal of Environmental Sciences. 22(11): 1800-1806.

[68] R. A. Shawabkeh, O. A. Khashman and G. I. Bisharat. (2011). Photocatalytic Degradation of Phenol using Fe-TiO2 by Different Illumination Sources. International Journal of Chemistry. 2(2): 10-18.

[69] S. Gao, X. Jia, S. Yang, Z. Li and K. Jiang . (2011). Hierarchical Ag/ZnO micro/nanostructure: Green synthesis and enhanced photocatalytic performance. Journal of Solid State Chemistry, 184(4): 764-769.

[70] H. Guo, J. Chen, W. Weng and S. Li. (2011). Hydrothermal synthesis of C-doped $Zn_3(OH)_2V_2O_7$ nanorods and their photocatalytic properties under visible light illumination. Applied Surface Science, 257(9): 3920-3923.

[71] H. Guo, K. Lin, Z. Zheng, F. Xiao and S. Li. (2011). Sulfanilic acid-modified P25 TiO_2 nanoparticles with improved photocatalytic degradation on Congo red under visible light. Dyes and Pigments. 92(3): 1278-1284.

[72] Z. He and H.Y. He. (2011). Synthesis and photocatalytic property of N-doped TiO_2 nanorods and nanotubes with high nitrogen content. Applied Surface Science. 258(1-2): 972-976.

[73] S. B. Khan, M. Faisal, M. M. Rahman and A. Jamal. (2011). Exploration of CeO_2 nanoparticles as a chemi-sensor and photo-catalyst for environmental applications. Science of The Total Environment. 409(15): 2987-2992.

[74] E. Kowsari and M. R. Ghezelbash. (2012). Ionic liquid-assisted, facile synthesis of ZnO/SnO_2 nanocomposites, and investigation of their photocatalytic activity. Material Letters68: 17–20.

[75] P. Madhusudan, J. Ran, J. Zhang, J. Yu and G. Liu. (2011). Novel urea assisted hydrothermal synthesis of hierarchical $BiVO_4/Bi_2O_2CO_3$ nanocomposites with enhanced visible-light photocatalytic activity. Applied Catalysis B: Environmental. 110: 286-295.

[76] T. Putta, M. Lu and J. Anotai. (2011). Photocatalytic activity of tungsten-doped TiO_2 with hydrothermal treatment under blue light irradiation. Journal of Environmental Management. 92(9): 2272-2276.

[77] L. Sun, D. Zhao, Z. Song, C. Shan, Z. Zhang, B. Li and D. Shen. (2011). Gold nanoparticles modified ZnO nanorods with improved photocatalytic activity. Journal of Colloid and Interface Science. 363(1): 175-181.

[78] Y. Tang, V. P. Subramaniam, T. H. Lau, Y. Lai, D. Gong, P. D. Kanhere, Y. H. Cheng, Z. Chen and Zhili Dong. (2011). In situ formation of large-scale Ag/AgCl nanoparticles on layered titanate honeycomb by gas phase reaction for visible light degradation of phenol solution. Applied Catalysis B: Environmental. 106 (3-4): 577-585.

[79] S. Wang and S. Zhou. (2011). Photodegradation of methyl orange by photocatalyst of CNTs/P-TiO_2 under UV and visible-light irradiation. Journal of Hazardous Materials. 185(1): 77-85.

[80] R. Wang, D. Xu, J. B. Liu, K.W. Li and H. Wang. (2011). Preparation and photocatalytic properties of $CdS/La_2Ti_2O_7$ nanocomposites under visible light. Chemical Engineering Journal. 168(1): 455-460.

[81] W. Xue, G. Zhang, X. Xu, X. Yang, C. Liu and Y. Xu. (2011). Preparation of titania nanotubes doped with cerium and their photocatalytic activity for glyphosate. Chemical Engineering Journal. 167(1): 397-402.

[82] Y. C. Zhang, Z. N. Du, K. W. Li and M. Zhang. (2011). Size-controlled hydrothermal synthesis of SnS_2 nanoparticles with high performance in visible light-driven photocatalytic degradation of aqueous methyl orange. Separation and Purification Technology. 81(1): 101-107.

[83] C. J. Brinker, and C.W. Scherer. (1990). Sol–Gel Science. Academic Press. San Diego, CA.

[84] L. V. Interrante, and M.J. Hampden-Smith. (1998). Chemistry of Advanced Materials — An Overview. Wiley-VCH. New York.

[85] X.Z. Li, F.B. Li, C.L. Yang and W.K. Ge. (2001). Photocatalytic activity of WOx-TiO_2 under visible light irradiation. Journal of Photochemistry and Photobiology A: Chemistry. 141: 209–217.

[86] Z. Sun, Y. Chen, Q. Ke, Y. Yang and J. Yuan. (2002). Photocatalytic degradation of a cationic azo dye by TiO_2/bentonite nanocomposite. Journal of Photochemistry and Photobiology A: Chemistry. 14(1-3): 169-174.

[87] R. Kun, K. Mogyorosi and I. Dekany. (2006). Synthesis and structural and photocatalytic properties of TiO_2/montmorillonite nanocomposites. Applied Clay Science. 32(1-2): 99-110.

[88] Y. Lin, S. Tseng, W. Huang and W. Wu. (2006). Enhanced Photocatalysis of Pentachlorophenol by Metal-Modified Titanium (IV) Oxide. Journal of Environmental Science and Health, Part B. 41(7): 1143-1158.

[89] A. V. Rupa, D. Manikandan, D. Divakar and T. Sivakumar. (2007). Effect of deposition of Ag on TiO_2 nanoparticles on the photodegradation of Reactive Yellow-17. Journal of Hazardous Materials. 147(3): 906-913.

[90] X. Yu, Y. Guo, L. Xu, X. Yang and Y. Guo. (2008). A novel preparation of mesoporous $Cs_xH_{3-x}PW_{12}O_{40}/TiO_2$ nanocomposites with enhanced photocatalytic activity. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 316(1-3): 110-118.

[91] Z. M. El-Bahy, A. A. Ismail and R. M. Mohamed. (2009). Enhancement of titania by doping rare earth for photodegradation of organic dye (Direct Blue). Journal of Hazardous Materials. 166(1): 138-143.

[92] A. Hameed, V. Gombac, T. Montini, L. Felisari and P. Fornasiero. (2009). Photocatalytic activity of

zinc modified Bi_2O_3. Chemical Physics Letters, 483(4-6): 483(4-6): 254-261.

[93] A. K. L. Sajjad, S. Shamaila, B. Tian, F. Chen and J. Zhang. (2009). One step activation of WO_x/TiO_2 nanocomposites with enhanced photocatalytic activity. Applied Catalysis B: Environmental. 91(1-2): 3097405.

[94] H. Liu, L. Yu,W. Chen, and Y. Li. (2012). The Progress of TiO_2 Nanocrystals Doped with Rare Earth Ions. Journal of Nanomaterials. Article ID 235879. 1-9.

[95] C. Madhu, M. B. Bellakki and V. Manivannan. (2010). Synthesis and characterization of cation-doprd $BiFO_3$ materials for photocatalytic applications. Indian Journal of Engineering & Material Sciences. 17: 131-139.

[96] A. Nilchi, S. Janitabar-Darzi, A.R. Mahjoub and S. Rasouli-Garmarodi. (2010). New TiO_2/SiO_2 nanocomposites Phase transformations and photocatalytic studies. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 361(1-3): 25-30.

[97] X. Yang, F. Ma, K. Li, Y. Guo, J. Hu, W. Li, M. Huo and Y. Guo. (2010). Mixed phase titania nanocomposite codoped with metallic silver and vanadium oxide: New efficient photocatalyst for dye degradation. Journal of Hazardous Materials. 175(1-3): 429-438.

[98] D. Zhang and F. Zeng. (2010). Structural, photochemical and photocatalytic properties of zirconium oxide doped TiO_2 nanocrystallites. Applied Surface Science, 257(3): 867-871.

[99] S. Zhongliang, L. Fumei and Y. Shuhua. (2010). Preparation and photocatalytic activity of B, Y co-doped nanosized TiO_2 catalyst. Journal Of Rare Earths. 28(5): 737-741.

[100] V. J. Babu, A. S. Nair, Z. Peining and S. Ramakrishna. (2011). Synthesis and characterization of rice grains like Nitrogen-doped TiO_2 nanostructures by electrospinning–photocatalysis. Materials Letters. 65(19-20): 3064-3068.

[101] M. A. Behnajady, H. Eskandarloo, N. Modirshahla and M. Shokri. (2011). Investigation of the effect of sol–gel synthesis variables on structural and photocatalytic properties of TiO_2 nanoparticles. Desalination. 278(1-3): 10-17.

[102] K. Chen, J. Li , W. Wang, Y. Zhang, X. Wang and H. Su. (2011). The preparation of vanadium-doped TiO_2–montmorillonite nanocomposites and the photodegradation of sulforhodamine B under visible light irradiation. Applied Surface Science. 257(16): 7276-7285.

[103] E. Costa, P. P. Zamora and A. J.G. Zarbin. (2011). Novel TiO_2/C Nanocomposites: Synthesis, Characterization and Application as a Photocatalyst for the Degradation of Organic Pollutants. Journal of Colloid and Interface Science. 368(1): 121-127.

[104] J. Deng, S. Banerjee, S. K. Mohapatra, Y. R. Smith, and M. Misra. (2011). Bismuth Iron Oxide Nanoparticles as Photocatalyst for Solar Hydrogen Generation from Water. Journal of Fundamentals of Renewable Energy and Applications. 1: 1-10.

[105] A. Eshaghi, R. Mozaffarinia, M. Pakshir and A. Eshaghi. (2011). Photocatalytic properties of TiO2 sol–gel modified nanocomposite films. Ceramics International. 37(1): 327-331.

[106] D. Y. Lee, B. Kim, N. I. Cho and Y. Oh. (2011). Electrospun Er^{3+}–TiO_2 nanofibrous films as visible light induced photocatalysts. Current Applied Physics. 11(3): Supplement S324-S327.

[107] K. Loganathan, P. Bommusamy, P. Muthaiahpillai and M. Velayutham. (2012). The Syntheses, Characterizations, and Photocatalytic Activities of Silver, Platinum, and Gold Doped TiO_2 Nanoparticles. Environmental Enggering Research. 16(2): 81-90.

[108] N. Lu, Y. Zhao, H. Xu, Y. Guo, X. Yuan , H. Peng and H. Qin. (2012). Design of polyoxometallate-titania composite film ($H_3PW_{12}O_{40}/TiO_2$) for the degradation of an aqueous dye Rhodamine B under the simulated sunlight irradiation. Journal of Hazardous Materials. 200: 1-8

[109] Y. Lv, L. Yu, X. Zhang, J. Yao, R. Zou and Z. Dai. (2011). P-doped TiO_2 nanoparticles film coated on ground glass substrate and the repeated photodegradation of dye under solar light irradiation.Applied Surface Science. 257(13): 5715-5719.

[110] X. Niu, S. Li, H. Chu and J. Z. Hou. (2011). Preparation, characterization of Y^{3+}-doped TiO_2 nanoparticles and their photocatalytic activities for methyl orange degradation. Journal of Rare Earths. 29(3): 225-229.

[111] H. Salavati, N. Tavakkoli and M. Hosseinpoor. (2012). Preparation and characterization of polyphosphotungstate/ZrO_2 nanocomposite and their sonocatalytic and photocatalytic activity under UV light illumination. Ultrasonics Sonochemistry, 19(3): 546-553.

[112] H. Shi, T. Zhang and H. Wang. (2011). Preparation and photocatalytic activity of La^{3+} and Eu^{3+} co-doped TiO_2 nanoparticles: photo-assisted

degradation of methylene blue. Journal of Rare Earths. 29(8): 746-752.

[113] D. Wang, L. Xiao, Q. Luo, X. Li, J. An and Y. Duan. (2011). Highly efficient visible light TiO_2 photocatalyst prepared by sol–gel method at temperatures lower than 300 °C. Journal of Hazardous Materials. 192(1): 150-159.

[114] Y. Wang, K. LU and C. Feng. (2011). Photocatalytic degradation of methyl orange by polyoxometalates supported on yttrium-doped TiO_2. Journal of Rare Earths, 29(9): 866-871.

[115] Q. Wu and S. Li. (2011). Synthesis of TiO_2/Al-MCM-41 Composites with Coal-Measure Kaolin and Performance in Its Photocatalysis.Materials Sciences and Applications, 2: 14-19.

[116] X. Yang, L. Zhu, L. Yang, W. Zhou and Y. Xu. (2011). Preparation and photocatalytic activity of neodymium doping titania loaded to silicon dioxide. Transactions of Nonferrous Metals Society of China. 21(2): 335-339.

[117] M. Faraji, Y. Yamini and M. Rezaee. (2010). Magnetic Nanoparticles: Synthesis, Stabilization, Functionalization, Characterization, and Applications. Journal of Iranian Chemical Socity. 7(1): 1-37.

[118] Y. Abdollahi, A. H. Abdullah, Z. Zainal and N. A. Yusof. (2011). Synthesis and characterization of Manganese doped ZnO Nanoparticles. International Journal of Basic & Applied Sciences. 11(4): 62-68.

[119] S. S. Srinivasan, J. Wade and E. K. Stefanakos. (2006). Synthesis and Characterization of Photocatalytic TiO_2-$ZnFe_2O_4$ Nanoparticles. Journal of Nanomaterials Article ID 87326: 1–4.

[120] N. Wang, J. Li, L. Zhu , Y. Dong and H. Tang. (2008). Highly photocatalytic activity of metallic hydroxide/titanium dioxide nanoparticles prepared via a modified wet precipitation process. Journal of Photochemistry and Photobiology A: Chemistry. 198(2-3): 282-287.

[121] H. Xia, H. Zhuang, T. Zhang and D. Xiao. (2008). Visible-light-activated nanocomposite photocatalyst of Fe_2O_3/SnO_2. Materials Letters, 62(6-7): 1126-1128.

[122] A. Hameed, V. Gombac, T. Montini, M. Graziani and P. Fornasiero. (2009). Synthesis, characterization and photocatalytic activity of NiO–Bi_2O_3 nanocomposites. Chemical Physics Letters. 472(4-6) 212-216.

[123] S. Yuan, Y. Li, Q. Zhang and H. Wang. (2009). ZnO nanorods decorated calcined Mg–Al layered double hydroxides as photocatalysts with a high adsorptive capacity. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 348(1-3): 76-81.

[124] B. Li and Y. Wang. (2010). Facile synthesis and photocatalytic activity of ZnO–CuO nanocomposite. Superlattices and Microstructures. 47(5): 615-623.

[125] H. R. Pouretedal and M. H. Keshavarz. (2010). Synthesis and characterization of $Zn_{1-X}Cu_XS$ and $Zn_{1-X}Ni_XS$ nanoparticles and their applications as photocatalyst in Congo red degradation. Journal of Alloys and Compounds. 501(1): 130-135.

[126] A. K. L. Sajjad, S. Shamaila, B. Tian, F. Chen and J. Zhang. (2010). Comparative studies of operational parameters of degradation of azo dyes in visible light by highly efficient WO_x/TiO_2 photocatalyst. Journal of Hazardous Materials. 177(1-3): 781-791.

[127] Z. Yang, X. Gong and C. Zhang. (2010). Recyclable Fe_3O_4/hydroxyapatite composite nanoparticles for photocatalytic applications. Chemical Engineering Journal. 165(1): 117-121.

[128] G. Fan, W. Sun, H. Wang and F. Li. (2011). Visible-light-induced heterostructured Zn–Al–In mixed metal oxide nanocomposite photocatalysts derived from a single precursor. Chemical Engineering Journal. 174(1): 467-474.

[129] M. G. Nair, M. Nirmala, K. Rekha and A. Anukaliani. (2011). Structural, optical, photo catalytic and antibacterial activity of ZnO and Co doped ZnO nanoparticles. Materials Letters. 65(12): 1797-1800.

[130] D. Pathania, Sarita and B. S. Rathore. (2011). Synthesis, characterization and photocatalytic application of bovine serum albumin capped cadmium sulphide nanopartilces. Chalcogenide latters. 8(6): 396-404.

[131] K. K. Senapati, C. Borgohain, K. C. Sarma and P. Phukan. (2011). Photocatalytic degradation of methylene blue in water using $CoFe_2O_4$–Cr_2O_3–SiO_2 fluorescent magnetic nanocomposite. Journal of Molecular Catalysis A: Chemical. 346(1-2): 111-116.

[132] C. Wang, H. Shi and Y. Li. (2011). Synthesis and characteristics of natural zeolite supported Fe^{3+}-TiO_2 photocatalysts. Applied Surface Science. 257(15): 6873-6877.

[133] S. Santra, R. Tapec, N. Theodoropoulou, J. Dobson, A. Hebard and W. Tan. (2001). Synthesis and Characterization of Silica-Coated Iron Oxide Nanoparticles in Microemulsion: The Effect of

Nonionic Surfactants. Langmuir. 17(10): 2900-2906.

[134] J. A. L. Perez, M.A. Lopez Quintela, J. Mira, J. Rivas and S.W. Charles. (1997). Advances in the Preparation of Magnetic Nanoparticles by the Microemulsion Method. Journal of Physical Chemistry: B. 101(41): 8045-8047.

[135] S. S. Srinivasan, J. Wade and E. K. Stefanakos. (2006). Visible Light Photocatalysis via CdS/TiO_2 NanocompositeMaterials. Journal of Nanomaterials Article ID 87326: 1–7.

[136] Y. Xiaodan, W. Qingyin, J. Shicheng and G. Yihang. (2006). Nanoscale ZnS/TiO_2 composites: Preparation, characterization, and visible-light photocatalytic activity. Materials Characterization. 57(4-5): 333-341.

[137] A. Zielinska, E. Kowalska, J. W. Sobczak, I. Lącka, M. Gazda, B. Ohtani, J. Hupka and A. Zaleska. (2010). Silver-doped TiO_2 prepared by microemulsion method: Surface properties, bio- and photoactivity. Separation and Purificati.on Technology. 72(3): 309-318.

[138] N. Ghows and M. H. Entezari. (2011). Exceptional catalytic efficiency in mineralization of the reactive textile azo dye (RB5) by a combination of ultrasound and core–shell nanoparticles (CdS/TiO_2). Journal of Hazardous Materials, 195: 132-138.

[139] H. Liu, G. Liu and X. Shi. (2010). N/Zr-codoped TiO_2 nanotube arrays: Fabrication, characterization, and enhanced photocatalytic activity. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 363(1-3): 35-40.

[140] J. Liu, X. Li, S. Zuo and Y. Yu. (2007). Preparation and photocatalytic activity of silver and TiO_2 nanoparticles/montmorillonite composites. Applied Clay Science. 37(3-4): 275-280.

[141] R. Tongpool and K. Setwong. (2008). Sulfur doping and its effect on TiO_2 photoactivity. Songklanakarin Journal of Science and Technology. 30(2): 201-206.

[142] D. R. Liu, C. D. Wei, B. Xue, X.G. Zhang and Y.S. Jiang. (2010). Synthesis and photocatalytic activity of N-doped NaTaO3 compounds calcined at low temperature. Journal of Hazardous Materials, 182(1-3): 50-54.

[143] M. M. Curri, R. Comparelli, P.D. Cozzoli, G. Mascolo and A. Agostiano. (2003). Colloidal oxide nanoparticles for the photocatalytic degradation of organic dye. Materials Science and Engineering: C. 23(1-2): 285-289.

[144] J. Moona, C. Y. Yun and K. Chungb, M. Kang and J. Yi. 2003. Photocatalytic activation of TiO_2 under visible light using Acid Red 44. Catalysis Today. 87: 77–86.

[145] O. S. N. Sum, J. Feng, X. Hu and P. L. Yue. (2004). Pillared laponite clay-based Fe nanocomposites as heterogeneous catalysts for photo-Fenton degradation of acid black 1. Chemical Engineering Science. 59(22-23): 5269-5275.

[146] J. Klongdee, W. Petchkroh, K. Phuempoonsathaporn, P. Praserthdam, A. S. Vangnai and V. Pavarajarn. (2005). Activity of nanosized titania synthesized from thermal decomposition of titanium (IV) n-butoxide for the photocatalytic degradation of diuron. Science and Technology of Advanced Materials. 6(3-4): 290-295.

[147] Z. Liu, B. Guo, L. Hong and H. Jiang. (2005). Physicochemical and photocatalytic characterizations of TiO_2/Pt nanocomposites. Journal of Photochemistry and Photobiology A: Chemistry. 172(1): 81-88.

[148] T. Xu, C. Zhang, X. Shao, K. Wu, and Y. Zhu. (2006). Monomolecular-Layer $Ba_5Ta_4O_{15}$ Nanosheets: Synthesis and Investigation of Photocatalytic Properties. Advance Functional Materials. 16: 1599-1607.

[149] G. Mascolo, R. Comparelli, M.L. Curri, G. Lovecchio, A. Lopez and A. Agostiano. (2007). Photocatalytic degradation of methyl red by TiO_2: Comparison of the efficiency of immobilized nanoparticles versus conventional suspended catalyst. Journal of Hazardous Materials, 142(1-2): 130-137.

[150] R. Albuquerque, Márcia., Neves, M. H. Mendonça, T. Trindade and O. C. Monteiro. (2008). Adsorption and catalytic properties of SiO_2/Bi_2S_3 nanocomposites on the methylene blue photodecolorization process. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 328(1-3): 107-113.

[151] M. A. Behnajady, N. Modirshahla, M. Shokri and B. Rad. (2008). Enhancement Of Photocatalytic Activity Of TiO_2 Nanoparticles By Silver Doping: Photodeposition Versus Liquid Impregnation Methods. Global NEST Journal, 10(1): 1-7.

[152] Y. D. Hou, X.C. Wang, L. Wu, X.F. Chen, Z.X. Ding, X.X. Wang and X.Z. Fu. (2008). N-Doped SiO_2/TiO_2 mesoporous nanoparticles with enhanced photocatalytic activity under visible-light irradiation. Chemosphere. 72(3): 414-421.

[153] Y. Jiang, Y. Sun, H. Liu, F. Zhu and H. Yin. (2008). Solar photocatalytic decolorization of C.I. Basic Blue 41 in an aqueous suspension of TiO_2–ZnO. Dyes and Pigments. 78(1): 77-83.

[154] K. M. Parida and N. Sahu. (2008). Visible light induced photocatalytic activity of rare earth titania nanocomposites. Journal of Molecular Catalysis A: Chemical. 287(1-2): 151-158.

[155] B. M. Uzunova, R. Todorovska, D. Dimitrov and D. Todorovsky. (2008). Lanthanide-doped titanium dioxide layers as photocatalysts. Applied Surface Science. 254(22): 7296-7302.

[156] A. Franco, M.C. Neves, M. M. L. R. Carrott, M.H. Mendonça, M.I. Pereira and O.C. Monteiro. (2009). Photocatalytic decolorization of methylene blue in the presence of TiO_2/ZnS nanocomposites. Journal of Hazardous Materials. 161(1): 545-550.

[157] H. Huang, X. Gu, J. Zhou, K. Ji, H. Liu and Y. Feng. (2009). Photocatalytic degradation of Rhodamine B on TiO_2 nanoparticles modified with porphyrin and iron-porphyrin. Catalysis Communications. 11(1): 58-61.

[158] C. Liu, T.Y. Yang, C.H. Wang, C.C. Chien, S.T. Chen, C.L. Wang, W.H. Leng, Y. Hwu , H.M. Lin, Y.C. Lee, C.L. Cheng, J.H. Je and G. Margaritondo. (2009). Enhanced photocatalysis, colloidal stability and cytotoxicity of synchrotron X-ray synthesized Au/TiO_2 nanoparticles. Materials Chemistry and Physics, 117(1): 74-79.

[159] P. Pawinrat, O. Mekasuwandumrong and J. Panpranot. (2009). Synthesis of Au–ZnO and Pt–ZnO nanocomposites by one-step flame spray pyrolysis and its application for photocatalytic degradation of dyes. Catalysis Communications, 10(10): 1380-1385.

[160] V. Stengl, S. Bakardjieva and N. Murafa. (2009). Preparation and photocatalytic activity of rare earth doped TiO_2 nanoparticles. Materials Chemistry and Physics, 114(1): 217-226.

[161] S. D. Wang, J. Zhang, Q. Luo, X. Li, Y. Duan and J. An. (2009). Characterization and photocatalytic activity of poly(3-hexylthiophene)-modified TiO2 for degradation of methyl orange under visible light. Journal of Hazardous Materials, 169(1-3): 546-550.

[162] L. S. Wang, M. W. Xiao, X. J. Huang and Y. D. Wu. (2009). Synthesis, characterization, and photocatalytic activities of titanate nanotubes surface-decorated by zinc oxide nanoparticles. Journal of Hazardous Materials. 161(1): 49-54.

[163] Z. Wang, C. Chen, F. Wu, B. Zou, M. Zhao, J. Wang and C. Feng. (2009). Photodegradation of rhodamine B under visible light by bimetal codoped TiO_2 nanocrystals. Journal of Hazardous Materials. 164(2-3): 615-620.

[164] Q. Yuan, Y. Liu, L. Li, Z.X. Li, C.J. Fang, W.T. Duan, X.G. Li and C.H. Yan. (2009). Highly ordered mesoporous titania–zirconia photocatalyst for applications in degradation of rhodamine-B and hydrogen evolution. Microporous and Mesoporous Materials. 124(1-3): 169-178.

[165] H. Zhu, R. Jianga, L. Xiaob, Y. Changb, Y. Guana, X. Li and G. Zeng. (2009). Photocatalytic decolorization and degradation of Congo Red on innovative crosslinked chitosan/nano-CdS composite catalyst under visible light irradiation. Journal of Hazardous Materials. 169: 933-940.

[166] H.W. Choi, E. J. Kim and S. H. Hahn. (2010). Photocatalytic activity of Au-buffered WO_3 thin films prepared by RF magnetron sputtering. Chemical Engineering Journal. 161(1-2): 285-288.

[167] Z. He, Y. Li, Q. Zhang and H. Wang. (2010). Capillary microchannel-based microreactors with highly durable ZnO/TiO_2 nanorod arrays for rapid, high efficiency and continuous-flow photocatalysis.Applied Catalysis B: Environmental. 93(3-4): 376-382.

[168] S. Z. Kang, T. Wu, X. Li and J. Mu. (2010). A facile gelatin-assisted preparation and photocatalytic activity of zinc oxide nanosheets. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 369(1-3): 268-271.

[169] O. Mekasuwandumrong, P. Pawinrat, P. Praserthdam and J. Panpranot. (2010). Effects of synthesis conditions and annealing post-treatment on the photocatalytic activities of ZnO nanoparticles in the degradation of methylene blue dye. Chemical Engineering Journal. 164(1): 77-84.

[170] C. Ren, B. Yang, M. Wu, J. Xu, Z. Fu, Y. lv, T. Guo, Y. Zhao and C. Zhu. (2010). Synthesis of Ag/ZnO nanorods array with enhanced photocatalytic performance. Journal of Hazardous Materials. 182(1-3): 123-129.

[171] H. Shu, J. Xie, H. Xu, H. Li, Z. Gu, G. Sun and Y. Xu. (2010). Structural characterization and photocatalytic activity of NiO/$AgNbO_3$. Journal of Alloys and Compounds, 496(1-2): 633-637.

[172] Zhai J., X. Tao, Y. Pu, X. F. Zeng and J. F. Chen. (2010). Core/shell structured ZnO/SiO_2 nanoparticles: Preparation, characterization and photocatalytic property. Applied Surface Science, 257(2): 393-397.

[173] L. Andronic, L. Isac and A. Duta. (2011). Photochemical synthesis of copper sulphide/titanium oxide photocatalyst. Journal of Photochemistry and Photobiology A: Chemistry. 221(1): 30-37.

[174] M. El-Kemary, Y. Abdel-Moneam, M. Madkour and I. El-Mehasseb. (2011). Enhanced photocatalytic degradation of Safranin-O by heterogeneous nanoparticles for environmental applications. Journal of Luminescence, 131(4): 570-576.

[175] H. Fan, C. Lu, W. W. Lee, M. Chiou and C. Chen. (2011). Mechanistic pathways differences between P25-TiO_2 and Pt-TiO_2 mediated CV photodegradation. Journal of Hazardous Materials. 185(1): 227-235.

[176] X. Feng, X. Qi, J. Li, L. Yang, M. Qiu, J. Yin, F. Lu and J. Zhong. (2011). Preparation, structure and photo-catalytic performances of hybrid Bi_2SiO_5 modified Si nanowire arrays. Applied Surface Science. 257(13): 5571-5575.

[177] J. Gong, C. Yang, W. Pu and J. Zhang. (2011). Liquid phase deposition of tungsten doped TiO_2 films for visible light photoelectrocatalytic degradation of dodecyl-benzenesulfonate. Chemical Engineering Journal. 167(1): 190-197.

[178] J. F. Guo, B. Ma, A. Yin, K. Fan and W. L. Dai. (2011). Photodegradation of rhodamine B and 4-chlorophenol using plasmonic photocatalyst of Ag–AgI/Fe_3O_4.SiO_2 magnetic nanoparticle under visible light irradiation. Applied Catalysis B: Environmental. 101(3-4): 580-586.

[179] Karunakaran A., V. Rajeswari and P. Gomathisankar. (2011). Optical, electrical, photocatalytic, and bactericidal properties of microwave synthesized nanocrystalline Ag–ZnO and ZnO. Solid State Sciences, 13(5): 923-928.

[180] C. Li, R. Chen, X. Zhang, S. Shu, J. Xiong, Y. Zheng and W. Dong. (2011). Electrospinning of CeO_2–ZnO composite nanofibers and their photocatalytic property. Materials Letters. 65(9): 1327-1330.

[181] J. Luan, M. Li, K. Ma, Y. Li and Z. Zou. (2011). Photocatalytic activity of novel Y_2InSbO_7 and Y_2GdSbO_7 nanocatalysts for degradation of environmental pollutant rhodamine B under visible light irradiation. Chemical Engineering Journal. 167(1): 162-171.

[182] K. Lv, J. Li, X. Qing, W. Li and Q. Chen. 2011. Synthesis and photo-degradation application of WO_3/TiO_2 hollow spheres. Journal of Hazardous Materials. 189(1-2): 32-335.

[183] A. Nezamzadeh-Ejhieh and Z.h Banan. (2012). Sunlight assisted photodecolorization of crystal violet catalyzed by CdS nanoparticles embedded on zeolite A. Desalinatin. 284: 157-166.

[184] H. Pang, Y. Li, L. Guan, Q. Lu and F. Gao. (2011). TiO_2/Ni nanocomposites: Biocompatible and recyclable magnetic photocatalysts. Catalysis Communications. 12(7): 611-615.

[185] B. Pare, B. Sarwan and S.B. Jonnalagadda. (2011). Photocatalytic mineralization study of malachite green on the surface of Mn-doped BiOCl activated by visible light under ambient condition. Applied Surface Science. 258(1): 247-253.

[186] P. Sathishkumar, R. Sweena, J. J. Wu and S. Anandan. (2011). Synthesis of CuO-ZnO nanophotocatalyst for visible light assisted degradation of a textile dye in aqueous solution. Chemical Engineering Journal. 171(1): 136-140.

[187] S. Shamaila, A. Khan L. Sajjad, F. Chen and J. Zhang. (2011). WO_3/BiOCl, a novel heterojunction as visible light photocatalyst. Journal of Colloid and Interface Science. 356(2): 465-472.

[188] D. Sharma, S. Sharma, B.S. Kaith, J. Rajput and M. Kaur. (2011). Synthesis of ZnO nanoparticles using surfactant free in-air and microwave method. Applied Surface Science. 257(22): 9661-9672.

[189] S. Song, F. Hong, Z. He, H. Wang, X. Xu and J. Chen. (2011). Influence of zirconium doping on the activities of zirconium and iodine co-doped titanium dioxide in the decolorization of methyl orange under visible light irradiation. Applied Surface Science. 257(23): 10101-10108.

[190] S. Swetha and R. G. Balakrishna. (2011). Preparation and Characterization of High Activity Zirconium-Doped Anatase Titania for Solar Photocatalytic Degradation of Ethidium Bromide. Chinese Journal of Catalysis. 32(5): 789-794.

[191] R. Wahab, I.H. Hwang, Y.S. Kim, J. Musarrat, M.A. Siddiqui, H.K. Seo, S. K. Tripathy and H. S. Shin. (2011). Non-hydrolytic synthesis and photo-catalytic studies of ZnO nanoparticles. Chemical Engineering Journal. 175: 450-457.

[192] J. Wang, X.M. Fan, Z.W. Zhou, and K. Tian. (2011). Preparation of Ag nanoparticles coated tetrapod-like ZnO whisker photocatalysts using photoreduction. Materials Science and Engineering: B. 176(13): 978-983.

[193] J. Wang, X.M. Fan, D.Z. Wu, J. Dai, H. Liu, H.R. Liu and Z.W. Zhou. (2011). Fabrication of CuO/T-ZnOW nanocomposites using photo-

deposition and their photocatalytic property. Applied Surface Science. 258(5): 1797-1805.

[194] Z. Wang, S. Zhu, S. Zhao and H. Hu. (2011). Synthesis of core–shell $Fe_3O_4SiO_2MS$ (M = Pb, Zn, and Hg) microspheres and their application as photocatalysts. Journal of Alloys and Compounds. 509(24): 6893-6898.

[195] J. Xia, A. Wang, X. Liu and Z. Su. (2011). Preparation and characterization of bifunctional, Fe_3O_4/ZnO nanocomposites and their use as photocatalysts. Applied Surface Science, 257(23): 9724-9732.

[196] Y. Yan, H. Sun, P. Yao, S. Z. Kang and J. Mu. (2011). Effect of multi-walled carbon nanotubes loaded with Ag nanoparticles on the photocatalytic degradation of rhodamine B under visible light irradiation. Applied Surface Science. 257(8): 3620-3626.

[197] D. Zhang, X. Liu and X. Wang. (2011). Growth and photocatalytic activity of ZnO nanosheets stabilized by Ag nanoparticles. Journal of Alloys and Compounds. 509(15): 4972-4977.

[198] L. Zhang, Y. He, Y. Wu and T. Wu. (2011). Photocatalytic degradation of RhB over $MgFe_2O_4/TiO_2$ composite materials. Materials Science and Engineering: B. 176(18): 1497-1504.

[199] Y. Zhang, Y. Guo, G. Zhang and Y. Gao. (2011). Stable TiO_2/rectorite: Preparation, characterization and photocatalytic activity. Applied Clay Science. 51(3): 335-340.

[200] M. A. Rauf, S. Ashraf and S.N. Alhadrami. (2005). Photolytic oxidation of Co-omassie BrilliantBlue with H_2O_2, Dyes and Pigments. 66: 197–200.

[201] M. H. Habibi and N. Talebian. (2007). Photocatalytic degradation of an azo dye X6G in water: a comparative study using nanostructured indium tin oxide and titanium oxide thin films, Dyes and Pigments. 73 (2007) 186–194.

[202] B. Yue, Y. Zhou, J. Xu, Z. Wu, X. Zhang, Y. Zou and S. Jin. (2002). Photocatalytic degradation of aqueous 4-chlorophenol by silica-immobilized polyoxometalates. Environmental Science & Technology. 36: 1325–1329.

[203] J. Saien and A.R. Soleymani. (2007). Degradation and mineralization of Direct Blue 71 in a circulating up flow reactor by UV/TiO_2 process and employing a new method in kinetic study. Journal of Hazardous Materials. 144: 506–512.

[204] N. M. Mahmoodi, M. Arami, N.Y. Limaee and N.S. Tabrizi. (2006). Kinetics of heterogeneous photocatalytic degradation of reactive dyes in an immobilized TiO_2 photocatalytic reactor. Journal of Colloid and Interface Science. 295: 159–164.

[205] M.N. Chong, B. Jin, C.W.K. Chow and C. Saint. (2010). Recent developments in photocatalytic water treatment technology: a review. Water Research. 44: 2997–3027.

[206] M.A. Rauf and S.S. Ashraf. (2009). Application of Advanced Oxidation Processes (AOP) to dye degradation—an overview, in: Arnold R. Lang (Ed.), Dyes and Pigments: New Research, Nova Science Publishers, Inc.

[207] J. Sun, L. Qiao, S. Sun and G. Wang. (2008). Photocatalytic degradation of Orange G on nitrogen-doped TiO_2 catalysts under visible light and sunlight irradiation. Journal of Hazardous Materials 155: 312–319.

[208] M. A. Rauf, M.A. Meetani and S. Hisaindee. (2011). An overview on the photocatalytic degradation of azo dyes in the presence of TiO_2 doped with selective transition metals. Desalination. 276(1-3): 13-27.

[209] X. Wang, Z. Yao, J. Wang, W. Guo and G. Li. (2008). Degradation of reactive brilliant red in aqueous solution by ultrasonic cavitation. Ultrasonics Sonochemistry. 15: 43–48.

[210] M. A. Behnajady, N. Modirshahla, M. Shokri and B. Rad. (2008). Enhancement Of Photocatalytic Activity Of TiO_2 Nanoparticles By Silver Doping: Photodeposition Versus Liquid Impregnation Methods. Global NEST Journal. 10(1): 1-7.

[211] K. Soutsas, V. Karayannis, I. Poulios, A. Riga, K. Ntampegliotis, X. Spiliotis and G. Papapolymerou. (2010). Decolorization and degradation of reactive azo dyes via heterogeneous photocatalytic processes. Desalination. 250: 345–350.

[212] A. Fujishima, X. Zhang and D.A. Tryk. (2008). TiO_2 photocatalysis and related surfacephenomena. Surface Science Reports 63: 515–582.

[213] N. Daneshvar, D. Salari and A.R. Khataee. (2003). Photocatalytic degradation of azo dye Acid Red 14 in water: investigation of the effect of operational parameters. Journal of Photochemistry and Photobiology A: Chemistry. 157: 111–116.

[214] J. M. Herrmann (2010). Photocatalysis fundamentals revisited to avoid several misconceptions. Applied Catalysis B: Environmental. 99: 461–468.

[215] C. M. So, M.Y. Cheng, J.C. Yu and P.K. Wong. (2002). Degradation of azo dye Procion Red MX-5B by photocatalytic oxidation. Chemosphere. 46: 905–912.

[216] T. Sauer, G. Cesconeto Neto, H.J. Jose and R.F.P.M. Moreira. (2002). Kinetics of Photocatalytic degradation of reactive dyes in a TiO_2 slurry reactor. Journal of Photochemistry and Photobiology A: Chemistry. 149: 147–154.

[217] Y. Li, S. Sun, M. Ma, Y. Ouyang and W. Yan. (2008). Kinetic study and model of the photocatalytic degradation of rhodamine B (RhB) by a TiO_2-coated activated carbon catalyst: effects of initial RhB content, light intensity and TiO_2 content in the catalyst. Chemical Engineering Journal. 142: 147–155.