REFERENCES

Agency for Toxic Substances and Disease Registry. Toxicological profile for chlorophenol. [Online]. 1999. Available from: http://www.atsdr.cdc.gov /toxprofiles/tp107.html [2009, June 18]

Bao xiu, Z., Xiang-zhong, LI., and Peng, W. Degradation of 2,4-dichlorophenol with a novel TiO_2/Ti-Fe-graphite felt photoelectrocatalytic oxidation process. Journal of environmental sciences 19 (January 2007): 1020-1024.

Barakat, M. A., Schaeffer, H., Hayes, G., and Shah, S. I. Photocatalytic degradation of 2-chlorophenol by Co-doped TiO_2 nanoparticles. Applied Catalysis 57 (October 2004): 23–30.

Chang, M. Y., Hsieh, Y. H., Cheng, T. C., Yao, K. S., Wei, M. C., and Chang, C. Y. Photocatalytic degradation of 2,4-dichlorophenol wastewater using Porphyrin/TiO_2 complexes activated by visible light. Thin solid films 517 (May 2009): 3888-3891.

Chemat Technology. Sol gel technology [Online]. 1998. Available from: http:// www.chemat.com/html/solgel.html [2009, June 19]

Chen, X., and Mao, S. Titanium Dioxide Nanomaterials: synthesis, properties, modifications, and applications. Chemical Review 107 (June 2007): 2891-2959.

Colon, G., Hidalgo, M.C., Navio, J. A., Pulido Melian, E., Gonzalez, O., and Dona, J. M. Influence of amine template on the photoactivity of TiO_2 naonparticles obtained by hydrothermal treatment. Applied Catalysis 78 (September 2007): 176-182.

De Lasa, H., Serrano, B., and Salaices, M. Photocatalytic reaction engineering. United state of America: Springer Science+Business Media, 2005.

Dow AgroSciences. 2,4-Dichlorophenol Safe Handling Guide [Online]. 2000. Available from: http://www.cdms.net/LDat/ld6M3000.pdf [2009, June 24]

EnGu, D., Yang, B. G., and Hu, Y. D. V and N co-doped nanocrystal anatase TiO_2 photocatalysts with enhanced photocatalytic activity under visible light irradiation. Catalysis Communications 9 (March 2008): 1472–1476.

Environmental Research and Training Center. Monitoring of endocrine disruptor compounds in the coastal hydrosphere of Thailand [Online]. 2001. Available from: http://www.greenpeace.to/publications/Bangpoo2003.pdf [2009, June 15]

Estevinho, B. N., Martins, I., Ratola, N., Alves, A., and Santos, L. Removal of 2,4-dichlorophenol and pentachlorophenol from waters by sorption using coal fly ash from a Portuguese thermal power plant. Journal of hazardous materials 143 (May 2007): 535-540

Fana, X., Chen, X., Zhu, S., Li, S., Yu, T., Ye, J., and Zou, Z. The structural, physical and photocatalytic properties of the mesoporous Cr-doped TiO_2. Journal of Molecular Catalysis 284 (April 2008): 155-160.

Fogler, H.S. Element of chemical reaction engineering. Fourth edition. United States of America: Person education publication, 2006.

Fujishima, A., Rao, T. N., and Tryk, D. A. Titanium dioxide photocatalysis. Journal of Photochemistry and Photobiology 1 (March 2000): 1-21.

Greenpeace Research Laboratories. The Bangpoo industrial estate, Samut-Prakan province, Thailand; An investigation of environmental pollutants [Online]. 2003. Available from: http://www.greenpeace.to/publications/Bangpoo2003. pdf [2009, June]

Hao, H., and Zhang, J. The Study of Iron (III) and nitrogen co-doped mesoporous TiO_2 photocatalyst:systhesis,characterization and activity. Microporous and mesoporous materials 121 (May 2009): 52-57.

Hench, L. L., and Weat, J. K. The sol-gel process. Chemical Review 90 (January 1990): 33-72.

Kargi, F., and Eker, S. Removal of 2,4-dichlorophenol and toxicity from synthetic wastewater in a rotating perforated tube biofilm reactor. Process Biochemistry 40 (May 2005): 2105-2111.

Karuppaiya, M., Sasikumar, E., Viruthagiri, T., and Vijayagopal, V. Optimization of Process Conditions Using Response Surface Methodology (RSM) for Ethanol Production from Waste Cashew Apple Juice by Zymomonas Mobilis. Chemical Engineering Communications 196 (November 2009): 1425-1435.

Litter, M. I. Heterogeneous photocatalysis Transition metal ions in photocatalytic systems. Applied catalysis 23 (November 1999): 89-114.

Ministry of Economy, Trade and Industry of Japan. Hazard assessment of 2,4-Dichlorophenol [Online]. 2008. Available from: http://www.meti.go.jp/english/report/downloadfiles/gED0307e.pdf [2009, June 25]

Meynen, V., Cool, P., and Vansant, E. F. Verified Syntheses of Mesoporous Materials. Microporous and Mesoporous Material 125 (October 2009): 170-223.

Momani, F. A., Sans, C. and Esplugas, S. A comparative study of the advanced oxidation of 2,4-dichlorophenol. Journal of Hazardous Materials 107 (Mar 2004): 123-129.

Ormad, M. P., Ovelleiro, J. L., and Kiwi, J. Photocatalytic degradation of concentrated solutions of 2,4-dichlorophenol using low energy light identification of intermediates. Applied Catalysis 32 (August 2001): 157-166.

Oturan, N., Panizza, M., and Oturan, M. A. Cold Incineration of Chlorophenols in Aqueous Solution by Advanced Electrochemical Process Electro-Fenton. Effect of Number and Position of Chlorine Atoms on the Degradation Kinetics. The Journal of Physical Chemistry 113 (September 2009): 10988-10993.

Pollution Control Department. Industrial Effluent Standards [Online]. 1996. Available from: http://www.pcd.go.th/info_serv/en_reg_std_water04.html#s1 [2009, July 8]

Rodriguez-Torres, C. E., Cabrera, A. F., Errico, L. A., Adan, A., Requejo, F. G., Weissmann, M., and Stewart, S.J Local structure and magnetic behaviour of Fe-doped TiO_2 anatase nanoparticles: experiments and calculations. Journal of Physics 20 (March 2008): 135210

Ryo, Y. B., Lee, M. S., Jeong, E. D., Kim, H. G., Jung, W. Y., Beak, S. H., Lee, G-D., Park, S. S., and Hong, S-S. Hydrothermal synthesis of titanium dioxides from peroxotitanate solution using different amine group-containing organics and their photocatalytic activity. Catalysis Today 124 (June 2007): 88-93.

Santi, M., Paveena, L., and Promarak, V. Synthesis and optical properties of nanocrystalline ZnO powders by a simple method using zinc acetate dihydrate and poly(vinyl pyrrolidone). Journal of Crystal Growth 289 (March 2006): 102-106.

Shah, S. I., Li, W., Huang, C.P., Jung, O., and Ni, C. Study of Nd^{3+}, Pd^{2+}, Pt^{4+} and Fe^{3+} dopant effect on the photoreactivity of TiO_2 nanoparticles. Proceedings of the National Academy of sciences of united of America 99 (January 2002): 6482-6486.

Tong, T., Zhang, J., Tian, B., Chen, F., and He, D. Preparation of Fe^{3+}-doped TiO_2 catalysts by controlled hydrolysis of titanium alkoxide and study on their photocatalytic activity for methyl orange degradation. Journal of Hazardous Material 155 (July 2008): 572-579.

U.S. Environmental Protection Agency. Priority pollutants [Online]. 2008. Available from: http://www.epa.gov/waterscience/methods/pollutants.htm [2009, July]

Yan, X., He, J., Evans, D. G., Zhu, Y., and Duan, X. Preparation Characterization and Photocatalytic Activity of TiO_2 Formed fromed a Mesoporous Precursor. Journal of Porous Material 11 (July 2004): 131-139.

Yu, J., Zhou, M., Cheng, B., and Zhao, X. Preparation, characterization and photocatalytic activity of in situ N,S-codoped TiO_2 powders. Journal of Molecular Catalysis 246 (March 2006): 176–184.

Yu J.C., Ho, W., Yu, J., Yip, H., Wong P. K., and Zhou, J. Efficient Visible-Light-Induced Photocatalytic Disinfection on Sulfur-Doped Nanocrystalline Titania. Journal of American Chemical Society 39 (January 2005): 1175–1179.

Zhao, W., Ma, W., Chen, C., Zhao, J., and Shuai, Z. Efficient Degradation of Toxic Organic Pollutants with $Ni_2O_3/TiO_{2-x}B_x$ under Visible Irradiation. Journal of American Chemical Society 126 (March 2004): 4782-4783.

Zhou. M., Yu, J., Cheng, B., and Yu, H. Preparation and Photocatalytic Activity of Fe-doped Mesoporous Titanium dioxide Nanocrystalline Photocatalysts. Material Chemistry and Physic 93 (March 2005): 159-163.

Zhou. M., Yu, J., Cheng, B., and Yu, H. Effects of Fe-doping on the photocatalytic activity of mesoporous TiO_2 powders prepared by an ultrasonic method. Journal of Hazardous Material 137 (October 2006): 1838-1847.

Zhu, K. R., Zhang, M. S., Hong, J. M., and Yin, Z. Size effect on phase transition sequence of TiO_2 nanocrystal. Materials Science and Engineering 403 (August 2005): 87-93.

APPENDICES

Appendix A

A.1 Calculated crystallite size

The broadening peak of TiO_2 corresponding to anatase (101) was selected to evaluate the crystallite size according to Equation 3.1 (Scherer's equation)

$$D = K\lambda / \beta\cos\theta \quad (3.1)$$

Where:

D	=	the crystallite size (nm)
K	=	the Scherrer constant (0.89)
λ	=	the X-ray wavelength (1.5496 Å)
β	=	the half-height width of the diffraction peak of anatase (degree)
θ	=	the diffraction angle (degree)

Table A.1 The half-height width and their angle from the diffraction peak of anatase and crystallite size.

Catalyst	β	2θ (deg.)	cosθ	D (nm)
TiO_2-P25	25.5620	25.5620	0.9093	0.0356
0.0Fe-N-TiO_2-6C	25.5520	25.5520	0.9134	0.0357
0.5Fe-N-TiO_2-6C	25.6040	25.6040	0.8910	0.0348
1.0Fe-N-TiO_2-6C	25.6100	25.6100	0.8883	0.0347
0.0Fe-N-TiO_2-12C	25.4280	25.4280	0.9567	0.0376
0.5Fe-N-TiO_2-12C	25.5260	25.5260	0.9237	0.0362
1.0Fe-N-TiO_2-12C	25.4700	25.4700	0.9437	0.0371
0.0Fe-N-TiO_2-18C	25.4480	25.4480	0.9507	0.0374
0.5Fe-N-TiO_2-18C	25.4380	25.4380	0.9538	0.0375
1.0Fe-N-TiO_2-18C	25.5220	25.5220	0.9252	0.0363

A.2 Light adsorption capability and Energy band gap.

- The UV-vis diffuse reflectance spectra of co-doping and commercial TiO_2

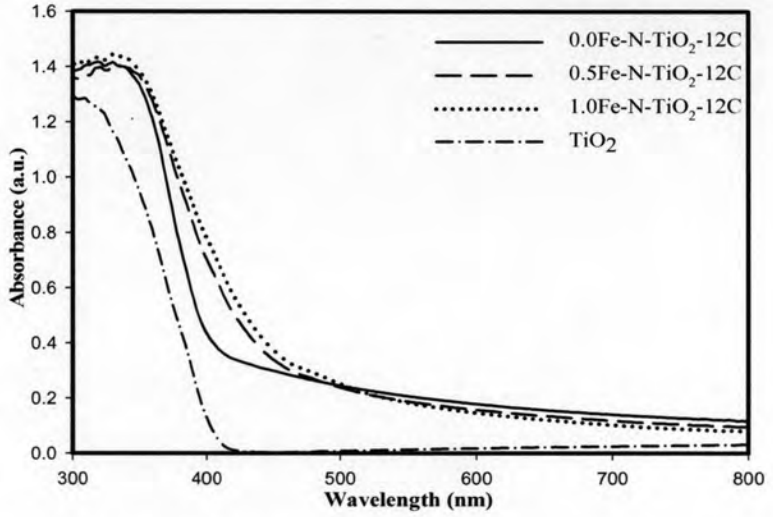

Figure A.1. UV-DRS spectra of TiO_2-P25 compared with difference mol%Fe

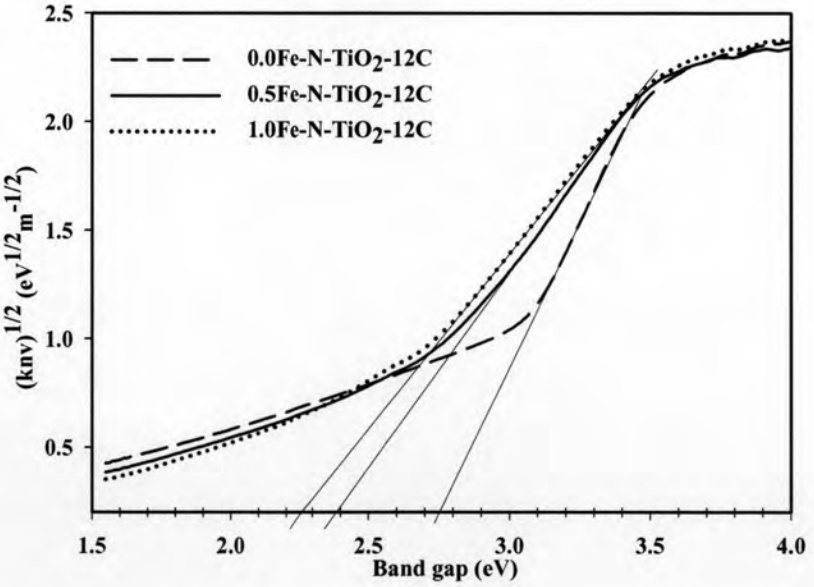

Figure A.2. Tauc plots of UV-DRS spectra of TiO_2-P25 compared with difference mol%Fe

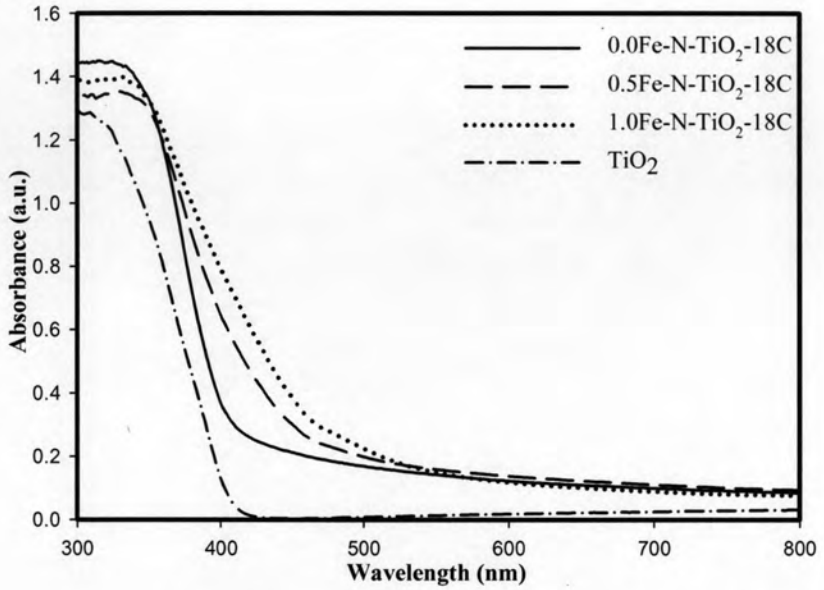

Figure A.3. UV-DRS spectra of TiO_2-P25 compared with difference mol%Fe

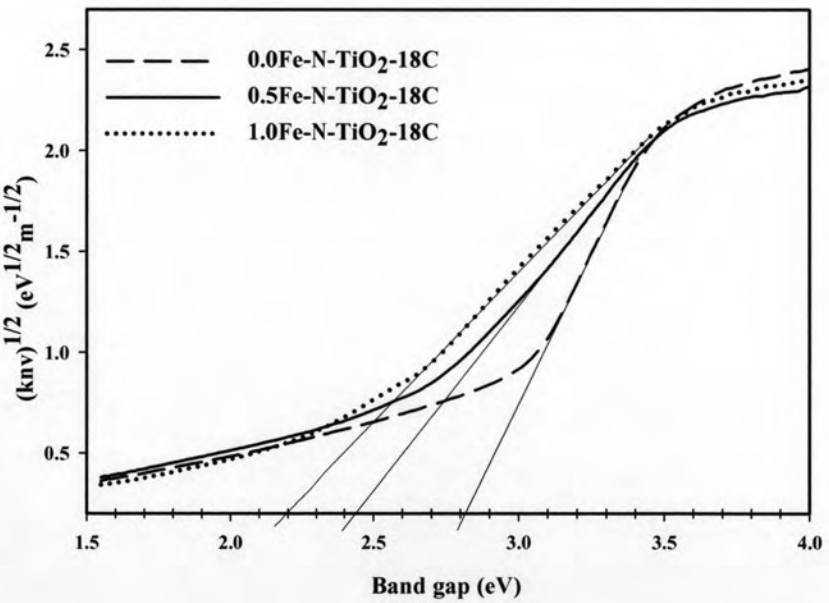

Figure A.4. Tauc plots of UV-DRS spectra of TiO_2-P25 compared with difference mol%Fe

A.3 Electrokinetic potential (zeta-potential) of photocatalysts surfaces

Table A.2 Zeta-potential of 1%Fe-N-TiO_2-6C

	Repeat										
pH	1	2	3	4	5	6	7	8	9	10	Average
1	117.3	87.28	86.19	95.76	117.3	94.7	110.4	83	136.3	96.55	102.48
2	19.91	16.49	14.58	22.59	20.08	17.78	14.58	14.45	12.01	9.609	16.21
4	-11.2	-14.2	-15.6	-16	-15.6	-15.8	-11.2	-10.3	-12	-16.7	-13.86
6	-19.9	-19.1	-27.2	-14.7	-19.1	-24.5	-25.3	-25.2	-21.3	-24	-22.03
8	-72.9	-54.1	-79.9	-77.8	-99.1	-83.1	-97.9	-93.9	-87.2	-91.5	-83.74
10	-98.2	-93.9	-83.1	-79.1	-78.9	-80.8	-92.9	-101	-94.9	-81.6	-88.44

Table A.3. Zeta-potential of 1%Fe-N-TiO_2-12C

	Repeat										
pH	1	2	3	4	5	6	7	8	9	10	Average
1	49.46	57.37	61.67	50.78	45.11	51.67	59.29	55.76	44.06		52.80
2	35.51	20.41	22.06	20.71	21.07	22.89	22.32	23.39	18.07		22.94
4	-15.2	-17.1	-19.9	-14.5	-21.5	-15.6	-27	-28.4	-27.3		-20.72
6	-15.3	-30.3	-19.5	-14.2	-26.3	-20.3	-22.1	-21.1	-24.7		-21.53
8	-13.5	-35.1	-34	-43.7	-42.3	-55.7	-40.7	-43.8	-54.5		-40.37
10	-60	-56.3	-44.8	-48.4	-44.2	-51.9	-41.8	-51.4	-51.8	-56.8	-50.74

Table A.4 Zeta-potential of 1%Fe-N-TiO_2-18C

	Repeat										
pH	1	2	3	4	5	6	7	8	9	10	Average
1	61.89	74.09	90.61	76.47	77.32	71.42	60.21	83.92	58.53	86.65	74.11
2	32.18	26.09	26.32	22.35	15.2	20.15	27	21.24	13.36	12.73	21.66
4	-9.8	-19.5	-16.9	-15.8	-6.7	-19.6	-25.3	-25.2	-26.2	-28.2	-19.32
6	-7.65	-14.4	-14.4	-10	-10.1	-15.9	-13.2	-14.6	-13.1	-14.7	-12.81
8	-27.5	-32.9	-27.4	-24.4	-21.2	-24	-19.5	-39.1	-30.4	-31.3	-27.77
10	-43.7	-56.2	-57.4	-56.3	-36	-59.1	-65	-59.1	-65.3	-56.2	-55.43

Appendix B

B.1 Calibration curve of 2,4-DCP

Table B.1 Standard samples of known concentration and their peak area results.

Standard no.	2,4-DCP Concentration (ppm)	Peak area
1	0.625	7.1
2	1.25	13.6
3	2.5	28.4
4	5	57.3
5	10	117.7
6	20	237.5
7	40	480.6
8	60	725.1
9	80	975.6
10	100	1205.9

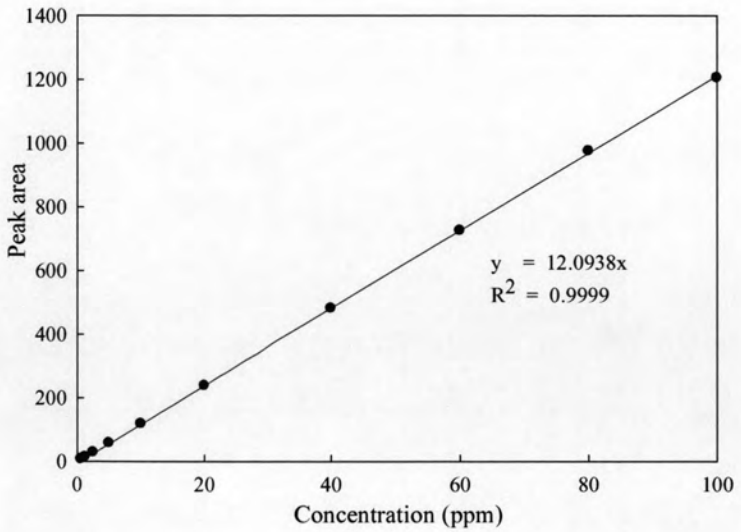

Figure B.1 Calibration curve for 2,4-DCP

B.2 Photocatalytic degradation of 2,4-DCP at difference concentrations.

Table B.2 Photocatalytic degradation of 5 ppm 2,4-DCP.

Time (min)	Peak Area	Conc.
Inst	58.3	5.12
0	58.7	4.98
15	54.4	4.65
30	51.8	4.30
45	50.2	4.20
60	47.9	4.00
90	43.9	3.65
120	40.8	3.39
150	37.2	3.09
180	32.0	2.66
210	26.3	2.18
240	20.2	1.68
270	16.57	1.38
300	13.2	1.09
360	9.04	0.75

Table B.3 Photocatalytic degradation of 10 ppm 2,4-DCP.

Time (min)	Peak Area	Conc.
Inst	119.9	9.95
0	118.3	9.90
15	114.4	9.55
30	111.7	9.38
45	108.5	9.00
60	103.2	8.67
90	98.0	8.13
120	96.2	7.99
150	93.4	7.75
180	89.0	7.39
210	85.8	7.12
240	83.0	6.89
270	79.7	6.61
300	75.9	6.30
360	69.8	5.79

Table B.4 Photocatalytic degradation of 15 ppm 2,4-DCP.

Time (min)	Peak Area	Conc.
Inst	175.8	15.37
0	166	14.91
15	163.3	14.55
30	159.1	14.10
45	156.6	13.50
60	151.6	13.20
90	149.9	12.45
120	143.2	11.89
150	138.3	11.48
180	129.3	10.73
210	128	10.63
240	120.3	9.99
270	114.1	9.47
300	115.2	9.56
360	102.7	8.53

Table B.5 Photocatalytic degradation of 20 ppm 2,4-DCP.

Time (min)	Peak Area	Conc.
Inst	230.6	20.23
0	230.7	19.98
15	216.6	19.43
30	212.8	19.04
45	209.7	18.40
60	210.6	18.00
90	198	16.44
120	193.8	16.09
150	187.2	15.54
180	185.1	15.37
210	169.5	14.07
240	173.4	14.40
270	168.5	13.99
300	162.5	13.49
360	151.9	12.61

Table B.6 Photocatalytic degradation of 25 ppm 2,4-DCP.

Time (min)	Peak Area	Conc.
Inst	283.8	25.57
0	287.9	25.11
15	273	24.53
30	265.7	24.25
45	261.5	23.75
60	258.7	23.25
90	251.6	20.89
120	242.3	20.12
150	235.6	19.56
180	234.7	19.49
210	221.7	18.41
240	228.6	18.98
270	212.3	17.63
300	203.7	16.91
360	197.7	16.42

Table B.7 Photocatalytic degradation of 15 ppm 2,4-DCP using TiO_2-P25 as photocatalytic.

Time (min)	Peak Area	Conc.
Inst	186.4	15.48
0	179.9	14.94
0	171.9	14.27
15	168	13.95
30	167.9	13.94
45	158.3	13.14
60	155.3	12.89
90	146.8	12.19
120	144.3	11.98
150	138.9	11.53
180	136.1	11.30
210	132.5	11.00
240	128.4	10.66
270	125	10.38
300	117	9.71

Table B.8 Photolysis of 15 ppm 2,4-DCP.

Time (min)	Peak Area	Conc.
0	185	15.36
0	186.4	15.48
15	187.8	15.59
30	186.3	15.47
45	187.6	15.58
60	186.2	15.46
90	186.5	15.49
120	187.2	15.54
150	187.2	15.54
180	186.9	15.52
210	185.2	15.38
240	187.3	15.55
270	185.8	15.43
300	182.7	15.17

B.3 Kinetic study

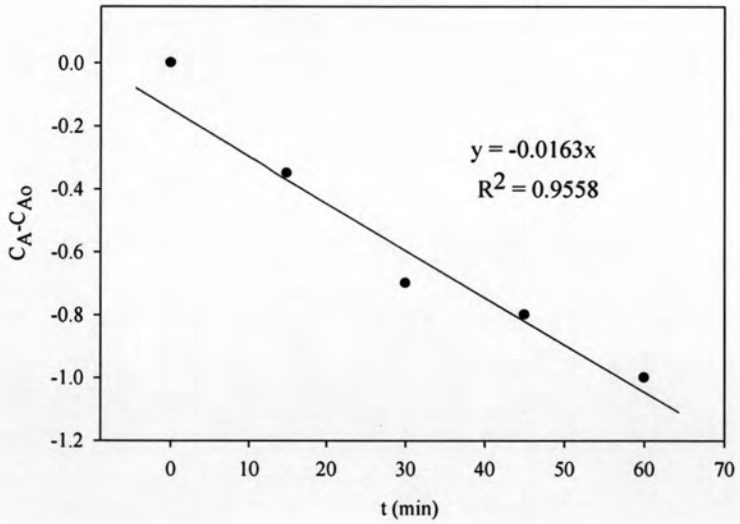

Figure B.2 The plot of C_A-C_{Ao} versus t for 5 ppm initial concentration.

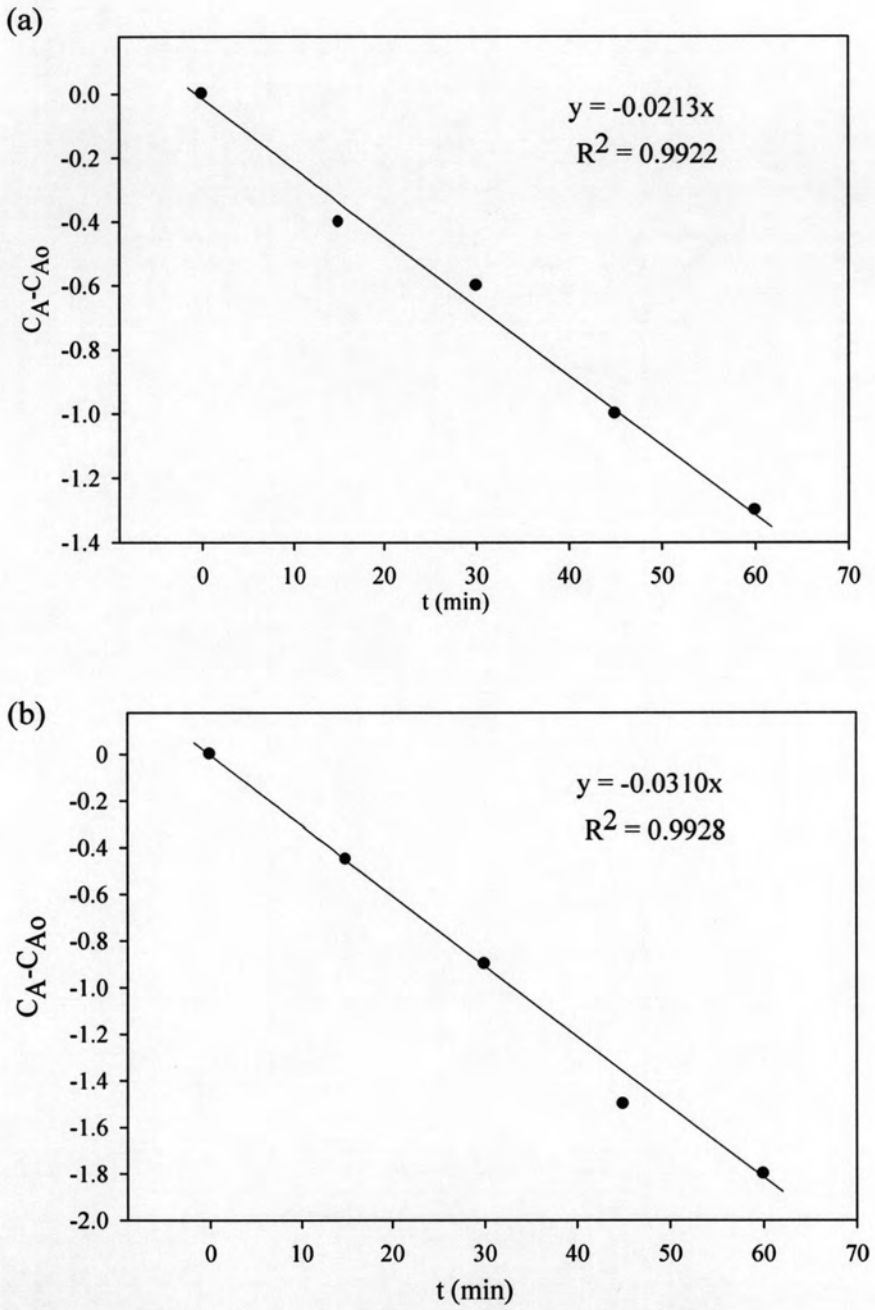

Figure B.3 The plots of C_A-C_{Ao} versus t for each initial concentration; (a) 10 ppm and (b) 15 ppm

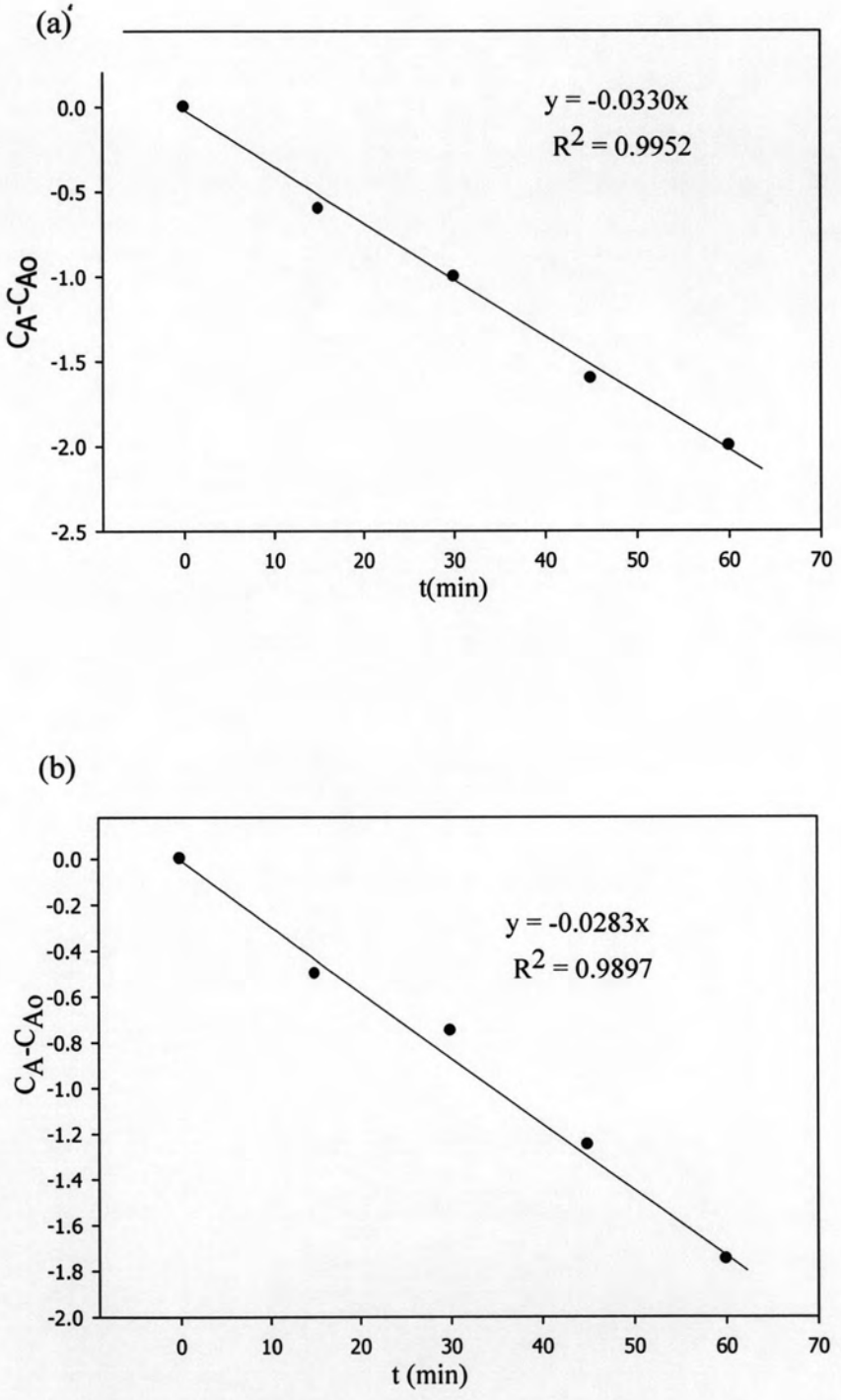

Figure B.4 The plots of C_A-C_{Ao} versus t for each initial concentration; (a) 20 ppm and (b) 25 ppm.

BIOGRAPHY

Miss Ploy Kosin was born on June 18, 1986 in Bangkok, Thailand. She obtained her Bachelor degree in Science (Health Science; Environmental Health) in 2007 from Thammasat University. In 2007, Ploy is the master degree student in the International program in Environmental Management at Chulalongkorn University. Her interest is in application of new technology, such as photocatalytic for water treatment.