## CONTENTS

Acknowledgements	iii
Abstract in thai	iv
Abstract in english	v
List of tables	ix
List of figures	х
List of abbreviation	xii
Chapter 1 Introductions	1
1.1 Reserch introduction	1
1.2 Reserch objectives	3
1.3 Hypothesis	3
1.4 Scopes of the study	3
1.5 Research contribution	4
Chapter 2 Literature review	
2.1 Photocatalysis of doped Titanium dioxide	5
2.2 Photocatalysis of Titanium dioxide with dopants	7
2.3 Hydrothermal method	9
2.4 Cerium	11
2.5 Photocatalysis of 2-chlorophenol	12
2.6 Photocatalytic kinetic reaction	14
2.6.1 Langmuir-Hinshelwood expression	16
2.6.2 Langmuir adsorption isotherm	17
2.7 The different studies on treatment of 2- chlorophenol using $TiO_2$	18
Chapter 3 Methodology	24
3.1 Optimization study of the modified TiO <sub>2</sub> catalyst	24
3.2 Materials and Chemicals	25

3.2.1 Chemicals	25
3.2.2 Experiment set-up	26
3.3 Experimental procedures	27
3.4 Synthesis of Titanium Dioxide	27
3.5 Comparison between various doped TiO <sub>2</sub>	30
3.6 2 <sup>k</sup> factorial design	30
3.7 Photocatalytic activity measurement	32
3.8 Synthesis parameters in photocatalytic experiments	32
3.9 Operating parameters in photocatalytic experiments	33
3.10 Comparison between various doped TiO <sub>2</sub>	33
3.11 Control parameters	33
3.12 Analytical methods	34
3.12.1 X-ray diffraction (XRD)	34
3.12.2 The scanning electron microscope (SEM)	34
3.12.3 Point of zero charge (pzc) analysis	35
Chapter 4 Results and Discussions	36
4.1 Characterization analysis	36
4.1.1 Scanning electron microscopy (SEM) analysis	36
4.1.2 X-ray Diffraction (XRD) Analysis	39
4.1.3 Point of zero charge (pzc) or surface charge	42
4.2 Feasibility of dopants on TiO <sub>2</sub> with 2-CP degradation	44
4.3 Control experiments 2 <sup>k</sup> factorial design	45
4.4 Effect of synthesize parameters	48
4.4.1 Effect of amount of dopant	48
4.4.2 Effect of calcination temperature	50
4.5 Control parameters	53
4.6 Effect of synthesize parameters	54
4.6.1 Effect of initial pH	54
4.6.2 Effect of photocatalyst dosage	55
4.6.3 Effect of initial 2-chlorophenol concentration	58
4.7 Kinetic model	59

4.7.1 Langmuir-Hinshelwood model	62			
4.8 Costs effective				
4.8.1 Calculation electricity costs for synthesized photocatalyst	64			
4.8,2 Calculation electricity costs to synthesized TiO <sub>2</sub> catalysts	65			
4.8.3 Calculation electricity costs for operating experiment	66			
4.9 Comparison the performances between Ce, $CuSO_4$ and V-doped $TiO_2$	66			
4.9.1 Comparison of synthesis method	68			
4.9.2 Comparison of amount of dopant	68			
4.9.3 Comparison of calcination temperature	68			
4.9.4 Comparison of initial pH	69			
4.9.5 Comparison of catalyst dosage	69			
4.9.6 Comparison of Initial 2-cholorhenol concentration	69			
4.9.7 Comparison of characterized photocatalyst TiO <sub>2</sub>	70			
4.9.8 Comparison of Cost effective between Ce-doped $TiO_2$ and				
CuSO <sub>4</sub> -doped TiO <sub>2</sub>	70			
Chapter 5 Conclusion and Recommendation				
5.1 Conclusions	71			
5.2 Recommendations for future stud	72			
References	73			
Appendices	82			
Appendix A	82			
Appendix B				
Appendix C	91			
Curriculum Vitae	93			

## LIST OF TABLES

Table 2.1 Band gap of materials that can be the catalyst	9
Table 2.2 MSDS of 2-chlorophenol	13
Table 2.3 Previous studies on the photocatalytic degradation of 2- chlorophenol	19
Table 3.1 Investigated variables for 2-chlorophenol removal	30
Table 3.2 Design of static batch experiments generated using 2 <sup>k</sup> factorial design	31
Table 3.3 Experimental ranges for synthesis parameters	32
Table 3.4 Experimental values for operating parameters in photodegradation	
experiments	33
Table 4.1 Summary of the calculated structural parameters of synthesized	
TiO <sub>2</sub> catalysts	41
Table 4.2 pH <sub>pzc</sub> values for TiO <sub>2</sub> synthesized	43
Table 4.3 Investigated variables for 2-chlorophenol removal	46
Table 4.4 Static batch experiments generated using 2 <sup>k</sup> factorial design	46
Table 4.5 Apparent first-order rate constants $K_{obs} t_{1/2}$ and $t_{1/2}^*$ of the	
photodegradation of 2-chlorophenol at different initial concentrations	59
Table 4.6 Apparent first-order rate constant and correlation coefficient on the	
photocatalytic oxidation of 2- chlorophenol at different initial	
concentration 11112112121201111	61
Table 4.7 Calculated values of specific rate constant, equilibrium adsorption	
constant and correlation coefficient of 2-chlorophenol	66
Table 4.8 Basic cost assessment for synthesis TiO <sub>2</sub> catalysts to degradation	
2-chlorophenol	63
Table 4.9 The cost assessment for cerium doped TiO <sub>2</sub> catalyst	64
Table 4.10 The power and electricity of equipment for synthesis TiO <sub>2</sub> catalysts	65
Table 4.11 The intensity and power of equipment for operating experiment	66
Table 4.12 The best condition and characterize of synthesized $TiO_2$	67

## LIST OF FIGURES

Figure 2.1 Reaction mechanisms	7
Figure 2.2 Periodic chart of the photocatalysis effects of various metal ion	
dopants in TiO <sub>2</sub>	8
Figure 2.3 Hydrothermal synthesis reactor	10
Figure 3.1 Process flow diagram of the methodology for the research study	25
Figure 3.2 Schematic diagram of the photocatalytic reactor	26
Figure 3.3 Experimental procedures	27
Figure 3.4 Synthesis of titanium dioxide procedures	28
Figure 3.5 Schematic for TiO <sub>2</sub> synthesis by hydrothermal method	29
Figure 4.1 SEM micrographs at a magnification of 10,000X showing the	
morphological structure and texture of the synthesized TiO <sub>2</sub> catalysts	
with Ce-doping at various concentrations (0.07, 0.28 and 0.35% mol)	37
Figure 4.2 SEM micrographs at a magnification of 1000X showing	
the morphological structure and texture of the synthesized $TiO_2$	
catalysts with Ce-doping at various concentrations	
(0.07, 0.28 and 0.35%mol)	38
Figure 4.3 XRD spectra of synthesized TiO <sub>2</sub> catalyst calcined at different	
Temperatures (a) 200°C; (b) 300°C (c) 400°C (d) 500°C and (e) 600°C	2 40
Figure 4.4 Point of zero charge of the synthetic TiO <sub>2</sub>	43
Figure 4.5 Photodegradation of 2-chlophenol at various doped TiO <sub>2</sub> compared	
to undoped TiO <sub>2</sub> under blue light irradiation	44
Figure 4.6 Main effect plot for %degradation and Pareto chart of the effects	
for the photocatalytic degradation of 2-chlorophenol using Ce-doped 7	ГiО <sub>2</sub>
under blue light illumination	47
Figure 4.7 Effect of amount of dopant on photocatalytic degradation of	
2-chlorophenol using Ce-doped TiO <sub>2</sub> under blue light illumination	49

Figure 4.8	Effect of calcination temperature on the photocatalytic	
	degradation of 2- chlorophenol using Ce-doped ${\rm TiO_2}$ under blue light	
	illumination	51
Figure 4.9	XRD spectra of synthesized TiO <sub>2</sub> catalyst calcined	
	at various calcination temperatures	52
Figure 4.10	) Control parameters on the photocatalytic degradation of	
	2-chlorophenol under blue light illumination; experimental conditions	s53
Figure 4.11	Effect initial pH on the photocatalytic degradation of	
	2-chlorophenol using Ce-doped $TiO_2$ under blue light illumination	54
Figure 4.12	2 Effect photocatalyst dosage on the photocatalytic degradation of	
	2-chlorophenol using Ce-doped $TiO_2$ under blue light illumination	57
Figure 4.13	B Effect of initial 2-chlorophenol concentration on	
	the photocatalytic degradation of 2-chlorophenol using Ce-doped TiC	<b>)</b> <sub>2</sub>
	under blue light illumination	58
Figure 4.14	Effect of the initial 2-chlorophenol concentration on	
	photocatalytic degradation	59
Figure 4.15	5 Linearized pseudo-first order kinetics plot for the photocatalytic	
	degradation at different concentration of 2-chlorophenol using	
	sTiO <sub>2</sub> /Ce 60	
Figure 4.16	5 Dependence of observed and estimated half-life on the initial	
	concentration of 2-chlorophenol	62
Figure 4.17	7 Linearized reciprocal kinetic plot of $K_{obs}^{-1}$ as a function of initial	
(	concentration on the photocatalytic oxidation of 2-chlorophenol	63
А	Il rights reserved	

## LIST OF ABBREVIATION

A.U	arbitrary unit
cb	Conduction band
vb	Valente band
Eg	Energy
eV	Electron volt
g	gram
L	Liter
mg	Milligram
min S	Minute
mL	Milliliter
mM	Millimetre
nm	Nanometre
SEM	Scanning electron microscope
UVA	Ultraviolet A
VIS	Visible light
°C	Degree Celsius
e	Electron
$h^+$	Hole
TiO <sub>2</sub>	Titanium dioxide
TiO <sub>2</sub> /Ce	Titanium dioxide dope with Cerium
TiO <sub>2</sub> /V Copyright	Titanium dioxide dope with Vanadium
TiO <sub>2</sub> /CuSO <sub>4</sub>	Titanium dioxide dope with Copper(II)sulfate
$\lambda$ max	Wavelength at which the absorbance is the greatest