

CONTENTS

	Page No.
Acknowledgements	i-iii
Abbreviations	xiii-xv
List of Figures	xvi-xxvi
List of Tables	xxvii-xxxi
Preface	xxxii-xxxiv
Chapter 1: Introduction	(1-38)
1.1 Introduction	1
1.2 Global water distribution	2
1.3 Environmental pollution	7
1.4 Water pollution	7
1.5 Water pollutants	9
1.5.1 Organic pollutants	9
1.5.2 Inorganic pollutants	9
1.5.3 Sediments	9
1.5.4 Radioactive materials	10
1.5.5 Thermal pollutants	10
1.6 Heavy metal contamination in aquatic system	10
1.6.1 Technologies for heavy metal removal from water and waste water	14
1.7 Adsorption	16
1.7.1 Types of adsorption	16
1.7.2 Adsorption from solutions	18

1.7.3 Film diffusion	19
1.7.4 Pore diffusion	20
1.8 Factors influencing adsorption	21
1.8.1 Concentration	21
1.8.2 Temperature	21
1.8.3 pH of the solution	22
1.8.4 Nature of adsorbate and adsorbent	22
1.8.5 Particle size	23
1.8.6 Agitation speed	24
1.8.7 Presence of foreign ions	24
1.9 Contacting systems and modes of operation	24
1.9.1 Batch System	25
1.9.2 Continuous-flow-system	25
1.10 Nanotechnology and Wastewater Treatment: A General Vision	25
1.10.1 Nano-adsorbents	27
1.10.2 Metal oxide nanoparticles as nano-adsorbents for sorption of heavy metals	28
1.10.3 Synthesis and characterization of nano-adsorbents	30
1.11 Scope of the work	37
1.12 Objective of the Thesis	38
Chapter: 2 Literature review	(39-50)
2.1 Introduction	39
2.2 Conventional adsorbents for removal of heavy metals from aqueous solutions	39
2.3 Literature review: A brief overview of metal oxide nanoparticles utilized as adsorbents for removal of metallic species from aqueous solutions	40

Chapter: 3 Materials and Methods	(51-73)
3.1 Introduction	51
3.2 Materials	51
3.3 Reagents	51
3.4 Instruments	52
3.5.1 Chromium	52
3.5.2 Nickel	52
3.6 Adsorbents	55
3.6.1 Nano-alumina (n-Al₂O₃)	57
3.6.2 Nano-cupric oxide (n-CuO)	58
3.7 Analytical procedures	58
3.7.1 Batch adsorption experiments	58
3.7.2 Design of experiment (DOE) for optimization of experimental parameters	60
3.7.2.1 Response surface methodology (RSM)	60
3.7.2.2 Box-Behnken design (BBD)	61
3.7.2.3 Analysis of variance (ANOVA)	63
3.7.2.4 Surface plots, Contour graphs and Optimization plot	64
3.8 Adsorption isotherm experiment	65
3.8.1 Langmuir isotherm model	65
3.8.2 Freundlich isotherm model	66
3.9 Adsorption kinetic experiments	67
3.9.1 Pseudo first order model	68
3.9.2 Pseudo-second-order model	68
3.9.3 Intra-particle diffusion model	69

3.9.4 Boyd model	70
3.10 Linear and non-linear analyses of isotherm and kinetic parameters	70
3.11 Adsorption thermodynamic study	71
3.11.1 Langmuir adsorption model	72
3.12 Desorption experiments	73
Chapter: 4 Synthesis and Characterization of Adsorbents	(74-87)
4.1 Introduction	74
4.2 Synthesis of nano-alumina (n-Al ₂ O ₃)	74
4.2.1 Experimental set-up for synthesis of nano-alumina	74
4.2.3 Characterization of synthesized nano-alumina	75
4.2.3.1 X-Ray diffraction analysis	75
4.2.3.2 Fourier transform infra-red analysis	76
4.2.3.3 Electron microscopic analysis	77
4.3 Synthesis of nano-Cupric oxide (n-CuO)	80
4.3.1 Green synthesis	80
4.3.2 Experimental set up for synthesis of CuO nanoparticles	81
4.3.3 Characterization of synthesized nano-cupric oxide	82
4.3.3.1 X-Ray diffraction analysis	82
4.3.3.2 Fourier transform infra-red analysis	82
4.3.3.3 Electron microscopic analysis	84
4.4 Determination of point of zero charge (pH _{zpc})	86
Chapter: 5 Adsorption study on removal of chromium on nano-alumina	(88-129)
5.1 Introduction	88
5.2 Results and discussions	90

5.2.1 Characterization of nano-alumina after adsorption of chromium	90
5.2.2 Adsorption Experiments	92
5.2.2.1 Effect of experimental parameters on the removal of chromium from aqueous solution	92
5.2.2.2 Design of experiment and data analysis for adsorption of chromium on nano-alumina	95
5.2.2.3 Analysis of variance (ANOVA)	98
5.2.2.4 Interaction effect of initial Cr(VI) concentration and Adsorbent dose	100
5.2.2.5 Interaction effect of pH and adsorbent dose	101
5.2.2.6 Interaction effect of pH and initial Cr(VI) concentration	102
5.2.2.7 Interpretation of process optimization of removal (%) of chromium on nano-alumina	103
5.2.3 Adsorption isotherm study	105
5.2.3.1 Linear analysis of adsorption isotherm	106
5.2.3.2 Non-linear analysis of adsorption isotherm	108
5.2.4 Adsorption kinetic modelling	112
5.2.4.1 Linear analysis of adsorption kinetics	113
5.2.4.2 Non-linear analysis of adsorption kinetics	117
5.2.4.3 Intra-particle diffusion	120
5.2.4.4 Boyd model	122
5.2.5 Adsorption thermodynamic study	123
5.2.5.1 Effect of temperature	123
5.2.5.2 Thermodynamic parameters	124
5.2.5.3 Activation energy	126
5.3 Desorption experiments	127

5.4 Conclusions	128
Chapter: 6 Adsorption study on removal of nickel on nano-alumina	(130-170)
6.1 Introduction	130
6.2 Results and discussions	131
6.2.1 Characterization of nano-alumina after adsorption of nickel	131
6.2.2 Adsorption Experiments	133
6.2.2.1 Effect of experimental parameters on the removal of Nickel from aqueous solution	134
6.2.2.2 Design of experiment and data analysis for adsorption of nickel on nano-alumina	137
6.2.2.3 Analysis of variance (ANOVA)	140
6.2.2.4 Interaction effect of initial Ni(II) concentration and adsorbent dose	141
6.2.2.5 Interaction effect of pH and adsorbent dose	143
6.2.2.6 Interaction effect of pH and initial Ni(II) concentration	144
6.2.2.7 Interpretation of process optimization of removal (%) of nickel on nano-alumina	145
6.2.3 Adsorption isotherm study	147
6.2.3.1 Linear analysis of adsorption isotherm	148
6.2.3.2 Non-linear analysis of adsorption isotherm	151
6.2.4 Adsorption kinetic modelling	154
6.2.4.1 Linear analysis of adsorption kinetics	155
6.2.4.2 Non-linear analysis of adsorption kinetics	159
6.2.4.3 Intra-particle diffusion	162
6.2.4.4 Boyd model	163
6.2.5 Adsorption thermodynamic study	164
6.2.5.1 Effect of temperature	164

6.2.5.2 Thermodynamic parameters	165
6.2.5.3 Activation energy	167
6.3 Desorption experiments	168
6.4 Conclusions	169
Chapter: 7 Adsorption study on removal of chromium on nano-cupric oxide	(171-210)
7.1 Introduction	171
7.2 Results and discussions	172
7.2.1 Characterization of nano-cupric oxide after adsorption of chromium	172
7.2.2 Adsorption Experiments	174
 7.2.2.1 Effect of experimental parameters on the removal of chromium from aqueous solution	174
 7.2.2.2 Design of experiment and data analysis for adsorption of chromium on nano-cupric oxide	177
 7.2.2.3 Analysis of variance (ANOVA)	180
 7.2.2.4 Interaction effect of initial Cr(VI) concentration and adsorbent dose	182
 7.2.2.5 Interaction effect of pH and adsorbent dose	183
 7.2.2.6 Interaction effect of pH and initial Cr(VI) concentration	185
 7.2.2.7 Interpretation of process optimization of removal (%) of chromium on nano-cupric oxide	185
7.2.3 Adsorption isotherm study	187
 7.2.3.1 Linear analysis of adsorption isotherm	188
 7.2.3.2 Non-linear analysis of adsorption isotherm	191
7.2.4 Adsorption kinetic modelling	195
 7.2.4.1 Linear analysis of adsorption kinetics	196

7.2.4.2 Non-linear analysis of adsorption kinetics	198
7.2.4.3 Intra-particle diffusion	202
7.2.4.4 Boyd model	204
7.2.5 Adsorption thermodynamic study	205
7.2.5.1 Effect of temperature	205
7.2.5.2 Thermodynamic parameters	206
7.2.5.3 Activation energy	208
7.3 Desorption experiments	209
7.4 Conclusions	210
Chapter: 8 Adsorption study on removal of nickel on nano-cupric oxide	(212-253)
8.1 Introduction	212
8.2 Results and discussions	214
8.2.1 Characterization of nano-cupric oxide after adsorption of nickel	214
8.2.2 Adsorption Experiments	216
8.2.2.1 Effect of experimental parameters on the removal of nickel from aqueous solution	216
8.2.2.2 Design of experiment and data analysis for adsorption of nickel on nano-cupric oxide	220
8.2.2.3 Analysis of variance (ANOVA)	223
8.2.2.4 Interaction effect of initial Ni(II) concentration and adsorbent dose	224
8.2.2.5 Interaction effect of pH and adsorbent dose	225
8.2.2.6 Interaction effect of pH and initial Ni(II) concentration	226
8.2.2.7 Interpretation of process optimization of removal (%) of nickel on nano-cupric oxide	227
8.2.3 Adsorption isotherm study	229

8.2.3.1 Linear analysis of adsorption isotherm	230
8.2.3.2 Non-linear analysis of adsorption isotherm	233
8.2.4 Adsorption kinetic modelling	237
8.2.4.1 Linear analysis of adsorption kinetics	238
8.2.4.2 Non-linear analysis of adsorption kinetics	240
8.2.4.3 Intra-particle diffusion	244
8.2.4.4 Boyd model	246
8.2.5 Adsorption thermodynamic study	247
8.2.5.1 Effect of temperature	247
8.2.5.2 Thermodynamic parameters	248
8.2.5.3 Activation energy	250
8.3 Desorption experiments	251
8.4 Conclusions	252
Summary	254-260
References	261-284
List of Research Publications	