

Table of Contents

Contents	Page No.
List of Figures	vii-xiv
List of Tables	xv-xvi
Chapter 1 Introduction and Literature Review	1-20
1.1 Introduction to conducting polymer nanocomposites	3
1.2 Polythiophene and its derivatives	3
1.3 Organic/inorganic fillers in conducting polymer nanocomposites.....	5
1.4 Carbon nanotubes as fillers in conducting polymer nanocomposites....	5
1.5 Synthetic strategies and development of conducting polythiophene-carbon nanotube nanocomposites.....	6
1.6 Applications of conducting polythiophene-carbon nanotube nanocomposites.....	8
1.6.1 Sensors.....	9
1.6.2 Preparation of higher-order nanocomposites.....	10
1.6.3 Supercapacitor applications.....	10
1.6.4 EMI shielding.....	11
1.6.5 Photovoltaic cells and photodiodes.....	11
1.6.6 Transistors.....	12
1.6.7 Thermoelectric materials.....	13
References.....	14
Chapter 2 AOT Assisted Preparation of Polythiophene-MWCNT Core-shell Nanocomposites	21-50
2.1 Introduction.....	23
2.2 Experimental.....	28
2.2.1 Materials and reagents.....	28
2.2.2 Measurements and instruments.....	28
2.2.3 Synthesis of PTCNT-100.....	29
2.2.4 Synthesis of PTCNT-300 [AOT-0].....	29
2.2.5 Synthesis of PT-25.....	30
2.2.6 Synthesis of PT-25[AOT-0].....	30
2.3 Results and discussion.....	30
2.3.1 Synthesis of polythiophene and polythiophene - MWCNT nanocomposites.....	30

Table of Contents

2.3.2	Characterization of PT and PTCNT nanocomposites.....	33
2.3.3	Morphological characteristics of PT and PTCNT nanocomposites.....	37
2.3.4	Role of AOT in the formation of nanocomposite.....	38
2.3.5	Mechanism of composite formation.....	40
2.3.6	Enhancement of properties.....	41
2.4	Conclusion	45
	References	46

Chapter 3	Polythiophene-functionalized MWCNT Nanocomposite: Preparation and Properties	51-79
------------------	---	--------------

3.1	Introduction.....	53
3.2	Experimental.....	58
3.2.1	Materials and reagents	58
3.2.2	Measurements and instruments.....	58
3.2.3	Synthesis of MWCNT-COOH 5M	59
3.2.4	Synthesis of PTCNT-COOH 300	59
3.2.5	Synthesis of PT2CNT-COOH 300	59
3.3	Results and Discussion	60
3.3.1	Synthesis and characterization of functionalized MWCNT-COOHs	60
3.3.2	Synthesis and characterization of PTCNT-COOH nanocomposites	63
3.4	Conclusion	74
	References	75

Chapter 4	Silver Nanoparticles Entangled Polythiophene-Functionalized MWCNT Ternary Nanocomposites: A Green Synthetic Approach and Enhancement in Properties	81-105
------------------	---	---------------

4.1	Introduction	83
4.2	Experimental	86
4.2.1	Materials and reagents used	86
4.2.2	Measurements and instruments	86
4.2.3	Synthesis of PTCNT-COOH 300 Ag	87
4.2.4	Synthesis of MWCNT-COOH Ag	87
4.2.5	Leaching study of PTCNT-COOH 300 Ag with different pH.....	87
4.3	Results and Discussion	88
4.3.1	Synthesis and characterization of PTCNT-COOH 300 Ag and	

Table of Contents

	<i>MWCNT-COOH Ag</i>	88
4.3.2	<i>Morphological analysis of ternary and binary silver nanocomposites ..</i>	93
4.3.3	<i>Electrical conductivity and thermal stability of ternary and binary nanocomposites</i>	95
4.4	<i>Conclusion</i>	100
	<i>References</i>	101
Chapter 5 Active Solvent Hydrogen Enhanced Catalytic Reduction of p-Nitrophenol using Binary and Ternary Silver Nanocomposites and its Antibacterial Action		107-145
5.1	<i>Introduction</i>	109
5.2	<i>Experimental</i>	112
5.2.1	<i>Materials and reagents</i>	112
5.2.2	<i>Measurements and Instruments</i>	112
5.2.3	<i>Reaction kinetics using different nanocatalyst concentrations</i>	113
5.2.4	<i>Recycling studies using nanocatalysts</i>	113
5.2.5	<i>Recycling effects of nanocatalysts on morphology and composition</i>	114
5.2.6	<i>TNC catalyzed reduction in different volume percentages of glycerol-water mixtures</i>	114
5.2.7	<i>Calibration curve of 4-aminophenolate to find the relative yield of product</i>	114
5.2.8	<i>Large scale reduction of p-nitrophenol</i>	115
5.2.9	<i>Antibacterial study using ternary nanocatalyst TNC</i>	115
5.3	<i>Results and Discussion</i>	116
5.3.1	<i>Comparison of TNC and BNC nanocatalysts</i>	116
5.3.2	<i>Optimization of nanocatalyst amount</i>	122
5.3.3	<i>Recycling studies</i>	124
5.3.4	<i>Elemental composition and morphology of recycled nanocatalysts</i>	125
5.3.5	<i>Optimization of solvent-water mixture for reduction</i>	129
5.3.6	<i>Optimization of [P-NP]: [NaBH₄] molar ratio</i>	130
5.3.7	<i>The proposed mechanism for catalytic reduction</i>	132
5.3.8	<i>Relative yield and industrial-scale reduction of p-nitrophenol</i>	134
5.3.9	<i>Antibacterial activity</i>	136
5.4	<i>Conclusion</i>	139

Table of Contents

References	140
Chapter 6 Ternary and Binary Silver Nanocatalysts for Reduction of Water Soluble and Insoluble Azodyes and Azobenzene	147-175
6.1 Introduction	149
6.2 Experimental	153
6.2.1 Materials and reagents	153
6.2.2 Measurements and Instruments	153
6.2.3 Catalytic decolourisation study of methyl orange and congo red using BNC-0.04 catalyst	153
6.2.4 UV-vis absorption study of reductive decolourisation of methyl orange and congo red	153
6.2.5 Catalytic decolourisation study of methyl red and sudan III using BNC-0.04 catalyst	154
6.2.6 UV-vis absorption study of reductive decolourisation of methyl red and sudan III	154
6.2.7 Large scale reduction of azobenzene	155
6.2.8 Recycling studies using nanocatalysts	155
6.3 Results and discussion	155
6.3.1 Ternary and binary silver nanocomposites (TNC and BNC) as nanocatalyst for reductive decolourisation of azo dyes	155
6.3.2 Optimization of the amount of catalyst for reduction of water-soluble azo dyes	157
6.3.3 Kinetics of reductive decolourisation of water soluble organic azo dyes	158
6.3.4 Optimization of the amount of catalyst for reductive decolourisation of water-insoluble/partially soluble organic azo dyes	160
6.3.5 Kinetics of reductive decolourisation of water-insoluble/partially soluble organic azo dyes	162
6.3.6 Kinetics of catalytic reduction of azobenzene, recyclability studies and mechanism	166

Table of Contents

6.4	<i>Conclusion</i>	171
	<i>References</i>	172
Chapter 7	CTAB Complexed Poly(3-thiophene ethanol)-- Functionalized MWCNT Nanocomposites for Supercapacitor Application	177-204
7.1	<i>Introduction</i>	179
7.2	<i>Experimental</i>	183
7.2.1	<i>Materials and reagents used</i>	183
7.2.2	<i>Measurements and instruments</i>	183
7.2.3	<i>Synthesis of PTE</i>	183
7.2.4	<i>Preparation of PTE-CTAB complex</i>	183
7.2.5	<i>Preparation of PTECNT COOH-10</i>	184
7.2.6	<i>Electrochemical characterization</i>	184
7.3	<i>Results and discussion</i>	184
7.3.1	<i>Preparation of poly(3-thiophene ethanol) (PTE) and PTECNT-COOH nanocomposites</i>	184
7.3.2	<i>Characterisation of PTE and PTECNT-COOH nanocomposites</i>	186
7.3.3	<i>Morphological and dispersion studies of polymer and PTECNT- COOH nanocomposites</i>	189
7.3.4	<i>Thermal stability and electrical conductivity of PTECNT-COOH nanocomposites</i>	192
7.3.5	<i>Electrochemical characterisation of PTECNT-COOH nanocomposites</i>	194
7.4	<i>Conclusion</i>	199
	<i>References</i>	200
Chapter 8	Summary and Conclusions.....	205-209
	Publications and Conference presentations.....	211-212

List of figures		
Chapter 1: Introduction and Literature Review		
Figure no:	Figure caption	Page No
1.1	<i>Structure of polythiophene and some of the substituted polythiophenes</i>	3
1.2	<i>Structures of positive and negative polarons and bipolarons formed in polythiophene via p-type and n-type doping respectively.....</i>	4
1.3	<i>PEDOT:PSS/CNT nanocomposites hydrogel (a), alcogel (b) and aerogel (c)</i>	6
1.4	<i>Flexible micro-supercapacitor fabricated from MnO₂/PEDOT/MWCNT nanocomposites conductive ink with polytetrafluoroethylene</i>	8
1.5	<i>Reversible ammonia sensing using polythiophene-carbon nanotube nanocomposites</i>	9
Chapter 2: AOT Assisted Preparation of Polythiophene-MWCNT Core-shell Nanocomposites		
Figure no:	Figure caption	Page No
2.1	<i>(a) Scheme for oxidative chemical polymerization of thiophene using FeCl₃ oxidant and (b) in-situ chemical oxidative polymerization of polythiophene with multiwalled carbon nanotubes (MWCNT) for nanocomposite preparation.....</i>	24
2.2	<i>(a) Schematic representation of interaction of carbon nanotubes with poly(9,9-bis (diethylaminopropyl)-2,7-fluorene-co-1,4-phenylene) and (b) illustration of the interaction of carbon nanotubes and different conducting polymers</i>	25
2.3	<i>Multiamphiphilic compatibilizer layer formations over CNT surface ...</i>	26
2.4	<i>Normal and reverse micelles formation in the bulk solution of organic solvents. Cylindrical assembly, hemispherical assembly, and a random assembly of the surfactants over CNT's surface</i>	27
2.5	<i>Schematic representation of the synthesis of polythiophene-MWCNT nanocomposite (PTCNT) in presence of AOT</i>	31
2.6	<i>Schematic representation of the synthesis of PT-25 in presence of AOT.....</i>	31
2.7	<i>FT-IR spectra of MWCNT, PT-25, PTCNT-100, PTCNT-200, PTCNT-300 and PTCNT-400</i>	33
2.8	<i>(A) Powder X-ray diffraction patterns of PT-25, PTCNT-100, PTCNT-200, PTCNT-300 and PTCNT-400. (B) A diagram exhibiting the ratio of I_{CNT} (intensity of the characteristic peak of MWCNT) to I_{PT} (intensity of characteristic X-ray diffraction peak of polythiophene) for PTCNT composites</i>	35
2.9	<i>Area under the X-ray diffraction peaks of A) amorphous region and B)</i>	36

	<i>crystalline region in PT-25 and PTCNT nanocomposites.</i>	
2.10	<i>Scanning electron microscopic (SEM) images of PT-25, MWCNT, PTCNT-100 and PTCNT-30</i>	37
2.11	<i>TEM images of MWCNT and PTCNT-100 and size calculation</i>	38
2.12	<i>Transmission electron microscopic (TEM) images of MWCNT, PTCNT-300 [AOT-0], PTCNT-100 and PTCNT-300</i>	39
2.13	<i>WXRD patterns of PTCNT-300 and PTCNT-300 [AOT-0]. Diagram exhibiting the ratio of I_{CNT} (intensity of characteristic peak of MWCNT) to I_{PT} (intensity of characteristic X-ray diffraction peak of polythiophene) for PTCNT-300 and PTCNT-300[AOT-0] (inset)</i>	40
2.14	<i>Mechanism of the formation of PT-25 and PTCNT nanocomposites</i>	41
2.15	<i>Electrical conductivity of PT-0, PT-25, PTCNT-100, PTCNT-200, PTCNT-400 and pristine MWCNT</i>	42
2.16	<i>Dispersions of MWCNT, PT-25, PTCNT-100 and PTCNT-300 in chloroform (A) and water (B). UV-vis absorption spectra of PTCNT-100, PTCNT-200, PTCNT-300 and PTCNT-400 recorded in chloroform medium (C)</i>	43
2.17	<i>Thermogravimetric analysis of PT-25, PTCNT-100 and PTCNT-300 ..</i>	44
2.18	<i>Illustration of the role of polythiophene, MWCNT and AOT in the PTCNT nanocomposite formation</i>	45

Chapter 3: Polythiophene-functionalized MWCNT Nanocomposite: Preparation and Properties

Figure no:	Figure caption	Page No
3.1	<i>Different surface functionalization strategies on carbon nanotubes</i>	54
3.2	<i>Combined covalent cum non-covalent functionalization of carbon nanotubes with molecular and polymer entities</i>	55
3.3	<i>Non-covalent functionalization (modification) of CNT with polymer and covalent functionalization (modification) of CNT with polymer.....</i>	58
3.4	<i>Schematic representation of the preparation of MWCNT-COOH.....</i>	60
3.5	<i>FTIR spectra of Pristine MWCNT, MWCNT-COOH 5M, MWCNT-COOH 10M and MWCNT-COOH-N 5M</i>	61
3.6	<i>Raman spectra of purified MWCNT and MWCNT-COOH</i>	62
3.7	<i>Schematic representation of synthesis of PTCNT-COOH nanocomposite</i>	63
3.8	<i>FT-IR spectra of pristine MWCNT, MWCNT-COOH, PTCNT-COOH 100, PTCNT-COOH 200, PTCNT-COOH 300 and PT-25</i>	65
3.9	<i>XPS spectra of pristine MWCNT, MWCNT-COOH, PTCNT-COOH 100 and PTCNT-COOH 300</i>	66
3.10	<i>Powder X-ray diffractograms of (A) MWCNT-COOH, PT-25, PTCNT-COOH 100, PTCNT-COOH 200, PTCNT-COOH 300 and pristine MWCNT (inset). (B) Comparison of X-ray diffraction diagram of</i>	

	<i>PTCNT-COOH 300, PT2CNT-COOH 300 and PT3CNT-COOH 300...</i>	67
3.11	<i>FE-SEM images of (A) MWCNT-COOH, (B) PTCNT-COOH 100, (C) PTCNT-COOH 300 and (D) HR-TEM image of PTCNT-COOH 300..</i>	68
3.12	<i>Illustration of the utilisation of defect group functionalization for the orientation of polythiophene over MWCNT surface</i>	69
3.13	<i>Dispersion of MWCNT-COOH in different solvents (A) and an aqueous dispersion of different nanocomposites (B). UV-vis spectra of PTCNT-COOH 100 in chloroform [a], PTCNT-COOH 300 in chloroform [b], PTCNT-COOH 300 in ethanol [c] and MWCNT-COOH in water [inset] (C).....</i>	70
3.14	<i>Four probe electrical conductivity of PTCNT-COOH 100, PTCNT-COOH 200, PTCNT-COOH 300, MWCNT-COOH and pristine MWCNT</i>	71
3.15	<i>TGA (A) and DTA (B) analysis of MWCNT-COOH, PTCNT-COOH 100 and PTCNT-COOH 300</i>	72
3.16	<i>Illustration of debundling effect of carbon nanotubes by carboxylic acid functionalization followed by non-covalent functionalization with polymer</i>	73
Chapter 4: Silver Nanoparticles Entangled Polythiophene - Functionalized MWCNT Ternary Nanocomposites: A Green Synthetic Approach and Enhancement in Properties		
Figure no:	Figure caption	Page No.
4.1	<i>Metal nanoparticles incorporation with different polymer-carbon nanotube nanocomposites and their scanning electron microscopic images</i>	83
4.2	<i>Different possibilities for the formation of carbon nanotube-metal nanoparticle nanocomposites</i>	84
4.3	<i>Schematic representation of the synthesis of PTCNT-COOH 300 Ag ...</i>	88
4.4	<i>FT-IR spectra of MWCNT-COOH, MWCNT-COOH Ag and PTCNT-COOH 300 Ag</i>	89
4.5	<i>FT Raman spectra of MWCNT-COOH Ag and PTCNT-COOH 300 Ag</i>	90
4.6	<i>XPS spectra of PTCNT-COOH 300 and PTCNT-COOH 300 Ag</i>	91
4.7	<i>WXR D pattern of PTCNT-COOH 300 Ag and MWCNT-COOH Ag</i>	91
4.8	<i>Dispersion of PTCNT-COOH 300 Ag (A) and MWCNT-COOH Ag (B) in different solvents. UV-vis spectra of PTCNT-COOH 300 Ag and MWCNT-COOH Ag in water and ethanol (C). UV-vis spectra of PTCNT-COOH 300 Ag in water with different concentrations (D) ...</i>	92
4.9	<i>FE-SEM images of MWCNT-COOH Ag (A), dispersed PTCNT-COOH 300 Ag (B), PTCNT-COOH 300 Ag (C (cropped image) and E) and electron diffraction pattern of PTCNT-COOH 300 Ag (D)</i>	93
4.10	<i>Transmission electron microscopic images of PTCNT-COOH 300 Ag (A) and its size calculation (by taking the average size of 10</i>	

	<i>nanoparticles) (B)</i>	94
4.11	<i>Scheme for the formation of silver nanoparticle embedded ternary nanocomposite.....</i>	95
4.12	<i>Four probe electrical conductivity measurements of PTCNT- COOH 300, PTCNT-COOH 300 Ag and MWCNT-COOH Ag and pristine MWCNT (A). The schematic illustration of polythiophene as a connecting bridge between MWCNT-COOH and silver nanoparticles (B).....</i>	96
4.13	<i>Thermograms (A) and differential thermograms (B) of PTCNT-COOH 300, MWCNT-COOH Ag and PTCNT-COOH 300 Ag</i>	97
4.14	<i>UV-vis spectra of PTCNT-COOH 300 Ag after 3 hours of stirring and washing with different media of different pH</i>	98
4.15	<i>Illustration of the formation of water-dispersible ternary nanocomposite and its advantageous outcomes</i>	100
Chapter 5: Active Solvent Hydrogen Enhanced Catalytic Reduction of p-Nitrophenol using Binary and Ternary Silver Nanocomposites and its Antibacterial Action		
Figure no:	Figure caption	Page No.
5.1	<i>Illustration of formation of colloidal silver nanoparticles without having host material (A) and formation of CNT hosted silver nanoparticles (B).....</i>	109
5.2	<i>UV-Vis spectra of p-nitrophenol, p-nitrophenolate ion and reduced product p-amino phenolate ion by adding a reducing agent and a suitable catalyst.</i>	110
5.3	<i>Accounting the benefits of nanocatalysts in model nitrophenol reduction reaction</i>	111
5.4	<i>Schematic representation of reactions of (a) p-nitrophenol with NaBH₄ and (b) silver nanocatalysts (BNC/TNC) catalyzed reaction of p-nitrophenol using NaBH₄</i>	116
5.5	<i>UV-vis absorption spectra for reduction of p-nitrophenol using catalyst TNC-0.02 (A), BNC-0.02 (B), TNC-0.04 (C), BNC-0.04 (D) TNC-0.06 (E), BNC-0.06 (F), TNC-0.10 (G)and BNC-0.10 (H) in consecutive time intervals</i>	118
5.6	<i>Linear relationship plot of ln (A/A₀) against time for p-nitrophenol reduction using TNC-0.02 (A), BNC-0.02 (B), TNC-0.04 (C), BNC-0.04 (D) TNC-0.06 (E), BNC-0.06 (F), TNC-0.10 (G)and BNC-0.10 (H).....</i>	119
5.7	<i>UV-vis absorption spectra of silver nanocolloid after one day of synthesis(A) and silver nanocolloid after 7 days of synthesis(B)</i>	120
5.8	<i>UV-vis absorption spectra of reduction of p-nitrophenol using NaBH₄ using catalyst homogeneous colloidal silver nanoparticles (A) and linear relationship plot of ln(A/A₀) against time on one day after the</i>	

	<i>synthesis of silver nanocolloid (B). UV-vis absorption spectra of reduction of p-nitrophenol using NaBH₄ using catalyst homogeneous colloidal silver nanoparticles (C) and linear relationship plot of ln(A/A₀) against time on seven days after the synthesis of silver nanocolloid (D), UV-vis absorption spectra of reduction of p-nitrophenol using NaBH₄ using PTCNT-COOH 300 as catalyst (E) and reduction of p-nitrophenol using NaBH₄ using MWCNT-COOH as catalyst (F)</i>	121
5.9	<i>Plot of (A/A₀) against time for TNC catalysed reactions (A) and BNC catalysed reactions (B) for different concentrations of catalyst 0.02 mg/mL, 0.04 mg/mL, 0.06 mg/mL, and 0.10 mg/mL taken in p-nitrophenol solution</i>	122
5.10	<i>UV-vis absorption spectra of TNC 0.06 catalysed (A) and BNC-0.06 catalysed reaction (B) for successive catalytic cycles. Catalytic conversion percentage of TNC-0.06 (C) and BNC-0.06 (D) in successive catalytic cycles</i>	124
5.11	<i>X-ray diffraction patterns of TNC and recycled TNCs (A), BNC and recycled BNCs (B) after 3rd, 6th and 9th catalytic cycles. FE-SEM images of TNC (C) and BNC (D) as pristine nanocatalyst</i>	125
5.12	<i>WXR D patterns of (A) byproduct separated from the reaction residue (B) BNC-3RC and (C) BNC-3RC after repeated centrifugation and washing</i>	126
5.13	<i>XPS spectra of TNC-3RC and BNC-3RC</i>	127
5.14	<i>FE-SEM images of TNC-3RC (A) and BNC-3RC (B), EDX colour mapping of sodium in TNC-3RC (C), sodium in BNC-3RC (D), silver in TNC-3RC (E) and silver in BNC-3RC (F). Schematic representation of existence of metaborate by-product over recycled catalyst (G)</i>	129
5.15	<i>Time of decolourization plotted against different volume percentage of solvent-water mixture using P-NP: NaBH₄ molar ratio 1:1000 with TNC-0.06, BNC-0.06, TNC-0.03 and BNC-0.03 catalysts.</i>	130
5.16	<i>Time of decolourization plotted against different NaBH₄ concentrations in water and 10% glycerol-water mixture using TNC-0.06 and BNC-0.06 catalysts (A). UV-vis absorption spectra of reduction of p-nitrophenol using catalyst TNC-0.06 [PNP: NaBH₄ molar ratio 1:100](B) using BNC-0.06 [PNP: NaBH₄ molar ratio 1:100] (C) and BNC-0.03 [PNP: NaBH₄ molar ratio 1:200] [D] in 10% glycerol-water solvent mixture. UV-vis absorption spectra of reduction of p-nitrophenol using catalyst BNC-0.01 [PNP: NaBH₄ molar ratio 1:200 (E) and linear relationship plot of ln(A/A₀) against time for BNC-0.01 for PNP: NaBH₄ molar ratio 1:200 (F) in 10% glycerol-water solvent mixture</i>	131

5.17	<i>Change in pH of glycerol-water mixture (20%) by the addition of NaBH₄</i>	132
5.18	<i>Mechanism of active solvent enhanced green catalytic reduction of p-nitrophenol using NaBH₄ in 10% glycerol-water mixture</i>	134
5.19	<i>Calibration plot of p-aminophenol in different concentrations (1 × 10⁻⁷ M to 5 × 10⁻⁴ M) (A), UV-vis absorption spectra of the standard solution of p-aminophenolate ion, p-aminophenolate obtained from catalytic reduction using TNC-0.06 and BNC-0.06 (in 1 × 10⁻⁴ M) (B), reduction of p-nitrophenol in concentrated solution (10 mL, 15 g/L) using P-NP: NaBH₄ molar ratio 1:25 and BNC-0.18 (0.18 mg/mL) in 10% glycerol-water mixture (C), and UV-vis spectrum p-aminophenolate produced by bulk concentration scale reduction (D)</i>	135
5.20	<i>Photographs of mixtures of E. coli bacteria culture with different concentrations of TNC taken after overnight incubation (A). The plot of optical density versus the concentration of TNC for the antibacterial study at 660 nm (B)</i>	136
5.21	<i>Plot of optical density against concentration of TNC in lactose broth used in antibacterial study (A) and plot and photographs of comparison of antibacterial activity of MWCNT-COOH, PTCNT-COOH 300, Ag NPs, BNC and TNC (B)</i>	138
5.22	<i>Illustration of involvement of active hydrogens in catalytic hydrogenation of p-nitrophenol</i>	139

Chapter 6: Ternary and Binary Silver Nanocatalysts for Reduction of Water Soluble and Insoluble Azodyes and Azobenzene

Figure no:	Figure caption	Page No.
6.1	<i>Consecutive reduction in azo compounds to form chemo-selective product hydrazo compounds and followed by non-selective product amino aromatics by-products</i>	150
6.2	<i>Illustration of photocatalytic transfer hydrogenation of azobenzene to hydrazobenzene (A) with alcohol on cadmium sulfide (adapted from Shiraishi et al.) 2012 and (B) using NaNbO₃ catalyst (adapted from Pei et al. 2020)</i>	151
6.3	<i>Synthesis of Hydrazoarenes formation from nitroarenes and azobenzene</i>	151
6.4	<i>Chemical structure of different azo dyes</i>	155
6.5	<i>Photographs of reductive decolourisation of water-soluble azo dyes methyl orange (initial stage (A), middle stage (B) and final stage (C), and congo red (initial stage (D), middle stage (E) and final stage (F). Plots of decolourisation time against catalyst concentration used for methyl orange(G) and Congo red (H).....</i>	157
6.6	<i>UV-vis absorption spectra of catalytic reduction of methyl orange (A) and congo red (B) using BNC-0.04 catalyst in different time intervals.</i>	

	<i>Linear relationship plot of $\ln (A/A_0)$ against time for reduction of methyl orange (C) and congo red (D) using catalyst BNC-0.04.</i>	158
6.7	<i>UV-vis absorption spectra of catalytic reduction of methyl orange (A) and congo red (B) using TNC-0.04 catalyst in different time intervals. Linear relationship plot of $\ln (A/A_0)$ against time for reduction of methyl orange (C) and congo red (D) using catalyst TNC-0.04.....</i>	160
6.8	<i>Photographs of reductive decolourisation of water-insoluble or partially soluble azo dyes methyl red (initial stage (A), middle stage (B) and final stage (C), and Sudan III (initial stage (D), middle stage (E) and final stage (F). Plots of decolourisation time against the catalyst concentration used for methyl red (G) and sudan III (H).</i>	161
6.9	<i>UV-vis absorption spectra of catalytic reduction of methyl red (A) and sudan III (B) using BNC-0.04 catalyst in different time intervals. Linear relationship plot of $\ln (A/A_0)$ against time for reduction of methyl red (C) and sudan III (D) using catalyst BNC-0.04.....</i>	162
6.10	<i>UV-vis absorption spectra of catalytic reduction of methyl red (A) and sudan III (B) using TNC-0.04 catalyst in different time intervals. Linear relationship plot of $\ln (A/A_0)$ against time for reduction of methyl red (C) and sudan III (D) using catalyst TNC-0.04.</i>	163
6.11	<i>UV-vis absorption spectra of catalytic reduction of azobenzene using BNC-0.04 (A) catalyst and TNC-0.04 (C) in different time intervals. Linear relationship plot of $\ln (A/A_0)$ against time for reduction of azobenzene using catalyst BNC-0.04 (B) catalyst and TNC-0.04 (D).</i>	167
	<i>Large scale reduction of azobenzene (E)</i>	
6.12	<i>Catalytic conversion percentage of BNC-0.04 (A) and TNC-0.04 (B) in successive catalytic cycles of azobenzene reduction.</i>	168
6.13	<i>NMR spectra of azobenzene (A) and catalytic reduction product of azobenzene (B). Photographs of purchased azobenzene (C) and isolated product of azobenzene after catalytic reduction with BNC-0.18 (D)</i>	169
6.14	<i>Illustration of plausible mechanism for catalytic chemoselective hydrogenation of azobenzene</i>	170
6.15	<i>Outline of reductive treatment of azo compounds carried out in present study and their advantageous outcomes</i>	171

Chapter 7: CTAB Complexed Poly(3-thiophene ethanol) - Functionalized MWCNT Nanocomposites for Supercapacitor Application

Figure no:	Figure caption	Page No.
7.1	<i>Schematic representations of three types of capacitance based on energy storage mechanism: electrical double layer capacitance (a), reversible faradaic capacitance (b), and reversible intercalation and</i>	

	<i>exfoliation capacitance (c)</i>	179
7.2	<i>Literature reports of functionalized conducting polymer-carbon nanotube nanocomposites: (A) SWCNT-Pyrene⁺-polythiophene nanocomposite (adapted from Rahman et al. 2005), (B) polythiophene-graft-poly(methyl methacrylate) (PMMA), for poly(styreneco-acrylonitrile) (multiwalled carbon nanotube (MWCNT) composite (adapted from Kim et al. 2005) (C) Single-Stranded DNA-Single-Walled Carbon Nanotube Hybrid (adapted from Ghosh et al. 2005) and (D) conducting polyfluorene copolymer-Wrapped Carbon Nanotubes (adapted from Berger et al. 2005).</i>	180
7.3	<i>EDC-coupled 3-thiophene ethanol monomer to functionalized MWCNT and subsequent in-situ polymerization to prepare nanocomposites.....</i>	181
7.4	<i>Schematic representation of synthesis of PTE-CTAB complex</i>	185
7.5	<i>Synthesis of PTECNT-COOH nanocomposites by solution blending method</i>	186
7.6	<i>FT-IR spectra of PTE, PTE-CTAB complex, MWCNT-COOH, PTECNT-COOH 10, PTECNT-COOH 15 and PTECNT-COOH 20</i>	187
7.7	<i>Wide angle X-ray diffractograms of PTE, PTE-CTAB complex, PTECNT-COOH 10, PTECNT-COOH 15 and MWCNT-COOH (inset)</i>	188
7.8	<i>Field emission scanning electron microscopic images of (a) PTE, (b) MWCNT-COOH, (c) PTECNT-COOH 10 and (d) PTECNT-COOH 15</i>	189
7.9	<i>UV-vis absorption spectra of PTE and PTE-CTAB complex</i>	190
7.10	<i>UV-visible spectra of PTECNT-COOH 10, PTECNT-COOH 15 and PTECNT-COOH 20 in ethanol and DMSO (A) and Dispersions of PTECNT-10, PTECNT-15 and PTECNT-20 in ethanol (B).....</i>	191
7.11	<i>Formation mechanism of PTECNT-COOH nanocomposites</i>	192
7.12	<i>Thermal stability of PTE, PTECNT-COOH 10, PTECNT-COOH 15 and PTECNT-COOH 20</i>	193
7.13	<i>Four probe electrical conductivity of PTE, PTECNT-COOH 15, PTECNT-COOH 20 and MWCNT-COOH</i>	194
7.14	<i>Cyclic voltammogram of PTE (a), PTECNT-COOH 10 (b), PTECNT-COOH 15 (c) and PTECNT-COOH 20 (d) in 1M HCl electrolyte.....</i>	195
7.15	<i>Cyclic voltammogram of PTECNT-COOH 20 for different scan rates in the electrolytes 1M HCl (a), 1M H₂SO₄ (b), 1M KOH (c) and 1M Na₂SO₄ (d).....</i>	196
7.16	<i>Galvanostatic charge-discharge profile of PTECNT-COOH 20 in 1M H₂SO₄ electrolyte (a) and Cycling stability study (cyclic voltammetry) of PTECNT-COOH 20 in 1M H₂SO₄ electrolyte up to 1000 cycles (b).</i>	197
7.17	<i>Illustration of advantageous outputs of PTECNT-COOH nanocomposites preparation and supercapacitor application</i>	199

List of Tables

Chapter 2: AOT Assisted Preparation of Polythiophene-MWCNT Core-shell Nanocomposites		
Table no:	Table heading	Page No
2.1	<i>Polythiophene (PT) and PTCNT nanocomposite samples with the amount of thiophene, AOT and MWCNT, monomer to surfactant mole ratio, monomer to FeCl₃ mole ratio and yield obtained in the preparation</i>	32
2.2	<i>CHNS elemental analysis data of sulfur, carbon and hydrogen in PT-25, PT-25[AOT-0], PT-25, PTCNT-100 and PTCNT-300.....</i>	34
Chapter 3: Polythiophene-functionalized MWCNT Nanocomposite: Preparation and Properties		
Table no:	Table heading	Page No
3.1	<i>Defect group functionalisation and their relevance studied in literature</i>	56
3.2	<i>Millimoles of thiophene, AOT, and ferric chloride, amount of functionalised MWCNT-COOH, mole ratio of monomer/AOT, mole ratio of monomer/FeCl₃, elemental composition of samples and yield</i>	64
3.3	<i>Comparison of conductivity values of MWCNT, MWCNT-COOH, PTCNT and PTCNT-COOH nanocomposites</i>	72
Chapter 4: Silver Nanoparticles Entangled Polythiophene-Functionalized MWCNT Ternary Nanocomposites: A Green Synthetic Approach and Enhancement in Properties		
Table no:	Table heading	Page No.
4.1	<i>Atomic concentration of samples from XPS spectra, pH of the samples, morphology of samples, thermal stability of samples, and electrical conductivity of samples</i>	89
4.2	<i>Comparison study of our work with similar systems reported in the literature</i>	99
Chapter 5: Active Solvent Hydrogen Enhanced Catalytic Reduction of p-Nitrophenol using Binary and Ternary Silver Nanocomposites and its Antibacterial Action		
Table no:	Table heading	Page No.
5.1	<i>Name of nanocatalyst, Initial concentrations of P-NP, NaBH₄, nanocatalyst, final concentrations of P-NP, NaBH₄, nanocatalysts, solvents, rate constant (k), and the activity factor</i>	117
5.2	<i>Comparing catalysts, concentrations of reagents, rate constants, and activity factors obtained in the present study with recent other</i>	

	<i>literature reports</i>	123
5.3	<i>The atomic percentage of C, O, Na, B, Ag, and S in TNC-3RC and BNC-3RC</i>	128
Chapter 6: Ternary and Binary Silver Nanocatalysts for Reduction of Water Soluble and Insoluble Azodyes and Azobenzene		
Table no:	Table heading	Page No.
6.1	<i>Literature reports of hydrogenation of azobenzene to hydrazobenzene .</i>	152
6.2	<i>Name of azo compounds, concentration and volume of azo compounds used, amount of NaBH₄ used, name of catalyst and concentration of catalyst with respective rate constant and activity factor in the catalytic reduction/decolourisation</i>	156
6.3	<i>Comparison of present study with literature reported for catalytic decolourisation methyl orange, congo red, methyl red and Sudan III using NaBH₄ as reducing agent, in terms of the amount of azo dye used, amount of NaBH₄ used, the concentration of catalyst, type of catalyst (homogeneous or heterogeneous) and obtained rate constant ..</i>	164
Chapter 7: CTAB Complexed Poly(3-thiophene ethanol) - Functionalized MWCNT Nanocomposites for Supercapacitor Application		
Table no:	Table heading	Page No.
7.1	<i>PTECNT-COOH samples with the amount of poly(3-thiophene ethanol), CTAB surfactant and MWCNT-COOH used and yield obtained in preparation</i>	186