DECLARATION

I hereby declare that the thesis entitled, "SYNTHESIS, CHARACTERIZATION AND APPLICATIONS OF TERPOLYMERS" submitted to Periyar University in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Chemistry is a record of original research work carried out by me under the guidance and supervision of Dr. V. Raj, Professor and Head, Department of Chemistry, Periyar University, Salem and that it has not formed before the basis for the award of any Degree, Diploma, Associateship, Fellowship or any other similar titles in this or any other University or Institution of higher learning.

Place: Salem
Date: 05.04.2018

Signature of the Candidate.

(Vasanthakumar V.)
ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Dr. V. Raj, Professor and Head, Department of Chemistry, Periyar University my supervisor and guide, who provided me the opportunity and guided me to pursue my Ph.D. degree in the academic area of chemistry. I have learned a lot from his outstanding knowledge and professional attitude, and I am grateful for his patient guidance and multi aspect supports which attribute to the accomplishment of this thesis.

It is very honourable to thank the Vice Chancellor and the Registrar of Periyar University for their help and support all the time and providing necessary facilities.

I express my sincere gratitude to Dr. Abdul R. Burkanudeen, Department of Chemistry, Jamal Mohamed College, Trichy and Raja S. Azarudeen Department of Chemistry, Coimbatore Institute of Technology, Coimbatore for providing enlightening discussion and scientific advice during my course of my research work.

I sincerely acknowledge and V. Anbarasu, Manager (Technical engineering) Cummins India Ltd, Pune and TUV Rheinland Ind. Pvt., Ltd, Bangalore for providing necessary and technical supports throughout my research work.

I extend my special thanks to Mrs. Hemalatha Arumugam for their consistent encouragement, support and love.

Thanks should also be extended to J. Felix Manavalan offices/sections in-charge, Department of chemistry in Periyar University for timely forwarding official documents during this course and who helped me directly or indirectly.

I am also very grateful to all my Friends & Research scholars (A. Priyadharsan, G. B. Gandhi Bhava, R. Ragunath, S. Muthumari, A. Raja, N. Sedhu, P. Priya, S. Mohanapriya, R. Renji, A. Sasirekha, A. Suganthi and R. Shefalika), other fellow graduate students, office people and lab assistants who always gave me encouragement, when I was in difficulties.

I am very much thankful to my father P. Vasudevan, mother V. Maheswari, my wife V. Saranya, my daughter V. Francy vasanthakumar, my sister T. Kamala and my brothers Singaravelan and V. Ayyadurai for their blessings, encouragement and having given me an opportunity for pursue higher study.

(Vasanth V.)
PREFACE

In recent years considerable amount of work has been devoted to synthesize polymer. In this regard terpolymer have attracted wide attention. Furthermore, terpolymer are found to play important role in environmental remediation and mechanical applications. Many terpolymer are reported in literature. Their properties depend on the nature of the chemical present in the terpolymer. By altering the structure it is possible to use many applications. Thus there is a continuing interest in the synthesis of terpolymer.

The thesis deals with studies on the synthesis and characterization and applications of some novel terpolymers in removal of toxic heavy metal ions and dyes, in DMFC as electrolyte and in-vitro biological applications. The thesis is divided into six chapters.

Chapter 1 deals with a general introduction to the various types of polymers and their historical development, processability, performance and applications of terpolymers in various fields. A details survey of literature on synthesis, properties and applications of terpolymer has also been presented along with scope and objectives of the present thesis work.

Chapter 2 deals with synthesis, characterization, removal of toxic metal ions and in-vitro biological applications of sulfanilamide-salicylic acid-formaldehyde terpolymer. The SASF terpolymer was synthesized by polymerization of sulfanilamide, salicylic acid and formaldehyde (SASF) in presence of glacial acetic acid as a catalyst. The characterization of the synthesized SASF terpolymer was conducted by various techniques such as elemental analysis, GPC, FTIR, UV-Visible, $^1$H NMR, $^{13}$C NMR, TGA, XRD, SEM and EDAX measurements. The synthesized SASF terpolymer was used for the removal of Ni$^{2+}$, Cu$^{2+}$, Pb$^{2+}$, Cd$^{2+}$, Hg$^{2+}$ and Zn$^{2+}$ metal ions from aqueous solution. The effect of factors affecting the metal ions adsorption on SASF terpolymer as function of electrolytes in different concentrations and the influence of pH in different ranges were studied by batch equilibrium technique. The metal ions removal efficiency increases with increase of pH and concentration of the electrolytes. The maximum removal percentage is achieved at pH 6-7. Inductively coupled plasma-optical emission spectroscopy was employed for the determination of all metal ions. The in-vitro antibacterial and anticancer activities of the SASF terpolymer were also investigated. The SASF terpolymer exhibits effective antibacterial activity against gram-
positive *Methicillin-resistant Staphylococcus aureus, Bacillus subtilis* and gram-negative *Salmonella typhi, Escherichia coli* bacterial strains. The cytotoxicity studies indicate that SASF terpolymer possesses much potential against Hela (mammalian cancer) cell line.

**Chapter 3** presents enhancing toxic metal ions and dye removal properties of nanostructured terpolymer formed by diaminodiphenylmethane-resorcinol-formaldehyde (DRF) by condensation polymerization method. The chemical structure, thermal stability, size and morphology of the synthesized DRF terpolymer were studied by various techniques such as SEM, EDX, FT-IR, TGA and XRD analyses. The obtained DRF terpolymer was applied for the removal of Cu$^{2+}$, Pb$^{2+}$, Cd$^{2+}$ and Hg$^{2+}$ heavy metal ions and MB dye from waste water. The concentrations of the selected heavy metal ions and MB dye were analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES) and UV/Vis spectroscopy. The metal ions adsorption capacity of DRF terpolymer was investigated as a function of electrolytes, pH of the solutions, adsorbent dose, contact time and desorption/reusability. The results demonstrate that the synthesized DRF terpolymer exhibits outstanding removal performance towards Cu$^{2+}$, Pb$^{2+}$, Cd$^{2+}$ and Hg$^{2+}$ divalent metal ions and excellent degradation capacity for MB dye from industrial waste water. This study provides significant new resources for eco-friendly applications.

**Chapter 4** demonstrates the facile and scalable approach to fabricate novel terpolymer based proton conducting membranes (PCMs) and elucidate the benefits of utilizing the terpolymer composite membranes as electrolytes for direct methanol fuel cells (DMFC). Ecofriendly terpolymer has been synthesized from terephthaldehyde, 2-aminothiophenol and formaldehyde (TAF) by condensation polymerization under optimized conditions. The chemical structure, thermal stability, size and morphology of the synthesized TAF terpolymer were studied by various techniques such as scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), Fourier transform infrared spectroscopy (FT-IR), thermogravimetric analysis and X-ray diffraction (XRD) analysis. The use of a novel cross-linkable terpolymer obtained by solution casting method under varied composition allows a multiple tuning of the different interfaces to produce composite membranes with improved properties. Membranes and their preliminary electrochemical properties (ion exchange capacity, proton conductivity, and swelling rates) were studied and optimized based on their
proton conductance. In addition to these, positron annihilation spectroscopic technique has been used to characterize the sizes and concentrations of free volume defects in the samples that can significantly alter the physical and thermodynamic properties of such complex polymer materials.

Chapter 5 presents adsorption of significant metal ions on DHF terpolymer. 1,5-diaminonaphthalene, 5-hydroxyisophthalic acid and formaldehyde (DHF) terpolymer was synthesized via condensation polymerization techniques using 2 M DMF as a catalyst. The characterization of the synthesized DRF terpolymer was conducted by various techniques such as elemental analysis, GPC, FTIR, TGA, XRD, SEM and EDAX measurements. The obtained terpolymer was further utilized for the removal of toxic metal ions such as Pb$^{2+}$, Cd$^{2+}$ and Hg$^{2+}$ from aqueous environments. The results demonstrate that the terpolymer with adsorption properties can effectively be utilized for the removal of pollutants the promising network structure of the DHF terpolymer is more advantageous than conventional techniques.

Chapter 6 covers a brief overall summary and conclusion of works discussed in Chapter 2 to Chapter 5 have been presented in this chapter.
## CONTENTS

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Contents</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>List of Figures</td>
<td>ix</td>
</tr>
<tr>
<td>II</td>
<td>List of Tables</td>
<td>xiii</td>
</tr>
</tbody>
</table>

**Chapter 1**  
*Introduction*

1.1 Polymer  
1.2 Polymer composites and blends  
1.3 Terpolymers  
1.3.1 Properties of terpolymer  
1.3.1.1 Mechanical properties of terpolymers  
1.3.1.2 Degradation properties of terpolymers  
1.3.1.3 Ion exchange properties of terpolymer resin  
1.3.1.4 Sorption characteristics of terpolymers  
1.3.1.5 Biological properties of terpolymeric materials  
1.3.2 Applications of terpolymers  
1.4 Environmental pollution  
1.4.1 Conventional techniques for removal of pollutants  
1.5 Adsorption  
1.5.1 Types of adsorption  
1.5.1.1 Physical Adsorption (Physisorption)  
1.5.1.2 Chemical Adsorption (Chemisorption)  
1.5.2 Contacting Systems and Modes of Operation  
1.5.3 Factors affecting adsorption  
1.5.3.1 Nature of adsorbent  
1.5.3.2 Nature of adsorbate  
1.5.3.3 Effect of concentration of adsorbate  
1.5.3.4 Effect of amount of adsorbent  
1.5.3.5 Nature of Solvent  
1.5.3.6 Effect of temperature  
1.5.3.7 Influence of pH

1-36
1.5.4 Conventional adsorbents

1.5.4.1 Activated Carbon
1.5.4.2 Silica gel
1.5.4.3 Fly ash
1.5.4.4 Zeolites
1.5.4.5 Clays
1.5.4.6 Polymeric Adsorbents

1.6 Terpolymer as adsorbent
1.7 Review of literature
1.8 Scope and objectives of the present work

References

Chapter 2
Synthesis, Characterization, Removal of toxic metal ions and in-vitro biological applications of sulfanilamide-salicylic acid-formaldehyde terpolymer

2.0 Abstract
2.1 Introduction
2.2 Experimental

2.2.1 Chemicals and reagents
2.2.2 Terpolymerization
2.2.3 Characterization of SASF terpolymer
2.2.4 ICP-OES Measurements
2.2.5 Batch sorption experiments
2.2.6 In vitro biological studies of the SASF terpolymer

2.2.6.1 Antimicrobial properties of terpolymer
2.2.7 Anticancer studies

2.2.7.1 Cell line and culture medium
2.2.7.2 MTT assay

2.3 Results and discussion

2.3.1 Analytical and elemental data
2.3.2 FTIR spectral analysis
2.3.3 UV-Visible spectral analysis
2.3.4 $^1$H NMR and $^{13}$C NMR Spectrum
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.5 Thermal behavior of the terpolymer</td>
<td>49</td>
</tr>
<tr>
<td>2.3.6 Binding capacity of SASF terpolymer with the metal ions</td>
<td>50</td>
</tr>
<tr>
<td>2.3.6.1 Effect of electrolytes and pH</td>
<td>50</td>
</tr>
<tr>
<td>2.3.7 X-ray diffraction studies</td>
<td>52</td>
</tr>
<tr>
<td>2.3.8 Morphological Study and EDAX Analysis</td>
<td>53</td>
</tr>
<tr>
<td>2.3.9 In vitro biological studies of the SASF terpolymer</td>
<td>55</td>
</tr>
<tr>
<td>2.3.9.1 Antibacterial screening activity</td>
<td>55</td>
</tr>
<tr>
<td>2.3.10 Cytotoxicity studies (in-vitro)</td>
<td>57</td>
</tr>
<tr>
<td>2.4 Conclusion</td>
<td>59</td>
</tr>
<tr>
<td>References</td>
<td>60</td>
</tr>
</tbody>
</table>

**Chapter 3**

**Enhancing Toxic Metal Ions and Dye Removal Properties of Nanostructured Terpolymer Formed by Diaminodiphenylmethane-Resorcinol-Formaldehyde**

3.0 Abstract                                                  64
3.1 Introduction                                              65
3.2 Experimental                                              67
  3.2.1 Chemicals and reagents                                 67
  3.2.2 Fabrication of nanostructured DRF terpolymer           67
  3.2.3 Characterizations of the synthetic DRF terpolymer      68
  3.2.4 Heavy metal ions removal experiments                   68
  3.2.5 Photocatalytic dye degradation                         69
3.3. Results and discussion                                    70
  3.3.1 FT-IR analysis                                         70
  3.3.2 Thermal analysis                                       71
  3.3.3 X-ray Diffraction analysis                             72
  3.3.4 Adsorption properties of the DRF terpolymer for metal Ions 73
    3.3.4.1 Effect of electrolytes                              73
    3.3.4.2 Effect of pH                                        74
    3.3.4.3 Effect of contact time                              76
    3.3.4.4 Effect of the dosage                               76
    3.3.4.5 Desorption and reusability                          77
  3.3.5 Surface morphology and EDX analysis                     77
Chapter 4
Tunable Physicochemical and Free Volume Characteristics of Novel Terpolymer-Poly(Vinyl Alcohol) Grafted Membranes For DMFC

4.0 Abstract 90
4.1 Introduction 91
4.2 Experimental 93
  4.2.1 Chemicals and reagents 93
  4.2.2 Synthesis of TAF terpolymer 93
  4.2.3 Fabrication of PVA-TAF composite membrane 94
  4.2.4 Characterization of PVA and PVA-TAF 94
  4.2.5 Determination of ion-exchange capacity 95
  4.2.6 Sorption and proton conductivity measurements 96
  4.2.7 Mechanical properties 96
  4.2.8 Methanol permeation studies 97
  4.2.9 Positron Annihilation spectral analysis measurement 97
4.3 Results and discussion 98
  4.3.1 $^1$H NMR, CHNS and GPC analysis 98
  4.3.2 FT-IR and XRD analysis 99
  4.3.3 Thermogravimetric analysis 103
  4.3.4 IEC, sorption and proton conductivity studies of PVA-TAF 104
  4.3.5 Mechanical properties of PVA-TAF composite membrane 105
  4.3.6 SEM and AFM morphological studies 107
  4.3.7 Proton conductivity testing 110
  4.3.8 Methanol Permeability and Free Volume Characteristics Analysis 112
  4.3.9 Positron Annihilation spectral analysis 113
  4.3.4 Electrochemical selectivity studies 116
4.4 Conclusions 117
References 118
Chapter 5
Environmental Impact of New DHF Terpolymer: Synthesis, Characterization and Its Toxic Metal Ions Removal Properties

5.0 Abstract
5.1 Introduction
5.2 Experimental
  5.2.1 Chemicals and reagents
  5.2.2 Terpolymerization
  5.2.3 Characterization of DHF terpolymer
  5.2.3.1 Characterization of DHF terpolymer
  5.2.3.2 ICP-OES measurement
  5.2.4 Adsorption experiment
5.3 Results and discussion
  5.3.1 Analytical and elemental data
  5.3.2 FT-IR spectral analysis
  5.3.3 Thermal behavior of the terpolymer
  5.3.4 Sorption capacity of DHF terpolymer with the metal ions
    5.3.4.1 Effect of electrolytes and pH
    5.3.5 Scanning electron microscopy and EDAX analysis
5.4 Conclusion
Reference

Chapter 6
Summary and Conclusions

Publications
(a) List of Publications from dissertation Work
(b) List of Publications outside dissertation Work
Reprints of publications on dissertation work
## List of Figures

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Figure Caption</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Chapter 1: Introduction</strong></td>
<td></td>
</tr>
<tr>
<td>Figure 1.1</td>
<td>Toxicity of heavy metals of dyes</td>
<td>10</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Various types of conventional techniques for removal of toxic metal ions</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td><strong>Chapter 2: Synthesis, Characterization, Removal of toxic metal ions and <em>in-vitro</em> biological applications of sulfanilamide-salicylic acid-formaldehyde terpolymer</strong></td>
<td></td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Synthesis sequence of SASF terpolymer</td>
<td>41</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>FT-IR Spectrum of SASF terpolymer</td>
<td>47</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>UV-Spectrum of SASF terpolymer</td>
<td>47</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>$^1$H NMR Spectrum of SASF terpolymer</td>
<td>48</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>$^{13}$C NMR Spectrum of SASF terpolymer</td>
<td>49</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>TGA and DTA Curves of SASF terpolymer</td>
<td>50</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Adsorption capacity of Ni$^{2+}$, Cu$^{2+}$, Pb$^{2+}$, Cd$^{2+}$, Hg$^{2+}$ and Zn$^{2+}$ ions on SASF terpolymer with different concentrations of (a) NaCl, (b) Na$_2$SO$_4$ and (c) NaNO$_3$ and (d) pH</td>
<td>52</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Images of (a) before and (b) after metal ions treated SASF terpolymer</td>
<td>52</td>
</tr>
<tr>
<td>Figure 2.9</td>
<td>X-ray diffraction (XRD) patterns of SASF terpolymer (a) before and (b) after metal ion treated</td>
<td>53</td>
</tr>
<tr>
<td>Figure 2.10</td>
<td>SEM images for metal ions unloaded SASF terpolymer with different magnification</td>
<td>54</td>
</tr>
<tr>
<td>Figure 2.11</td>
<td>SEM images for metal ions loaded SASF terpolymer with different magnification</td>
<td>54</td>
</tr>
<tr>
<td>Figure 2.12</td>
<td>(a) EDAX Analysis and their spectrum process of SASF terpolymer and (b) after metal ions loaded SASF terpolymer</td>
<td>55</td>
</tr>
</tbody>
</table>
Figure 2.13 Antibacterial activity of SASF terpolymer. Clear inhibition zone formed against the growth of (a) B. subtilis, (b) S. typhi, (c) E. coli and (d) S. aureus (MRSA)  

Figure 2.14 Fluorescence images showing the viability of control cells and different concentration of treated HeLa cancer cells on SASF terpolymer (after 24 hr treatment)

Chapter 3 Enhancing Toxic Metal Ions and Dye Removal Properties of Nanostructured Terpolymer Formed by Diaminodiphenylmethane-Resorcinol-Formaldehyde

Figure 3.1 Scheme for the synthesis of DRF terpolymer  
Figure 3.2 FTIR spectra of (a) as synthesized, (b) metal ion adsorbed and (c) dye degraded DRF terpolymer  
Figure 3.3 TG and DTGA (inset) curves for the DRF terpolymer  
Figure 3.4 XRD patterns of terpolymer (a) before, (b) after sorption of metal ions and (c) dye degraded terpolymer  
Figure 3.5 The removal percentage of Cu$^{2+}$, Pb$^{2+}$, Cd$^{2+}$ and Hg$^{2+}$ metal ions on DRF under various conditions. (a) Effect of Na$_2$SO$_4$. (b) NaNO$_3$. (c) pH. (d) Contact Time. (e) Dosage and (f) Reusability  
Figure 3.6 The possible mechanism for the adsorption of heavy metal ions onto the as-synthesized DRF terpolymer  
Figure 3.7 Morphology of DRF terpolymer at various magnifications  
Figure 3.8 Morphology of metal ions treated DRF terpolymer at various magnifications  
Figure 3.9 (a) SEM image and the corresponding EDX spectrum of unloaded DRF terpolymer and Elemental mapping of DRF terpolymer (b) C Ka mapping, (c) N Ka mapping and (d) O Ka mapping  
Figure 3.10 EDX analysis of the metal ions treated DRF terpolymer  
Figure 3.11 (a) UV-visible Diffuse reflectance spectrum and (b) Tauc plot of the DRF terpolymer
### List of Figures

| Figure 3.12 | (a) Absorption spectra of the MB solution under visible light in the presence of DRF terpolymer. (b) Photocatalytic decomposition rates of MB dye | 82 |
| Figure 3.13 | (a) Cycling degradation curve for DRF terpolymer. (b) Kinetic linear fitting curves of MB over blank and DRF terpolymer samples under visible light irradiation | 82 |

#### Chapter 4 Tunable Physicochemical and Free Volume Characteristics of Novel Terpolymer-Poly(Vinyl Alcohol) Grafted Membranes For DMFC

| Figure 4.1 | Schematic diagram for synthesis TAF terpolymer and PVA-TAF composite membrane | 94 |
| Figure 4.2 | $^1$H NMR spectra of TAF terpolymer in DMSO-d$_6$ | 99 |
| Figure 4.3 | FT-IR Spectrum of synthesized TAF terpolymer, Pristine PVA and various content of PVA-TAF terpolymer composite membrane | 101 |
| Figure 4.4 | XRD pattern of pristine PVA and PVA-TAF terpolymer composite membranes with various contents of TAF | 102 |
| Figure 4.5 | (a) TGA and (b) differential TG (dTG) curves of the pristine PVA and PVA-TAF terpolymer composite membrane with various contents of TAF under nitrogen atmosphere | 103 |
| Figure 4.6 | Tensile strength and elongation at break of PVA and PVA-TAF terpolymer composite membranes as a function of different TAF content loading | 106 |
| Figure 4.7 | Chemical/oxidative stability of PVA-TAF terpolymer composite membranes | 107 |
| Figure 4.8 | Surface morphologies of (a) PVA-TAF1, (b) PVA-TAF2, (c) PVA-TAF3 and (d) PVA-TAF4 and (e-f) EDX spectra for PVA-TAF3 terpolymer composite membrane insets in the panel are the elemental analysis results | 108 |
| Figure 4.9 | Mapping analysis of PVA-TAF3 terpolymer composite membrane (a) C Ka1 mapping, (b) O Ka1 mapping, (c) N Ka1 mapping and (d) S Ka1 mapping | 109 |
| Figure 4.10 | AFM micrographs for surface topography of the various content of PVA-TAF terpolymer composite membrane: (a-b) | 110 |
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Effect of proton conductivity with temperature of PVA-TAF terpolymer composite membrane in various matrices and (b) ln σ vs. 1000/T plot</td>
<td>112</td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>Methanol permeability at different methanol concentrations varied from 0.5 M to 4M for Pristine PVA and for various contents of TAF in PVA-TAF terpolymer composite membranes</td>
<td>113</td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>The free volume radius and fractional free volume concentration in PVA and PVA-TAF terpolymer composite membrane as a function of different TAF content loading</td>
<td>115</td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>The electrochemical selectivity of PVA and PVA-TAF terpolymer composite membrane as a function of different TAF content loading</td>
<td>116</td>
</tr>
</tbody>
</table>

Chapter 5 Environmental Impact of New DHF Terpolymer: Synthesis, Characterization and Its Toxic Metal Ions Removal Properties

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Synthesis route of the DHF terpolymer</td>
<td>125</td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>FT-IR spectra of before and (b) after metal-loaded DHF terpolymer</td>
<td>129</td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>XRD patterns of DHF (a) before and (b) after metal ions removal</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>TGA thermogram of DHF terpolymer</td>
<td>130</td>
</tr>
<tr>
<td>(a) &amp; (b)</td>
<td>The removal percentage of Pb^{2+}, Cd^{2+} and Hg^{2+} metal ions in DHF terpolymer under various conditions. (a) Effect of NaCl (Na_2SO_4 (c) NaNO_3 and (d) pH</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>SEM image of the DHF terpolymer</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>EDX analysis and the spectral analysis of the DHF terpolymer</td>
<td>133</td>
</tr>
</tbody>
</table>
# List of Tables

<table>
<thead>
<tr>
<th>Table No.</th>
<th>Table Caption</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Chapter 1: Introduction</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table 1.1 Sources and effects of heavy metals and dyes on human beings</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Table 1.2 Disadvantages of Conventional Techniques</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td><strong>Chapter 2: Synthesis, Characterization, Removal of toxic metal ions and <em>in-vitro</em> biological applications of sulfanilamide-salicylic acid-formaldehyde terpolymer</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table 2.1 ICP OES: Operational conditions and instrumental parameters</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Table 2.2 Cytotoxic reactivity grade and their description</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Table 2.3 Elemental data of the SASF terpolymer</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Table 2.4 GPC data of the SASF terpolymer</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Table 2.5 TGA and DTA Curves of SASF terpolymer</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Table 2.6 Antibacterial effect of SASF terpolymer at different concentrations</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Table 2.7 Cytotoxic reactivity grade for the SASF terpolymer</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td><strong>Chapter 3 Enhancing Toxic Metal Ions and Dye Removal Properties of Nanostructured Terpolymer Formed by Diaminodiphenylmethane-Resorcinol-Formaldehyde</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table 3.1 TGA data of the DRF terpolymer</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>Table 3.2 Comparison of Cd$^{2+}$, Cu$^{2+}$, Hg$^{2+}$ and Pb$^{2+}$ adsorption properties with different form of sorbents</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td><strong>Chapter 4 Tunable Physicochemical and Free Volume Characteristics of Novel Terpolymer-Poly(Vinyl Alcohol) Grafted Membranes For DMFC</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table 4.1 Results of GPC and CHNS Analysis of TAF Terpolymer</td>
<td>99</td>
</tr>
</tbody>
</table>
Table 4.2  Thermal characteristics of PVA and PVA-TAF terpolymer composite membrane with various contents of TAF at various temperatures 104

Table 4.3  Physicochemical Properties of PVA and various PVA-TAF terpolymer composite membranes 105

Table 4.4  Positron Lifetimes and Intensities in the PVA-TAF composite. Typical Errors Are 0.002 Ns, 0.008 Ns, 0.080 Ns, 1.08%, 1.08% And 0.09% Respectively 113

Chapter 5 Environmental Impact of New DHF Terpolymer: Synthesis, Characterization and Its Toxic Metal Ions Removal Properties

Table 5.1  ICP OES: Operational conditions and instrumental parameter 126

Table 5.2  Elemental and GPC data of the DHF terpolymer 128

Table 5.3  TGA data of the DHF terpolymer 131