

Table of Contents

CHAPTER 1 RATIONALE AND OBJECTIVE	1
CHAPTER 2 LITERATURE REVIEW	3
2.1 INTRODUCTION.....	3
2.2 SYNTHESIS OF POLYIMIDES	3
2.2.1 Classical Two-Step Method	4
2.2.1.1 Poly(amic acid) Formation.....	4
2.2.1.2 Thermal (Bulk) Imidization.....	11
2.2.1.3 Solution Imidization.....	14
2.2.1.4 Chemical Imidization	18
2.2.2 Additional Routes to Polyimides.....	18
2.2.2.1 Polyimides From Dianhydrides and Diisocyanates.....	18
2.2.2.2 Nucleophilic Aromatic Substitution.....	20
2.2.2.3 Ester-Acid Route	26
2.2.2.4 Transimidization	26
2.2.2.5 Other Routes to Polyimide Formation.....	32
2.3 POLYIMIDE PROPERTIES AND APPLICATIONS.....	33
2.3.1 Characterization and Properties of Polyimides	33
2.3.1.1 Molecular Weight and Functional Group Analysis via Titration Measurements.....	33
2.3.1.2 Structural Characterization.....	34
2.3.1.3 Glass Transition Temperature and Thermal Stability	35
2.3.1.4 Insolubility/Infusibility.....	37
2.3.2 Polyimide Applications	42
2.3.2.1 Polyimides in Electronics.....	42
2.3.2.2 Polyimides as Optical Waveguides	45
2.3.2.3 Polyimides in Aerospace	46
2.3.2.4 Polyimide Adhesives in Aerospace and Microelectronics ...	48
2.4 GAS TRANSPORT IN POLYMERIC MEMBRANES	60

2.4.1 Porous Membranes	60
2.4.2 Dense Membranes	62
2.4.2.1 Rubbery Polymers (Elastomers).....	63
2.4.2.1.1 Theory of Gas Permeation.....	63
2.4.2.1.2 A Physical Description of Gas Permeation	66
2.4.2.2 Glassy Polymers	68
2.4.2.2.1 Theory of Gas Permeation.....	68
2.4.2.2.2 A Physical Description of Gas Permeation	69
2.4.3 Predictive Techniques for Gaseous Transport in Polymers	70
2.4.3.1 Empirical Correlations	70
2.4.3.2 Molecular Modeling via Computer Simulations.....	71
2.4.3.3 Recent Advances in Molecular Modeling	72
2.4.3.4 The Current State of the Art.....	75
2.5 STRUCTURE-PROPERTY RELATIONSHIPS IN SELECTIVE	
GAS SEPARATION	80
2.5.1 Repeat Unit Design to Increase Permeability and Selectivity	81
2.5.2 <i>Meta</i> versus <i>Para</i> Isomers.....	84
2.5.3 Chemical or Electrostatic Crosslinking, and Annealing	88
CHAPTER 3 EXPERIMENTAL	92
3.1 MATERIALS	92
3.1.1 Solvents	92
3.1.2 Monomer Purification	95
3.1.2.1 Diamines.....	95
3.1.2.2 Dianhydrides	100
3.1.3 Endcap Purification	105
3.1.4 Epoxy Resins.....	106
3.2 MONOMER SYNTHESIS	107
3.2.1 Reagents	107
3.2.2 Synthetic Procedure.....	111
3.2.2.1 Synthesis of 1-phenyl-1,3,3-trimethylindane	111

3.2.2.2	Synthesis of 5(6)-nitro-1-(4-nitrophenyl)-1,3,3-trimethylindane (dinitrophenylindane or DNPI)	113
3.2.2.3	Synthesis of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (diaminophenylindane or DAPI).....	113
3.2.2.4	Synthesis of 5,6-dinitro-1-(4-nitrophenyl)-1,3,3-trimethylindane (trinitrophenylindane or TNPI)	121
3.2.2.5	Synthesis of 5,6-diamino-1-(4-aminophenyl)-1,3,3-trimethylindane (triaminophenylindane or TAPI).....	125
3.2.2.6	Synthesis of 4-hydroxy- α -methylstyrene (isopropenylphenol or IPP)	125
3.2.2.7	Synthesis of 6-hydroxy-1-(4-hydroxyphenyl)-1,3,3-trimethylindane (dihydroxyphenylindane or DHPI).....	131
3.3	CHARACTERIZATION METHODS	134
3.3.1	Intrinsic Viscosity (IV).....	134
3.3.2	Gel Permeation Chromatography (GPC) or Size Exclusion Chromatography (SEC).....	134
3.3.3	Fourier Transform Infrared Spectroscopy (FTIR).....	134
3.3.4	Polymer Solubility.....	134
3.3.5	Thermogravimetric Analysis (TGA)	135
3.3.6	Differential Scanning Calorimetry (DSC).....	135
3.3.7	Water Sorption	135
3.3.8	Polyimide Oligomer and Epoxy Resin Titrations	135
3.3.9	Refractive Index (RI) Measurement.....	136
3.3.10	Permeation Apparatus	137
3.3.11	Melting Point (m.p.) Measurement	137
3.3.12	High Performance Liquid Chromatography (HPLC)	137
3.3.13	Nuclear Magnetic Resonance (NMR) Spectroscopy.....	139
3.4	POLYMERIZATION METHODS.....	140
3.4.1	Ester-Acid Precursor Method for the Formation of High Molecular Weight 5,5'-[2,2,2-Trifluoro-1-(trifluoromethyl)ethylidene] bis-	

1,3-isobenzene furandione (6FDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	140
3.4.2 Chemical Imidization of High Molecular Weight 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	143
3.4.3 Solution Imidization of High Molecular Weight 4,4'-bis [4-(3,4-dicarboxyphenoxy)]biphenyl dianhydride (BPEDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	143
3.4.4 Thermal Imidization of High Molecular Weight 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	146
3.5 SYNTHESIS OF CONTROLLED MOLECULAR WEIGHT POLYIMIDE OLIGOMERS.....	148
CHAPTER 4 RESULTS AND DISCUSSION	150
4.1 MONOMER SYNTHESIS	150
4.1.1 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane and 5,6-diamino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI and TAPI) Synthesis	150
4.1.2 6-hydroxy-(4-hydroxyphenyl)-1,3,3-trimethylindane (DHPI) Synthesis.....	151
4.2 MOLECULAR WEIGHT AND THERMAL CHARACTERIZATION OF NOVEL POLYIMIDES	155
4.2.1 Characterization of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides via Ester-acid Solution Imidization	155
4.2.2 Effect of Imidization Method on High Molecular Weight 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	171
4.2.3 Effect of the DAPI Isomeric Ratio on Thermal Properties	171

4.2.4	Biphenylether Dianhydride (BPEDA) and bisphenol A dianhydride (BPADA) Based Polyimides	173
4.2.5	Polyimides Based on 2,2-bis(3-amino-4-methylphenyl)hexafluoropropane (Bis-AT-AF).....	176
4.2.6	Hexafluoroisopropylidene dianhydride (6FDA) Based Polyimides	178
4.2.7	Polyimides Derived from 3,7-diamino-2,8-dimethyl-dibenzothiophene-5,5-dioxide (DDBT)	181
4.3	GAS PERMSELECTIVITY STUDIES PERFORMED ON NOVEL POLYIMIDES	181
4.3.1	Permselective Behavior of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides	183
4.3.2	Effect of the DAPI Isomeric Ratio on Polymer Permeability and Selectivity.....	187
4.3.3	Permselective Behavior of 5,5'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene]bis-1,3-isobenzene-furandione Dianhydride (6FDA) Based Polyimides.....	187
4.3.4	Polymer Permeability and Selectivity of Polyimides Derived from 3,7-diamino-2,8-dimethyl-dibenzothiophene-5,5-dioxide (DDBT)	190
4.4	MOLECULAR WEIGHT AND THERMAL CHARACTERIZATION OF POLYIMIDES CONTAINING HYDROXYL MOIETIES	190
4.4.1	Characterization of Polyimides Containing 4,4'-diamino-3,3'-dihydroxybenzidine (HAB)	193
4.4.2	Polyimides Derived from 2,2-bis(3-amino-4-hydroxyphenyl)hexafluoropropane (Bis-AP-AF).....	196
4.4.3	Polyimides Based on 2,4-diaminophenol (DAP)	200
4.5	GAS PERMSELECTIVITY STUDIES PERFORMED ON POLYIMIDES CONTAINING HYDROXYL MOIETIES	207

4.5.1	Permselective Behavior of 4,4'-diaminobiphenyl-3,3'-diol (HAB) Based Polyimides	209
4.5.2	Polymer Permeability and Selectivity of Polyimides Derived from 2,4-diaminophenol.....	212
4.6	APPLICABLE CROSSLINKING MECHANISMS FOR HOLLOW FIBER TECHNOLOGY.....	212
4.6.1	Curing Studies of Amine Terminated Oligomers with Epoxy-Cast from Chloroform	214
4.6.2	Curing Studies of Amine, Phenol and Acetylene Containing Polymers-Cast from NMP.....	217
	CHAPTER 5 CONCLUSIONS	226
	REFERENCES	229
	VITA	240

List of Figures

Figure 2.1	A Heterocyclic Imide Linkage	3
Figure 2.2.1.1.1	Common Dianhydrides and Diamines	6
Figure 2.2.1.1.2	A Model for a 4:1 Ratio of NMP Complexation with a Di(amic acid) Repeat Unit	10
Figure 2.2.1.2.1	The Repeat Unit of Kapton-H Formed from PMDA and ODA.....	13
Figure 2.2.1.3.1	Remaining Amic Acid Content and Intrinsic Viscosity as a Function of Reaction Time: (A) at 140°C; (B) at 150°C; (C) at 180°C.....	17
Figure 2.2.2.2.1	A-B Type Monomer to Form Polyimides	25
Figure 2.2.2.3.1	Dianhydrides for Methanolysis Reactions	28
Figure 2.3.2.1.1	Coefficient of Thermal Expansion of Various Metals, Ceramics and Organic Polymers.....	43
Figure 2.3.2.1.2	Typical Negative-Imaging Photosensitive Polyimide.....	44
Figure 2.3.2.2.1	Flip-Chip Configuration with Waveguide	47
Figure 2.3.2.4.1	Effect of Adhesion Viscosity on Interfacial Contact	51
Figure 2.3.2.4.2	Hierarchy of Spontaneously Adsorbed Layers on a Metal Surface	52
Figure 2.3.2.4.3	Sketches of Adhesive Joint Geometries.....	54
Figure 2.3.2.4.4	DSC Thermogram of $M_n=3,000$ g/mol BPADA/ <i>m</i> -PDA Phenyl Ethynyl Phthalic Anhydride Capped Polyetherimide Oligomers	57
Figure 2.3.2.4.5	Rheological Characterization of BPADA/ <i>m</i> -PDA Phenyl Ethynyl Phthalic Anhydride Capped Polyetherimide.....	57
Figure 2.3.2.4.6	Adhesion Properties of PolyimideIsoindoloquinazolinedione (PIQ) to SiO ₂ with and without Adhesion Promoter (aminosilane).....	58
Figure 2.4.1.1	Total Flow in Porous Membranes Consists of Knudsen and Poiseuille Processes.....	61

Figure 2.4.2.1.1.1 Gaseous Diffusion Across a Semipermeable Membrane.....	64
Figure 2.4.3.3.1 Molecular Dynamic Simulations of a “Jump” of an O ₂ Molecule in a Glassy –CH ₂ - Matrix. Changes in the Potential Energy Surfaces of “Cages” Enclosing the Penetrant Molecule	73
Figure 2.4.3.3.2 Movement and “Jump” of CO ₂ Molecules Inside the Matrix of 6FDA-4,4’-PDA Polyimide	74
Figure 2.4.3.4.1 Log (α_{O_2/N_2}) vs. Log (P _{O₂}). The Current State of the Art Polymers for Gas Selectivity Defines an Upper-Bound	76
Figure 2.4.3.4.2 S _{He} /S _{N₂} vs. Log (P _{He})	77
Figure 2.4.3.4.3 Log (D _{He} /D _{N₂}) vs. Log (P _{He})	78
Figure 2.5.1.1 6F Biphenyl Showing Steric Hindrance Between Ph-H’s and F’s (A) 2-Dimensional (B) 3-Dimensional , Ball and Stick (C) 3-Dimensional, Space Filling.....	82
Figure 2.5.1.2 Effects of <i>ortho</i> -Substituents on C-N Bond Rotation.....	85
Figure 2.5.1.3 Hydroxyl-containing Diamine Monomers	86
Figure 2.5.2.1 Differences in Intrasegmental (rotational) Mobility of Two Polyimide Isomers: PMDA-4,4’-ODA (<i>para</i> -isomer) and PMDA-3,3’-ODA (<i>meta</i> -isomer)	87
Figure 3.2.2.1.1 ¹ H NMR Spectrum for 1-phenyl-1,3,3-trimethylindane	114
Figure 3.2.2.1.2 HMQC of 1-phenyl-1,3,3-trimethylindane	115
Figure 3.2.2.1.3 ¹³ C NMR of 1-phenyl-1,3,3-trimethylindane.....	116
Figure 3.2.2.1.4 IR Spectra of 1-phenyl-1,3,3-trimethylindane, 5(6)-nitro-1-(4-nitrophenyl)-1,3,3-trimethylindane and 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane	117
Figure 3.2.2.2.1 ¹ H NMR of 5(6)-nitro-1-(4-nitrophenyl)-1,3,3-trimethylindane	119
Figure 3.2.2.2.2 DQCosY of 5(6)-nitro-1-(4-nitrophenyl)-1,3,3-trimethylindane	120
Figure 3.2.2.3.1 ¹ H NMR of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane.....	122

Figure 3.2.2.3.2	DQCosY of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane	123
Figure 3.2.2.4.1	¹ H NMR of 5,6-dinitro-1-(4-nitrophenyl)-1,3,3-trimethylindane	126
Figure 3.2.2.4.2	DQCosY of 5,6-dinitro-1-(4-nitrophenyl)-1,3,3-trimethylindane	127
Figure 3.2.2.5.1	DQCosY of 5,6-dinitro-1-(4-nitrophenyl)-1,3,3-trimethylindane.....	128
Figure 3.2.2.6.1	Reaction Apparatus for the Synthesis of 4-hydroxy- α -methylstyrene..	130
Figure 3.2.2.7.1	¹ H NMR of 6-hydroxy-1-(4-hydroxyphenyl)-1,3,3-trimethylindane	132
Figure 3.2.2.7.2	DQCosY of 6-hydroxy-1-(4-hydroxyphenyl)-1,3,3-trimethylindane...	133
Figure 3.3.10.1	Gas Permeation Apparatus.....	138
Figure 3.4.1.1	Polymerization Apparatus.....	142
Figure 4.1.2.1	Reported Monomeric Derivatives of 1-phenyl-1,3,3-trimethylphenylindane	153
Figure 4.2.1.1	3-D Model of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane ..	157
Figure 4.2.1.2	High Performance Liquid Chromatography of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane.....	158
Figure 4.2.1.3	Monomers Used with 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane for the Synthesis of Polyimides	159
Figure 4.2.1.4	FTIR Spectrum of High Molecular Weight 6FDA/DAPI Showing Absorptions Due to Cyclic Imide Functionalities.....	161
Figure 4.2.1.5	High Resolution ¹ H NMR of DAPI/PMDA.....	162
Figure 4.2.1.6	Raw GPC Chromatogram of High Molecular Weight 6FDA/DAPI Polyimide	164
Figure 4.2.1.7	DSC Thermogram of High Molecular Weight BPDA/DAPI Showing a Broad Glass Transition Temperature	165
Figure 4.2.1.8	Dynamic TGA of High Molecular Weight BTDA/DAPI in Air (10°C/min)	167
Figure 4.2.1.9	Isothermal TGA of PMDA/ODA Based Kapton and 6FDA/DAPI Based Polyimide at 400°C Under Nitrogen	168
Figure 4.2.6.1	Three Dimensional Projections of 6FDA and BPDA.....	179

Figure 4.3.1.1	Permselectivity Behavior of DAPI Containing Homopolyimides Relative to the Upper Bound.....	186
Figure 4.3.3.1	Permselectivity Behavior of 5,5'-[2,2,2-Trifluoro-1-(trifluoromethyl)ethylidene] bis-1,3-isobenzene-furadione (6FDA) Containing Homopolyimides Compared to the Upper Bound.....	191
Figure 4.4.1	Hydrogen Bonding in Polyimides which Contain Hydroxyl Moieties in the Backbone.....	194
Figure 4.4.1.1	FTIR Spectrum of BPADA:DSDA(1:1)/HAB	197
Figure 4.4.1.2	FTIR Spectrum of 6FDA/HAB.....	198
Figure 4.4.1.3	Percent Water Sorption Versus Time for 6FDA/HAB	199
Figure 4.4.2.1	Chemical Structures and T_g of Bis-AP-AF/BPADA and Bis-AT-AF/BPADA.....	202
Figure 4.4.2.2	FTIR Spectrum of Bis-AP-AF/BPADA	203
Figure 4.4.3.1	Gel Permeation Chromatogram of DAP/BPADA Based Polyimide	205
Figure 4.4.3.2	FTIR of DAP/BPADA.....	206
Figure 4.4.3.3	Chemical Structure and Glass Transition Temperature of 6FDA/DAP and 6FDA/ <i>m</i> -PDA Based Polyimide	208
Figure 4.5.1.1	Permselectivity Behavior of HAB Containing Homopolyimides Compared to the Upper Bound	211
Figure 4.6.1.1	DSC Thermogram of 15kg/mole Amine Terminated Polyimide with Epon 828.....	218
Figure 4.6.1.2	Elution Volume as a Function of Cure Time at 210°C.....	219
Figure 4.6.2.1	Chemical Structures of the Four Reactive Polymers Investigated.....	220
Figure 4.6.2.2	GPC Chromatograms of 5kg/mole Phenol Terminated Polyimide Cured at 150°C with MY721.....	224

Figure 4.6.2.3	GPC Chromatograms of 37kg/mole BPADA/DAP Cured at 150°C with MY721	225
Figure 5.1	Research Summary: Permselectivity Behavior of Polyimides Synthesized and Characterized in this Research	225

List of Schemes

Scheme 2.2.1.1.1 Isomeric Polyamic Acid Formation via Nucleophilic Substitution at an Anhydride Carbonyl	5
Scheme 2.2.1.1.2 Three Common Routes to Facilitate the Conversion of Polyamide Acids to Polyimides	12
Scheme 2.2.1.3.1 Synthesis of m-BAPPO Based Polyimides via Solution Imidization...	15
Scheme 2.2.1.3.2 Reaction Mechanism for the Solution Imidization Process	16
Scheme 2.2.1.4.1 Chemical Imidization and Isoimidization of Poly(amic acid)s	19
Scheme 2.2.2.1.1 Proposed Route to Polyimides from Dianhydrides and Diisocyanates via an Imide-Anhydride Seven-Membered Ring.....	21
Scheme 2.2.2.1.2 Preparation of a Polyimide from a Dianhydride and a Diisocyanate with Bulky Substituents.....	22
Scheme 2.2.2.2.1 Synthesis of Polythioetherimides by Aromatic Nucleophilic Substitution.....	23
Scheme 2.2.2.2.2 The Meisenheimer Transition State.....	24
Scheme 2.2.2.2.3 Synthesis of Polyarylene Ethers from Bis(trialkylsilyl)ethers of Bisphenols and Activated Bishalo Compounds	25
Scheme 2.2.2.3.1 Synthesis of Phthalic Anhydride and/or Phenylethynyl Phthalic Anhydride Endcapped Polyimides via the Ester-Acid Route	27
Scheme 2.2.2.3.2 Synthesis of the Three Isomers of Diester-Diacids Prepared from Bridged Dianhydrides.....	29
Scheme 2.2.2.3.3 PMR-15 Resin Chemistry Utilizing the Ester-Acid Route.....	30

Scheme 2.2.2.4.1 Synthesis of Perfectly Alternating Segmented Imide Siloxane Copolymers.....	31
Scheme 2.3.2.4.1 PMR-15 Resin Chemistry.....	55
Scheme 3.2.2.1.1 Synthesis of 1-phenyl-1,3,3-trimethylindane from α -methylstyrene..	112
Scheme 3.2.2.2.1 Synthesis of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) from 1-phenyl-1,3,3-trimethylindane.....	118
Scheme 3.2.2.4.1 Synthesis of 5,6-diamino-1-(4-aminophenyl)-1,3,3-trimethylindane (TAPI) from 1-phenyl-1,3,3-trimethylindane	124
Scheme 3.2.2.6.1 Synthesis of 6-hydroxy-1-(4-hydroxyphenyl)-1,3,3-trimethylindane (DHPI)	129
Scheme 3.4.1.1 Ester-Acid Precursor Method for the Formation of High Molecular Weight 5,5'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene] bis-1,3-isobenzofurandione (6FDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	141
Scheme 3.4.2.1 Chemical Imidization of High Molecular Weight 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	144
Scheme 3.4.3.1 Solution Imidization of High Molecular Weight 4,4'-bis[4-(3,4-dicarboxyphenoxy)]biphenyl dianhydride (BPEDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	145
Scheme 3.4.4.1 Thermal Imidization of High Molecular Weight 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)	147
Scheme 4.1.2.1 Proposed Polyimide Monomers from Reactions with 6-hydroxy-(4-hydroxyphenyl)-1,3,3-trimethylindane (DHPI)	154

Scheme 4.6.1.1 Typical Chain Extension/Curing of Epoxy Resins with Amines 215

List of Tables

Table 2.2.1.1.1	Electron Affinity of Representative Aromatic Dianhydrides.....	7
Table 2.2.1.1.2	Basicity pK_a of Diamines and Their Reactivity Towards 1,2,4,5-benzenetetracarboxylic dianhydride (PMDA)	9
Table 2.2.2.3.1	E_a (eV) and Relative Abundance of <i>meta</i> - and <i>para</i> -Positions.....	29
Table 2.3.1.2.1	Infrared Absorption Bands of Imides and Related Compounds	36
Table 2.3.1.3.1	Common Dianhydrides and Diamines with Various Structural Features	38
Table 2.3.1.4.1	The Effect of Bridging Unit on the Glass Transition Temperature (T_g).	39
Table 2.3.1.4.2	The Effect of Catenation on the Glass Transition Temperature (T_g).	41
Table 2.3.2.3.1	Curable Polyimides for Aerospace Applications	49
Table 2.5.1.1	Effect of the Structure of Substituted Diamines on Glass Transition Temperature, Permeability, Diffusion, and Solubility Coefficient Ratios for the System O_2/N_2	83
Table 2.5.1.2	Permeability for Hydroxyl-containing 5,5'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene]bis-1,3-isobenzene-furandione (6FDA) Based Polyimides	86
Table 2.5.2.1	Gas Permeabilities and Selectivities for Diamine Isomers	87
Table 2.5.3.1	Permeability Coefficients for Unirradiated and Irradiated Polyimide Films at 35°C and 2 Atmospheres	90
Table 4.2.1.1	Molecular Weight and Thermal Analysis of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides	163

Table 4.2.1.2	Solubility of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides in Common Solvents	169
Table 4.2.1.3	Refractive Index Values and Dielectric Constant Approximation of 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides.....	170
Table 4.2.2.1	Molecular Weight and Thermal Characterization of 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/ 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides	172
Table 4.2.3.1	Molecular Weight and Thermal Characterization of 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA)/ 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides Upon Altering the DAPI Isomeric Ratio	174
Table 4.2.4.1	Molecular Weight and Thermal Characterization of High Molecular Weight 4,4'-bis[4-(3,4-dicarboxyphenoxy)]biphenyl dianhydride (BPEDA) and 2,2'-bis[4-(3,4-dicarboxyphenoxy)phenyl] propane dianhydride (BPADA) Based Polyimides.....	175
Table 4.2.5.1	Molecular Weight and Thermal Analysis of 2,2-bis(3-amino-4-methylphenyl)hexafluoropropane (Bis-AT-AF) Based Polyimides.....	177
Table 4.2.6.1	Molecular Weight and Thermal Analysis of Hexafluoroisopropylidene Dianhydride (6FDA) Based Polyimides	180
Table 4.2.7.1	Molecular Weight and Thermal Analysis of 3,7-diamino-2,8-dimethyldibenzothiophene-5,5-dioxide (DDBT).....	182
Table 4.3.1.1	Oxygen Permeability and Oxygen/Nitrogen Selectivity Values for 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI) Based Polyimides.....	185

Table 4.3.2.1	Isomeric Ratio Effect on 5(6)-amino-1-(4-aminophenyl)-1,3,3-trimethylindane (DAPI)/ 3,3',4,4'-benzophenonetetracarboxylic dianhydride (BTDA) Oxygen Permeability and Oxygen/Nitrogen Selectivity Values	188
Table 4.3.3.1	Oxygen Permeability and Oxygen/Nitrogen Selectivity Values for 5,5'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene] bis-1,3-isobenzene-furandione (6FDA) Based Polyimides	189
Table 4.3.4.1	Oxygen Permeability and Oxygen/Nitrogen Selectivity Values for 3,7-diamino-2,8-dimethyl-dibenzothiophene-5,5-dioxide (DDBT) Based Polyimides.....	192
Table 4.4.1.1	Molecular Weight and Thermal Analysis of 4,4'-diamino-3,3'-dihydroxybenzidine (HAB).....	195
Table 4.4.2.1	Molecular Weight and Thermal Analysis of 2,2-bis(3-amino-4-hydroxyphenyl)hexafluoropropane (Bis-AP-AF)	201
Table 4.4.3.1	Molecular Weight and Thermal Analysis of 2,4-Diaminophenol (DAP).....	204
Table 4.5.1.1	Oxygen Permeability and Oxygen/Nitrogen Selectivity Values for 3,3'-dihydroxy-4,4'-diamino-biphenyl (HAB) Based Polyimides	210
Table 4.5.2.1	Oxygen Permeability and Oxygen/Nitrogen Selectivity Values for 2,4-diaminophenol (DAP) and 1,3-phenylenediamine (<i>m</i> -PDA) Derived Polyimides.....	213
Table 4.6.1.1	Molecular Weight and Thermal Characterization of Amine Terminated Oligomers.....	216
Table 4.6.2.1	Molecular Weight and Thermal Characterization of Functional Polyimides.....	222
Table 4.6.2.2	Cure System Compositions.....	223