



# PROCESS ECONOMICS PROGRAM

SRI INTERNATIONAL

Menlo Park, California

94025

Process Economics Report No. 45A

POLYOLS FOR POLYURETHANES

(May 1982)

## ABSTRACT

Polyols evaluated in this report are: a trifunctional polyester polyol; three polyols of high functionality made from sucrose, sucrose-amine, and an aromatic compound containing nitrogen; a polyester polyol made from formaldehyde via formose; two polymer polyols grafted with acrylonitrile and with acrylonitrile/styrene, respectively; a polyol containing dispersed polyurea; a polytetramethylene ether glycol and a copolyester polyol made from tetrahydrofuran and ethylene; a polyester polyol made from adipic acid, diethylene glycol, and trimethylolpropane; a polyol made from residue in dimethyl terephthalate manufacture; and polybutadiene polyol.

A semicontinuous process and a continuous process are evaluated and compared for the production of a trifunctional polyether polyol with a mol wt of 3,000. The continuous process is competitive with the prevalently used semicontinuous process only if the reaction rate is accelerated by adding a chemical to promote the contact of the potassium hydroxide catalyst with the reactants.

Phosphorus- and halogen-containing polyols are reviewed.

Report No. 45A

# **POLYOLS FOR MAKING POLYURETHANES**

**SUPPLEMENT A**

by **YEN-CHEN YEN**  
contributions by **TUNG-SHENG TSAO**

May 1982

A private report by the  
**PROCESS ECONOMICS PROGRAM**

Menlo Park, California 94025

For detailed marketing data and information, the reader is referred to one of the SRI programs specializing in marketing research. The CHEMICAL ECONOMICS HANDBOOK Program covers most major chemicals and chemical products produced in the United States and the WORLD PETROCHEMICALS Program covers major hydrocarbons and their derivatives on a worldwide basis. In addition, the SRI DIRECTORY OF CHEMICAL PRODUCERS services provide detailed lists of chemical producers by company, product, and plant for the United States and Western Europe.

## CONTENTS

|   |  |    |
|---|--|----|
| 1 | INTRODUCTION . . . . .   | 1  |
| 2 | SUMMARY . . . . .  | 3  |
|   | General Aspects . . . . .  | 3  |
|   | Technical Aspects of SRI's Design Cases . . . . .  | 9  |
|   | A Polyol from Glycerol, Propylene Oxide, and Ethylene<br>Oxide by a Semicontinuous Process . . . . . | 9  |
|   | A Polyol from Glycerol, Propylene Oxide, and Ethylene<br>Oxide by a Continuous Process . . . . .     | 10 |
|   | A Polyol from Sucrose . . . . .  | 10 |
|   | A Sucrose-Amine Polyol . . . . .   | 10 |
|   | An Aromatic N-Containing Polyol . . . . .  | 10 |
|   | A Polyol from Formaldehyde . . . . .   | 11 |
|   | A Polyol Grafted with Acrylonitrile . . . . .  | 11 |
|   | A Polyol Grafted with Acrylonitrile and Styrene . . . . .  | 11 |
|   | A Polyurea Polyol . . . . .  | 12 |
|   | Polytetramethylene Ether Glycol (PTMEG) . . . . .  | 12 |
|   | A Copolyether Glycol from THF and Ethylene Oxide . . . . .   | 12 |
|   | A Polyester Polyol from Adipic Acid<br>and Diethylene Glycol . . . . .                               | 13 |
|   | A Polyester Polyol from a Residue in DMT Manufacture . . . . .                                       | 13 |
|   | Polybutadiene Polyol . . . . .   | 13 |
| 3 | INDUSTRY STATUS . . . . .  | 15 |
| 4 | GENERAL DISCUSSION ON POLYETHER POLYOLS . . . . .  | 27 |
|   | Catalyst . . . . .   | 27 |
|   | Purification . . . . .   | 29 |
|   | Polyglycols and Difunctional Polyols . . . . .   | 30 |
| 5 | TRIFUNCTIONAL POLYOLS . . . . .  | 41 |
|   | A Semicontinuous Process for Making Polyols<br>from Glycerol . . . . .                               | 41 |
|   | Process Description . . . . .  | 41 |
|   | Process Discussion . . . . .   | 44 |
|   | Cost Estimates . . . . .   | 44 |
|   | A Continuous Process for Making Polyol from Glycerol . . . . .                                       | 55 |
|   | Process Description . . . . .  | 55 |
|   | Process Discussion . . . . .   | 57 |
|   | Cost Estimates . . . . .   | 58 |

## CONTENTS

|   |  |     |
|---|--|-----|
| 6 | <b>POLYETHER POLYOLS WITH HIGH FUNCTIONALITY . . . . .</b>   | 65  |
|   | Polyols from Nonreducing Sugar and a Polyhydric Alcohol<br>with More than 4 C's . . . . .                | 65  |
|   | Polyols from Reducing Sugars and Other Carbohydrates . . . .   | 68  |
|   | Nitrogen-Containing Polyols . . . . .  | 68  |
|   | Polyols Containing Aromatic or Heterocyclic Rings . . . . .  | 70  |
|   | <b>A Process for Making a Polyol from Sucrose . . . . .</b>  | 77  |
|   | Process Description . . . . .  | 77  |
|   | Process Discussion . . . . .   | 77  |
|   | Cost Estimates . . . . .   | 78  |
|   | <b>A Process for Making a Sucrose-Amine Polyol . . . . .</b>   | 85  |
|   | Process Description . . . . .  | 85  |
|   | Process Discussion . . . . .   | 86  |
|   | Cost Estimates . . . . .   | 86  |
|   | <b>A Process for Producing an Aromatic N-Containing Polyol . . .</b>                                     | 93  |
|   | Process Description . . . . .  | 93  |
|   | Cost Estimates . . . . .   | 93  |
|   | <b>Operation of the Units as a Part of a Large Plant . . . . .</b>                                       | 100 |
| 7 | <b>POLYOL FROM FORMALDEHYDE VIA FORMOSE . . . . .</b>  | 101 |
|   | Chemistry . . . . .  | 101 |
|   | Review of Processes . . . . .  | 104 |
|   | Process Description . . . . .  | 106 |
|   | Process Discussion . . . . .   | 109 |
|   | Cost Estimates . . . . .   | 109 |
| 8 | <b>POLYMER POLYOLS . . . . .</b>   | 119 |
|   | Chemistry . . . . .  | 119 |
|   | Review of Processes . . . . .  | 120 |
|   | <b>A Process for Making a Polymer Polyol Grafted<br/>           with Acrylonitrile . . . . .</b>         | 128 |
|   | Process Description . . . . .  | 128 |
|   | Cost Estimates . . . . .   | 128 |
|   | <b>A Process for Making a Polymer Polyol Grafted<br/>           with Acrylonitrile/Styrene . . . . .</b> | 137 |
|   | Process Description . . . . .  | 137 |
|   | Cost Estimates . . . . .   | 138 |
| 9 | <b>POLYOLS MADE FROM OTHER POLYOLS . . . . .</b>   | 147 |
|   | Modified Polyols . . . . .   | 147 |
|   | <b>A Process for Making a Polyol Containing<br/>           a Dispersed Polyurea . . . . .</b>            | 151 |

## CONTENTS

|    |   |     |
|----|---|-----|
| 9  | POLYOLS MADE FROM OTHER POLYOLS (continued)   |     |
|    | Process Description . . . . .   | 151 |
|    | Cost Estimates . . . . .  | 152 |
| 10 | POLYTETRAMETHYLENE ETHER GLYCOL . . . . .   | 159 |
|    | Chemistry . . . . .   | 159 |
|    | Review of Processes . . . . .   | 161 |
|    | A Process for Making Polytetramethylene Ether Glycol . . . . .                              | 165 |
|    | Process Description . . . . .   | 165 |
|    | Process Discussion . . . . .  | 168 |
|    | Cost Estimates . . . . .  | 168 |
|    | A Process for Making Copolyether Glycol from THF and EO . . . . .                           | 179 |
|    | Process Description . . . . .   | 179 |
|    | Process Discussion . . . . .  | 181 |
|    | Cost Estimates . . . . .  | 182 |
| 11 | POLYESTER POLYOLS . . . . .   | 191 |
|    | Chemistry . . . . .   | 191 |
|    | Review of Processes . . . . .   | 192 |
|    | A Process for Making a Polyester Polyol from<br>Adipic Acid and Diethylene Glycol . . . . . | 203 |
|    | Process Description . . . . .   | 203 |
|    | Process Discussion . . . . .  | 203 |
|    | Cost Estimates . . . . .  | 203 |
|    | A Process for Making a Polyester Polyol from a<br>Residue in DMT Manufacture . . . . .      | 210 |
|    | Process Description . . . . .   | 210 |
|    | Process Discussion . . . . .  | 211 |
|    | Cost Estimates . . . . .  | 212 |
| 12 | POLYBUTADIENE POLYOLS . . . . .   | 223 |
|    | Chemistry . . . . .   | 223 |
|    | Anionic Polymerization . . . . .  | 224 |
|    | Free Radical Polymerization . . . . .   | 224 |
|    | Degradation of High Mol Wt Polymers . . . . .   | 226 |
|    | Review of Processes . . . . .   | 226 |
|    | Applications of Polybutadiene Polyols . . . . .   | 232 |
|    | Polyurethane Formation . . . . .  | 232 |
|    | Polyesters Formation . . . . .  | 232 |

|                              |   |             |     |
|------------------------------|---|-------------|-----|
| 12                           | POLYBUTADIENE POLYOLS                       | (continued) |     |
|                              | Hydrogenation of Polybutadiene Polyols      |             | 233 |
|                              | Halogenation of Polybutadiene Polyols       |             | 233 |
|                              | A Process for Making Polybutadiene Polyol   |             | 234 |
|                              | Process Description                         |             | 234 |
|                              | Process Discussion                          |             | 240 |
|                              | Cost Estimates                              |             | 240 |
| 13                           | PHOSPHORUS- OR HALOGEN-CONTAINING POLYOLS   |             |     |
|                              | Phosphorus-Containing Polyols               |             | 247 |
|                              | Halogen-Containing Polyols                  |             | 254 |
| APPENDIX A                   | DESIGN AND COST BASIS                       |             | 259 |
| APPENDIX B                   | EFFECT OF THE CHEMICAL STRUCTURE OF POLYOLS |             | 261 |
| APPENDIX C                   | SOME PHYSICAL DATA USED IN THE DESIGN       |             | 263 |
| APPENDIX D                   | SPECIFICATIONS OF FINISHED PRODUCTS         |             | 265 |
| CITED REFERENCES             |   |             | 269 |
| PATENT REFERENCES BY COMPANY |   |             | 293 |

## ILLUSTRATIONS

|      |  |     |
|------|--|-----|
| 5.1  | Polyol (Mol Wt 3,000) from Glycerol and PO/EO<br>by Semicontinuous Process<br>Flowsheet . . . . .  | 301 |
| 5.2  | Polyol (Mol Wt 3,000) from Glycerol and PO/EO<br>by Semicontinuous Process<br>Effect of Operating Level and Plant Capacity<br>on Production Cost and Product Value . . . . . | 54  |
| 5.3  | Polyol (Mol Wt 3,000) from Glycerol and PO/EO<br>by Continuous Process<br>Flowsheet . . . . .  | 303 |
| 6.1  | Polyol from Sucrose<br>Flowsheet . . . . .   | 305 |
| 6.2  | Sucrose-Amine Polyol<br>Flowsheet . . . . .  | 307 |
| 6.3  | Aromatic N-Containing Polyol<br>Flowsheet . . . . .  | 309 |
| 7.1  | Polyol from Formaldehyde Via Formose<br>Flowsheet . . . . .  | 311 |
| 8.1  | Polymer Polyol, Acrylonitrile Grafted<br>Flowsheet . . . . .   | 313 |
| 8.2  | Polymer Polyol, Acrylonitrile-Styrene Grafted<br>Flowsheet . . . . .   | 315 |
| 9.1  | Polyol Containing Polyurea in Dispersion<br>Flowsheet . . . . .  | 317 |
| 10.1 | Polytetramethylene Ether Glycol<br>Flowsheet . . . . .   | 319 |
| 10.2 | Polytetramethylene Ether Glycol<br>Effect of Operating Level and Plant Capacity<br>on Production Cost and Product Value . . . . .  | 178 |
| 10.3 | Copolyether Glycol from THF and EO<br>Flowsheet . . . . .  | 321 |
| 10.4 | Copolyether Glycol<br>Effect of Operating Level and Plant Capacity<br>on Production Cost and Product Value . . . . .   | 190 |



## ILLUSTRATIONS

|      |  |     |
|------|--|-----|
| 11.1 | Polyester Polyol from Adipic Acid<br>and Diethylene Glycol . . . . .       | 204 |
| 11.2 | Polyester Polyol from Residue<br>in DMT Manufacture<br>Flowsheet . . . . . | 323 |
| 12.1 | Polybutadiene Polyol<br>Flowsheet . . . . .                                | 325 |

## TABLES

|     |  |    |
|-----|--|----|
| 2.1 | Trifunctional Polyether Polyol, Wet Mol Wt 3,000<br>Cost Features . . . . .                                      | 5  |
| 2.2 | Polyols for Rigid Foams<br>Cost Features . . . . .   | 7  |
| 2.3 | Polyols Useful in Elastomers and High Resilience Foams<br>Cost Features . . . . .                                | 8  |
| 3.1 | Polyols Produced in the United States<br>for Polyurethane Application . . . . .                                  | 16 |
| 3.2 | U.S. Producers of Polyether Polyols<br>for Polyurethane Applications . . . . .                                   | 19 |
| 3.3 | Polyether Polyols for Polyurethane Uses<br>in the United States in 1979 . . . . .                                | 20 |
| 3.4 | Polyols Producers in Western Europe . . . . .  | 22 |
| 3.5 | Polyether Polyols Producers in Japan . . . . .   | 24 |
| 3.6 | Polyether Polyols Producers in Other Countries . . . . .   | 25 |
| 4.1 | Catalysts for Oxyalkylation<br>Patent Summary . . . . .  | 31 |
| 4.2 | Continuous Tubular Reactors<br>Patent Summary . . . . .  | 32 |
| 4.3 | Purification of Polyols<br>Patent Summary . . . . .  | 33 |
| 4.4 | Stabilizers for Polyols<br>Patent Summary . . . . .  | 36 |
| 4.5 | Polyglycols and Difunctional Polyols<br>Patent Summary . . . . .   | 38 |
| 5.1 | Several Grades of Polyols from Glycerol<br>by Semicontinuous Process<br>Production Capacity of Polyols . . . . . | 42 |
| 5.2 | Several Grades of Polyols from Glycerol<br>by Semicontinuous Process<br>Major Equipment . . . . .                | 46 |
| 5.3 | Several Grades of Polyols from Glycerol<br>by Semicontinuous Process<br>Utilities Summary . . . . .              | 47 |

## TABLES

|      |   |    |
|------|---|----|
| 5.4  | Polyol (Mol Wt 3,000) from Glycerol and PO/EO<br>by Semicontinuous Process<br>Design Bases and Assumptions . . . . .                                  | 48 |
| 5.5  | Polyol (Mol Wt 3,000) from Glycerol and PO/EO<br>by Semicontinuous Process<br>Stream Flows . . . . .  | 49 |
| 5.6  | Several Grades of Polyols from Glycerol<br>by Semicontinuous Process<br>Capital Investment . . . . .  | 50 |
| 5.7  | Polyol (Mol Wt 3,000) from Glycerol and PO/EO<br>by Semicontinuous Process<br>Production Costs . . . . .  | 51 |
| 5.8  | Production Costs and Product Value<br>of Various Grades of Polyols . . . . .  | 53 |
| 5.9  | Comparison of Cost Features of Production of a<br>Polyol (Mol Wt 3,000, PO/EO) in a Single-Product Plant<br>and in a Multiple-Product Plant . . . . . | 53 |
| 5.10 | Polyol (Mol Wt 3,000) from Glycerol<br>and PO/EO by Continuous Process<br>Design Bases and Assumptions . . . . .                                      | 56 |
| 5.11 | Polyol (Mol Wt 3,000) from Glycerol<br>and PO/EO by Continuous Process<br>Stream Flows . . . . .  | 59 |
| 5.12 | Polyol (Mol Wt 3,000) from Glycerol<br>and PO/EO by Continuous Process<br>Major Equipment . . . . .   | 60 |
| 5.13 | Polyol (Mol Wt 3,000) from Glycerol<br>and PO/EO by Continuous Process<br>Utilities Summary . . . . .   | 61 |
| 5.14 | Polyol (Mol Wt 3,000) from Glycerol<br>and PO/EO by Continuous Process<br>Capital Investment . . . . .  | 62 |
| 5.15 | Polyol (Mol Wt 3,000) from Glycerol<br>and PO/EO by Continuous Process<br>Production Costs . . . . .  | 63 |

## TABLES

|      |   |    |
|------|---|----|
| 6.1  | Polyols from Sucrose<br>Patent Summary . . . . .  | 66 |
| 6.2  | Polyols from Reducing Sugars, Starch, and<br>Complex Carbohydrates<br>Patent Summary . . . . .                  | 69 |
| 6.3  | Nitrogen-Containing Polyether Polyols<br>from Alkylene Oxides for Polyurethane Uses<br>Patent Summary . . . . . | 72 |
| 6.4  | Aromatic Polyols<br>Patent Summary . . . . .  | 76 |
| 6.5  | Polyol from Sucrose<br>Design Bases and Assumptions . . . . .   | 79 |
| 6.6  | Polyol from Sucrose<br>Stream Flows . . . . .   | 79 |
| 6.7  | Polyol from Sucrose<br>Major Equipment . . . . .  | 80 |
| 6.8  | Polyol from Sucrose<br>Utilities Summary . . . . .  | 81 |
| 6.9  | Polyol from Sucrose<br>Capital Investment . . . . .   | 82 |
| 6.10 | Polyol from Sucrose<br>Production Costs . . . . .   | 83 |
| 6.11 | Sucrose-Amine Polyol<br>Design Bases and Assumptions . . . . .  | 87 |
| 6.12 | Sucrose-Amine Polyol<br>Stream Flows . . . . .  | 87 |
| 6.13 | Sucrose-Amine Polyol<br>Major Equipment . . . . .   | 88 |
| 6.14 | Sucrose-Amine Polyol<br>Utilities Summary . . . . .   | 89 |
| 6.15 | Sucrose-Amine Polyol Based on Texaco Patent<br>Capital Investment . . . . .                                     | 90 |
| 6.16 | Sucrose-Amine Polyol<br>Production Costs . . . . .  | 91 |

TABLES

|      |   |     |
|------|---|-----|
| 6.17 | Aromatic N-Containing Polyol<br>Design Bases and Assumptions . . . . .              | 94  |
| 6.18 | Aromatic N-Containing Polyol<br>Stream Flows . . . . .                              | 94  |
| 6.19 | Aromatic N-Containing Polyol<br>Major Equipment. . . . .                            | 95  |
| 6.20 | Aromatic N-Containing Polyol<br>Utilities Summary . . . . .                         | 96  |
| 6.21 | Aromatic N-Containing Polyol<br>Capital Investment . . . . .                        | 97  |
| 6.22 | Aromatic N-Containing Polyol<br>Production Costs . . . . .                          | 98  |
| 7.1  | Formose, Formit and Polyols from Formaldehyde<br>Summary of Bayer Patents . . . . . | 105 |
| 7.2  | Polyol from Formaldehyde via Formose<br>Design Bases and Assumptions . . . . .      | 107 |
| 7.3  | Polyol from Formaldehyde via Formose<br>Stream Flows . . . . .                      | 110 |
| 7.4  | Polyol from Formaldehyde via Formose<br>Major Equipment . . . . .                   | 111 |
| 7.5  | Polyol from Formaldehyde via Formose<br>Utilities Summary . . . . .                 | 113 |
| 7.6  | Polyol from Formaldehyde via Formose<br>Capital Investment . . . . .                | 114 |
| 7.7  | Polyol from Formaldehyde via Formose<br>Production Costs . . . . .                  | 116 |
| 8.1  | Polymer Polyols<br>Patent Summary . . . . .   | 122 |
| 8.2  | Polymer Polyol, Acrylonitrile Grafted<br>Design Bases and Assumptions . . . . .     | 130 |
| 8.3  | Polymer Polyol, Acrylonitrile Grafted<br>Stream Flows . . . . .                     | 131 |
| 8.4  | Polymer Polyol, Acrylonitrile Grafted<br>Major Equipment . . . . .                  | 132 |

## TABLES

|      |   |     |
|------|---|-----|
| 8.5  | Polymer Polyol, Acrylonitrile Grafted<br>Utilities Summary . . . . .                    | 133 |
| 8.6  | Polymer Polyol, Acrylonitrile Grafted<br>Capital Investment . . . . .                   | 134 |
| 8.7  | Polymer Polyol, Acrylonitrile Grafted<br>Production Costs . . . . .                     | 135 |
| 8.8  | Polymer Polyol, Acrylonitrile/Styrene Grafted<br>Design Bases and Assumptions . . . . . | 139 |
| 8.9  | Polymer Polyol, Acrylonitrile/Styrene Grafted<br>Stream Flows . . . . .                 | 140 |
| 8.10 | Polymer Polyol, Acrylonitrile/Styrene Grafted<br>Major Equipment . . . . .              | 141 |
| 8.11 | Polymer Polyol, Acrylonitrile/Styrene Grafted<br>Utilities Summary . . . . .            | 142 |
| 8.12 | Polymer Polyol, Acrylonitrile/Styrene Grafted<br>Capital Investment . . . . .           | 143 |
| 8.13 | Polymer Polyol, Acrylonitrile/Styrene Grafted<br>Production Costs . . . . .             | 144 |
| 9.1  | Modified Polyols<br>Patent Summary . . . . .  | 148 |
| 9.2  | Dispersion-Containing Polyols<br>Patent Summary . . . . .                               | 150 |
| 9.3  | Polyol Containing Dispersed Polyurea<br>Design Bases and Assumptions . . . . .          | 153 |
| 9.4  | Polyol Containing Dispersed Polyurea<br>Stream Flows . . . . .                          | 154 |
| 9.5  | Polyol Containing Dispersed Polyurea<br>Major Equipment . . . . .                       | 155 |
| 9.6  | Polymer Containing Dispersed Polyurea<br>Utilities Summary . . . . .                    | 155 |
| 9.7  | Polyol Containing Dispersed Polyurea<br>Capital Investment . . . . .                    | 156 |
| 9.8  | Polyol Containing Dispersed Polyurea<br>Production Costs . . . . .                      | 157 |

## TABLES

|       |   |     |
|-------|---|-----|
| 10.1  | Polytetramethylene Ether Glycol (PTMEG)<br>from Tetrahydrofuran (THF)<br>Patent Summary . . . . . | 162 |
| 10.2  | Copolyether Polyols from THF and Alkylene Oxides<br>Patent Summary . . . . .                      | 164 |
| 10.3  | Polytetramethylene Ether Glycol<br>Design Bases and Assumptions . . . . .                         | 166 |
| 10.4  | Polytetramethylene Ether Glycol<br>Stream Flows . . . . .   | 169 |
| 10.5  | Polytetramethylene Ether Glycol<br>Major Equipment . . . . .                                      | 171 |
| 10.6  | Polytetramethylene Ether Glycol<br>Utilities Summary . . . . .                                    | 174 |
| 10.7  | Polytetramethylene Ether Glycol<br>Capital Investment . . . . .                                   | 175 |
| 10.8  | Polytetramethylene Ether Glycol<br>Production Costs . . . . .                                     | 176 |
| 10.9  | Copolyether Glycol from THF and EO<br>Design Bases and Assumptions . . . . .                      | 180 |
| 10.10 | Copolyether Glycol from THF and EO<br>Stream Flows . . . . .                                      | 183 |
| 10.11 | Copolyether Glycol from THF and EO<br>Major Equipment . . . . .                                   | 184 |
| 10.12 | Copolyether Glycol from THF and EO<br>Utilities Summary . . . . .                                 | 186 |
| 10.13 | Copolyether Glycol from THF and EO<br>Capital Investment . . . . .                                | 187 |
| 10.14 | Copolyether Glycol from THF and EO<br>Production Costs . . . . .                                  | 188 |
| 11.1  | Polyester Polyols for Polyurethane Uses<br>Patent Summary . . . . .                               | 194 |
| 11.2  | Polyols from Lactones<br>Patent Summary . . . . .   | 202 |

## TABLES

|       |   |     |
|-------|---|-----|
| 11.3  | Polyester Polyol from Adipic Acid and Diethylene Glycol<br>Design Bases and Assumptions . . . . . | 205 |
| 11.4  | Polyester Polyol from Adipic Acid and Diethylene Glycol<br>Stream Flows . . . . .                 | 205 |
| 11.5  | Polyester Polyol from Adipic Acid and Diethylene Glycol<br>Major Equipment . . . . .              | 206 |
| 11.6  | Polyester Polyol from Adipic Acid and Diethylene Glycol<br>Utilities Summary . . . . .            | 206 |
| 11.7  | Polyester Polyol from Adipic Acid and Diethylene Glycol<br>Capital Investment . . . . .           | 207 |
| 11.8  | Polyester Polyol from Adipic Acid and Diethylene Glycol<br>Production Costs . . . . .             | 208 |
| 11.9  | Polyester Polyol from Residue in DMT Manufacture<br>Design Bases and Assumptions . . . . .        | 213 |
| 11.10 | Polyester Polyol from Residue in DMT Manufacture<br>Stream Flows . . . . .                        | 214 |
| 11.11 | Polyester Polyol from Residue in DMT Manufacture<br>Major Equipment . . . . .                     | 215 |
| 11.12 | Polyester Polyol from Residue in DMT Manufacture<br>Utilities Summary . . . . .                   | 216 |
| 11.13 | Polyester Polyol from Residue in DMT Manufacture<br>Capital Investment . . . . .                  | 217 |
| 11.14 | Polyester Polyol from Residue in DMT Manufacture<br>Production Costs . . . . .                    | 219 |
| 12.1  | Polybutadiene Polyols Preparation<br>Patent Summary . . . . .                                     | 228 |
| 12.2  | Polybutadiene Polyol<br>Design Bases and Assumptions . . . . .                                    | 235 |
| 12.3  | Polybutadiene Polyol<br>Stream Flows . . . . .  | 237 |
| 12.4  | Polybutadiene Polyol<br>Major Equipment . . . . .   | 238 |
| 12.5  | Polybutadiene Polyol<br>Utilities Summary . . . . .   | 239 |



TABLES

|      |   |     |
|------|---|-----|
| 12.6 | Polybutadiene Polyol<br>Capital Investment . . . . .  | 241 |
| 12.7 | Polybutadiene Polyol<br>Production Costs . . . . .  | 243 |
| 13.1 | Phosphorus-Containing Polyols<br>as Reactive Flame Retardants in Polyurethane<br>Patent Summary . . . . . | 248 |
| 13.2 | Halogenated Polyols Useful in Polyurethanes<br>Patent Summary . . . . .                                   | 256 |
| B.1  | Effect of the Chemical Structure of Polyols . . . . .   | 261 |