

Report No. 19-A

**LINEAR POLYETHYLENE
AND POLYPROPYLENE**
Supplement A

by **ROBERT L. MAGOVERN**
Consultant

October 1969

A private report by the

PROCESS ECONOMICS PROGRAM



STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

CONTENTS

1	INTRODUCTION	1
2	SUMMARY	3
3	INDUSTRY STATUS	13
4	CHEMISTRY OF PROPYLENE AND ETHYLENE POLYMERIZATION	31
	General	31
	Polypropylene	34
	Isotactic Catalyst	35
	Mechanism Studies	38
	Kinetics	41
	Polyethylene	41
	Ziegler Catalysts	41
	Metal Oxide and Solid Catalysts	42
5	POLYOLEFIN PROPERTIES AND APPLICATIONS	45
	Linear Polyethylene by the Ziegler Process	45
	Linear Polyethylene by Metal Oxide Catalysts	45
	Ethylene Polymers	47
	High Molecular Weight Ethylene Polymers	48
	Polypropylene	50
6	REVIEW OF POLYPROPYLENE PROCESSES	55
	Avisun Corporation	58
	Dow Chemical Company	60
	Eastman Kodak Company	61
	Esso Research and Engineering Company	66
	Hercules Incorporated	67
	Montecatini-Edison Sp A.	69
	Phillips Petroleum Company	71
	Rexall Drug and Chemical Company	73
	Shell Oil Company	74
	Others	83
7	PRODUCTION OF POLYPROPYLENE	85
	Process Discription	87
	Process Discussion	99
	Cost Estimates	107
	Capital Costs	107
	Production Costs	108

CONTENTS

8	PRODUCTION OF LINEAR POLYETHYLENE	113
	Review of Processes	113
	Phillips Particle Form Process	113
	Solvay and Cie. (Belgium)	114
	Particle Form Process Description	117
	Process Discussion	127
	Cost Estimates	135
	Capital Costs	135
	Production Costs	135
	Comparison with Other Processes	142
9	PRODUCTION OF POLYPROPYLENE FIBERS	155
	Industry Status	155
	Review of Processes	158
	Dyeing	158
	Fiber Formation by Melt-Spinning	160
	Fiber Formation by Fibrillation and Film Slitting	161
	Fiber Processing	162
	Production of Continuous Filament Yarn	164
	Process Discussion	167
	Capital Cost	168
	Production Costs	168
	APPENDIX A DESIGN AND COST BASIS	175
	APPENDIX B PHYSICAL DATA	181
	APPENDIX C RAW MATERIAL SPECIFICATIONS	183
	APPENDIX D PROPERTIES OF POLYETHYLENE	185
	APPENDIX E PROPERTIES OF POLYPROPYLENE	189
	CITED REFERENCES	195
	PATENT REFERENCES BY COMPANY	241

ILLUSTRATIONS

4.1	The Titanium Layer in γ -TiCl ₃ , Showing Cleavage to Ti ₈ Units	36
6.1	Polypropylene Process--Rexall Patent	75
6.2	Polypropylene Process--Shell Patent	78
6.3	Polymer Solids Drying and Recovery--Shell Patent	79
7.1	Polypropylene Production	91
7.2	Polypropylene Plant Stream Balance	103
7.3	Effect of Operating Level and Plant Capacity on Production Cost	111
8.1	Linear Polyethylene--Particle Form	119
8.2	Linear Polyethylene--Particle Form Effect of Operating Level and Plant Capacity on Production Cost	141
8.3	Linear Polyethylene by a Ziegler Catalyst Effect of Operating Level and Plant Capacity on Production Cost	151
8.4	Linear Polyethylene by a Metal Oxide Catalyst Effect of Operating Level and Plant Capacity on Production Cost	152
9.1	Production of Polypropylene Continuous Filament Yarn	165
9.2	Production of Polypropylene Continuous Filament Yarn Effect of Yarn Denier on Fixed Capital Requirement and Production Cost	173

TABLES

3.1	Polyethylene Production and Sales	13
3.2	Linear Polyethylene Uses	15
3.3	Estimated World Consumption of Polyethylene	16
3.4	Estimated World Polyethylene Production Capacity	17
3.5	Linear Polyethylene Plant Capacities	19
3.6	Polypropylene Plant Capacities	25
5.1	Melt Index-Dependent Properties of Phillips Ethylene Homopolymers	46
5.2	Physical Properties of Polyolefins Made by the Phillips Process	49
5.3	Melt Flow-Intrinsic Viscosity-Molecular Weight Relationships for Typical Commercial Polypropylene	51
5.4	Relationship of Structural Parameters to Physical Properties of Polypropylene	52
6.1	Avisun Polypropylene Catalyst Systems Patent Summary	59
6.2	Eastman Polypropylene Catalyst Systems Patent Summary	62
6.3	Montecatini Polypropylene Catalyst Systems Patent Summary	70
6.4	Phillips Polypropylene Catalyst Systems Patent Summary	72
6.5	Shell Polypropylene Catalyst Systems Patent Summary	76
7.1	Comparison of Polypropylene Process Steps	86
7.2	Polypropylene Major Process Equipment and Utilities Summary	91
7.3	Polypropylene Stream Flows	97
7.4	Polypropylene Total Capital Investment	105
7.5	Polypropylene Production Costs	109

TABLES

8.1	Olefin Polymerization by Solvay and Cie Patent Summary	115
8.2	Linear Polyethylene--Particle Form Major Process Equipment and Utilities Summary	119
8.3	Linear Polyethylene--Particle Form Stream Flows	125
8.4	Phillips Loop-Type Reactor Descriptions	129
8.5	Linear Polyethylene--Particle Form Total Capital Investment	137
8.6	Linear Polyethylene--Particle Form Production Costs	139
8.7	Linear Polyethylene Comparison of Processes	142
8.8	Linear Polyethylene by a Ziegler Catalyst Total Capital Investment	143
8.9	Linear Polyethylene by a Ziegler Catalyst Production Costs	145
8.10	Linear Polyethylene by a Metal Oxide Catalyst Total Capital Investment	147
8.11	Linear Polyethylene by a Metal Oxide Catalyst Production Costs	149
9.1	Polypropylene Fiber Consumption in the United States . . .	156
9.2	Companies Producing Polypropylene Multifilaments and Staple	157
9.3	Production of Polypropylene Slit Film Fabric	163
9.4	Production of Polypropylene Continuous Filament Yarn Major Process Equipment and Utilities Summary	165
9.5	Production of Polypropylene Continuous Filament Yarn Total Capital Investment	169
9.6	Polypropylene Continuous Filament Yarn-165 Denier Production Costs	170
9.7	Polypropylene Continuous Filament Yarn-840 Denier Production Costs	171

TABLES

D.1	Properties of Polyethylene	185
D.2	Effect of Basic Molecular Properties on Physical Properties of Polyethylene	187
E.1	Properties of Polypropylene	189
E.2	Physical Properties of Polypropylene Copolymers	191
E.3	Chemical Resistance of Polypropylene	192