

Report No. 44

AMMONIA

by ROBERT G. MULLER

November 1968

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	DEVELOPMENT OF AMMONIA PROCESSES	27
5	CHEMISTRY	35
	Ammonia Synthesis	35
	Steam Reforming	42
	Carbon Monoxide Shift Conversion	45
	Methanation	46
6	AMMONIA BY STEAM REFORMING NATURAL GAS	49
	Review of Processes	49
	Synthesis Conditions	49
	Synthesis Converters	51
	Synthesis Catalysts	55
	Synthesis Loop	55
	Reforming Processes	58
	Reforming Conditions	59
	Shift Conversion	61
	Carbon Dioxide Removal	62
	Methanation	64
	Cryogenic Purification Processes	65
	Other Gas Purification Processes	68
	Compression	68
	Process Description	72
	Materials of Construction	85
	Process Discussion	87
	Process Variations and Innovations	100
	Cost Estimates	108
	Capital Costs	109
	Production Costs	114
7	AMMONIA BY STEAM REFORMING NAPHTHA	121
	Steam Reforming Naphtha	121
	Naphtha Desulfurization	125
	Process Description	127
	Process Discussion	141
	Cost Estimates	147

CONTENTS

7	(Continued)	
	Capital Costs	147
	Production Costs	151
8	PROBLEMS ASSOCIATED WITH NEW AMMONIA PLANTS	157
9	OTHER PROCESSES FOR AMMONIA	165
	Other Synthetic Ammonia Processes	165
	By-product Ammonia Processes	171
	New Ammonia Processes	172
10	STORAGE AND DISTRIBUTION OF AMMONIA	175
APPENDIX A	DESIGN AND COST BASIS	187
APPENDIX B	PHYSICAL DATA	191
APPENDIX C	TYPICAL ANHYDROUS AMMONIA SPECIFICATIONS	193
APPENDIX D	SAFETY AND HANDLING	195
	CITED REFERENCES	197

ILLUSTRATIONS

3.1	Ammonia Production Capacity and Total Ammonia Consumption in the United States	15
6.1	Conversion of Ammonia in Different Types of Synthesis Converters	53
6.2	C. F. Braun Cryogenic Purifier	67
6.3	Ammonia by Steam Reforming Natural Gas Synthesis Gas Section	79
6.4	Ammonia by Steam Reforming Natural Gas Synthesis Section	81
6.5	Ammonia by Steam Reforming Natural Gas Effect of Plant Capacity on Capital Cost	113
6.6	Ammonia by Steam Reforming Natural Gas Effect of Natural Gas Cost on Total Production Cost	118
6.7	Ammonia by Reforming Natural Gas Effect of Operating Rate and Production Level on Production Cost	120
7.1	Ammonia by Steam Reforming Naphtha Synthetic Gas Section	135
7.2	Ammonia by Steam Reforming Naphtha Synthesis Section	137
7.3	Ammonia by Steam Reforming Naphtha Effect of Plant Capacity on Capital Cost	150
7.4	Ammonia by Steam Reforming Naphtha Effect of Naphtha Cost on Total Production Cost	155
7.5	Ammonia by Steam Reforming Naphtha Effect of Operating Rate and Production Level on Production Cost	156

TABLES

2.1	Summary of Costs for Ammonia by Steam Reforming	7
3.1	Ammonia Plant Capacities	
	United States	17
3.2	Annual Consumption of Nitrogen Fertilizers	24
5.1	Equilibrium Percentage of Ammonia in 3:1 Hydrogen to Nitrogen Gas Mixtures	36
6.1	Ammonia by Steam Reforming Natural Gas Major Process Equipment and Utilities Summary	79
6.2	Ammonia by Steam Reforming Natural Gas Stream Flows	83
6.3	Ammonia by Steam Reforming Natural Gas Total Capital Investment	110
6.4	Ammonia by Steam Reforming Natural Gas Production Costs	115
7.1	Ammonia by Steam Reforming Naphtha Major Process Equipment and Utilities Summary	133
7.2	Ammonia by Steam Reforming Naphtha Stream Flows	139
7.3	Ammonia by Steam Reforming Naphtha Total Capital Investment	148
7.4	Ammonia by Steam Reforming Naphtha Production Costs	153
9.1	Comparison of Processes for Hydrogen Production	166
10.1	Estimated Costs in Manufacturing and Marketing Anhydrous Ammonia	185