

Report No. 148

**COSTS OF SYNTHESIS GASES
AND METHANOL**

PART I I

by **JANET E. DINGLER**
SATISH NIRULA
WALTER SEDRIKS

February 1983

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

4	SYNGASES, HYDROGEN, AND METHANOL FROM THE STEAM REFORMING OF NATURAL GAS	1
	Chemistry of Steam Reforming	4
	Discussion of the Assumed Technical Basis	8
	Steam Reforming Stage	11
	Carbon Dioxide Separation	19
	Flue Gas Scrubbing	24
	Hydrogen Production	24
	Methanol Production	25
	H ₂ :CO Ratio Adjustment by Separation Processes	30
	Values Assigned to Steam	34
	Process Description	37
	Cases A and B: Syngas Streams with H ₂ :CO Ratios of 3:1 and 2:1 Obtained by CO ₂ Addition to Reformer Feed	37
	Case C: Hydrogen by Conventional Steam Reforming of Natural Gas (Including CO Shift Stages and Methanation)	44
	Case D: Methanol from Natural Gas by ICI Low Pressure Process (High Efficiency Design)	47
	Separation Processes for Adjusting H ₂ :CO Ratio	54
	Cryogenic Separation by Liquid Methane Wash	54
	Pressure Swing Adsorption (PSA)	55
	Tenneco's Cosorb [®] System.	56
	Monsanto's Prism [®] Separators	58
	Cost Estimates	59
	Basic Cases	59
	Syngas H ₂ :CO Ratio Adjustment by H ₂ Skimming	62
	Costs of Syngas Compression	92
	Effect of Scale of Operation	98
5	SYNGASES AND HYDROGEN BY THE PARTIAL OXIDATION OF VACUUM RESIDUE	123
	Brief Description of Cases Examined	124
	Chemistry	128
	Characterization of Partial Oxidation	
	Reactor Performance	129
	Brief Review of Processes	132
	Partial Oxidation Stage	132
	Acid Gas Removal System	134

CONTENTS

5	SYNGASES AND HYDROGEN BY THE PARTIAL OXIDATION OF VACUUM RESIDUE (continued)	
	Sulfur Recovery	135
	Process Description	135
	Cost Estimates	141
6	COAL GASIFICATION	149
	Historic Development	152
	Technical Background	154
	General Considerations	154
	Variability of Coal	155
	Temperature Constraints	159
	Gasification Pressure	160
	Flow Characteristics	161
	Fixed Bed	164
	Fluidized Bed	165
	Entrained Flow	166
	Stoichiometric Considerations	167
	Selection of Base Case for Cost Evaluation	178
	Base Case Design--Methanol from Coal	182
	Overall Plant Design	182
	Process Description	191
	Process Discussion	195
	Gasification	195
	Shift, COS Hydrolysis, and Acid Gas Removal	196
	Methanol Synthesis and Refining	197
	Cost Estimates--Methanol from Coal	198
	Capital Investment	198
	Production Costs and Product Value	204
	ROI and Profitability	206
	Discussion of Costs	208
	Derived Cost Modules	214
	Rationale for Cost Allocations	214
	Methanol-from-Syngas Unit	216
	Syngases of Various H ₂ :CO Ratios, and Hydrogen	217
	1. Methanol Syngas from Coal (Module 13)	220
	2. Methanol from Coal-Derived Syngas (Module 27)	223
	3. Syngas (H ₂ :CO = 0.75) from Coal (Module 1)	226
	4. Syngases (H ₂ :CO = 1.0, 1.5, 2.0) from Coal (Modules 2, 7, 8)	231
	5. Hydrogen from Coal (Module 22)	234
	Conclusions	238

CONTENTS

7 CARBON MONOXIDE SEPARATION FROM SYNGAS 267
 Main Features of Separation Modules 271
 Cost Estimates 278

CITED REFERENCES 293

PATENT REFERENCES 299

ILLUSTRATIONS

4.1	Carbon Formation	7
4.2	Effect of Temperature on the Reaction Equilibrium Constants in Steam Methane Reforming Reactions	9
4.3	Equilibrium Concentration of Methane as a Function of Temperature, Pressure, and Steam Ratio for Methane in a Steam Methane Reformer	10
4.4	H_2/CO Ratio as a Function of CO_2 Addition to Reformer Feed	15
4.5	Schematic Diagram for H_2 Skimming Processes	32
4.6	Steam Generation Capital as a Function of Pressure	36
4.7	Syngas ($H_2:CO$ Ratio = 3:1) by Steam Reforming of Natural Gas Flow Sheet	301
4.8	Syngas ($H_2:CO$ Ratio = 2:1) by Steam Reforming of Natural Gas Flow Sheet	303
4.9	Hydrogen from Steam Reforming of Natural Gas Flow Sheet	305
4.10	Methanol from Natural Gas by ICI LP Process (High Efficiency Design) Flow Sheet	307
4.11	$H_2:CO$ Separation by Methane Wash Flow Sheet	311
4.12	Tenneco's COSORB Process Flow Sheet	313
4.13	Flue Gas Scrubbing System Flow Sheet	315
4.14	Flowsheet for Hydrogen Production Using P.S.A.	317
4.15	Syngas Cost as a Function of $H_2:CO$ Ratio	81
4.16	Costs for Adjusting Syngas $H_2:CO$ Ratio	90
4.17	CO_2 Import Compared with H_2 Skimming (Showing CO_2/H_2 Breakeven Values)	91

ILLUSTRATIONS

4.18	Brake Horsepower Requirements as a Function of Syngas Compression Pressure	94
4.19	Syngas Compression Capital as a Function of Final Pressure and Scale of Operation	95
4.20	Syngas Compression Costs as a Function of Pressure	96
4.21	Scale Exponent as a Function of Capacity	100
4.22	Capital Cost as a Function of Capacity	101
5.1	Schematic Diagram Showing Process Stages for Partial Oxidation Cases Examined	125
5.2	Partial Oxidation Reactor Performance Effects of Feed Oxygen/Oil Ratio and Soot Recycle	131
5.3	Syngas ($H_2:CO$ Ratio = 1) by Partial Oxidation of Vacuum Residue Partial Oxidation/Soot Recycle Sections	138
6.1	Coal Gasification Modules	150
6.2	Main Gasifier Types and Illustrative Temperature Profiles	163
6.3	Feed Stoichiometric and Energy Constraints on Gasification Reactions (Without Methane Formation)	170
6.4	Product Stoichiometric and Energy Constraints	171
6.5	Coal and Oxygen Requirements as a Function of Coal Heating Value	175
6.6	Coal and Oxygen Requirements as a Function of Slurry Feed Solids Content	165
6.7	Methanol from Coal Schematic Flow Diagram Flow Sheet	319
6.8	Methanol from Coal Main Steam and Power Sources and Uses Flow Sheet	321
6.9	Methanol from Coal Variation of Unit Capital Requirements with Scale	202
6.10	Methanol from Coal Variation of Capital Costs with Capacity	203

ILLUSTRATIONS

6.11	Methanol from Coal Product Values	207
6.12	Sensitivity of Methanol Product Value to Capital Investment and Coal Price	211
6.13	Syngas from Coal Variation of Capital Costs with Capacity	222
6.14	Methanol Syngas ($H_2/CO = 2.26$) from Coal Product Values as a Function of Capacity	224
6.15	Methanol from Coal Derived Syngas Variation of Capital Costs with Capacity	225
6.16	Syngas from Coal Product Value as a Function of Capacity	228
6.17	Syngas from Coal Product Value as a Function of H_2/CO Ratio and Scale of Production	230
6.18	Sensitivity of Syngas Product Value to Capital Investment and Coal Price	235
6.19	Large Scale Hydrogen from Coal Variation of Capital Costs with Capacity	237

TABLES

4.1	Steam Reformer Conditions	12
4.2	Assumed Composition of Natural Gas Feedstock	13
4.3	Effect of CO ₂ Addition to Reformer Feed	14
4.4	Effect of Syngas H ₂ :CO Ratio on Reformer Design Parameters	17
4.5	Some Selected Acid Gas Removal Processes and Their Main Features	20
4.6	ICI Methanol Process Trend Toward Energy Reduction	27
4.7	Syngas (H ₂ :CO Ratio = 3:1) from Steam Reforming of Natural Gas, with CO ₂ Recycle Major Equipment	40
4.8	Syngas (H ₂ :CO Ratio = 3:1) from Steam Reforming of Natural Gas, with CO ₂ Recycle Stream Flows	41
4.9	Syngas (H ₂ :CO Ratio = 2:1) from Steam Reforming of Natural Gas, with CO ₂ Import Major Equipment	42
4.10	Syngas (H ₂ :CO Ratio = 2:1) from Steam Reforming of Natural Gas, with CO ₂ Import Stream Flows	43
4.11	Hydrogen (97%) from Steam Reforming of Natural Gas Major Equipment	45
4.12	Hydrogen (97%) from Steam Reforming of Natural Gas Stream Flows	46
4.13	Methanol from Natural Gas by ICI LP Process (High Efficiency Design) Major Equipment	51
4.14	Methanol from Natural Gas by ICI LP Process (High Efficiency Design) Stream Flows	53
4.15	Syngas (H ₂ :CO Ratio = 3:1) from Steam Reforming of Natural Gas, with CO ₂ Recycle Capital Investment	64
4.16	Syngas (H ₂ :CO Ratio = 3:1) from Steam Reforming of Natural Gas, with CO ₂ Recycle Production Costs	65

TABLES

4.17	Syngas ($H_2:CO$ Ratio = 2:1) from Steam Reforming of Natural Gas, with CO_2 Import Capital Investment	66
4.18	Syngas ($H_2:CO$ Ratio = 2:1) from Steam Reforming of Natural Gas, with CO_2 Import Production Costs	67
4.19	Hydrogen (97 vol%, 200 psia) from Steam Reforming of Natural Gas Capital Investment	68
4.20	Hydrogen (97 vol%, 220 psia) from Steam Reforming of Natural Gas Production Costs	69
4.21	Methanol from Natural Gas by ICI LP Process (High Efficiency Design) Capital Investment	70
4.22	Methanol from Natural Gas by ICI LP Process (High Efficiency Design) Production Costs	71
4.23	Crude Syngas from Steam Reforming of Natural Gas Capital Investment	72
4.24	Crude Syngas from Steam Reforming of Natural Gas Production Costs	73
4.25	Carbon Dioxide from Flue Gas Scrubbing with MEA Solution (UCC Amine Guard) Major Equipment	74
4.26	Carbon Dioxide from Flue Gas Scrubbing with MEA Solution (UCC Amine Guard) Stream Flows	75
4.27	Carbon Dioxide from Flue Gas Scrubbing with MEA Solution (UCC Amine Guard) Capital Investment	76
4.28	Carbon Dioxide from Flue Gas Scrubbing with MEA Solution (UCC Amine Guard) Production Costs	77
4.29	Syngas ($H_2:CO$ Ratio = 1) from Steam Reforming of Natural Gas, with CO_2 Import Production Costs for 10^{11} scf/yr	78

TABLES

4.30	Summarized Costs for Products from Natural Gas Steam Reforming	80
4.31	Economic Comparison of Skimming Processes	82
4.32	Syngas (H ₂ :CO Ratio = 2) from the Skimming of 3:1 Syngas; Prism [®] Separators Production Costs for 73.9 x 10 ⁹ scf/yr	83
4.33	Syngas (H ₂ :CO Ratio = 1) from the Skimming of 3:1 Syngas; Prism [®] Separators Production Costs for 47.5 x 10 ⁹ scf/yr	85
4.34	Syngas (H ₂ :CO Ratio = 1) from the Skimming of 2:1 Syngas; Prism [®] Separators Production Costs for 63.7 x 10 ⁹ scf/yr	87
4.35	Costs for H ₂ :CO Ratio Adjustment by CO ₂ Import and/or Skimming Surplus H ₂	89
4.36	Syngas Compression Costs	97
4.37	Cases Examined to Illustrate Effect of Plant Capacity on Production Economics	102
4.38	Syngas (H ₂ :CO Ratio = 2) from Steam Reforming of Natural Gas, with CO ₂ Import Production Costs for 33 x 10 ⁹ scf/yr	103
4.39	Syngas (H ₂ :CO Ratio = 2) from Steam Reforming of Natural Gas, with CO ₂ Import Production Costs for 16.5 x 10 ⁹ scf/yr	105
4.40	Syngas (H ₂ :CO Ratio = 1) from Steam Reforming of Natural Gas, with CO ₂ Import Production Costs for 6.7 x 10 ⁹ scf/yr	107
4.41	Syngas (H ₂ :CO Ratio = 1) from Skimming of Syngas of 2:1 Ratio Production Costs for 6.7 x 10 ⁹ scf/yr	109
4.42	Hydrogen (97 vol%, 220 psia) from Steam Reforming of Natural Gas (Conventional) Production Costs for 200 Million lb/yr	111
4.43	Hydrogen (97 vol%, 220 psia) from Steam Reforming of Natural Gas (Conventional) Production Costs for 100 Million lb/yr	113

TABLES

4.44	Hydrogen (97 vol%, 220 psia) from Steam Reforming of Natural Gas (Conventional) Production Costs for 50 Million lb/yr	115
4.45	Methanol from Natural Gas by the ICI Process Production Costs for 728 Million lb/yr	117
4.46	Methanol from Natural Gas by the ICI Process Production Costs for 364 Million lb/yr	119
4.47	Methanol from Natural Gas by the ICI Process Production Costs for 182 Million lb/yr	121
5.1	Some Characteristics of Assumed Vacuum Residue Feedstock	124
5.2	Key Parameters for Partial Oxidation Cases Examined	127
5.3	Syngas (H ₂ :CO Ratio = 2:1) by Partial Oxidation of Vacuum Residue Stream Flows	140
5.4	Syngas (H ₂ :CO Ratio = 2:1) by Partial Oxidation of Vacuum Residue Production Costs	143
5.5	Syngas (H ₂ :CO Ratio = 1:1) by Partial Oxidation of Vacuum Residue Production Costs	145
5.6	Hydrogen (98%) by Partial Oxidation of Vacuum Residue Production Costs	147
6.1	Product Compositions and Flow Rates	151
6.2	Typical Syngas Compositions from Various Gasifiers	157
6.3	Partial Oxidation Comparisons	158
6.4	Typical Coal Compositions and Higher Heating Values	159
6.5	Gasifier Characteristics	162
6.6	Methanol from Coal Stream Flows	184
6.7	Methanol from Coal Utilities Summary	186
6.8	Trains per Unit	188
6.9	Mass Balance Around Texaco Gasifiers (10,000 Metric Tons/Day Methanol)	189

TABLES

6.10	Water Quality Data Bleed Stream - Eastern Coal	190
6.11	Methanol from Coal Total Fixed Capital	199
6.12	Methanol from Coal Investment as a Function of Capacity	201
6.13	High Pressure Steam Production Cost	218
6.14	Methanol Syngas from Coal Investment and Product Value as a Function of Capacity . .	221
6.15	Methanol From Coal-Derived Syngas Investment as a Function of Capacity	223
6.16	Syngas ($H_2:CO = 0.75$) from Coal Investment and Product Value as a Function of Capacity . .	229
6.17	Syngas ($H_2:CO = 1.0$) from Coal Investment and Product Value as a Function of Capacity . .	232
6.18	Syngas ($H_2:CO = 1.5$) from Coal Investment and Product Value as a Function of Capacity . .	232
6.19	Syngas ($H_2:CO = 2.0$) from Coal Investment and Product Value as a Function of Capacity . .	233
6.20	Large Scale Hydrogen Production from Coal Investment and Product Value as a Function of Capacity . .	238
6.21	Methanol from Coal Production Costs	242
6.22	Methanol Syngas from Coal ($H_2:CO = 2.26$) Production Costs	252
6.23	Methanol from Coal-Derived Syngas Production Costs	254
6.24	Syngas ($H_2:CO = 0.75$) from Coal Production Costs	256
6.25	Syngas ($H_2:CO = 1.0$) from Coal Production Costs	258

TABLES

6.26	Syngas ($H_2:CO = 1.5$) from Coal Production Costs	260
6.27	Syngas ($H_2:CO = 2$) from Coal Production Costs	262
6.28	Hydrogen (97%) from Coal Production Costs	264
7.1	Details of Cost Modules Examined for Production of Carbon Monoxide	269
7.2	Syngas and Carbon Monoxide Product Compositions for Cost Modules	270
7.3	Carbon Monoxide Costs from Various Separation Modules . .	279
7.4	Carbon Monoxide By Cryogenic Separation of Crude Syngas from Natural Gas Production Costs	280
7.5	Carbon Monoxide by COSORB [®] Separation of Crude Syngas from Natural Gas Production Costs	282
7.6	Carbon Monoxide by COSORB [®] Separation of Syngas ($H_2:CO$ Ratio = 3.1) from Natural Gas Production Costs	284
7.7	Carbon Monoxide by Cryogenic Separation of Syngas ($H_2:CO$ Ratio = 3.1) from Natural Gas Production Costs	286
7.8	Carbon Monoxide by Cryogenic Separation of Syngas ($H_2:CO$ Ratio = 2.1) from Partial Oxidation of Vacuum Residue Production Costs	288
7.9	Carbon Monoxide by COSORB [®] Separation of Methanol Syngas from Coal Production Costs	290