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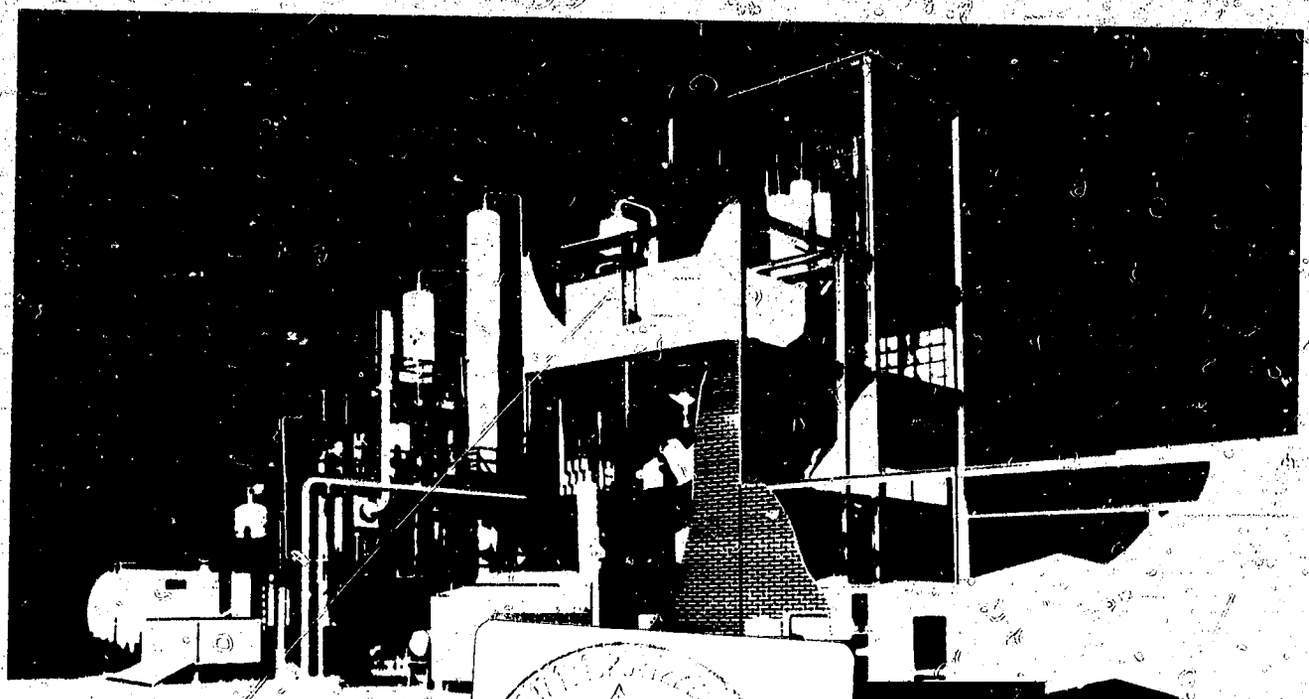
October 1975 - March 1979

FEASIBILITY OF THE SILANE PROCESS FOR PRODUCING SEMICONDUCTOR-GRADE SILICON

JPL Contract 954334

June 1979



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LOW-COST SOLAR ARRAY PROJECT

FEASIBIBILITY OF THE SILANE PROCESS FOR PRODUCING SEMICONDUCTOR-GRADE SILICON

FINAL REPORT (Phases I and II)

Period Covered: October 1975 - March 1979

Jet Propulsion Laboratory (JPL) Contract 954334

ABSTRACT

The commercial production of low-cost semiconductor-grade silicon is an essential requirement of the JPL/DOE (Department of Energy) Low-Cost Solar Array (LSA) Project. A 1000-metric-ton-per-year commercial facility using the Union Carbide Silane Process will produce molten silicon for an estimated price of $7.56/kg (1975 dollars, private financing), meeting the DOE goal of less than $10/kg.

Conclusions and technology status are reported for both contract phases, which had the following objectives:

- Establish the feasibility of Union Carbide's Silane Process for commercial application, and
- Develop an integrated process design for an Experimental Process System Development Unit (EPSDU) and a commercial facility, and estimate the corresponding commercial plant economic performance.

To assemble the facility design, the following work was performed: (a) collection of Union Carbide's applicable background technology; (b) design, assembly, and operation of a small integrated silane-producing Process Development Unit (PDU); (c) analysis, testing, and comparison of two high-temperature methods for converting pure silane to silicon metal; and (d) determination of chemical reaction equilibria and kinetics, and vapor-liquid equilibria for chlorosilanes.

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TABLE OF CONTENTS

SECTION NO.	PAGE NO.
Abstract	ii
1. INTRODUCTION	1
1.1 Background	1
2. SUMMARY AND CONCLUSIONS	8
2.1 Process Design	8
2.2 Economic Performance	9
2.3 Silane Production (PDU)	10
2.4 Free-space Silane Pyrolysis PDU	10
2.5 PDU for Free-space Silicon Powder Consolidation	10
2.6 Fluid-bed Silane Pyrolysis	11
2.7 Thermodynamic Data	12
2.8 Proposed Future Work	13
3. PROCESS RESEARCH AND DEVELOPMENT PROGRAM	15
3.1 Silane Production Process Development Unit	15
3.1.1 Program and Design Basis	15
3.1.2 Description of PDU	15
3.1.2.1 Hydrogenation Section	15
3.1.2.2 Redistribution and Distillation	25
3.1.3 PDU Performance Assessment	28
3.1.3.1 Raw Material Characterization	31
3.1.3.2 Hydrogenation Performance	31
3.1.3.3 Redistribution and Distillation Performance	36
3.1.3.4 Corrosion Data	41
3.2 Silane Pyrolysis and Silicon Consolidation	45
3.2.1 Free-space Reactor	49
3.2.1.1 Program Goals	49
3.2.1.2 Equipment and Reactor Model	49
3.2.1.2.1 Reactor and Settling Chamber	49
3.2.1.2.2 Connected Assembly	55
3.2.1.2.3 Reactor Model and Heat-transfer Mechanism	58

TABLE OF CONTENTS (Continued)

SECTION NO.		PAGE NO.
3.2.1.3	Silane Pyrolysis Experiments	58
3.2.1.3.1	Pyrolysis Efficiency	58
3.2.1.3.2	Demonstration of Reactor System Capability	60
3.2.1.4	Product Properties	63
3.2.1.4.1	Silicon Powder Morphology	63
3.2.1.4.2	Gas Injector and Reactor Wall and Lid Deposits	64
3.2.1.4.3	Silicon Purity	66
3.2.2	Free-space Reactor Powder Melting and Consolidation	66
3.2.2.1	Program Goals	66
3.2.2.2	Compaction and Sintering	67
3.2.2.3	Melt Consolidation	70
3.2.2.4	Casting Methods	75
3.2.2.4.1	Suction Cast Rods	75
3.2.2.4.2	Vacuum-cast Pellets	77
3.2.2.4.3	Cast-mold Casting	77
3.2.2.5	Comparative Economics of Suction Casting and Rapid Pulling	80
3.2.2.6	Melter Development of EPSDU	81
3.2.3	Fluid-bed Silane Pyrolysis	81
3.2.3.1	Program Goals	81
3.2.3.2	Silane Pyrolysis Experiments	82
3.2.3.2.1	Fluid-bed Pyrolysis	82
3.2.3.2.2	Horizontal Tube Experiments	93
3.2.3.3	Fluidization Studies	96
3.2.3.3.1	Fundamental Bed Behavior	96
3.2.3.3.2	Distributor Design	103
3.2.3.3.3	Attrition Experiments	104
3.2.3.4	Analytical Model	108
3.2.3.5	Capacitive Heating	118
3.2.3.5.1	Electrical Behavior	120
3.2.3.6	Commercial-scale Economic Performance	130

TABLE OF CONTENTS (Continued)

SECTION NO.		PAGE NO.
4.	REACTION KINETICS AND THERMODYNAMIC AND PHYSICAL PROPERTIES	136
4.1	Chemical Reactions	136
4.1.1	Equilibrium Constants (K_p) and Heat of Reaction (ΔH)	138
4.2	Heat-of-formation Values	139
4.3	Reaction Kinetics	143
4.3.1	Silicon Tetrachloride (STC) Hydrogenation	143
4.3.1.1	Experimental Apparatus and Procedure	144
4.3.1.2	Kinetic Data Evaluation	147
4.3.2	Catalyst Properties and Reaction Mechanism	159
4.3.2.1	Trichlorosilane Redistribution Kinetics	169
4.3.2.2	Dichlorosilane Redistribution Kinetics	172
4.3.2.3	Experimental Results	185
4.4	Vapor-liquid Equilibria	188
4.4.1	Binary VLE of Chlorosilane Mixtures	188
4.4.1.1	K Value Model	188
4.4.1.2	Silicon Tetrachloride-trichlorosilane, Binary, Vapor-liquid Equlibria	189
4.4.1.3	Dichlorosilane-trichlorosilane, Binary Vapor-liquid Equilibria	189
4.4.2	Vapor-liquid Equilibria of Chlorosilane, Light-gas Mixtures	196
4.4.2.1	Henry's Constant	196
4.4.3	Experimental Apparatus and Procedure	197
4.4.3.1	DCS-TCS Vapor-liquid Equilibria	197
4.4.3.2	Vapor Pressure of DCS and TCS	197
4.4.3.3	Gas Solubility in DCS, TCS, and STC	203
4.4.4	Settler Impurity Rejection Performance	203
5.	COMMERCIAL PLANT DESIGNS	210
5.1	1000 MT/yr Commercial Plant	216
5.1.1	Introduction	216
5.1.2	Process Design	216
5.1.2.1	Process Description	216
5.1.2.1.1	Hydrogenation	217

TABLE OF CONTENTS (Continued)

SECTION NO.		PAGE NO.
5.1.2.1.2	Distillation/Redistribution	219
5.1.2.1.3	Silane Pyrolysis/Consolidation	224
5.1.2.1.4	Waste Disposal	225
5.1.2.2	Major Process Controls	227
5.1.2.3	Rationale for Selection of Operating Conditions	236
5.1.2.3.1	Hydrogenation	236
5.1.2.3.2	Distillation Columns	237
5.1.2.3.3	Chlorosilane Redistribution Reactors	238
5.1.2.3.4	Pyrolysis	239
5.1.2.4	Contaminant Removal Summary	239
5.1.2.5	Process Performance	244
5.1.2.5.1	Plant Battery Limits	244
5.1.2.5.1.1	Raw Materials	244
5.1.2.5.1.2	Utilities	245
5.1.2.5.1.3	Consumables	246
5.1.2.5.1.4	By-products and Wastes	246
5.1.3	Plant Design	247
5.1.3.1	Process Equipment	247
5.1.3.2	Chemical Handling and Safety	247
5.1.3.3	Instrumentation and Control	248
5.2	120 MT/yr Commercial Plant	249
5.2.1	Introduction	249
5.2.2	Process Design	250
5.2.3	Plant Design	250
6.	COMMERCIAL PLANT ECONOMICS	251
6.1	1000 MT/yr Commercial Plant Economics	251
6.2	120 MT/yr Commercial Plant Economics	254
7.	RECOMMENDED FUTURE ACTION	258
7.1	Silane Pyrolysis	258

TABLE OF CONTENTS (Continued)

SECTION NO.		PAGE NO.
7.2	Analytical Techniques	259
7.3	Vapor-liquid Equilibrium Data	259
7.4	STC Hydrogenation Kinetics	259
7.5	Waste Disposal Burners	260
7.6	Experimental Process System Development Unit (EPSDU)	260
8.	REFERENCES	261
9.	GLOSSARY	263

APPENDIX NO.		PAGE NO.
A	Summary of the Statement of Work and the Contract Deliverables	A-1
B	Critical Properties, Vapor Pressure, Enthalpy, and Latent Heat Constants	B-1
B.1	Introduction	B-2
C	1000 MT/yr Commercial Plant (Issue 1)	C-1
D	120 MT/yr Commercial Plant (Issue 1)	D-1
E	1000 MT/yr Commercial Plant (Issue 2)	E-1

ILLUSTRATIONS

FIGURE NO.		PAGE NO.
2-1	— Union Carbide Silane Process (Simplified Flow Schematic)	8
3-1	Hydrogenation Section of Silane PDU	16
3-2	Redistribution Section of Silane PDU	17
3-3	Hydrogenation Reactor Scrubber/Settler	21
3-4	Process Development Unit	22
3-5	Pressure Drop vs Bed Height for the Hydrogenation Reactor	24
3-6	Hydrogenation Reactor Temperature Profile (27-inch Bed Height)	37
3-7	$HSiCl_3$ Disproportionation Unit Redistribution	40
3-8	Hydrogenation Reactor Corrosion Test Coupons	46
3-9	Free-space Reactor and Settling Chamber Assembled	50
3-10	Settling Chamber Schematic	51
3-11	Free-space Reactor Lid Schematic	53
3-12	Free-space Reactor Gas-flow Diagram	54
3-13	Connected Assembly Schematic	56
3-14	Photograph of the Inside of the Melter	57
3-15	Model of Free-space Reactor Axi-symmetric Jet	59
3-16	Operating Conditions for High Silane Conversion Efficiencies	61
3-17	SEM Micrographs of Free-space Reactor Powder (5000X)	65
3-18	SEM Micrograph of Loose Free-space Reactor Powder Sintered at 1300°C (5000X)	68
3-19	Effect of Isostatic Pressure on Compact Density	69
3-20	SEM Micrograph of a Sintered Flame	71
3-21	Silicon Melter Schematic	72
3-22	Dross-free 152 mm Diameter Castings	74
3-23	Schematic of Setup for Melting Silicon Fragments	76
3-24	Suction-cast Silicon Rods	78
3-25	Sectional, Vacuum-cast Pellets	79
3-26	Fluid-bed Reactor View Showing Particles of Silicon Supported by the Gas Distributor	83
3-27	Fluid-bed Reactor Gas-flow Diagram	84

ILLUSTRATIONS (continued)

FIGURE NO.		PAGE NO.
3-28	Gas Distributor for Fluid-bed Reactor	86
3-29	Photomicrograph of -60/+100 Mesh Silicon Particles (50X)	89
3-30	Photomicrograph of Sectioned Silicon Particle Coated at 500°C (1000X)	91
3-31	Photomicrograph of Sectioned Silicon Particles Coated at 600°C (1000X)	92
3-32	Photomicrograph of Silicon Fiber (900X)	95
3-33	Fluidization Behavior of -35/+60 Mesh Silicon Particles	98
3-34	Fluidization Behavior of -60/+100 Mesh Silicon Particles	99
3-35	Density Match Between Helium in Cold Bed and Silane-Hydrogen Mixture in Hot Bed at Various Silane Mole Fractions and Temperatures in Hot Bed	101
3-36	Pressure Drop through Bed vs Helium Velocity in Bed Under Partial Vacuum	102
3-37	Boot Section for Particle Segregation	105
3-38	Segregation Data for Preliminary Tests	106
3-39	Rate of Fines Generation for Semiconductor-Grade Silicon Particles at U/U_{mf} = 2 and 5	107
3-40	Critical Mole Fraction of Silane as a Function of Temperature	110
3-41	Silane Concentration vs Energy Consumption with Bed Temperature	111
3-42	Surface Reaction Rate vs T^{-1} (K^{-1})	114
3-43	Reactor Length for 99% Silane Conversion vs Temperature for Several Particle Sizes	115
3-44	Reactor Diameter for 1 kg/hr Silicon Production vs Temperature for Several Particle Sizes	116
3-45	Energy Consumption per kg of Silicon Produced vs Temperature	117
3-46	Energy Flux through the Walls vs Bed Temperature	119
3-47	Schematic Diagram of Capacitively Coupled Heating of Fluid Bed	121
3-48	Current vs Frequency of Bed in State H	123
3-49	Current vs Frequency of Bed in State L	124
3-50	Performance of Coated Electrode	125

ILLUSTRATIONS (continued)

FIGURE NO.		PAGE NO.
3-51	Maximum Temperature Difference in Bed (Normalized to Input Power) vs Flow Velocity (Normalized to Minimum Fluidization Velocity)	126
3-52	Schematic of Bed Showing Points of Temperature Measurement	128
3-53	Electrically Sintered Particles >10 Mesh	131
3-54	Schematic Diagram of Fluid-bed Pyrolysis	132
4-1	Equilibrium Constants for Reactions 4-1 through 4-4 as a Function of Temperature	137
4-2	Laboratory Pressure Hydrogenation Reactor	145
4-3	Plot of Partial Pressure Parameter vs Reactor Residence Time, 500°C, 206 PSIA, H_2/STC: 2.04:1, $P_{e,TCS}$ = 21.1 PSIA	160
4-4	Plot of Partial Pressure Parameter vs Reactor Residence Time, 500°C, 206 PSIA, H_2/STC: 5.04:1, $P_{e,TCS}$ = 13.29 PSIA	161
4-5	Plot of Partial Pressure Parameter vs Reactor Residence Time, 450°C, 206 PSIA, H_2/STC: 2.04:1, $P_{e,TCS}$ = 20.50 PSIA	162
4-6	Plot of Partial Pressure Parameter vs Reactor Residence Time, 450°C, 206 PSIA, H_2/STC: 5.04:1, $P_{e,TCS}$ = 12.94 PSIA	163
4-7	Plot of Partial Pressure Parameter vs Reactor Residence Time, 450°C, 65 PSIA, H_2/STC: 1.3:1, $P_{e,TCS}$ = 5.83 PSIA	164
4-8	Plot of Partial Pressure Parameter vs Reactor Residence Time, 500°C, 65 PSIA, H_2/STC: 1.3:1, $P_{e,TCS}$ = 6.01 PSIA	165
4-9	Effluent Product Composition from TCS Redistribution Reactor at 81°C Containing A-21 Resin Catalyst. Bed Diameter = 0.43 Inches	170
4-10	Effluent Product Composition from TCS Redistribution Reactor at 81°C Containing A-21 Resin Catalyst. Bed Diameter = 0.43 Inches	173
4-11	Effluent Product Composition from Liquid TCS Redistribution Reactor at 56°C Containing A-21 Resin Catalyst. Bed Diameter = 0.43 Inches	174

ILLUSTRATIONS (continued)

FIGURE NO.		PAGE NO.
4-12	Reaction Rate Constant as a Function of Temperature. Top Three Curves are from DCS Redistribution Reactor.	175
4-13	Effluent Product Composition from Liquid DCS Redistribution Reactor at 56°C Containing A-21 Resin Catalyst. Bed Diameter = 0.43 Inches	182
4-14	Effluent Product Composition from Liquid DCS Redistribution Reactor at 32°C Containing A-21 Resin Catalyst. Bed Diameter = 0.43 Inches	183
4-15	Effluent Product Composition from Liquid DCS Redistribution Reactor at 81°C Containing A-21 Resin Catalyst. Bed Diameter = 0.43 Inches	184
4-16	Flow Diagram of DCS Redistribution Unit	186
4-17	Comparison of Experimental and Calculated K Values for STC-TCS Binary at 740 TORR.	191
4-18	Liquid Activity Coefficient for STC-TCS Binary at 740 TORR.	192
4-19	Comparison of Experimental and Calculated K Values for DCS-TCS Binary at 300 psia	193
4-20	Liquid Activity Coefficient for DCS-TCS Binary at 300 psia	194
4-21	Comparison of K Values Calculated with Wilson Parameters from 100 psia Data with Experimental 300 psia Data for DCS-TCS Binary at 300 psia	195
4-22	Scrubber/Settler for the Silane PDU	209
5-1	1000 MT/yr Commercial Plant Process Flow Diagram (5 sheets)	211
5-2	TCS/STC Column 432-04 Temperature Profile with Varying Reboiler Duty	229
5-3	TCS/STC Column 432-04 Temperature Profile with Varying Distillation Product Flow	231
5-4	TCS/STC Column 432-04 Control-Loop Process Gain Diagram for Distillate Flow	232
5-5	Silane Column 432-08 Temperature Profile	234

TABLES

TABLE NO.		PAGE NO.
III-1	Hydrogenation Reactor Design Summary	19
III-2	Operating Results Silane PDU Dichlorosilane Section	29
III-3	Silane Product from Final Integrated PDU Operation	30
III-4	Coarse Grind Silicon Size Distribution	32
III-5	Metallurgical Silicon Analysis by Size Fraction	32
III-6	Typical Composition of Cement Copper	33
III-7	Metallurgical Silicon/Copper Reaction Mass	34
III-8	AMBERLYST® A-21 Properties	35
III-9	Nitrogen Content of AMBERLYST® A-21 Chlorosilane Redistribution Catalyst	42
III-10	Typical Carbon Bed Operating Data	43
III-11	Cumulative Yield for Several Crushing Methods	88
III-12	Cumulative Property Data for Crushed Silicon	88
III-13	Temperature Distributions/Results for Tests 1 and 2	129
III-14	1000 MT/year Fluid-bed Pyrolysis System Equipment List and Description	134
III-15	1000 MT/year Fluid-bed Pyrolysis System Preliminary Economic Analysis Summary	135
IV-1	Equilibrium Constant (Kp) and Heats of Reaction (ΔH)	140
IV-2	Heats of Formation	141
IV-3	Comparison of Heats of Reaction: Observed, Calculated from JANAF Tables, Calculated from Adjusted (ΔH^{o})	142
IV-4	Hydrogenation of STC Product Composition Data	146
IV-5	Hydrogenation of STC at 112 psia with 2% Cu/Si	148
IV-6	Hydrogenation of STC in 5 cm Dia. Reactor with 2% Cu/Si	149
IV-7	Silicon Tetrachloride Hydrogenation Chemical Analysis Data. P = 206 psia, T = 500°C, H_2:STC = 2.04:1	151
IV-8	Silicon Tetrachloride Hydrogenation Chemical Analysis Data. P = 206 psia, T = 500°C, H_2:STC = 5.04.:1	152
IV-9	Silicon Tetrachloride Hydrogenation Chemical Analysis Data. P = 206 psia, T = 450°C, H_2:STC = 2.04:1	153
IV-10	Silicon Tetrachloride Hydrogenation Chemical Analysis Data. P = 206 psia, T = 450°C, H_2:STC = 5.04:1	154
IV-11	Silicon Tetrachloride Hydrogenation Chemical Analysis Data. P = 65 psia, T = 450°C, H_2:STC = 1.3:1	155

TABLES (continued)

TABLE NO.		PAGE NO.
IV-12	Silicon Tetrachloride Hydrogenation Chemical Analysis Data. P - 65 psia, T = 500°C, H_2:STC = 1.3:1	156
IV-13	Kinetic Data Correlation	157
IV-14	Disproportionation of TCS and DCl Gas in the Presence of A-21 Resin Catalyst at 60°C	168
IV-15	Catalytic Redistribution of Trichlorosilane	176
IV-16	DCS Redistribution Data Calculated with Second-order Rate Equations at 32°C	180
IV-17	DCS Redistribution Data Calculated with Second-order Rate Equations at 56°C	180
IV-18	DCS Redistribution Data Calculated with Second-order Rate Equations at 80°C	181
IV-19	Chlorosilanes Redistribution Equilibria	187
IV-20	PTxy Data for Trichlorosilane (1) — Silicon Tetrachloride (2) at 740 TORR	190
IV-21	Gas Solubility in Chlorosilanes, Henry's Constants (atm/mole Fraction)	198
IV-22	PTx Data for Dichlorosilane (1) — Trichlorosilane (2)	199
IV-23	Vapor-liquid Equilibrium for Dichlorosilane (1) — Trichlorosilane (2)	200
IV-24	Vapor-liquid Equilibrium for Dichlorosilane (1) — Trichlorosilane (2)	201
IV-25	Pure Component Vapor Pressure	202
IV-26	Experimental Data N_2, CH_4, CO_2, and HCl in Dichlorosilane	204
IV-27	Experimental Data N_2, CH_4, CO_2, and HCl in Trichlorosilane	205
IV-28	Experimental Data N_2, CH_4, CO_2, and HCl in Silicon Tetrachloride	206
IV-29	Scrubber/Settler Efficiencies	208
V-1	Process Impurities	240
V-2	Product Silane Impurity Analysis	243

SECTION 1
INTRODUCTION

This report presents the conclusions from two phases of work by the Union Carbide Corporation (UCC) for the Jet Propulsion Laboratory under Contract 954334. Phase I began in October, 1975, and Phase II in October, 1977.

This contract, a part of the JPL/DOE (Department of Energy) Low-Cost Solar Array (LSA) Project, had the objective to develop the process technology for the manufacture of semiconductor-grade silicon in a large commercial plant by 1986, at a price of not more than $10 per kilogram of silicon based on 1975 dollars.

1.1 BACKGROUND

Union Carbide began producing metallurgical-grade (M-G) silicon at Niagara Falls, N.Y., in the 1920's and, in the early 1930's, expanded production capacity by constructing a new facility in Alloy, W. Va. The corporation is still a major commercial supplier of metallurgical silicon.

Because of a continuing interest in silicon chemistry, a series of research projects that began at the Tonawanda Laboratories in 1940 resulted in the development of several commercially useful silicon compounds. Two processes researched during this effort have direct application to the present silane-silicon process:

- The copper-catalyzed, high-temperature hydrogenation reaction for producing trichlorosilane from M-G silicon and silicon tetrachloride in a fluid-bed reactor.

- The technique for redistributing trichlorosilane to dichlorosilane.

These research projects led ultimately to the construction of a large commercial facility for producing silicon compounds in Sistersville, W. Va., in 1955 and to the formation of the Silicones Division in 1956. Further research in

many areas over the ensuing years has produced a number of relevant accomplishments:

- Research work at Sistersville in the early 1960's resulted in the perfection of purification processes capable of reducing boron and phosphorous contaminants in trichlorosilane to extremely low levels, and in the development of analytical techniques to detect fractional part-per-billion concentrations of these contaminants in trichlorosilane.

- In the early 1970's chlorosilane redistribution equilibria and kinetics were studied extensively using various catalysts. Rohm and Haas' Amberlyst® A-21 catalyst was found to support highly satisfactory redistribution reaction rates for chlorosilanes. This catalyst was used to produce commercial dichlorosilane by redistributing trichlorosilane, and to produce silane by redistributing dichlorosilane. These two distribution reactions over A-21 catalyst are used in the present silane-silicon process.

- Union Carbide began producing silane by the trichlorosilane-ethanol process in 1955 and by the molten-salt process in 1957. In 1967, the Union Carbide facility at Keasbey, N.J., began producing commercial silane by the molten-salt process for the electronics industry.

- In 1957 the technology for producing semiconductor-grade silicon by pyrolyzing trichlorosilane in heated quartz tubes was developed at the Parma, Ohio, Research Laboratories, and silane produced by the molten-salt process was pyrolyzed to yield silicon metal. The trichlorosilane pyrolysis technology was used between 1958 and 1963 to produce lump semiconductor-grade silicon for the electronics industry.

Although Union Carbide had been heavily involved in many facets of the silicon and silicones business over the years, the technology was scattered throughout several divisions and locations. In 1974, a corporate task force was established to assess Union Carbide's total capability and direct future

activities in a coherent fashion. As a result, the wide expertise was made available to support a more focused effort. The available technologies included silicon chemistry; gas-phase pyrolysis; fluid-bed technology; analytical and electronic evaluation; economic analysis and forecasting; safety, hazards, and toxicity; molten-salt technology; and process engineering.

Corporate research activities were resumed in early 1975 with a program for producing high-purity, granular silicon metal by pyrolyzing silane. Later that year, this process and Union Carbide's background technology were described in a presentation to JPL. As a result, JPL issued a request for proposal to study the feasibility of the silane-silicon process for producing polycrystalline silicon in accordance with the stringent economic goals of the LSA project. The silane process work was continued under corporate funding until Contract 954334 was awarded by JPL in late 1975.

Phases I and II of the contract were authorized as separate efforts directed toward the specific needs of the LSA project for meeting its goal: the large volume, low-cost production of semiconductor-grade silicon by 1986. As a result of a unified and focused effort involving several divisions, the program technical goals and milestones have been attained, as documented in this final report. The following divisions have participated in this effort:

Chemicals & Plastics (Sistersville, W. Va.) - production of silane by disproportionation of chlorosilanes.

Carbon Products (Parma, Ohio) - pyrolysis of silane to silicon powder in a free-space reactor and subsequent consolidation of the powder by melting.

Linde (Tonawanda, N.Y.) - engineering for 25-, 100-, and 1000 MT/yr-silicon facilities and fluid-bed pyrolysis development.

Linde (Keasbey, N.J.) - supply of silane for pyrolysis studies at Parma.

Metals (Alloy, W. Va.) - supply of sized M-G silicon for Sistersville.

Corporate R&D (Tarrytown, N.Y.) - supporting work on hydrogenation kinetics, silane pyrolysis, and silicon evaluation.

1.2 SCOPE OF WORK PERFORMED DURING CONTRACT

The objective of the Phase I program was to conduct feasibility investigations to establish the practicality of the following three concepts:

- High-volume, low-cost production of silane, as an intermediate for obtaining semiconductor-grade silicon, based on the synthesis of silane by the catalytical disproportionation of chlorosilanes resulting from the reaction of hydrogen, M-G silicon, and silicon tetrachloride.

- Subsequent pyrolysis of silane to semiconductor-grade silicon in free-space and fluid-bed reactors.

- High-frequency, capacitive heating of silicon seed particles suitable for silane pyrolysis in a fluidized bed.

The program for the silane investigation began in October 1975. A small process development unit (PDU), capable of operating under pressure, was designed, constructed, and operated to demonstrate the conversion of dichlorosilane to silane, and later to test the conversion of trichlorosilane to silane. A hydrogenation reactor was added as a front end for the PDU, and the combined system demonstrated the closed-cycle production of high-purity silane from M-G silicon and hydrogen. The program also included an experimental investigation of the kinetics of hydrogenation and redistribution reactions.

The pyrolysis investigation program began in January 1977. A silane pyrolysis PDU, designed around an existing free-space reactor, was assembled and operated to produce high-purity silicon powder. Some of the powder, melted in a quartz crucible, was either suction-cast to produce polycrystalline rods or frozen in a crucible. A silicon boule was pulled from re-melted fragments for purity analysis and resistivity measurements. Silane

pyrolysis tests in a company-owned fluid-bed reactor demonstrated that silicon seed particles could be coated with continuous and coherent layers of silicon; however, Union Carbide and JPL agreed that this technology was not as mature as free-space silane pyrolysis. Therefore, Union Carbide conducted a thorough review of the technical status of fluid-bed pyrolysis, and submitted recommendations concerning the required effort, cost, and schedule necessary to develop this technology.

The capacitive heating investigation was initiated in October 1977. A fluid-bed system, which incorporated high-frequency, capacitive heating of silicon bed particles, was designed, assembled, and tested. The results showed that capacitive heating can be used to heat silicon particles to silane-pyrolysis temperatures, while keeping the bed wall at a cooler temperature than the particles. The program also included theoretical modeling of fluid-bed silicon deposition.

In October of 1977, building on the promising technology base being developed under Phase I, Union Carbide conducted an 18-month Phase II program in parallel with the remaining Phase I effort. The three objectives of Phase II were to:

- Provide an information base for experimental silane and silicon facilities through technical/experimental studies and engineering optimizations.

- Prepare a preliminary design for an Experimental Process System Development Unit (EPSDU) sized to produce 100 metric tons of silicon per year.

- Perform economic analyses to project product costs from commercial facilities.

Providing the information base necessary to satisfy the first objective became quite involved. Much of the data required for preparing a process design with confidence either did not exist or was of questionable accuracy.

As a result of the analytical and experimental studies conducted under this task, accurate process design data were acquired in the following areas:

- Thermodynamic data for chlorosilanes and process impurities.
- Heats of formation and vapor/liquid equilibrium of chlorosilanes.
- Equilibrium constants and kinetics for hydrogenation and redistribution reactions.

The activities associated with satisfying the second objective, developing a preliminary process design for the silane-silicon process, constituted the main effort for Phase II. In accordance with the original plan, a detailed process design for a 25 MT/yr experimental unit was developed based on data from the Sistersville PDU and data made available from the information-base generation effort. Investment and operating cost data were developed for the 25 MT/yr unit and for a 1000 MT/yr commercial unit based on the same process. An analysis showed that costs of the unit were relatively insensitive to unit size; consequently, JPL and Union Carbide agreed that a 100 MT/yr experimental unit would be more appropriate. A detailed process design package was prepared for the 100 MT/yr EPSDU which includes:

- Process flow diagram.
- Heat and mass balance.
- Equipment functional design and specifications.
- Process controls and instrumentation.
- Layout.

Using the EPSDU-sized process equipment as the basis, a 120 MT/yr commercial plant design was assembled and investment, operating, and product costs were computed. (The capacity is 120 MT/yr for the commercial unit with the same process equipment as the 100 MT/yr EPSDU because of expected higher process on-stream time for commercial operations.) The same process has been used to size all items of equipment for a 1000 MT/yr commercial facility and to compute economic performance.

The economic analyses for satisfying the third objective were performed based on the process design developed for the 1000 MT/yr facility. The primary effort was in obtaining equipment costs from vendors and in developing engineering, installation, and operating costs. Considerable engineering design effort was necessary to develop the installed cost of the facility. The results of the analysis are summarized in Section 2.2, Economic Performance.

The individual technical tasks in the Phase I and Phase II programs have been completed; the resulting technological and economic data base for the silane-to-silicon process provides a firm basis for the future work aimed at commercialization.

SECTION 2
SUMMARY AND CONCLUSIONS

2.1 PROCESS DESIGN

The process selected to produce semiconductor-grade silicon is depicted in Figure 2-1 and described in Section 5.1.2. This process converts powdered, 98%-pure, metallurgical-grade (M-G) silicon to trichlorosilane (TCS) in a hot, fluid-bed reactor fluidized with a hot, equimolar, hydrogen/silicon tetrachloride (STC) gas feed. The hot vapor product from the reactor, which contains 15% TCS, is quench-cooled to its dewpoint to reject heavy, non-volatile metal chloride contaminants. Further cooling condenses the crude TCS/product from a hydrogen-rich recycle stream. The product is fed to a stripping column which frees the feed liquid of all dissolved gases. In the TCS distillation column, the gas-free liquid is separated into STC for recycling and an overhead product of TCS and lighter chlorosilanes. The overhead product is further processed in a second distillation column to separate TCS as bottoms liquid. The TCS is recycled to the first distillation column through a catalyst-filled redistribution reactor that partially converts it to STC and dichlorosilane (DCS).

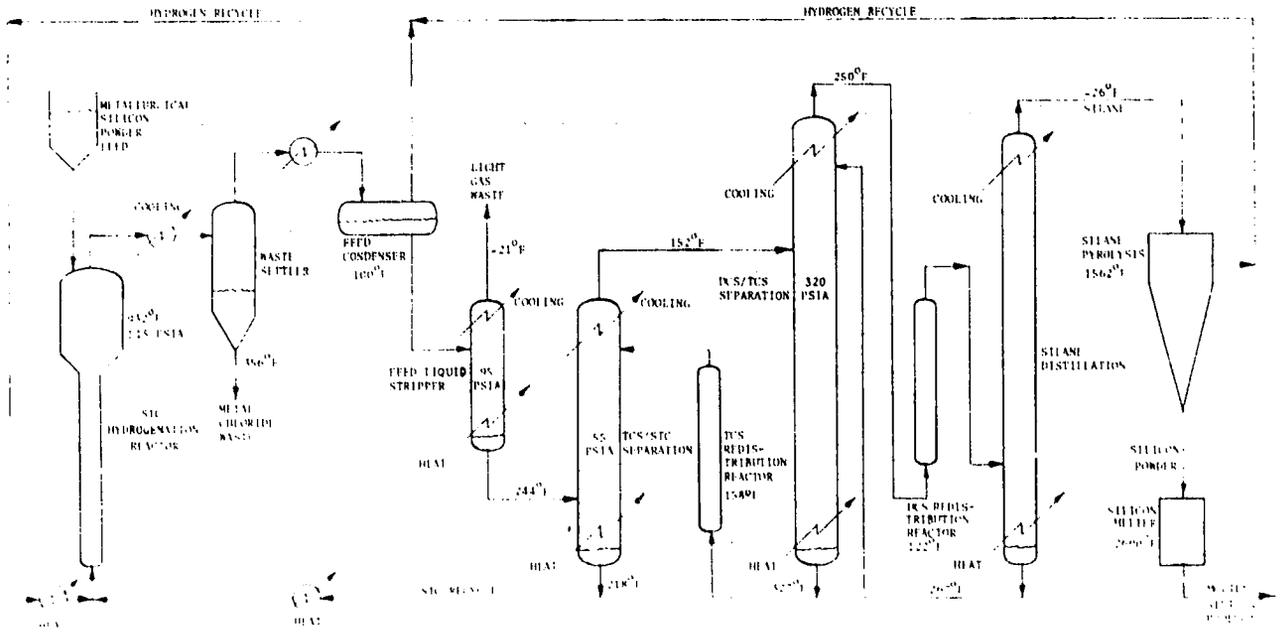

FIGURE 2-1 UNION CARBIDE SILANE PROCESS (SIMPLIFIED FLOW SCHEMATIC)

Overhead product from the second distillation, DCS and lighter, is fed through another catalytic redistribution reactor, which partially converts it to silane. The silane-rich mixture is processed through the final silane polishing column, which rejects all chlorosilanes and residual contaminants downward for recycle back to the second istillation column. Pure silane (Table V-2) leaves the top of the column and is pyrolyzed in a high-temperature reactor to high-purity product silicon powder for melting and to hydrogen for recycle.

2.2 ECONOMIC PERFORMANCE

Process designs for commercial facilities have been assembled based on the Union Carbide silane process (Section 5). Investment, operating, and product cost for 1000 metric ton/year (MT/yr) and 120 MT/yr silicon facilities are summarized below and detailed in Section 6 and Appendices C and D.

1975 Dollars

	1000 MT/Yr Silicon Facility		120 MT/Yr Silicon Facility	
	Public Financing @ 9% Interest	Private Financing @ 20% DCF	Public Financing @ 9% Interest	Private Financing @ 20% DCF
Total Investment, $M	6697	6697	3763	3763
Annual Operating Cost W/O deprec. & capital charges), $M	4658	4838	1645	1739
Molten Silicon Product Cost, $/kg	5.76	7.56	18.61	26.42

Even at 20% discounted cash flow rates (DCF), the estimated product cost of $7.56/kg for molten silicon is lower than the $10/kg (1975 dollars) DOE goal for 1986 production. By agreement, this cost does not include a cost for converting molten silicon to solid product.

Since the plants are small compared to typical facilities in the chemical process industry, the investment requirements and total operating cost are only mildly dependent on plant size. The product cost is, therefore, strongly dependent on plant size.

2.3 SILANE PRODUCTION PDU

A small silane production Process Development Unit (PDU), capable of producing 0.09 kg/hr of silane from metallurgical silicon, was designed, constructed, and operated for 278 hours. A total of 3191 grams of high-purity silane was produced, yielding an epitaxial deposit of 120 Ωcm N-type silicon (Table III-3). This process is similar in most respects to the commercial plant design described in Section 5. The PDU demonstrated the feasibility of high-purity silane production by the Union Carbide process.

2.4 FREE-SPACE SILANE PYROLYSIS PDU

A 194 mm I.D. cylindrical, quartz-lined, free-space reactor was successfully employed for the homogeneous decomposition of silane into hydrogen and into submicron silicon powder. To achieve this conversion at near 100% efficiency, silane was injected vertically downward, as an axial turbulent jet, into the reactor, whose wall temperature was maintained between 600 and 1000°C. The maximum conversion rate attempted yielded 2.8 kg of silicon/hr. The reactor was operated for 40 hours at a silicon production rate of 0.5 kg/hr in a series of 5 consecutive 8-hr experiments. To eliminate buildup of loosely adhering deposits, an externally operated mechanical scraping device was used. Between experiments the reactor was not opened or serviced except for the pneumatic transfer of the silicon powder to a storage hopper. No impurities were detected in powders analyzed with an emission spectrograph using the cathode layer technique.

2.5 PDU FOR FREE-SPACE SILICON POWDER CONSOLIDATION

Integrated facilities producing wafers or photovoltaic devices will be able to use product melt directly, but off-site applications will require consolidation of the fluffy, low-density, free-space powder for easier handling and reduced possibility of contamination.

Commercially available Czrochalski single-crystal pulling furnaces can likely be modified to melt free-space silicon powder. Two Czrochalski furnace manufacturers have suggested modifications to their commercial equipment to utilize free-space silicon powder. One manufacturer proposed the pulling of a polycrystalline ingot from the melt at higher rates than those used for a single crystal pull. A second company proposed transferring the melt through a quartz tube to a cooled solidification chamber, where a semi-crystalline ingot can be pulled.

These two suggested methods and the suction casting method developed by Union Carbide represent the best first-generation techniques. For future large-scale commercial operations, a more economical alternative will probably be desirable, since preliminary economic analysis indicates that rapid pulling or suction casting would add $8/kg to the product price.

2.6 FLUID-BED SILANE PYROLYSIS

Heterogeneous pyrolysis of silane in a fluid-bed reactor has been investigated as an alternate process for converting silane to polycrystalline silicon. Based on current technology and assuming 10% silane feed concentration, a preliminary economic analysis suggests that fluid-bed pyrolysis may be capable of converting silane to high-purity silicon at an incremental cost of $0.75/kg (1975 dollars). These costs are based on extrapolation of technology that is still in its infancy. However, the attractive economic potential warrants further development of this process.

Preliminary R&D activity on this technology has yielded the following results.

- A mathematical model for heterogeneous decomposition of silane in a fluid bed has provided fundamental understanding of the temperature/composition profile favoring heterogeneous decomposition over the homogeneous gas-phase formation of fine powder.

- A bubbling fluidized bed, fed with a 1% silane/helium mixture for 48 hours, yielded significant quantities of dense, coherently

coated silicon particles and minimum quantities of fine powder (See Section 3.2.3.2). These positive preliminary results warrant further development effort. Slugging and spouting fluidization regimes were tested with less success.

- High-frequency (0.1-1.0 MHz) capacitive heating has been demonstrated analytically and experimentally for directly heating the powder in a silicon fluidized bed to 1445°F by energy dissipation. In this heating method, the wall is cooler than the bed. In the conventional method, the wall is 100°-500°F hotter than the bed for the required heat transfer. Because silane pyrolysis reaction rate and the tendency for powder-forming homogeneous decomposition increase rapidly with temperature, hot reactor walls may result in silicon dust and the formation of wall deposits.

2.7 THERMODYNAMIC DATA

- By determining chemical equilibrium constants for the trichlorosilane redistribution as a function of temperature and by using van't Hoff's equation (Denbigh, Ref. 1), the uncertainty of published heats of formation for chlorosilane family compounds was reduced significantly (Table IV-2).

- Chemical equilibrium constants for STC hydrogenation and the three chlorosilane redistribution reactions have been established as a function of temperature from experimental data (Table IV-1, Figure 4-1).

- Binary DCS-TCS vapor/liquid equilibrium data have been measured. These data and open literature TCS-STC data have been modeled to determine vapor and liquid fugacities and liquid-phase activity coefficients (Section 4.4.1, Figures 4-17 to 4-21) for distillation column design.

- Henry's constant has been measured for light gases in chlorosilanes and used for reducing vapor-liquid equilibrium data.

The data were used to design the settler system and first distillation column (stripper) (Table IV-21).

- Recently measured and open literature data have been analyzed to yield improved critical properties, vapor pressures, and vapor and liquid enthalpies for the chlorosilane family (Appendix B).

- The kinetics of liquid-phase TCS redistribution across a catalytic bed of Rohm & Haas Amberlyst® A-21 amine resin has been measured. It is hypothesized that chlorosilane reacts with the catalyst to form an ionic amine-chlorosilane salt. (Further reaction with a second molecule of chlorosilane forms two different chlorosilanes through rearrangement of the H and Cl (Section 4.3.2.1.). Reaction stoichometry corresponds to second-order kinetic behavior. Second-order reversible reaction rate constants (Figures 4-9 through 4-11) are velocity (Reynolds No.) dependent, and exhibit an Arrhenius-type temperature dependency (Figure 4-12). Insufficient data were available to divide the mass transfer resistance into diffusion and catalyst surface activity components. However, the data permit accurate sizing of the catalytic TCS redistribution reactor.

- Kinetic rates of liquid-phase DCS redistribution across Amberlyst® A-21 resin have been measured. A computer program established best-fit, second-order kinetic rate constants for the three redistribution reactions. These rate constants, when plotted against composition and time, fit the observed data well (Figures 4-13 through 4-15, Tables IV-15 through IV-19). The constants also exhibit Arrhenius temperature dependence (Figure 4-12).

2.8 PROPOSED FUTURE WORK

To expedite commercial feasibility of the silane process for producing quality polycrystalline silicon, Union Carbide has proposed a program for designing, installing, and operating an Experimental Process System Development Unit (EPSDU). The purpose of this program is to establish

the feasibility of a process capable of the high-volume production of silicon that is suitable for solar cells at a cost of less than $10 per kilogram. Highlights of the proposed program are as follows:

- Develop technically and economically improved methods for converting silane to polycrystalline silicon.

- Develop analytical methods for detecting extremely low levels of impurities in silane so as to assess product silane quality.

- Obtain diborane and phosphine-silane vapor-liquid equilibria data for design of the silane purification column.

- Obtain additional experimental data and understanding of silicon tetrachloride fluid-bed hydrogenation kinetics.

- Design and test burners for flame oxidation of process waste.

- Design, assemble, and operate a 100 MT/yr EPSDU to demonstrate all technical and economic aspects of the UCC silane process.

SECTION 3
PROCESS RESEARCH AND DEVELOPMENT PROGRAM

3.1 SILANE PRODUCTION PROCESS DEVELOPMENT UNIT

3.1.1 Program and Design Basis

A Process Development Unit (PDU) was designed and constructed to demonstrate the feasibility and practicality of the overall metallurgical silicon-to-silane process. The main objective was to demonstrate that high-purity silane could be produced in an integrated process. The unit was designed for continuous operation at a production rate of about 0.09 kg/hr of SiH_4 while consuming only metallurgical silicon, hydrogen, and only enough $SiCl_4$ to account for losses from impurity rejection. Buffer storage of intermediate chlorosilanes was permitted within the context of continuous operation to adjust for variations in throughput of the various subsections.

3.1.2 Description of PDU

The detailed flow sheet for the integrated PDU is shown in Figures 3-1 and 3-2. The two basic subdivisions were hydrogenation and redistribution. In the hydrogenation section, $SiCl_4$ and H_2 were contacted with copper catalyst and metallurgical-grade silicon to produce a mixture of STC, TCS and H_2. In the second section, redistribution and distillation converted the TCS to silane and STC. Both sections could be operated simultaneously or individually with storage buffer tanks.

3.1.2.1 Hydrogenation Section

The hydrogenation reactor section consisted of a 7.62 cm diameter x 120 cm high fluid-bed reactor, a $SiCl_4$ vaporizer and superheater, a dust scrubber and product collection system, and a raw material feed control system.

The hydrogen, regulated at 300 psi from compressed gas cylinders, was controlled using a Moore constant flow controller. The rate of flow was

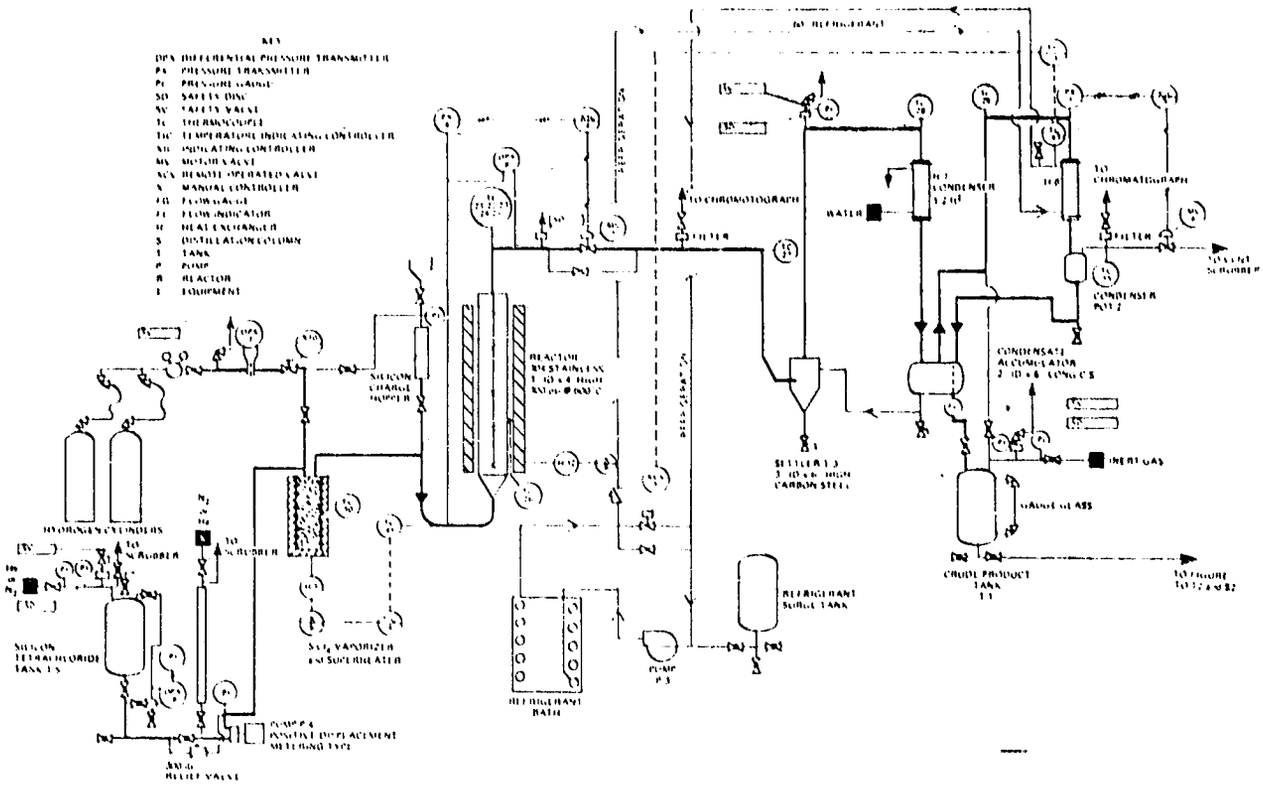

FIGURE 3 - 1

HYDROGENATION SECTION OF SILANE PDU

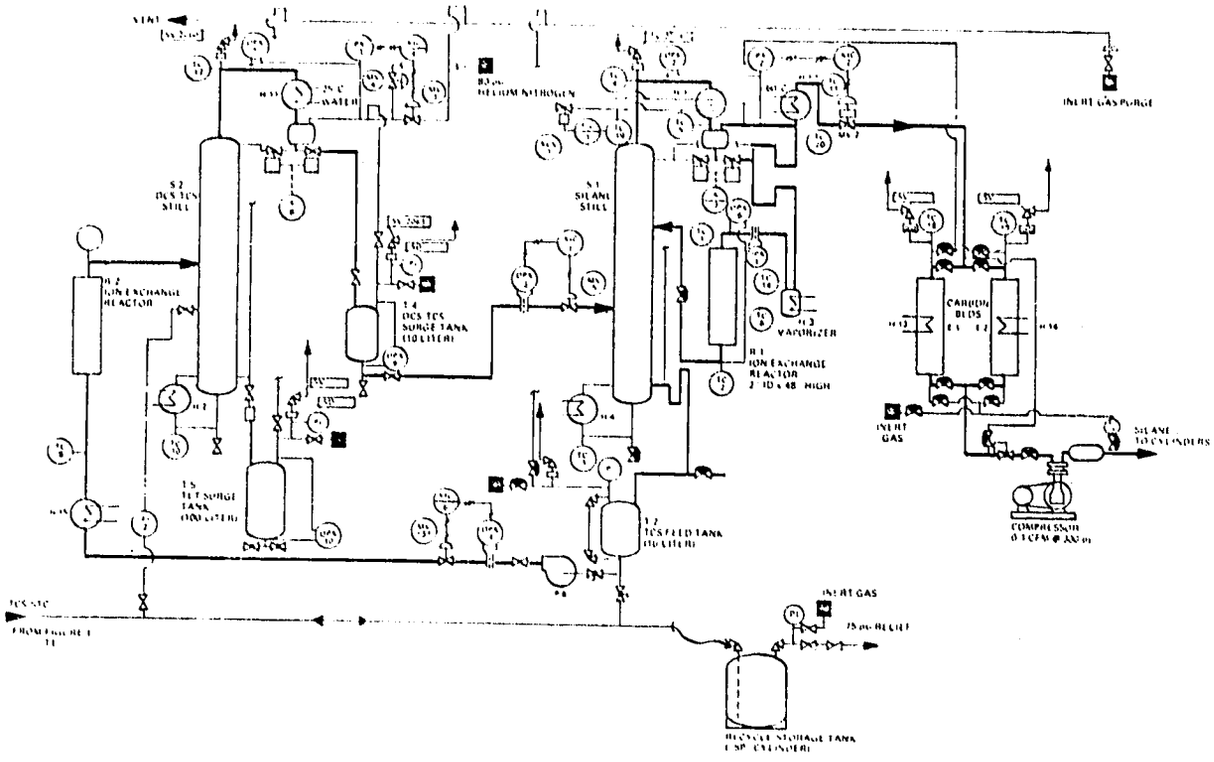

FIGURE 3 - 2

REDISTRIBUTION SECTION OF SILANE PDU

measured as the pressure drop across a 10-foot coil of 1/8" tubing using a pneumatic differential transmitter.

Silicon tetrachloride stored in a 30-gallon tank was fed to the unit by a diaphragm positive displacement metering pump. A 275 psi relief valve on the pump discharge permitted operation at a constant differential pressure; a calibrated sight glass reservoir on the pump suction permitted rapid checking of flow rate at any time.

The combined hydrogen and STC streams were vaporized and superheated in an electrically heated furnace, with gases passed through a coil within the furnace. The design parameters for the vaporizer were:

Feed: H_2	559 g mole/hr
$SiCl_4$	7.5 g mole/hr
Inlet Conditions	25°C, 300 psia
Outlet	500°C, 300 psia
Tube Diameter	3/8" O.D.
Vaporizer Wall Temp.	600°C
Vaporizer Radiative Heater	1200°C
Total Length of Tubing Required	10.0 ft

The preheated gases entered the fluid-bed reactor through a cone-shaped distributor. Provision was made for momentarily diverting a portion of the hydrogen through the copper/silicon charge hopper to pneumatically convey fresh solids into the reactor.

The hydrogenation reactor consisted of a 7.62 cm diameter x 120 cm high 304 stainless steel tube, which was well insulated and electrically heated for the lower 60 cm length. An Inconel-sheathed thermocouple bundle with five equally spaced couples extended from the top to the bottom of the reactor. The inlet cone-shaped distributor of 17° half angle was machined from a 7.62 cm diameter block of graphite, and the flanged closures at top and bottom were sealed with Grafoil gaskets. A reactor design summary is given in Table III-1. Following the reactor, a bellows sealed control valve

TABLE III-1

HYDROGENATION REACTOR DESIGN SUMMARY

Conditions	150 psia; 500°C
Gas residence time	10 seconds
H_2:$SiCl_4$ ratio	2.1
Gas density	0.547 lb/ft^3
Gas viscosity	0.0300 cp
Solid density	137 lb/ft^3
Average particle	(65 x 150 mesh) = 150 μ
Estimated shape factor	0.67
Estimated voidage at minimum fluidization	0.56
Estimated minimum fluidization velocity (U_{mf})	2.1 cm/sec
At 2 x U_{mf} =	4.2 cm/sec
Total reactor height	120 cm
Diameter (nominal 3" sched. 40 pipe)	7.62 cm
Entrance cone half-angle	17°

with stellite trim reduced the pressure from 275 to less than 150 psi, the design pressure of the product recovery section.

The hot gases and entrained solids from the reactor entered a scrubber/settler chamber (Figure 3-3). This chamber, 7.62 cm diameter by 15.2 cm high with a conical bottom and tangential inlet nozzles, was used to bubble the hot gases through the condensed product liquid. A stable inventory of liquid was maintained by gravity flow from the condensate accumulator.

The saturated cooled vapors flowed through two 2-ft^2 areas of stainless steel, fixed-tube, sheet condensers cooled with water or chilled refrigerant. Liquid/vapor phase separation was accomplished after each condenser, with the liquid returning to an accumulator. The refrigerated condenser was cooled by recirculated R-11 from a coil immersed in a dry ice/ethanol/R-113 bath.

An overflow tube on the accumulator maintained a constant liquid level in both the accumulator and the settler. The condensed product was collected in a 10-liter tank; uncondensed gases were routed via a pressure control valve to a water scrubber and an atmospheric vent.

Provision was made for sampling the reactor product stream and the uncondensed vent gas by on-line chromatography. A helium carrier diluted the sample, ensuring an all-vapor stream to the gas chromatograph. Small filters at the sample point eliminated dust from the sample system.

The entire section was protected from overpressure by relief valves on all sections of significant volume that could be isolated by valves. These safety relief valves were Circle Seals placed downstream of a Black-Sivals, and Bryson vacuum-supported rupture disks. The space between the rupture disk and the relief valve was monitored with a pressure gauge to ensure the integrity of the disk. The relief valves exhausted into a nitrogen-purged header vented to the atmosphere. This disk and valve arrangement prevented direct contact of the chlorosilanes with the relief valve and ensured a leak-proof system (Figure 3-4).

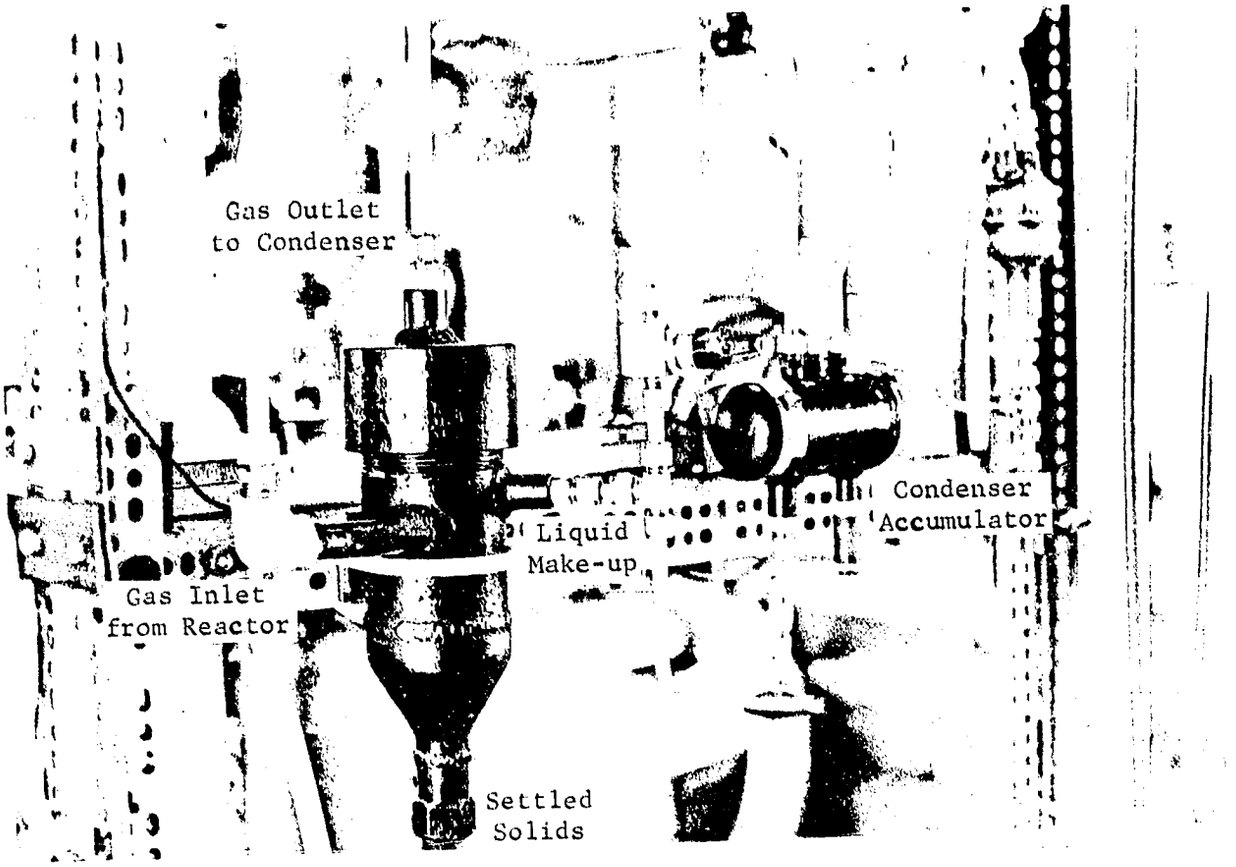

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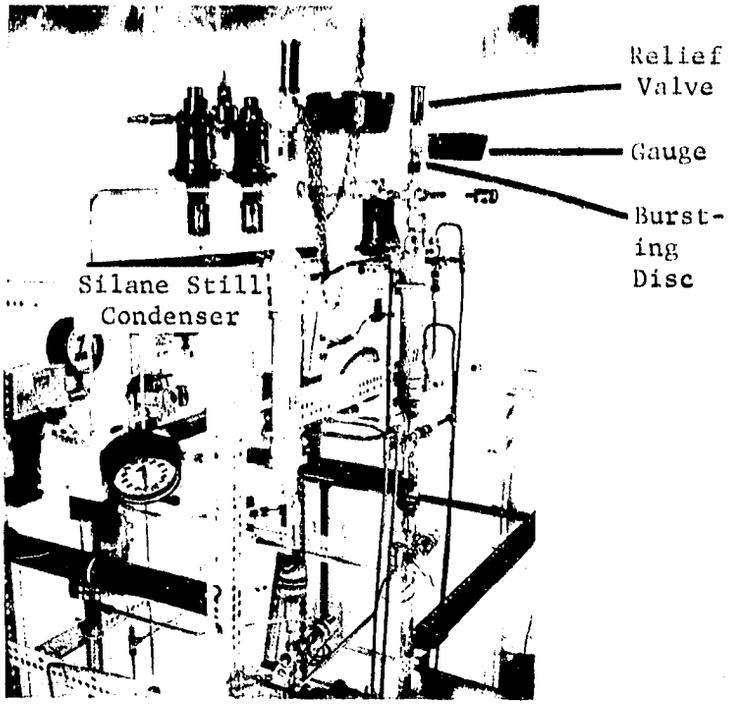
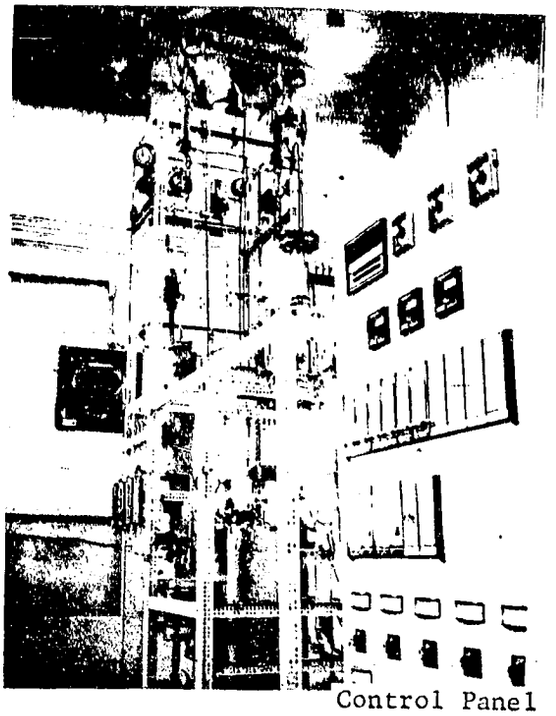
FIGURE 3 - 3

HYDROGENATION REACTOR SCRUBBER/SETTLER





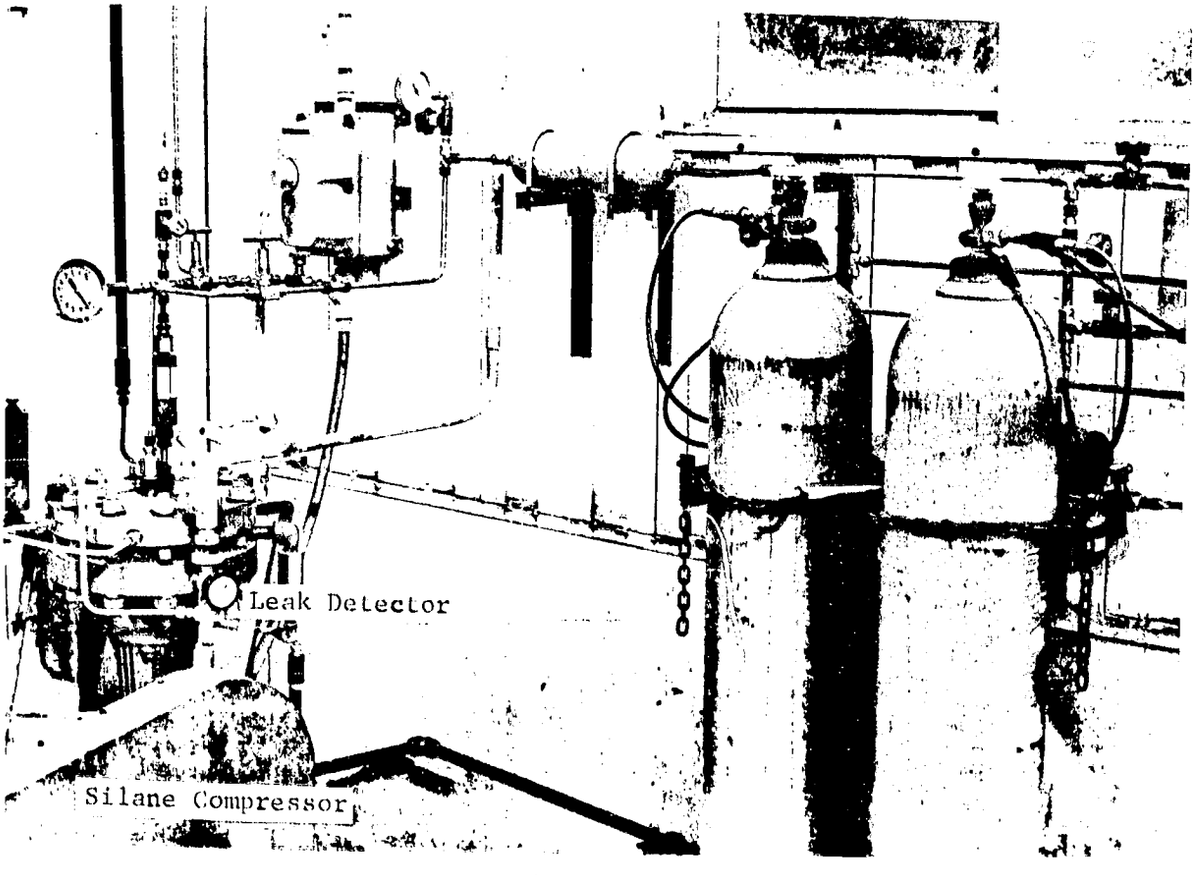


FIGURE 3 - 4

PROCESS DEVELOPMENT UNIT

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The H_2 and STC feed control system was described previously. The temperature of the hydrogen and vaporized STC feed was controlled indirectly by using a controller to sense the wall temperature of the preheater and adjust electrical power accordingly. The set point was manually adjusted to the appropriate gas temperature, thereby providing burn-out protection for the preheater. The reactor temperature was controlled in the same manner.

A differential pressure meter was used to determine the inventory in the fluid-bed hydrogenation reactor. To determine fluidization character, a calibration curve (Figure 3-5) was used in conjunction with visual observation using a 6.62 cm diameter glass column with a conical graphite injector cone as in the steel reactor. A 65 x 150 mesh silicon, fluidized with nitrogen was used to obtain the bed height (silicon inventory) vs pressure drop relation. A second determination was made using N_2 at 100 psi in the steel reactor while charging a copper/silicon mixture pneumatically to verify proper operation of the charging arrangement. The quality of fluidization while a corrosion test specimen rack was installed was also observed, confirming that there were no adverse effects.

The internal reactor temperature profile as well as the inlet and exit temperatures were indicated on a multipoint digital indicator. Chromel-Alumel couples were used in service above 300°C; copper-constantan couples were used at lower temperatures. This feature was common to the entire PDU.

The system pressure control was split into two sections. The pressure in the fluidized bed was controlled by a bellows sealed valve with stellite trim for abrasion resistance. Pressure was sensed with a pressure transmitter feeding a pneumatic indicating controller. A similar arrangement using a standard design control valve was used for the condenser system. This dual system permitted the use of lower-pressure-rated components in the condenser section. It was recognized that solids carryover from the fluid-bed reactor would cause some difficulty with a control valve there. The temperature of the refrigerated condenser was controlled by a solenoid valve on the circulating pump by-pass through an on-off type indicating controller.

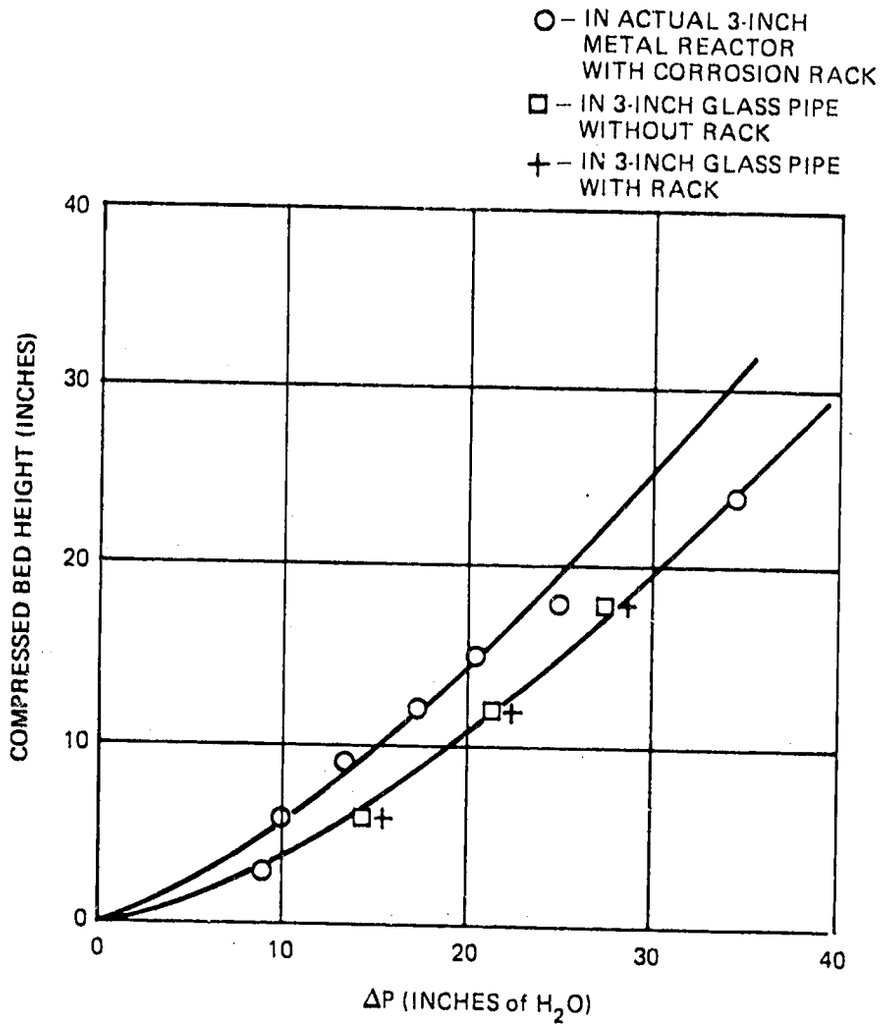


FIGURE 3 - 5

PRESSURE DROP VS BED HEIGHT
FOR THE HYDROGENATION REACTOR

3.1.2.2 Redistribution and Distillation

The redistribution section of the PDU (Figure 3-2) consisted of two distillation columns, two packed bed redistribution reactors, two parallel carbon beds, a compressor for packaging the final silane product, and various tanks for buffer storage of chlorosilane intermediates.

A mixture of STC and TCS from the hydrogenation section was fed through flow meter FI-2 to the lower feed point of the first distillation column (S-2). A second feed to the column from the first redistribution reactor (R-2) entered the middle feed point. The column bottoms product, chiefly STC, was recycled to the hydrogenation reactor section. The overhead product, DCS and TCS, flowed via buffer tank T-4 to the second distillation column (S-1). A second feed to the S-1 was vaporized product from the second redistribution reactor (R-1), containing a modest amount of silane. In the S-1, TCS was removed as the bottoms product which flowed via buffer tank T-2 to the R-2 where it was converted to a mixture of DCS, TCS, and STC. The overhead vapor from the S-1 entered a partial condenser. A portion of the condensate was returned to the column as reflux, and a portion was vaporized and returned through the R-1 where it was converted to a mixture richer in silane, while the noncondensable vapor flowed to a cold trap. The cold trap condensed more chlorosilanes, which were returned and combined with the partial condenser liquid product. The noncondensable silane then flowed through one of a pair of refrigerated carbon beds. The carbon beds adsorbed any remaining chlorosilanes, and the silane product was then compressed into high-pressure gas cylinders.

The first distillation column (S-2) was designed to achieve a 98% recovery of TCS from STC based on an average feed composition of 20% DCS, 77% TCS, and 3% STC. Using the approximate Gilliland tray count method and assuming average ideal relative volatility values, a column with 28 theoretical trays operating at 1.1 reflux ratio was required. The ¼" protruded metal packing selected for this service had a height equivalent to a theoretical plate (HETP) of 2 inches at 80% of flooding loading. This defined the column height at 60 inches.

The estimated throughput for the column (32 lb/hr) resulted in a column of 5 cm diameter to handle the flow at 70% of the flooding rate at the reflux ratio of 1.10. With the column diameter (5 cm) and packed height (152 cm) determined, the reboiler and condenser heat duty (7,000 BTU/hr) was calculated from the reflux ratio overhead product rate and heat of vaporization. A 5-ft^2 heat transfer area condenser was selected and piped so that half the exchanger would function as a downflow unit with sub-cooling, and the other half as an upflow condenser and guard trap. The reboiler selected was a 2.5 kw electric immersion unit.

The second column (S-1), which separated TCS from DCS and the lower boiling silanes, was similarly designed. S-1 was specified as 2.54 cm diameter by 152 cm high and equipped with a 700 watt reboiler and 2 ft^2 area condenser. The operating pressure of 40 psig was selected as high enough to permit efficient condensation of DCS with available cooling, and low enough to allow vapor phase operation of the second redistribution reactor within the allowable temperature range of the resin.

The design of the redistribution reactors was based on the residence time required to approach equilibrium as determined from laboratory studies for liquid-phase TCS or vapor-phase DCS feed, as appropriate. To permit isothermal operation, each reactor was wrapped with insulated copper tubing carrying tempered water. The retainers for the Amberlyst® A-21 catalyst were cylindrical UOP Johnson Wedge wire elements with a nominal 0.152 mm opening. These retainers adequately retained the resin, only 1.0% of which is less than 0.252 mm. The units were installed with vapor flow in a downward direction to avoid fluidization, or with upward TCS liquid flow for the same reason (the bulk density of the resin is less than that of liquid TCS).

The size of the carbon beds was determined from the experimentally determined capacity of the sorbate (Union Carbide JXC carbon) for DCS and

the quantity of silane gas desired to be purified between regenerations. An arbitrary regeneration cycle of 8 hours was selected. A pair of carbon beds, each 5 cm in diameter by 122 cm high, containing 1000 grams of carbon were selected. The anticipated DCS capacity would be 60 grams. Since the expected concentration of chlorosilanes in the SiH_4 feed was 9%, the beds were placed on an 8-hour cycle, allowing for 50% regeneration efficiency. To remove the heat of adsorption, coils containing flowing refrigerant were installed within the beds. Electric strip heaters were clamped on the outside wall to heat the beds to 200°C for regeneration. Provision was made for desorbing the beds back into the silane cold trap, exhausting to vent, and purging with He, N_2, or SiH_4.

To compress the gaseous SiH_4 product into high-pressure cylinders, a diaphragm compressor was selected. The compressor was a Pressure Products Inc., Model 8042, with a capacity of 0.3 cu ft/min at 1 atmosphere suction and 300 psi discharge. For safety and purity retention, the packless compressor used the flexing of its stainless steel diaphragm for the pumping action, with no moving seals. A special triple diaphragm design permitted the detection of a broken diaphragm and an orderly shutdown without hazard (Figure 3-4).

The control functions are shown on the process flow sheet (Figure 3-2). Heat inputs to the distillation columns were controlled manually based on the column pressure drop as indicated by differential pressure transmitters. Column reflux ratios were controlled by manually set interval timers that opened (or closed) twin solenoid valves on the condensate return flows. The column reboiler levels were controlled by an overflow arrangement with rough float liquid drainers. The crude STC/TCS flow was manually set and indicated on a glass rotameter. The interstage flows of chlorosilanes were maintained by pneumatic indicating controllers acting on bellows-sealed automatic control valves. The flow was measured by integral-orifice, differential-pressure transmitters that had been bench-calibrated. Process temperatures were indicated by a multi-point digital indicator using copper-constantan thermocouples.

On-line analysis of all product and intermediate streams was provided by a gas chromatograph and a sample flow switching manifold. Filtered samples of gas or liquid streams were purged semi-continuously through a manifold where they were vaporized, when necessary, and mixed with helium to prevent condensation. The streams were carried by helium to a gas sample valve on the chromatograph, with a cycle time for analysis of about 7 minutes. This analysis determined the composition of the five chlorosilanes and HCl. Samples for other analyses were taken in flasks or cylinders for off-line processing.

3.1.3 PDU Performance Assessment

The PDU was constructed in three increments. First, the distillation column S-1, reactor R-1, associated tanks, condensers, and the small carbon bed were assembled. This portion could accept as feed either pure DCS from an independent source, or a DCS/TCS mixture produced from the integrated operation of the total PDU. This initial portion of the PDU was operated with a DCS feed to produce 3.2 kg silane of modest quality at a rate of 0.08 kg/hr at 93% efficiency based on the DCS feed (Table III-2).

Following this successful demonstration, the second portion of the PDU--the distillation column S-2, reactor R-2 and associated ancillary equipment--was installed. The original small, nonregenerable carbon trap was replaced by two larger regenerable units. The two-section portion could accommodate TCS, DCS or a TCS/STC mix (from the hydrogenation reactor) as feed while producing only silane and STC. The second section was operated independently of the first section for final debugging. The hydrogenation reactor section, constructed last, was integrated into the other portion of the unit by sharing common feed and product tankage. Although the unit was capable of totally integrated continuous operation, the hydrogenation section was operated alternately, in practice, with the distillation/redistribution section using the common feed/product tankage as a buffer. In this sequential mode, 3.2 kg of high-purity $SiCl_4$ was produced in 181 operating hours with an overall yield based on silicon metal of 85% (Table III-3). Hydrogenation reaction kinetics were determined at 191 psig,

TABLE III-2

OPERATING RESULTS SILANE PDU DICHLOROSILANE SECTION

Dichlorosilane Feed Rate	760 gram/hr.
Silane Production Rate	80 gram/hr.
System Pressure	345 KPa
Reactor Residence Time	8.75 seconds
Reactor Temperature	55°C

STREAM COMPOSITIONS SILANE PDU

Sample Point	SiH_4	H_3SiCl	H_2SiCl_2	$HSiCl_3$	$SiCl_4$
Feed to R-1	18.6	35.5	43.1	2.8	-
Feed from R-1 to S-1	28.5	20.3	32.0	19.1	.1
Distillate from S-1	-	0.04	1.22	94.05	4.7
Condenser Vapor Product	86.39	7.37	4.92	1.33	-
Carbon Bed Inlet (Cold Trap Exit)	96.26	3.65	0.09	-	-
Carbon Bed Inlet (Final Product)	< 99	-	-	-	-

Cylinder	LK 289962	LK 268192	LK 23683
SiH_4	1900 gram	450 gram	1000 gram
Chlorosilane	< 1 ppm		
Soloxane	< 1 ppm		
Methylsilane	< 2 ppm		
Disilane	< 2 ppm		
Carbon Dioxide	20 ppm		
Hydrogen	1.52 %		
Nitrogen	1.10 %		
Methane	< 10 ppm		
Silicon via Epitaxy			
Resistivity	50 ohm/cm	10 ohm/cm	10 ohm/cm
Conductivity Type	N	N	N

TABLE III-3

SILANE PRODUCT FROM FINAL INTEGRATED PDU OPERATION

Cylinder No.	LK 290145	LK 290044
Hydrogen	14.37 %	15.05 %
Nitrogen	2.03 %	2.56 %
Methane	< 50 ppm	< 50 ppm
Methylsilane	99 ppm	91 ppm
Siloxane	35	53
Chlorosilane	51	31
Disilane	66	53
Dichlorosilane	< 8	< 8
Trichlorosilane	217	81
Silicon Tetrachloride	70	60
Trisilane	83	75
Tetrasilane	171	144
Silicon via Epitaxy		
Resistivity	20 ohm/cm	120 ohm/cm
Conduction Type	N	N

carbon bed performance was assessed, and distillation column and redistribution reactor performance were roughly assessed. Mechanical reliability was reviewed from the standpoint of EPSDU operations, and corrosion-test specimens from the redistribution and hydrogenation reactors were evaluated.

3.1.3.1 Raw Material Characterization

The metallurgical silicon feed for $SiCl_4$ hydrogenation studies was determined to have the particle size distribution shown in Table III-4; composition by spectroscopic analysis of the individual size fractions is shown in Table III-5.

For experiments in the high-pressure, fluid-bed reactor, the 65 x 100 mesh fraction was used. This fraction was found to be more easily handled in small reactors at modest gas velocities. It is difficult to use the unclassified material because of the small operating latitude between the fluidization of coarse particles and the elutriation of fines. The typical composition of cement copper shown in Table III-6 is a varied mixture of metallic and copper oxides with small amounts of other metal sulfates.

Silicon tetrachloride was 99.99% pure with less than 10 parts per million total metallic impurities. The hydrogen was Linde standard "high purity."

Typical composition of the metallurgical silicon/copper reaction mass before and after hydrogenation is shown in Table III-7.

The Amberlyst® A-21 was typical material described in Table III-8.

3.1.3.2 Hydrogenation Performance

The hydrogenation section was operated over a range of pressure temperatures and contact times to evaluate reactor performance and to prepare a quantity of TCS/STC for later use in the integrated performance demonstration. During one 22-hour operating period, 52 kg of a 25% TCS/75% STC

TABLE III-4

COARSE GRIND SILICON SIZE DISTRIBUTION

Mesh Size	Microns	Weight Fraction
+ 48 mesh	+297	56.05
48 x 65	297 x 210	14.15
65 x 100	210 x 149	16.95
100 x 150	149 x 105	5.56
150 x 200	105 x 74	3.02
200 x 325	74 x 44	2.86
-325	-44	1.42

The individual fractions were analyzed by atomic absorption spectroscopy; a modest variation in the purity was found between the fractions.

TABLE III-5

METALLURGICAL SILICON ANALYSIS BY SIZE FRACTION

Mesh	Fe %	Cu ppm	Al %	Ca ppm	Pb ppm	Mn %
+48	.52	38	.28	5	19	.03
48 x 65	.57	32	.32	5	18	.08
65 x 100	.48	36	.30	6	20	.06
100 x 150	.65	39	.36	6	10	.08
150 x 200	.83	47	.47	7	35	.09
200 x 325	1.33	88	.76	9	14	.17
-325	2.01	203	1.07	9	34	.21

TABLE III-6

TYPICAL COMPOSITION OF CEMENT COPPER

	Mean %	Standard Deviation %
Total Copper	85.3	4.2
Metallic Copper	35.6	20.8
Cuprous Oxide	35.0	20.6
Cupric Oxide	23.3	17
Iron	1.18	2.3
Aluminum	0.27	0.37
Magnesium	0.08	0.13
Lead	0.08	0.07
Arsenic	0.04	0.04
Sulfates	0.84	0.77
Surface Area, m^2/g	3.3	2.73
Mean Diameter, microns	7.0	1.27

TABLE III-7

METALLURGICAL SILICON /COPPER REACTION MASS

	Before Reaction	After 17% Conversion
Fe, %	0.60	0.60
Cu	0.42	0.44
Al	0.07	0.06
Ca	0.10	0.09
Mn	0.06	0.05
Pb, ppm	16	20

TABLE III-8

AMBERLYST® A-21 PROPERTIES

Property	Amberlyst® A-21
Appearance	Hard, spherical, light tan, water-saturated beads
Ionic form	Free base
Moisture holding capacity, percent	46 to 53
Exchange capacity:	
Weight capacity, meq./g. dry resin	4.5 to 5.0
Volume capacity, meq./ml.	1.4 to 1.7
Density, lbs./cu. ft.	38 to 42
Effective size, mm.	0.40 to 0.55
Uniformity coefficient	2.0 maximum
Fines, by wet sieve analysis through #50 sieve, percent	1.0 maximum
Hydraulic expansion, free base form at 2.0 gpm/cu. ft., 30°C, percent	120 maximum
Whole bead content, percent	100
Porosity, percent	35 to 45
Average pore diameter, Å	700 to 1200
Surface area, $m.^2/g.$	20 to 30
Solids, percent	47 to 55
Percent swelling from dry state to solvent-saturated state -	
Hexane	20
Toluene	25
Diethylether	22
Acetone	22
Absolute ethanol	30
Water	25

mixture was prepared while operating at 190-200 psig, a 5:1 H_2:STC molar feed ratio, 530°C average reactor temperature, and a flow rate to achieve 25 seconds residence time in a 92 cm high bed of silicon having 0.19% Cu/Si alloy. Experimental STC hydrogenation data are presented and reaction kinetics defined in Section 4.3.1.2. In general, the PDU performed as expected. Fluidization quality was adequate and predictable by pressure drop measurement which followed the same behavior as determined in the glass tube experiment, Figure 3-5. Elutriation accounted for less than 10% of the silicon reaction mass. The H_2:STC feed was vaporized and preheated as described in Section 3.1.2.1. With the outlet temperature controllable to within 10°C, the gases were preheated to the planned reactor temperature. The reactor temperature profile for this slightly endothermic process, Figure 3-6, showed a maximum due to slight heating of the reactant gases from the reactor wall in the first few inches of the reactor followed by decline as the gases left the heated zone 24 inches from the reactor inlet. For data analysis, the average reactor temperature was chosen.

3.1.3.3 Redistribution and Distillation Performance

During initial operation of the PDU redistribution section in February 1977, dichlorosilane was used as the feed meterial. Only the second reactor and distillation column were used to produce 0.080 kg/hr of SiH_4 at a yield of 93% according to the reactions:

$$4\ H_2SiCl_2 \rightleftharpoons 2\ H_3SiCl + 2\ HSiCl_3$$

$$2\ H_3SiCl \rightleftharpoons H_2SiCl_2 + SiH_4$$

Pure DCS was fed to the R-1 reactor to supplement the flow of mixed silanes from column S-1 distillate. Since the TCS product was collected in T-2 and not recycled, only R-1, S-1, and associated equipment were operated. Typical operating condition stream compositions and silane product analysis are listed in Table III-2. This phase of the program successfully produced three cylinders of SiH_4 containing a total of 3.35 kg. Analysis of the

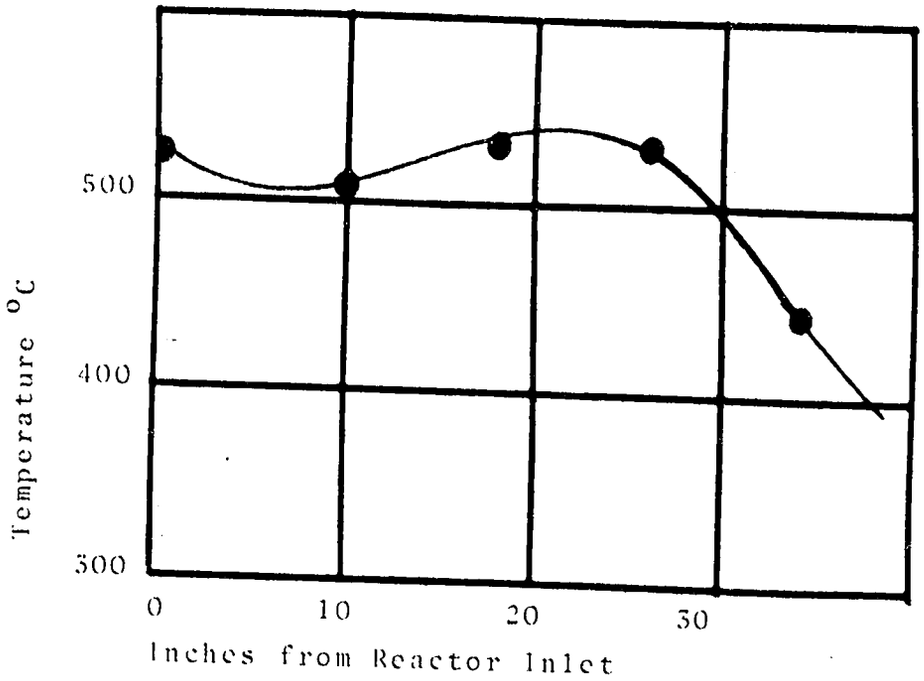


FIGURE 3-6

HYDROGENATION REACTOR TEMPERATURE PROFILE

(27-INCH BED HEIGHT)

material, Table III-2, indicated that modest electronic quality had been attained and that a small amount of gaseous impurities more volatile than SiH_4 were present. The PDU had no provision for removing light gases. The DCS-to-silane portion of the PDU operated reasonably well after the initial period of de-bugging. The vapor capacity of the 2.5 cm diameter distillation column was close to the design limit, as determined by pressure drop and feed/reboiler vapor rates. The measured column efficiency showed about 93% recovery of TCS from DCS compared to the ideal system design basis of 98%. It was not, however, the purpose of the PDU to quantify vapor-liquid separation efficiencies, plate value, and precise reflux ratios. The redistribution reactor product mix closely approached an equilibrium mixture as determined by the feed and product compositions; the reactor was generously sized to ensure this mixture. Reactor pressure drop was low (1" of water column/ft of bed) except when liquid chlorosilanes were inadvertently allowed to condense.

The cold trap after the partial condenser of the distillation column enriched the silane concentration to about 95% and provided stability for minor process fluctuations. The original 1" diameter x 3 ft long carbon bed had low sorption capacity. The silane flow was only routed through it to the compressor and product tanks when analysis of the cold trap outlet indicated less than 5% chlorosilanes. The original carbon trap was not designed for efficient regeneration. The main operational difficulty of the DCS-silane unit was condensation of chlorosilanes in the redistribution reactor, resulting in high pressure drop and lowered recycle rates (hence, lowered silane production). This condensation occurred when the bed operating temperature was close to the reactant gas dewpoint, especially during startup before much silane or MCS was present. Heating the feed gas a few degrees by heat tracing the inlet line resolved the problem. The analysis of the product silane, Table III-3, shows a modestly high-quality silane (20-120 Ω/cm resistivity). Thus, the feasibility of the process was demonstrated.

Integrated operation of the entire process for converting metallurgical silicon and hydrogen to silane was demonstrated when two cylinders of silane totaling 4.4 kg were produced over a 181-hour operating period.

The hydrogenation of STC has been described earlier in this report. The product from that reaction was fed to the enlarged redistribution section and converted into silane, and the unit was operated as described in paragraph 3.1.2.1. Typical operating conditions for the TCS/STC distillation column and TCS redistribution reactor when operating as part of the integrated PDU are shown in Figure 3-7. The distillation column and reactor again performed close to the design conditions, with only minor variations. The TCS-rich bottoms from column S-1 (labeled "From Silane Unit" in Figure 3-7) had more DCS than those from that portion operated alone. The distillation column in the "Silane Unit" now had to separate DCS from a more dilute feed and some DCS was left in the bottoms, resulting in only a slightly higher recycle rate. The high efficiency of the S-1 column resulted in essentially no loss of TCS back to the hydrogenation unit. The only material loss in the overall integrated operation was in the scrubber settler of the hydrogenation section. All hydrochlorosilanes were converted eventually to silane and silicon tetrachloride.

The efficiency for boron removal -- an important indicator for the overall purification scheme -- was demonstrated. The total boron level in the feed to the trichlorosilane redistribution reactor was measured as 0.13 parts per billion. The distillate from the first distillation column, which is the DCS/TCS feed to the silane still, was analyzed at 0.04 parts per billion total boron. The resistivity and conductivity type of silicon epitaxially deposited from the silane product also indicated low boron levels (Table III-2).

The carbon beds used for final removal of chlorosilanes performed well in spite of momentary process upsets which resulted in higher concentrations of chlorosilanes in the feed gas. Regeneration by heating to 200°C and purging with recycled pure SiH_4 back to the final condenser was routine. Regeneration was performed whenever H_2SiCl_2 was detected in the product gas by on-line chromatography.

The activity of the ion exchange resin was not measured directly. Laboratory kinetic studies identified an early rapid (23%) decline in activity,

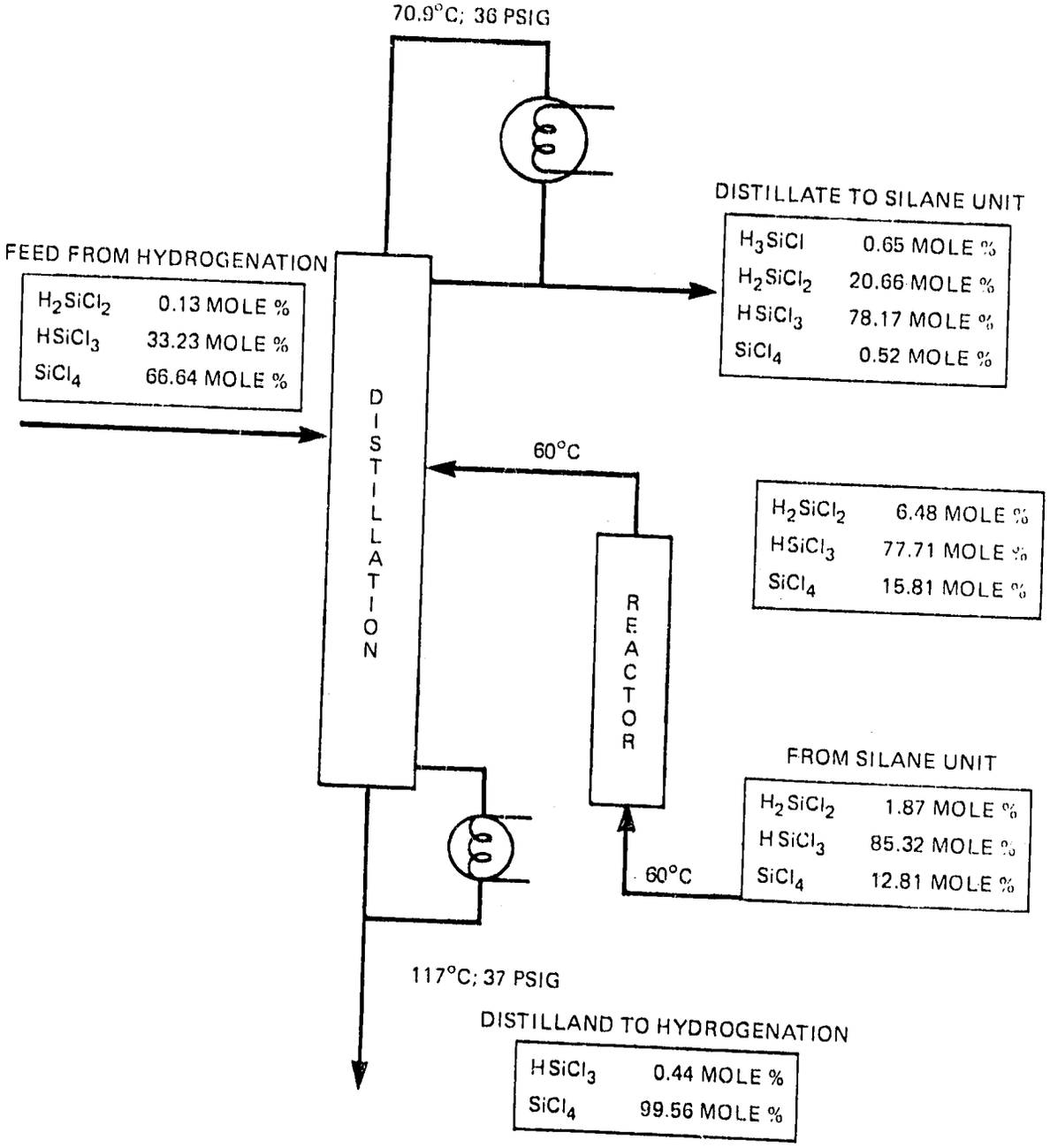


FIGURE 3-7

$HSiCl_3$ DISPROPORTIONATION UNIT REDISTRIBUTION

which then stabilized and seemed to be dependent on the level of nitrogen remaining on the tertiary amine functional resin. Samples of the resin catalyst from the PDU were analyzed for nitrogen content (Table III-9); these samples indicate, by linear extrapolation, a life expectancy of about 1500 hours after the initial rapid decline. However, the data do not show whether the decline is linear or asymptotic. Previous experience had shown no substantial decline in activity after 1600 hours of operation. The nitrogen value is likely lost by evaporation or leaching into the vapor chlorosilane stream, followed by rejection to the STC stream through distillation. The slight amine odor of fresh A-21 would indicate that some volatile compounds are present.

Total chlorosilane loading on the carbon beds was not known with precision. Occasional pressure upsets during otherwise routine operation forced higher than normal amounts of MCS and DCS into the beds. The operating cycle was extended beyond the 8-hour design criteria because analysis of the effluent indicated low levels of chlorosilanes (Table III-10). At the normal production rate of 0.08 kg/hr of silane and an average chlorosilane content of 3.74%, 109 grams of chlorosilanes were adsorbed in 20 operating hours. Each carbon bed contained 1600 grams of carbon, and minimum loading at the beginning of the regeneration period was 6.8%. At the bed operating temperature, 7% DCS can be adsorbed on the Union Carbide JXC carbon at a relative pressure of 0.005. This agrees well with the operating experience, which showed $\sim$ 0.5% DCS after 20 hours. With desorption at 200°C and purging with pure SiH_4, less than 0.1% DCS should have been retained.

3.1.3.4 Corrosion Data

Based on specimen coupons exposed to the process environment for 6,000 hours, carbon steel was determined to be an adequate material of construction for the redistribution reactors. Samples of 316 stainless steel and carbon steel were placed on a rack inside one of the redistribution reactors. The samples were removed for examination after about 6,000 hours exposure to liquid chlorosilanes and to the ion exchange resin catalyst.

TABLE III-9

NITROGEN CONTENT OF AMBERLYST® A-21

CHLOROSILANE REDISTRIBUTION CATALYST

Cummulative Reaction Time, Hours	Wt. % N
0	6.25
8	4.8
70	4.5
300	3.8

TABLE III-10

TYPICAL CARBON BED OPERATING DATA

Hours Onstream	PSIG	°C	%SiH_4	%H_3SiCl	Outlet Analysis %H_2SiCl_2	%$HSiCl_3$	%$SiCl_4$
0.08	15	24.5	99.87	0.04	0.01	0.08	--
6.5	15	- 3.5	99.96	0.04	--	--	--
7.0	15	- 3.5	99.96	0.04	--	--	--
16.5	15	- 3.5	99.00	0.80	0.19	0.01	--
18.5	15	29.6	98.82	1.03	0.15	--	--
					--	--	--
4.0	15	20.9	99.97	0.01	0.01	0.01	--
6.0	15	16.3	99.77	0.19	0.01	0.03	--
9.0	-15	9.9	99.86	0.09	--	0.05	--
9.5	15	13.1	99.78	0.19	--	0.03	--
14.0	15	9.1	99.84	0.15	0.005	0.005	--
15.0	15	17.9	99.82	0.18	--	--	--

Gas Flow Rate = 80 gram/hr SiH_4

6.8 wt% chlorosilanes

Average penetration rates and visual observations are shown below:

Corrosion Rack Results
Trichlorosilane Redistribution Reactor

Liquid Only Phase	Penetration, Inches/yr	Comments
Carbon Steel	0.0003	
316 S.S.	Nil	Crevice corrosion Light pitting
Catalyst & Liquid Phase		
Carbon Steel	0.0007	
316 S.S.	Nil	Crevice corrosion Pitting attack

Carbon steel proved to be the best choice of material with an average penetration rate of <0.0007 inches/yr. All metal loss was uniform, with no indication of pitting attack. The 316 S.S. exhibited pitting attack at the crevice formed between the coupon and the mounting hardware (also 316 S.S.). These results show that the distillation storage and transfer lines processing the chlorosilanes can be constructed of carbon steel provided that the temperatures do not limit the mechanical properties. Stainless steel would be suitable for low-temperature processing.

Less positive answers were obtained from the fluid-bed hydrogenation reactor. All exposed coupons, either in the fluidizing region or in the free vapor space above the bed, were heavily covered with loose, flaking scale; showing exceptionally high corrosion rates. The chrome-plated carbon steel coupon showed some promise: the chrome plate remaining appeared to be unharmed.

Corrosion Rack Results

Hydrogenation Reactor	Penetration Rate, In/yr
316 S.S.	0.8240
Inconel 825	0.4113
Incoloy 800	0.1578
Chrome Plated Steel	1.5713
26-1 S.S. Alloy	0.9148
Titanium	reactive
304 S.S.	1.457
Carbon Steel	heavily scaled
Inconel 625	heavily scaled
3 RE-60	0.990

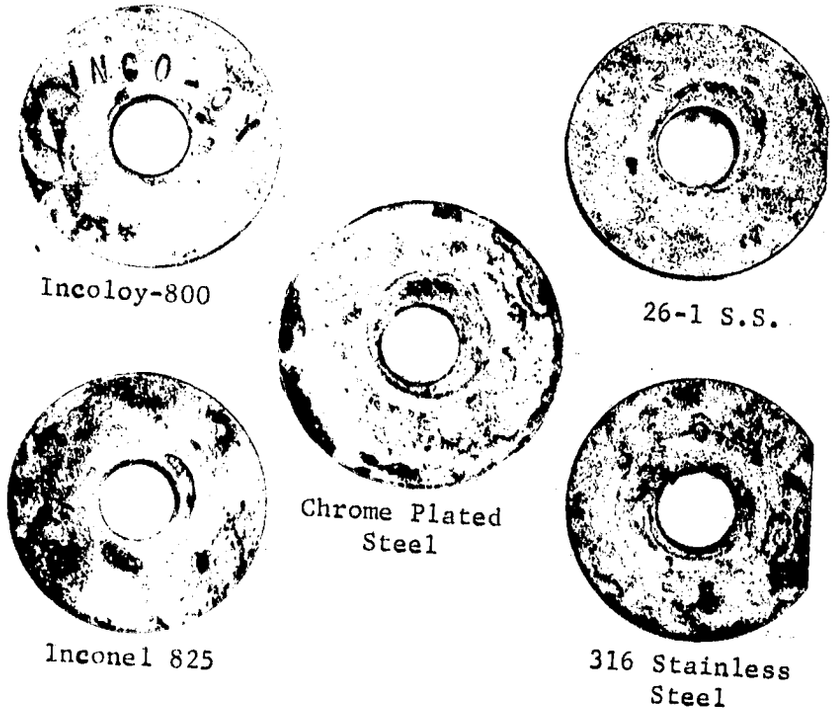
Figure 3-8 shows photographs of coupons that have been removed from the reactor and de-scaled. Also shown is a magnified view of an Inconel thermocouple sheath used in the experimental reactor. The thickness of the Inconel sheath is 0.02 inches. Loose scale deposits are seen, and on failed sheaths the structure has changed from austenitic to ferritic.

The primary corrosive effects are due to HCl and nascent hydrogen. There is no evidence of silicon penetration of the substrate. However, there is evidence of nascent hydrogen penetration, implying a need for high chrome-nickel alloys. But because HCl is present at the reaction temperature, high nickel alloys are also significantly attacked. Based on current information, the best material for the hydrogenation reactor is Incoloy 800, a 40% Ni, 21% Cr, 31% Fe alloy with good strength at process temperatures and good resistance to hydrogen and hydrogen chloride.

3.2 SILANE PYROLYSIS AND SILICON CONSOLIDATION

During Phases I & II of the program, the feasibility of pyrolyzing silane into semiconductor-grade silicon was demonstrated. Silane pyrolysis was investigated by two fundamentally different techniques: homogeneous decomposition in a free-space reactor, and heterogeneous decomposition in a fluid-bed reactor. Decomposition of silane in a free-space reactor results in the production of submicron silicon particles which require a further step of consolidation into a more acceptable form of product. As part of

Inconel Thermocouple Sheath 36 hours @ 500 °C



Test Coupons from Hydrogenation Reactor 36 hours @ 500 °C

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FIGURE 3-8

HYDROGENATION REACTOR CORROSION TEST COUPONS

this program, the feasibility of melting the free-space pyrolysis powder in quartz crucibles and of suction casting 3/4-inch diameter polycrystalline rods was also demonstrated.

Homogeneous gas phase decomposition of silane is accomplished in a quartz-lined free-space reactor. Silane is introduced as a turbulent jet vertically down into the reactor. The reactor walls are kept hot by external heating. The injected silane, mixing with hot recirculating gas in the reactor, heats up rapidly and decomposes into silicon powder and hydrogen. The decomposition is exothermic with a heat of reaction 8.1 k cal/mole. The reaction starts at temperatures above 400°C and becomes extremely rapid above 600°C. In the operation of the free-space reactor, it is essential that silane decompose completely before it contacts the wall to preclude silane decomposition and silicon deposit formation on the wall and subsequent plugging of the reactor. The actual location of the reaction zone is determined by the interaction of fluid dynamics, heat and mass transfer, and reaction kinetics. In the free-space reactor development, the emphasis was on demonstrating the feasibility of silane pyrolysis.

The pyrolysis-product silicon powder is separated from the effluent hydrogen by a porous metal filter, and the powder is collected in a hopper. This powder is typically less than one micron in average particle diameter, and has a low bulk density. Because of these characteristics it would be difficult to transport the powder to off-site locations without contamination. For this purpose, compaction and sintering were investigated as a means of consolidating the powder. Although the rapid pulling of polycrystalline rods was not investigated, a rough economic study compared the cost-effectiveness of this technique with that of suction casting rods on a commercial scale. Various free-space reactor powder melting and casting techniques were investigated as a means of obtaining fully dense silicon for sample analysis. These methods were the suction casting of rods, vacuum casting of pellets, and cold mold casting. It was also demonstrated that the free-space reactor powder could be melted directly in Czochralski furnaces without prior consolidation.

In the alternative fluid-bed pyrolysis concept, silane is decomposed heterogeneously on hot silicon seed particles. The resulting silicon coatings are of high purity; the free-flowing characteristics of the particles offer the potential of direct feed stock for a Czochralski furnace. This concept is attractive as a backup or alternate system to free-space pyrolysis, particularly to meet the 1986 cost/performance objectives of the LSA project. However, this method is still in an early stage of development; it requires considerable R&D work to determine its capability. In the reported phase of work, preliminary experiments were conducted to study the feasibility of this concept. These experiments included pyrolysis experiments using dilute silane as well as inert gas fluidization and bed heating experiments. A theoretical model was developed to simulate plating reaction in a fluid-bed reactor. An in-depth technical assessment of fluid-bed pyrolysis technology identified critical areas that require further development. Finally, a preliminary economic analysis assessed the potential cost-effectiveness of this pyrolysis method toward meeting the 1986 goals. This analysis, though of a preliminary quality, has indicated that the cost of pyrolyzing silane in a commercial fluid-bed system with 10% feed silane concentration, could be less than $1/kg (exclusive of silane cost). Thus, it is concluded that, if technically successful, this approach has an excellent potential for meeting the 1986 cost goals. To resolve the technical uncertainties and advance this technology, a comprehensive R&D program has been recommended in the proposed Phase III program.

The work accomplished in silane pyrolysis and silicon consolidation under the reported phase is described in detail below. The discussion is divided into the following subsections:

3.2.1 Free-space Reactor

3.2.2 Free-space Reactor Powder Melting and Consolidation

3.2.3 Fluid-bed Silane Pyrolysis

3.2.1 Free-space Reactor

3.2.1.1 Program Goals

The objective of the free-space reactor program was to demonstrate the feasibility of converting silane (SiH_4) into semiconductor-grade silicon. As an example of this demonstration, the conversion was to be maintained for five continuous eight-hour experiments at a silicon production rate of 0.5 kg/hr. During this five-day demonstration, the free-space reactor would not be opened or serviced except for the pneumatic removal of the silicon powder that accumulated in the settling chamber located beneath the reactor. This powdered silicon was to be converted into a dross-free liquid. To achieve all this, it was necessary to develop a filter system for separating the powdered silicon from the gas phase, devise various means of conveying the powder from the settling chamber to a melting furnace, design a furnace capable of melting the powder continuously, and connect the free-space reactor and melter together in a manner that would minimize exposure of the silicon powder to atmospheric contaminants.

3.2.1.2 Equipment and Reactor Model

3.2.1.2.1 Reactor and Settling Chamber

The current free-space reactor evolved from engineering design data obtained through the operation of smaller units. The reactor is a Schedule 80 Monel pipe, 914 mm long, with an inside diameter of 194 mm. An induction coil, 610 mm long, was centered on the Monel reactor. The induction coil was energized by a 30 KW Ajax Magnathermic Corp. induction heating power source operating at an output frequency of 4200 Hertz. Figure 3-9 shows the reactor positioned on top of the powder collection (settling) chamber, and Figure 3-10 is a schematic of the settling chamber. The top of the reactor contained a water-cooled, pressure-tight, stainless steel lid. A water-cooled injector projected through the center of the lid 114 mm into the reactor. The injector height was adjustable, and a Swagelok fitting permitted a leak-tight seal. The current lid, shown

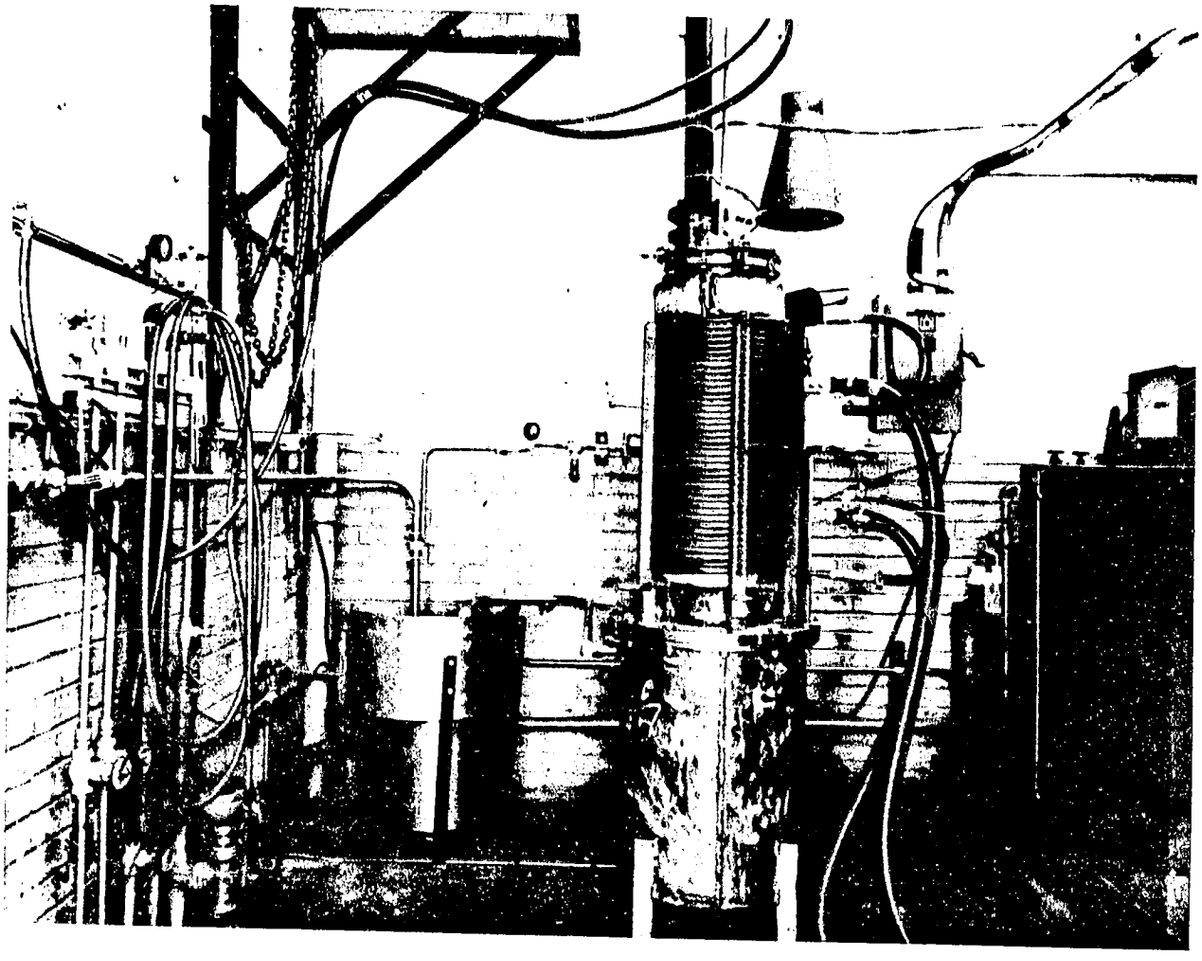

FIGURE 3 - 9

FREE-SPACE REACTOR AND SETTLING CHAMBER ASSEMBLED

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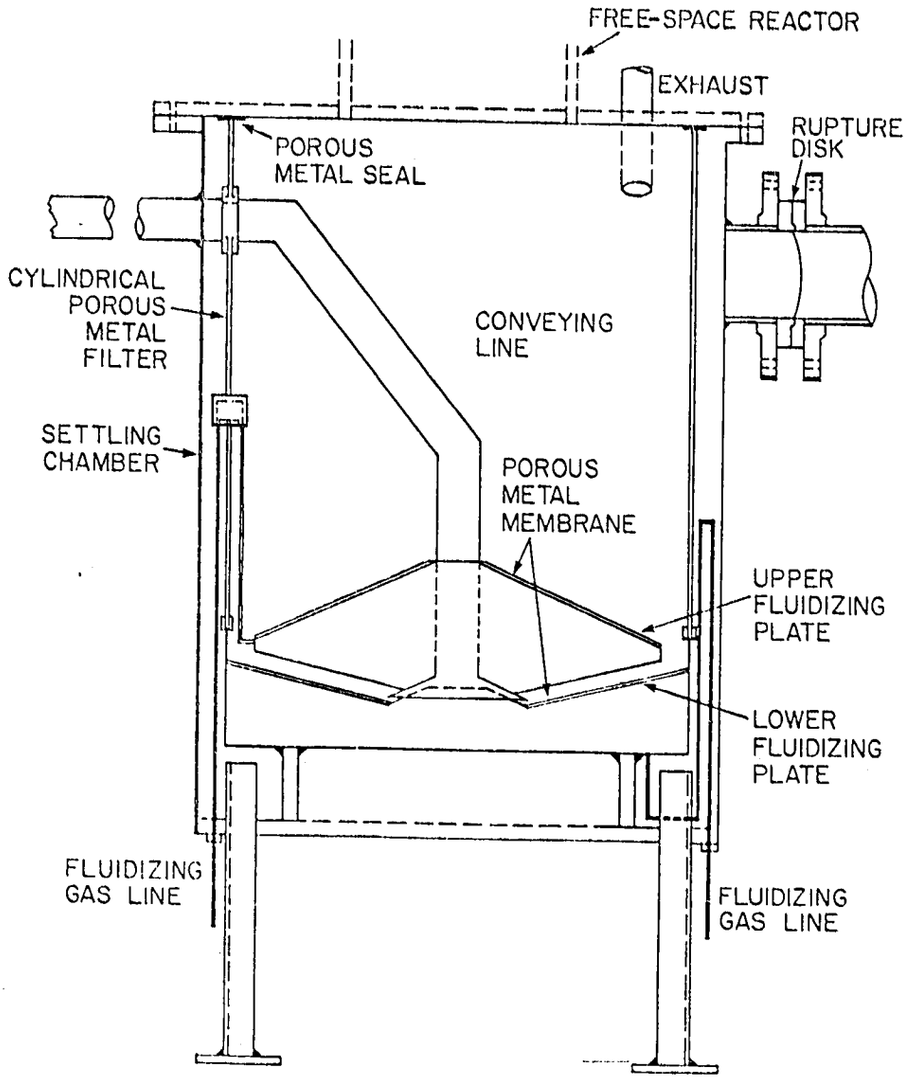

FIGURE 3 - 10

SETTLING CHAMBER SCHEMATIC

schematically in Figure 3-11, contained a porous metal sheet (30 μm average) pore size) through which a gas could be fed into the reactor. The lid also contained a mechanical powder stripper that could be extended a maximum of 152 mm into the reactor. One part of the mechanical stripper surrounded the water-cooled injector; a ring fastened to the same plunger rod was slightly smaller than the reactor I.D. The inside of the reactor contained a quartz liner.

A hydraulically operated lifter was used to position and remove the reactor from the settling chamber. Beneath the induction coil, the reactor was insulated with a 50 mm thick layer of Johns-Manville Cerafelt. A 102 mm high removable collar of Cerafelt was also positioned above the induction coil. Figure 3-12 is a schematic of the gas flow control system. Auxiliary equipment included a hydrogen detector (TLV Sniffer, Part No. 23-7356) for leak checking and for detecting external leaks while in operation at elevated temperatures, a 24-position recorder, a NRC vacuum gauge, and a Welsh Duo Seal vacuum pump (Model No. 1397).

Also shown in Figure 3-12 are hygrometer probes (Panametrics, Model 2000 hygrometer) that were positioned in the gas line attached to the injector and in the gas exhaust line. The probes continuously monitored the dewpoint of the system, which was used as an in-process monitor of air leaks. Thermocouples were positioned along the outside length of the reactor, and a porous metal filter, located inside the settling chamber, separated the silicon powder from the gas phase. A burn port was used to burn the hydrogen and undecomposed silane. The gasket material in heat-affected areas (e.g., reactor-to-lid and reactor-to-base seals) was Grafoil®*. Swagelok fittings with either Teflon or stainless steel ferrules were the predominant pipe and tube connections.

*Grafoil® is a registered trademark of Union Carbide Corporation.

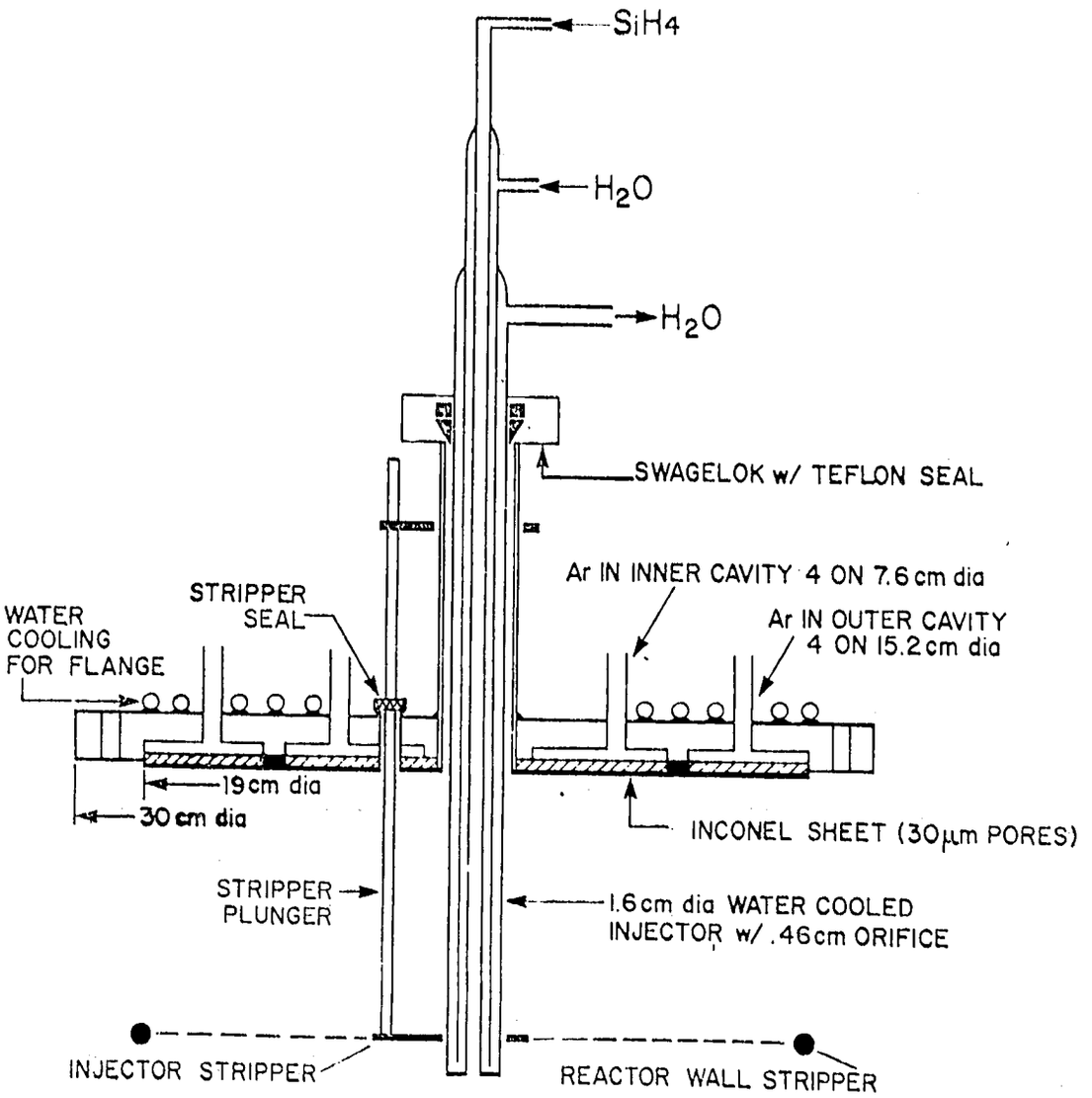

FIGURE 3 - 11

FREE-SPACE REACTOR LID SCHEMATIC

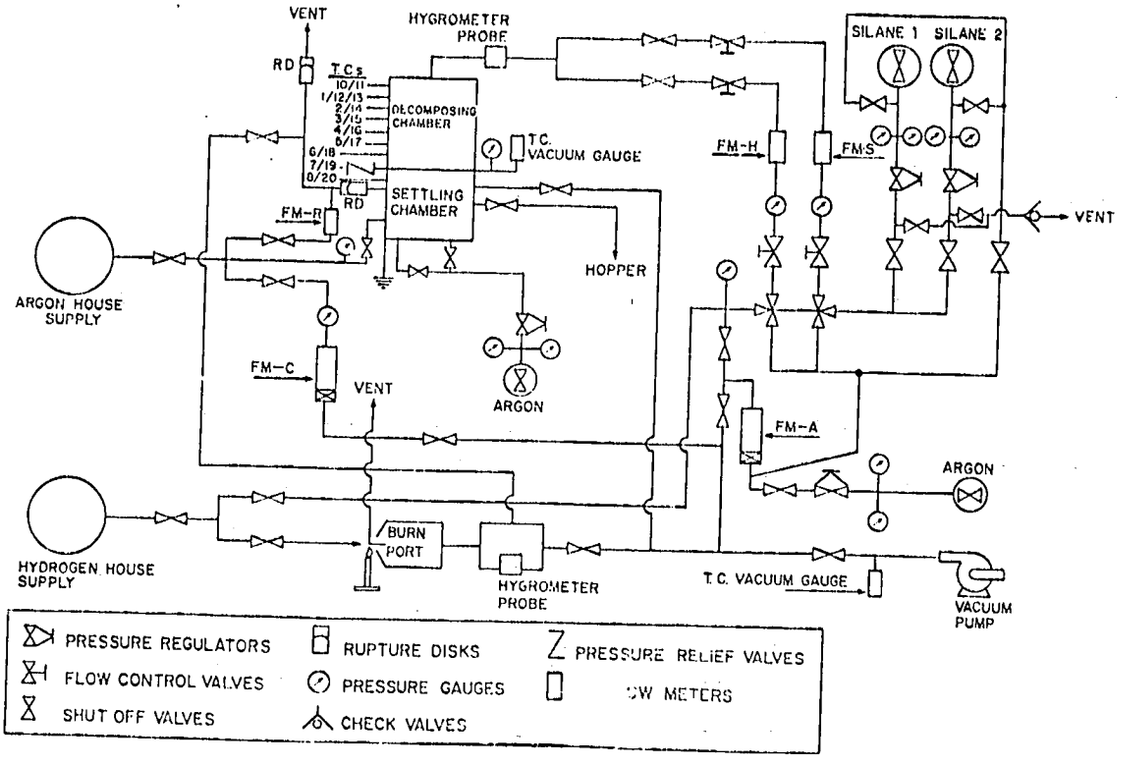

FIGURE 3 - 12

FREE-SPACE REACTOR GAS-FLOW DIAGRAM

3.2.1.2.2 Connected Assembly

To produce semiconductor-grade polycrystalline silicon, a connected assembly was developed capable of producing and melting silicon powder without exposing it to atmospheric contaminants. The connected assembly (Figure 3-13) minimized powder handling and eliminated the need for opening and contaminating the reactor assembly. In practice, powder that was produced in the free-space reactor accumulated in the settling chamber. After terminating an experiment, the free-space reactor and settling chamber were purged with argon and cooled to room temperature. To comply with safety regulations, silicon powder could not be transferred out of the settling chamber until it was purged of hydrogen. The storage hopper was located approximately 2.4 m higher and 3.4 m away from the settling chamber. The most effective powder transfer was realized by reducing the pressure in the storage hopper below ambient using the suction of a commercial vacuum cleaner while simultaneously pressurizing the reactor and settling chamber combination with argon to approximately 5 psig. When at pressure, the ball valve connecting the two systems was opened for four seconds. The pressurization/depressurization sequence was repeated four times when the settling chamber contained approximately 4 kg of silicon powder. This quantity of powder could be transferred to the storage hopper in less than three minutes.

The powder storage hopper had a capacity of 100 liters. The hopper lid contained a porous metal filter (30 μm average pore size) for gas powder separation during pneumatic powder transfer from the settling chamber. The fluid slide located in the conically shaped lower portion of the hopper aided in gravity feeding of the powder to the bottom of the hopper. A vertical auger inside the hopper with an attached sweep-arm controlled the rate of powder discharge from the hopper.

Figure 3-14 is a view of the inside of the melter showing the quartz feed tube and auger. The 46 mm diameter quartz feed tube extended from the bottom of the hopper at a 10° downward pitch. The enclosed auger directed the silicon powder to the vertical section of the quartz tube

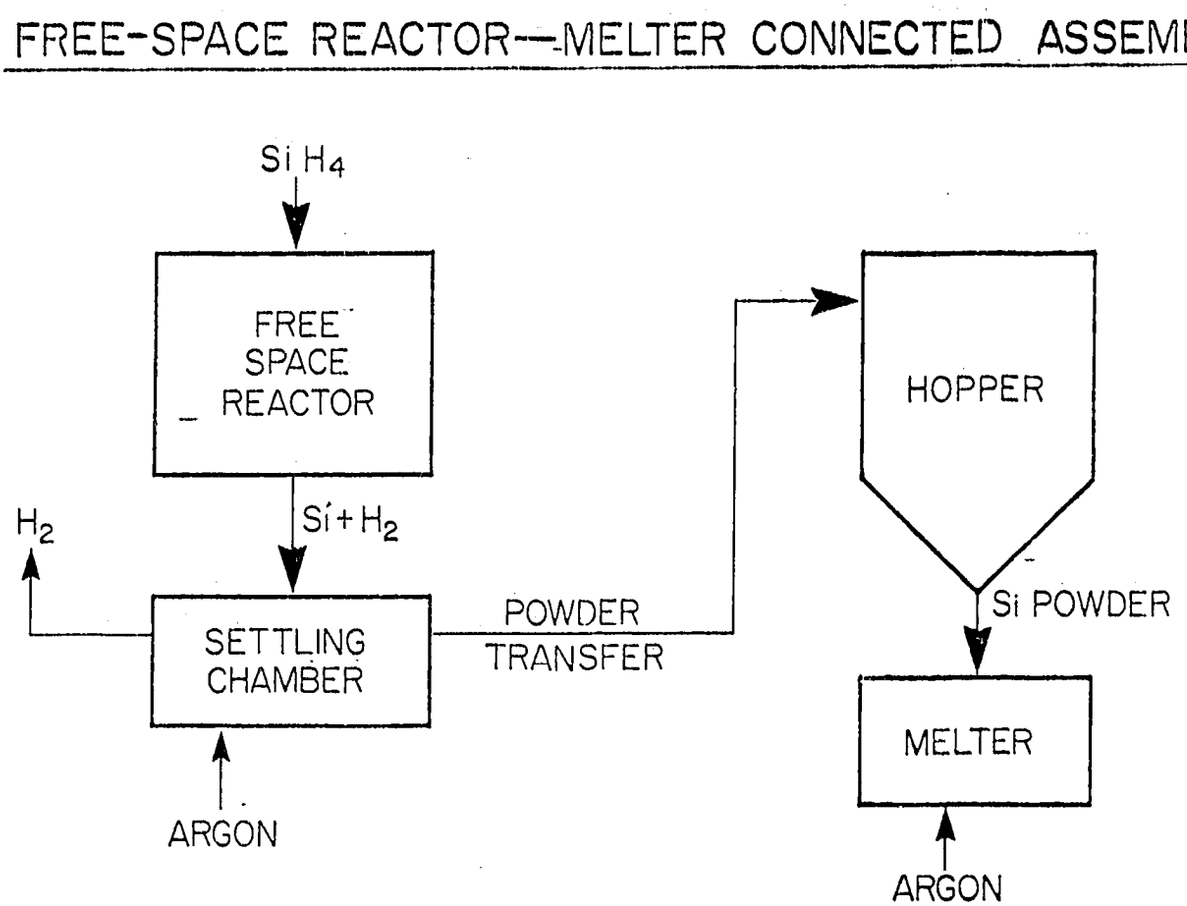

FIGURE 3 - 13

CONNECTED ASSEMBLY SCHEMATIC

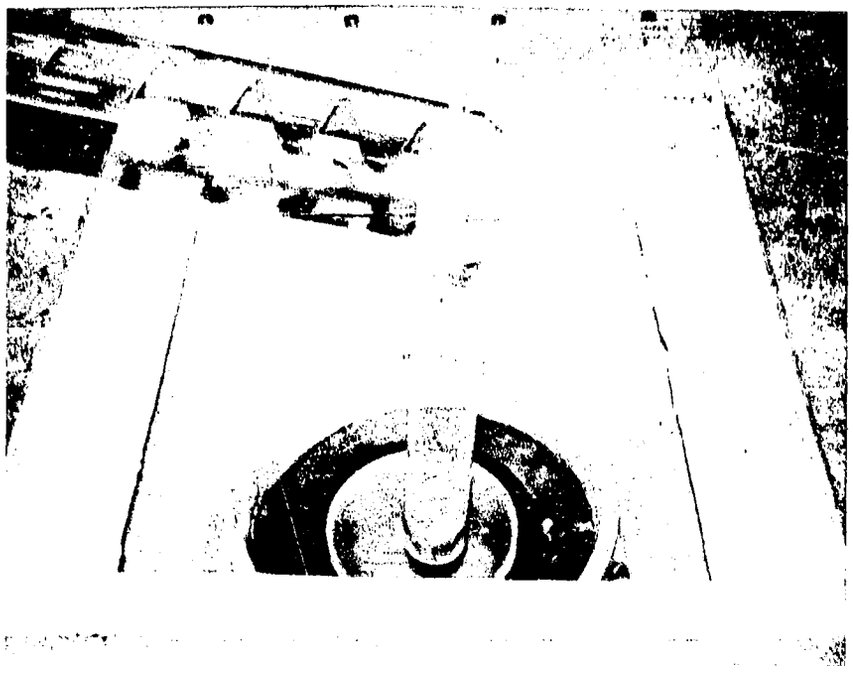

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FIGURE 3 - 14

PHOTOGRAPH OF THE INSIDE OF THE MELTER

where it fell into the quartz melting crucible. Thermocouples positioned adjacent to and touching the bottom of the graphite susceptor were used to monitor the temperature of the system.

3.2.1.2.3 Reactor Model and Heat-transfer Mechanism

Qualitatively, the operation of the free-space reactor is as sketched in Figure 3-15. Silane gas enters the heated reaction chamber as a free axi-symmetric jet whose behavior, as far as its entrainment characteristics are concerned, is like a submerged jet developing in surroundings consisting of a higher-density fluid. The silane jet expands and ultimately reaches the reactor wall; the remainder of the reactor is a region of parallel flow development. The silane is heated by mixing with entrained hot fluid (a mixture of gas and fine particulates) from the recirculation zone, and by radiation from the hot reactor wall. At elevated temperatures, this reaction is almost instantaneous.

Two mechanisms were considered for transferring heat from the reactor wall to the fluid surrounding the submerged jet. One heat-transfer mechanism was based on convective correlations. A second heat-transfer mechanism was based on transferring the heat by radiation from the reactor wall to a gas containing fine particulates. For the convective correlation mechanism, a reactor wall temperature several hundred degrees higher than the experimentally measured value was calculated. The radiation heat-transfer mechanism yielded close to the measured wall temperature for reasonable values of all parameters. Consequently, it was felt that radiation was the dominant mode of heat transfer.

3.2.1.3 Silane Pyrolysis Experiments

3.2.1.3.1 Pyrolysis Efficiency

A qualitative correlation was made between the color of the exhaust flame and the silane-to-silicon conversion efficiency. When the outer fringe of the flame was white, while the bulk of the flame was colorless or light orange, the conversion efficiency was approximately 99%. When the

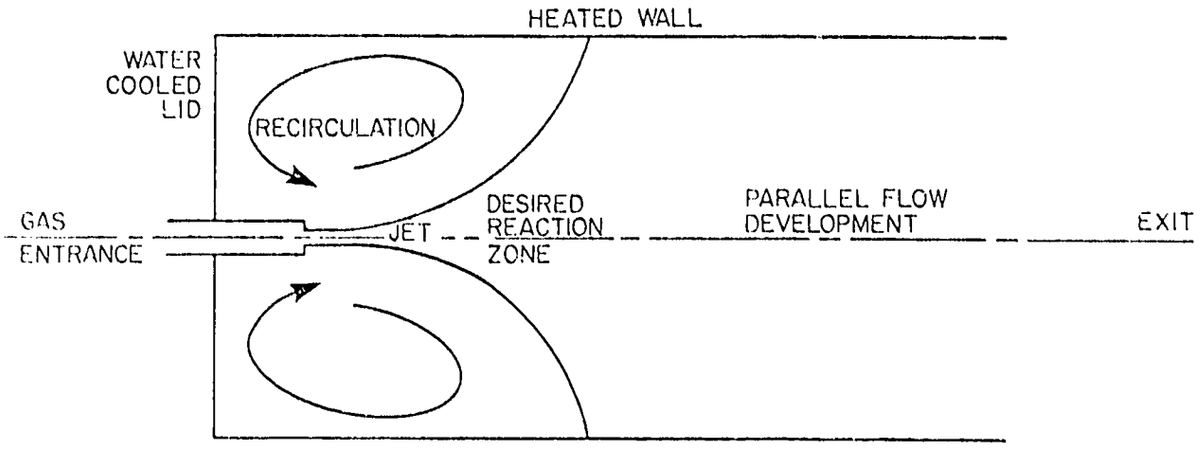

FIGURE 3 - 15

MODEL OF FREE-SPACE REACTOR AXI-SYMMETRIC JET

entire flame was white, bordering on bright white, the conversion efficiency was approximately 97%. For lower efficiencies, the flame became a brilliant white and it was impossible to distinguish marked differences.

The efficient conversion of silane-to-silicon in the free-space reactor was dependent upon the transfer of heat into the core of the injected silane stream. Several experiments were conducted to determine the minimum operating temperature for the complete conversion of silane-to-silicon at various silane flow rates. A constant silane volume throughput was maintained while the reactor temperature was varied. The color of the exhaust flame was monitored as an indication of the conversion efficiency. The data (given in Figure 3-16) showed that for the current reactor-injector configuration, a reactor wall temperature near the center of the hot zone of at least 800°C was needed for complete conversion. When silane was injected into the free-space reactor at a Reynolds number below 2000, a higher reactor temperature was needed to obtain complete conversion. A Reynolds number greater than 2000 corresponds to a turbulent jet stream. Similarly, for Reynolds numbers above 6000, the reactor temperature had to be gradually increased above the 800°C minimum to accommodate the higher gas velocities. Small increases in temperature above the threshold value greatly increased the efficient production of silicon for the given reactor configuration.

Thermodynamic calculations* indicated that an adiabatic conversion of silane-to-silicon may occur at approximately 400°C in the free-space reactor. The kinetic data (Hogness, Ref. 2) indicated that the reaction rate at that temperature was too slow to support an efficient decomposition in this reactor. A minimum silane-to-silicon conversion of 97% was not obtained when the reactor wall center temperature was below 800°C.

3.2.1.3.2 Demonstration of Reactor System Capability

As a demonstration of the capability of the current free-space reactor, silicon powder was produced from silane at the rate of 2.8 kg/hr

*Thermo-chemical data obtained from the JANAF Tables (Stull and Prophet, Ref. 3).

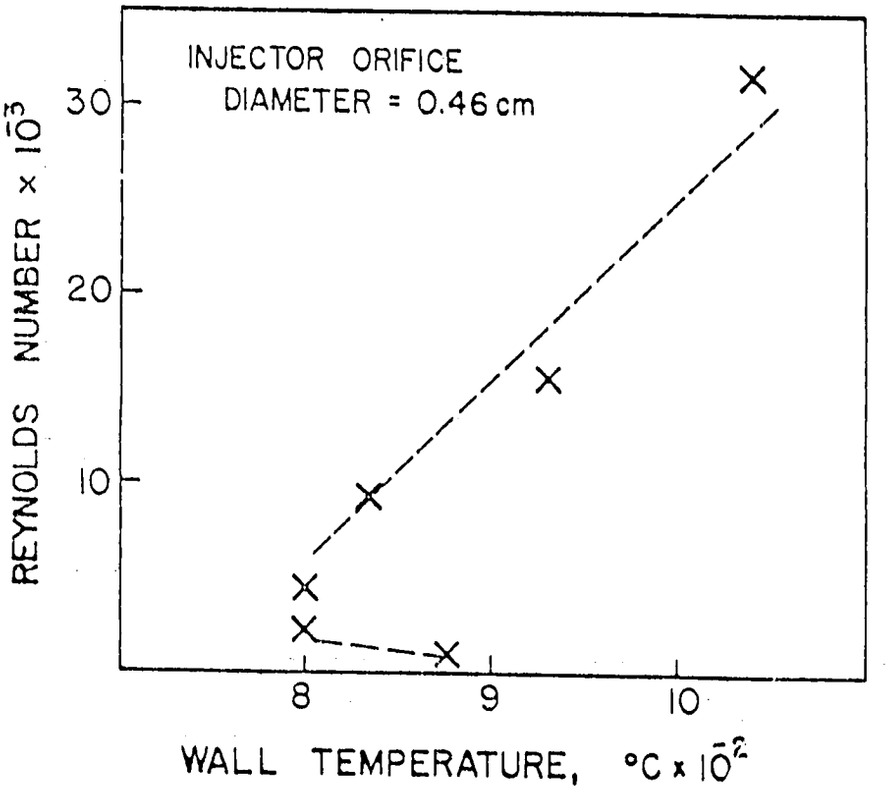

FIGURE 3 - 16

OPERATING CONDITIONS FOR HIGH SILANE CONVERSION EFFICIENCIES

for one hour. In addition, the free-space reactor was operated for 40 hours, producing silicon powder at the rate of 0.5 kg/hr. The 40-hour run consisted of five (5) consecutive eight-hour experiments in which the reactor wall (near the gas injector tip) was kept at $715^{o} \pm 15^{o}C$. At two-hour intervals during each eight hours of operation, the powder stripper was lowered 152 mm and then raised to touch the water-cooled lid (refer to Figure 3-11). Immediately thereafter, argon was pulsed through the porous plate to dislodge any powder that might have accumulated on the lid. A three-second burst of argon through the outer cavity and then through the inner cavity was used. The mechanical strip and argon pulse procedure was repeated followed by a mechanical strip.

The silane flow into the reactor was not altered during the powder dislodging procedure. After each eight hours of operation, the powder dislodging sequence was also repeated before the free-space reactor and settling chamber assembly were purged with argon. When the reactor had cooled to room temperature, the silicon powder was pneumatically transferred to the storage hopper. Between eight-hour runs, the reactor was not opened. After the fifth run, the powder stripping sequence, — argon flush, cool-down, and pneumatic powder transfer — were conducted. Subsequently, the reactor was dismantled and inspected.

The lid, injector, and stripping mechanism were free of powder with no indication of a silicon or silane reaction with any of the components. This included the mechanical stripper which momentarily projected approximately 38 mm below the tip of the injector during a powder dislodging operation. The top 152 mm (the length of the stripper stroke) of the reactor had a very thin (1 to 2 mm) coating of loose silicon powder. The powder adhering to the quartz liner in the next 80 mm from the lid, tapered from very thin at the ends to a maximum center thickness of 60 mm. Most of the rest of the reactor liner contained randomly spaced nodules (10-25 mm protrusions) of attached powder with quartz visible between some of the nodules. Beneath the powder deposits, the quartz liner remained intact. Lower sections of the quartz liner were rainbow colored. The settling chamber was empty except for small powder deposits perched on protrusions (nuts,

bolts, tubing, etc.). It was inferred from the results of the 40-hour operation that the eight-hour experiments could have been continued indefinitely.

After each of the five consecutive eight-hour experiments, it was demonstrated that the silicon powder could be transferred via connecting pipes to subassemblies and further processed without exposure to atmospheric contaminants. After each eight-hour experiment, the silicon powder was pneumatically transferred to the storage hopper. Powder bagging capabilities were demonstrated by discharging powder produced in the first three runs from the hopper directly into attached plastic bags. The discharge rate was controlled by the rotational speed of the vertical auger inside the hopper. Powder from the last two runs of the series was used to demonstrate that free-space reactor powder could be fed directly through additional pipes to a melter. This operation was also carried out under an argon atmosphere. A description of the melter and the melting operation is given in Section 3.2.2.3, Melt Consolidation. A description of the cast product follows.

3.2.1.4 Product Properties

3.2.1.4.1 Silicon Powder Morphology

The morphology of the silicon powder formed in the free-space reactor depended upon operating conditions. The powder obtained from experiments conducted at reactor center wall temperatures around 950° to 1000°C was light brown in color, while the powder formed below 900°C tended to be light to dark gray. The high-temperature brown powder exhibited poor flow characteristics. As the powder color changed from light to dark gray with decreasing temperature, the flow characteristics improved. In addition, the average surface areas (as determined by the BET gas adsorption method) of the silicon powders increased from approximately 4 m^2/gm to 10 m^2/gm with increasing temperature. Calculations of the average particle size (based on spherically shaped particles) ranging from 0.6 μm to 0.26 μm, respectively, were in agreement with scanning electron microscope (SEM) observations. The silicon powder formed at center wall temperatures below 900°C had bulk densities in the 0.12 to 0.17 g/cc range. The high tempera-

ture powder had bulk densities around 0.01 g/cc. All powders examined had particles ranging in size from submicron to low micron. The SEM micrograph (Figure 3-17) shows that the smaller particles were nearly spherical in shape, while the larger particles had a botryoidal form.

The size of the particles obtained in the free-space reactor was also dependent upon conditions other than reactor temperature. For example, preheating the silane before injecting it into the reactor tended to reduce the average particle size. Injection of the silane into the bottom of the reactor and exhausting gas out the top had the reverse effect; average particle sizes of 1-2 microns were obtained. Insufficient data are presently available for predicting the precise nature of the silicon powder obtained under all reactor operating and configuration variations.

3.2.1.4.2 Gas Injector and Reactor Wall and Lid Deposits

During all silane pyrolysis experiments, some of the silicon powder was deposited on the gas injector and on the reactor wall and lid. When the free-space reactor was operated (without the mechanical powder stripper) at a silicon production rate of 0.5 kg/hr., the powder bridged the reactor, below the injector tip, some time between six and eight hours after starting. Initially, the bridge was very porous. Experimental evidence indicated that some bridges contained channels. Once the bridge formed, it was only a matter of time before sufficient resistance to the flow of silane would register on the flow meter. After some experiments, massive growth of agglomerated and chemically vapor deposited silicon was found attached to the bridge silicon. The reactor lid modifications (installation of a mechanical stripper and a porous lid plate for gas flushing) and alterations in the operating procedure prevented the powder from building up to a critical thickness.

Two additional silicon growths were observed. The first was a cone-shaped growth attached to the top of the injector. This growth had a hole through the center, and, although not bonded to the injector, seemed to be an extension of the injector. Unlike packed powder, the cones had structural integrity and, in some cones, dense metallic silver layers were

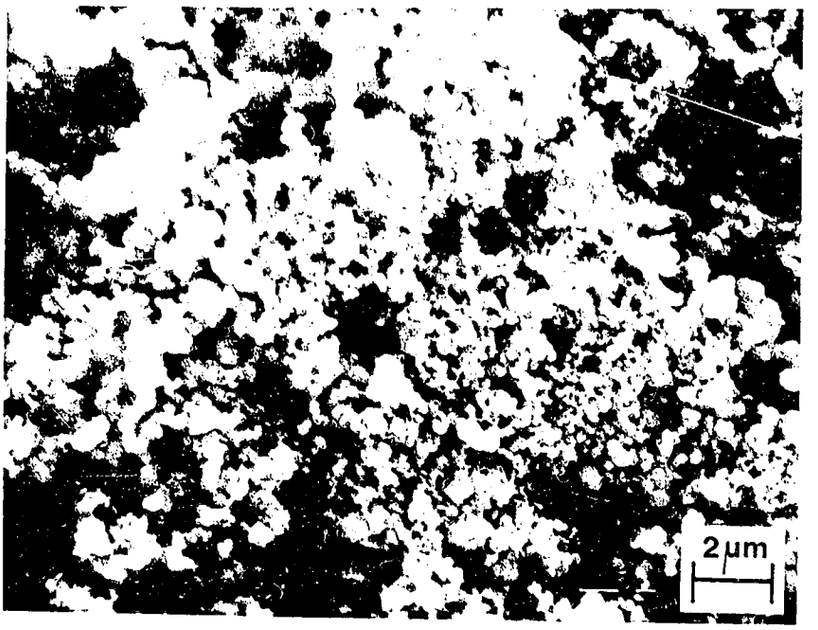

FIGURE 3 - 17

SEM MICROGRAPHS OF FREE-SPACE REACTOR POWDER (5000 X)

seen. It was found that no injector tip deposits formed when the temperature inside the reactor near the gas injector tip was kept below approximately 600°C. The second deposit also had structural integrity and evidence of some dense metallic sections. This deposit was firmly bonded to the quartz liner, where the expanded silane jet reached the quartz, and grew toward the symmetry axis of the reactor. It was found that this deposit did not form when the outside reactor wall temperature near the center of the hot zone was kept above approximately 800°C. To prevent the deposits with structural integrity from forming on the injector and wall, the free-space reactor was operated under a controlled temperature gradient. This was accomplished by water-cooling the reactor lid, positioning the injector tip 114 mm from the lid, and operating the reactor at a minimum wall temperature (near the center of the hot zone) of 800°C.

3.2.1.4.3 Silicon Purity

Impurity analyses of free-space reactor powder and cast samples were conducted with an emission spectrograph using the cathode-layer technique. An impurity concentration technique coupled with emission spectrographic analysis was also attempted; however, contamination attributed to processing and handling occurred. After long-duration and consecutive experiments were conducted (with the reactor remaining closed between experiments), impurities were no longer detected with the cathode-layer technique. No impurities were detected by the cathode-layer technique in fragments from the 152 mm diameter castings obtained from the melt of the last two consecutive runs.

3.2.2 Free-space Reactor Powder Melting and Consolidation

3.2.2.1 Program Goals

The objectives of the consolidation segment of the program were to:

1. Provide an inexpensive, high-purity feedstock for the fluid-bed reactor.

2. Demonstrate that free-space reactor powder can be densified into an acceptable form for transporting and melting for single-crystal or ribbon growth.

3. Demonstrate that as-formed powder can be melted, producing semiconductor-grade polycrystalline silicon or melt.

3.2.2.2 Compaction and Sintering

Several methods were investigated for consolidating the free-space reactor powder. One method involved vacuum-sintering the free-space reactor powder that was poured (not packed) into quartz crucibles. Initially, the powders had an apparent density of 0.12 g/cc and a surface area of 7.5 m^2/g. When sintered at 1300°C for one hour, the powder density increased to 0.30 g/cc and the surface area was reduced to 0.8 m^2/g. Figures 3-17 and 3-18 show scanning electron micrographs of the free-space reactor powder in their as-produced condition and after the 1300°C treatment, respectively. Loose powder sintering was effective in promoting particle growth, but did not appear promising as a means of reducing the total volume of the material.

Free-space reactor powder was dry pressed in single-action steel dies. No binders or lubricants were added. Pellets compacted at a pressure of 16,000 psi (110 MPa) appeared to be free of delaminations; however, delaminations were apparent after sintering at 1375°C for one hour. A green density of 47% of the theoretical value was obtained. The sintering increased the strength of the pellets but did not significantly increase their density.

Free-space reactor powder was isostatically pressed. This process consisted of filling a flexible mold with powder, sealing it, and then subjecting the mold to a fluid pressure. The pressure acted uniformly in all directions on the powder. Small compacts (38 mm diameter x 203 mm long rubber bag molds) were crack free and were used to determine the green density as a function of compaction pressure (data shown in Figure 3-19). Large compacts (121 mm diameter x 559 mm long mold) broke into several pieces after pressing at 20,000 psi (138 MPa). Isostatic pressing of free-space

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FIGURE 3 - 18

SEM MICROGRAPH OF LOOSE FREE-SPACE REACTOR POWDER SINTERED AT 1300 °C (5000 X)

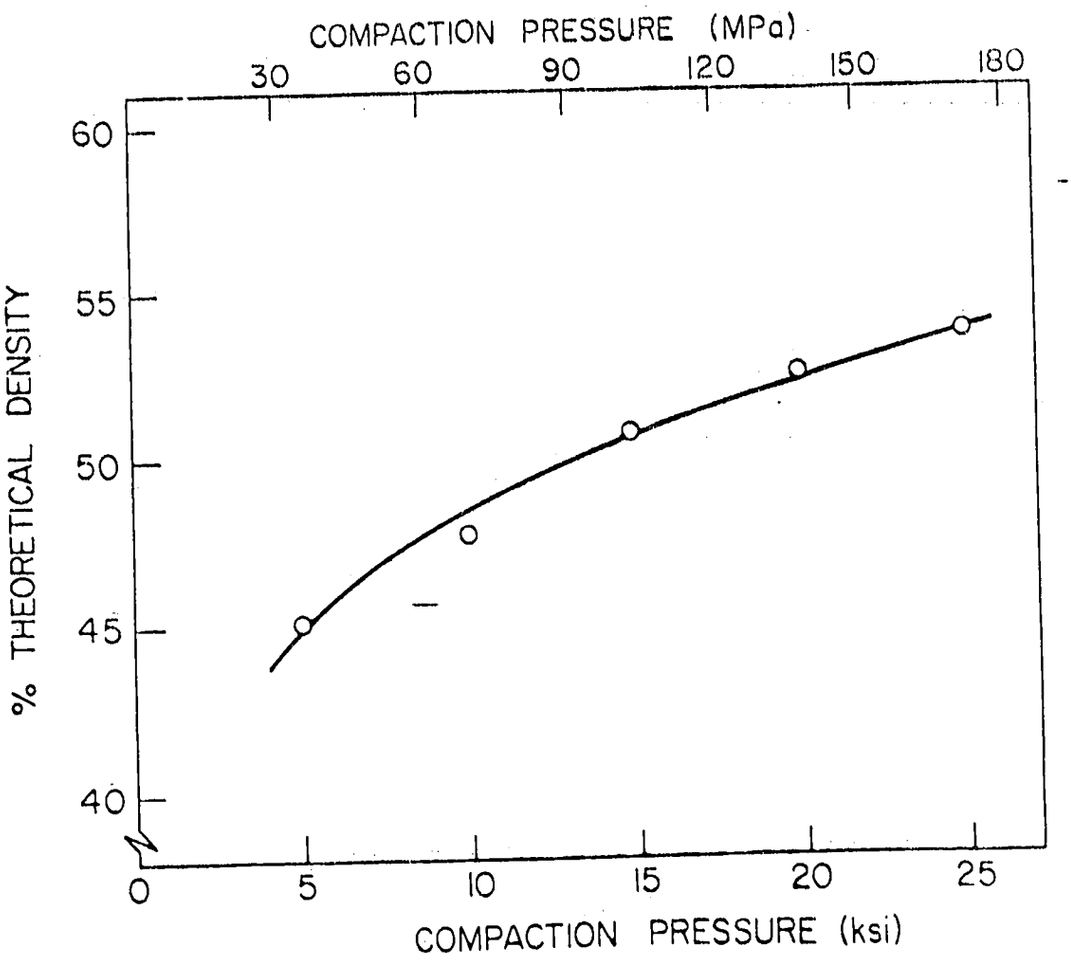

FIGURE 3 - 19

EFFECT OF ISOSTATIC PRESSURE ON COMPACT DENSITY

reactor powder may be a suitable means of increasing the bulk density of powder to facilitate shipment and storage.

Free-space reactor powder was rolled directly into flakes and sintered for one hour at 1350°C. A SEM micrograph of a sintered flake (shown in Figure 3-20) revealed that the edges of the flake had undergone significant particle growth or coalescence. X-ray fluorescence analysis revealed that iron, nickel, and chromium were present. These elements were probably introduced during the rolling process and may have acted as sintering promoters. Additional work on direct rolling of free-space reactor powder will be necessary to minimize contamination.

3.2.2.3 Melt Consolidation

The melter for free-space reactor powder consisted of a furnace containing a 152 mm diameter quartz crucible. This melter is the last link in the connected assembly and was not used for quality control. Figure 3-21 is a schematic (not to scale) of the melter. During melting operations, silicon powder was transferred from the storage hopper through the quartz tube (which has a 10° downward pitch) by means of the enclosed auger. The powder was dropped through the vertical section of the quartz tube into the quartz crucible. The end of the tube projected slightly below the rim of the crucible. The crucible was supported by a graphite susceptor that was supported by an alumina pedestal. Five layers of carbon felt* and a cylindrical opaque quartz sleeve surrounded the susceptor. The induction coil (energized by an Ajax power source whose maximum output is 30 KW at a frequency of 4200 Hertz) was positioned around the quartz sleeve. The induction coil and internal parts were enclosed by two courses of firebrick. The base of the furnace was Transite and firebrick while the lid was a split graphite plate wrapped in Grafoil® ** (a radiation shield). Firebricks were placed on top of the graphite plate. Two sight tubes, a vent, and three argon inlet tubes, projected through the lid. Argon was also introduced

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* Union Carbide Corporation Grade WDF carbon felt.

** Grafoil® is a registered trademark of Union Carbide Corporation.

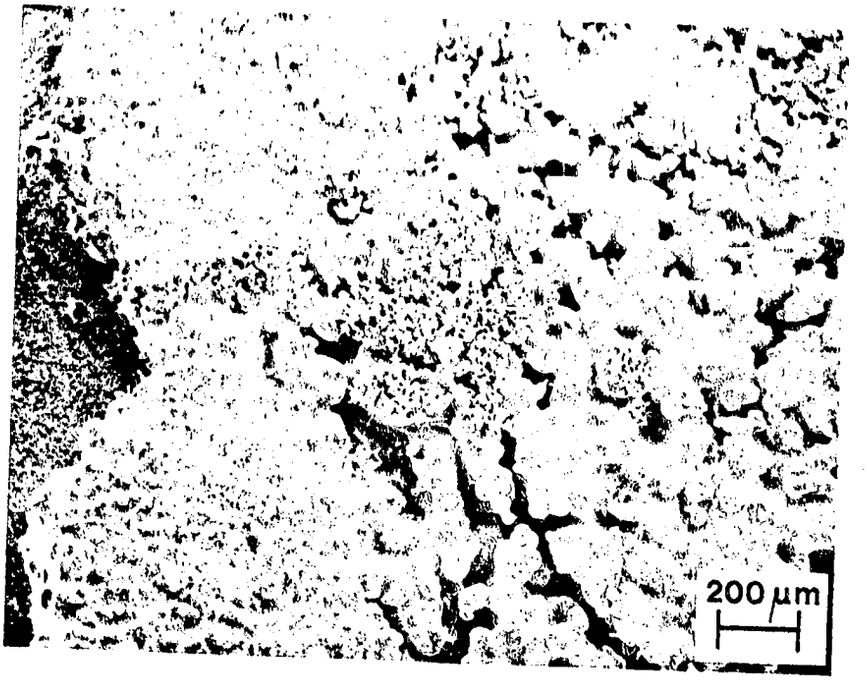
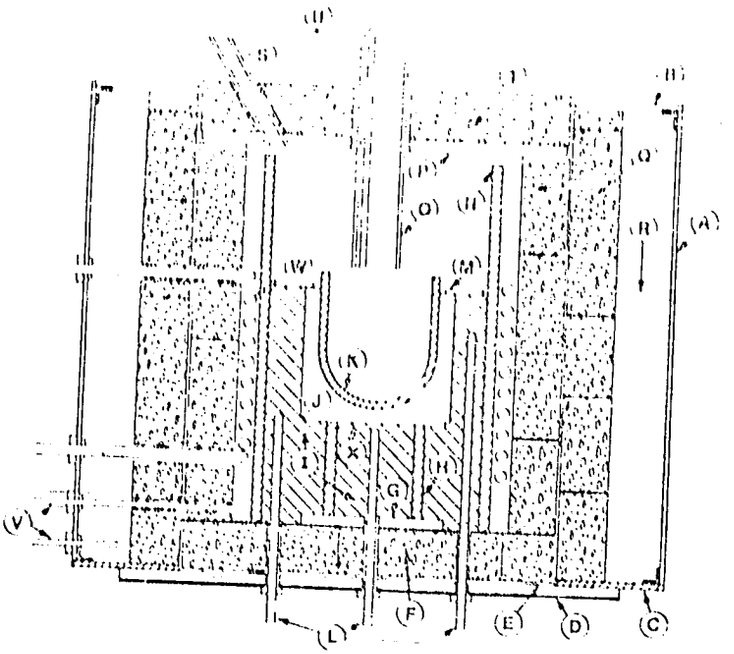


FIGURE 3 - 20

SEM MICROGRAPH OF A SINTERED FLAKE



LEGEND

A	Plexiglass chamber 762 mm x 762 mm x 610 mm high x 13 mm thick -- all joints sealed
B	Transite top 6 mm thick w/483 mm x 483 mm access opening -- rubber gasketed
C	Linen-based Bakelite 13 mm thick 2/483 mm x 483 mm cut out
D	Transite base 19 mm thick 660 mm x 660 mm
E	Grafoil®, 0.4 mm thick, over entire Transite base
F	Firebrick base
G	Alundum base for pedestal approximately 10 mm thick - 178 mm diameter
H	Alumina pedestal 133 mm OD x 114 mm high, 10 mm wall
I	Carbon felt insulation
J	Susceptor, purified graphite, 178 mm diameter - 152 mm high, accepts a 152 mm diameter crucible
K	Quartz crucible - 152 mm diameter - 178 mm high
L	Thermocouple wells (3) sealed through Transite base w/Swagelocks
M	Grafoil® ring 0.4 mm x 152 mm I.D. x 279 mm O.D.
N	Opaque quartz 279 mm I.D. x 305 mm O.D. x 457 mm
O	Transfer and powder feed tube - 51 mm diameter quartz
P	AEJ Graphite 13 mm thick x 476 mm x 476 mm w/Grafoil® underside
Q	Double-walled firebrick w/staggered joints
R	Void area for argon atmosphere
S	Alumina sight tube for visual observation and exhaust
T	Firebrick insulation
U	Argon supply for crucible
V	Argon supply for furnace (2), 1-each for inner and outer chambers
W	Work coil, water cooled 121 111 mm off base 241 mm long
X	Single layer of carbon felt

FIGURE 3 - 21

SILICON MELTER SCHEMATIC

through the Transite base. The outer sides of the furnace consisted of plexiglass sealed against an aluminum frame.

The largest dross-free silicon casting produced from free-space reactor powder was 5.3 kg. The powder for this casting was fed continuously into the melter from the storage hopper at a programmed rate. At the start of a run the powdered silicon was slowly fed into the hot (1550°-1600°C) crucible. Once the molten puddle of silicon was obtained, the silicon appeared to suscept, and the power required to maintain temperature decreased approximately 20 percent. As the surface area of the molten silicon increased, the powder feed rate was increased. For the 5.3 kg melt an average melting rate of 2.8 kg per hour was obtained. For another melt, a melting rate of 6 kg per hour was maintained for 35 minutes. During those 35 minutes, the powder melted as rapidly as it was fed into the quartz crucible. Figure 3-22 is a photograph of one of the dross-free castings. The quartz crucible typically fractured at the silicon interface; the top portion of the crucible is not shown in the photograph. During the powder melting operation, very little silicon powder dispersion occurred inside the furnace assembly.

Two separate melts were made from free-space reactor powder produced in the fourth and fifth experiments of the five consecutive runs. Attempts were made to select quartz-free fragments from each casting and have Crysteco, Inc., pull 5 cm diameter <111> orientation crystals. Every effort was made to minimize the introduction of contaminants not associated with the process of producing the silicon powder and melting it in the connected free-space reactor assembly. Consequently, the silicon fragments sent to Crysteco were not acid-leached or washed. Crysteco reported that after the two charges were melted, quartz slivers and flakes were seen floating on the melt surfaces. The floating quartz particles interfered with the single-crystal pulls and a boule was obtained that was half single and half polycrystalline while a second boule was entirely polycrystalline. These crystals will be evaluated by Union Carbide Corporation in the near future.

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FIGURE 3 - 22

DROSS-FREE 152 mm DIAMETER CASTINGS

In addition to melting free-space reactor powder continuously in the melter, compacted powder was also melted and cast. Approximately 2 kg of free-space reactor powder was isostatically compacted at 20,000 psi (138 MPa). The compact was fractured into irregular-shaped fragments which were loaded into the melter as shown in the schematic of Figure 3-23. The charge was divided approximately 50/50 between the crucible and the feed tube. During melting, practically no smoking occurred, and clean casting was obtained.

3.2.2.4 Casting Methods

The silicon powder produced in the free-space reactor could not be fully characterized in its as-formed state. Several methods were investigated for melting and casting the silicon into fully dense, crack-free forms. The methods investigated were suction casting of rods, vacuum melting and casting of pellets, and chill-mold casting. The first two methods provided solid silicon samples for quality control. Suction-casting and chill-mold casting methods have the potential of providing a polycrystalline silicon form acceptable to the single-crystal growers. They also provide a means of extracting silicon from quartz melting crucibles for multiple melting and casting cycles.

3.2.2.4.1 Suction Cast Rods

The suction casting of silicon rod was demonstrated using a modified version of the melter described in Section 3.2.2.3, Melt Consolidation. After the charge was fully melted, the temperature of the melt was adjusted to slightly higher than the melting point of silicon. One end of an open-ended quartz tube was inserted into the melt. The silicon was sucked up the tube by rapidly reducing the gas pressure inside the tube. Rapid cooling and solidification of the silicon occurred due to radiant heat losses. For most castings, the rapid cooling prevented the silicon from reacting with the quartz tube. After the end of the tube that was submerged in the melt was broken off, the cast rods were slid out. In some cases (where silicon wet the quartz, or the quartz was bent, or contained a necked-down region), the quartz tube had to be broken to release the

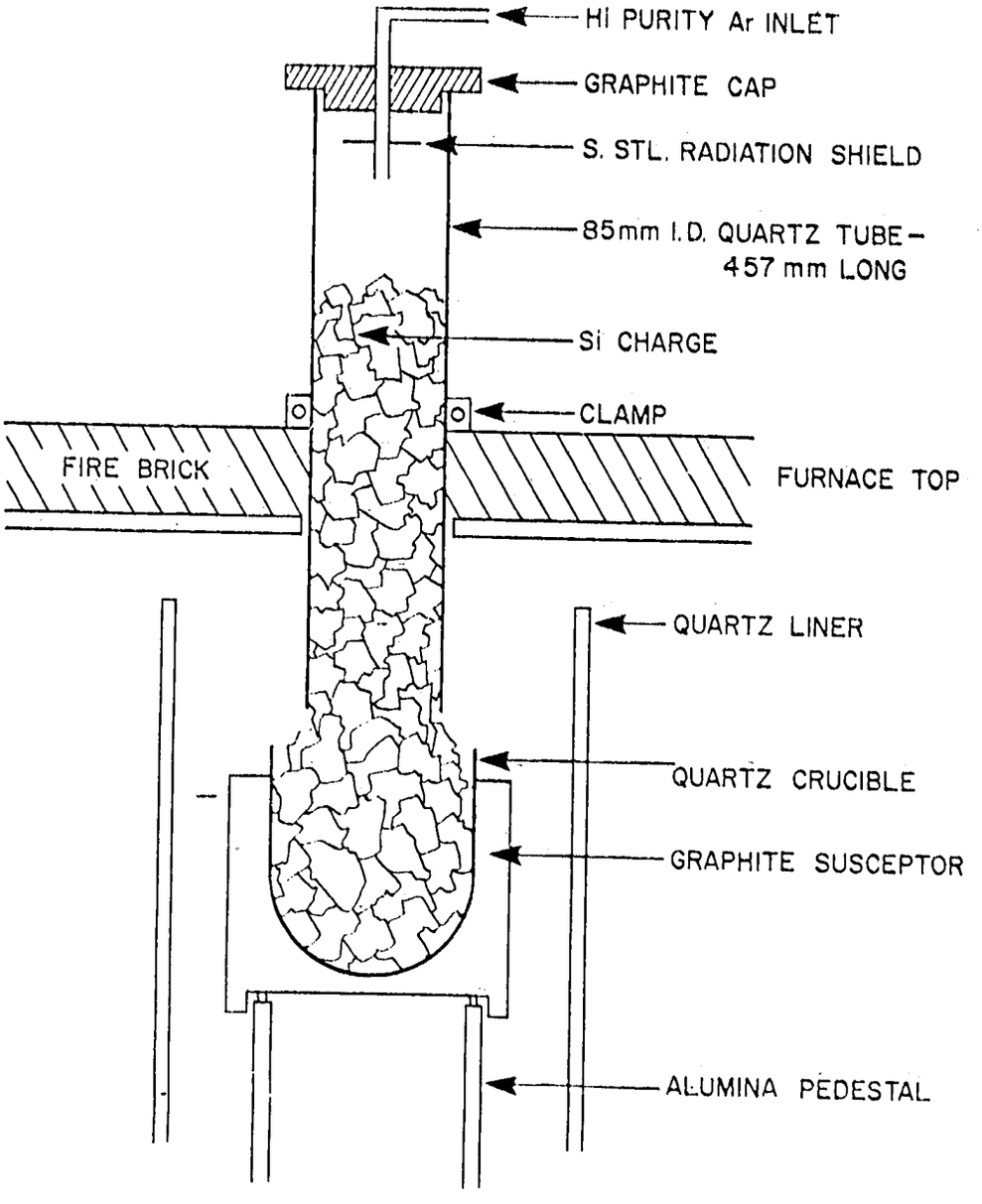

FIGURE 3 - 23

SCHEMATIC OF SETUP FOR MELTING SILICON FRAGMENTS

casting. Figure 3-24 is a photograph of two castings. Silicon rods ranging from 4 mm to 19 mm in diameter and up to 300 mm long were suction cast.

3.2.2.4.2 Vacuum-cast Pellets

A method was developed for melting silicon and casting it under vacuum conditions into crack-free, solid pellets for rapid product and process evaluation. The polycrystalline silicon properties that could be determined from the pellets were electrical resistivity, conductivity type, and purity. Silicon was loaded into a specifically designed quartz test tube (24 mm diameter x 152 mm long). The lower closed end of the tube was a blown bubble whose wall thickness was approximately 0.1 mm. The tube and silicon were heated in a vertical graphite resistance furnace under vacuum. The molten silicon solidified in the thin wall bubble, which broke on cooling, leaving a silicon pellet free of cracks. Adhering quartz was removed with hydrofluoric acid. A typical vacuum-cast pellet, sectioned, is shown in Figure 3-25. The protrusion at the surface of the pellet was the last silicon to freeze.

3.2.2.4.3 Cold-mold Casting

A single, cold-mold, casting-experiment was performed to demonstrate feasibility. The casting procedure was to melt silicon in a quartz crucible at atmospheric pressure under an inert atmosphere. A clear quartz siphon tube was then inserted into the silicon. The other end of the siphon tube was lower than the melt and projected into a tapered graphite mold housed in a vacuum-tight chamber. Once the siphoning action was started (by reducing the pressure in the vacuum-tight chamber), the molten silicon flowed continuously into the graphite mold. Cold-mold casting may be adapted to a continuous melting and casting process in which castings of any desired configuration can be obtained. The life of the quartz melting crucible would be extended while the cold mold itself can be fabricated out of a variety of materials (e.g., graphite or water-cooled copper). The casting did not adhere to the graphite mold.

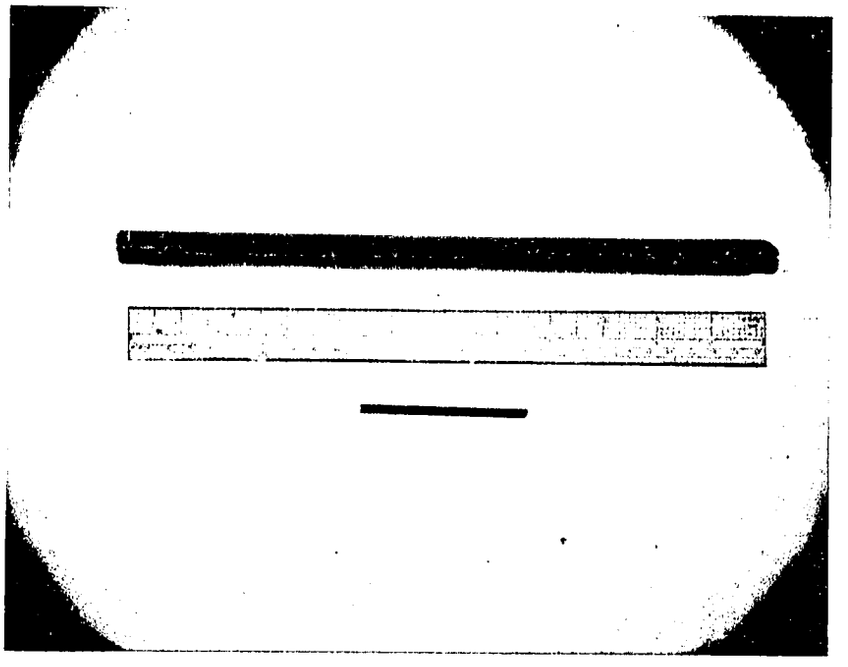

FIGURE 3 - 24

SUCTION-CAST SILICON RODS

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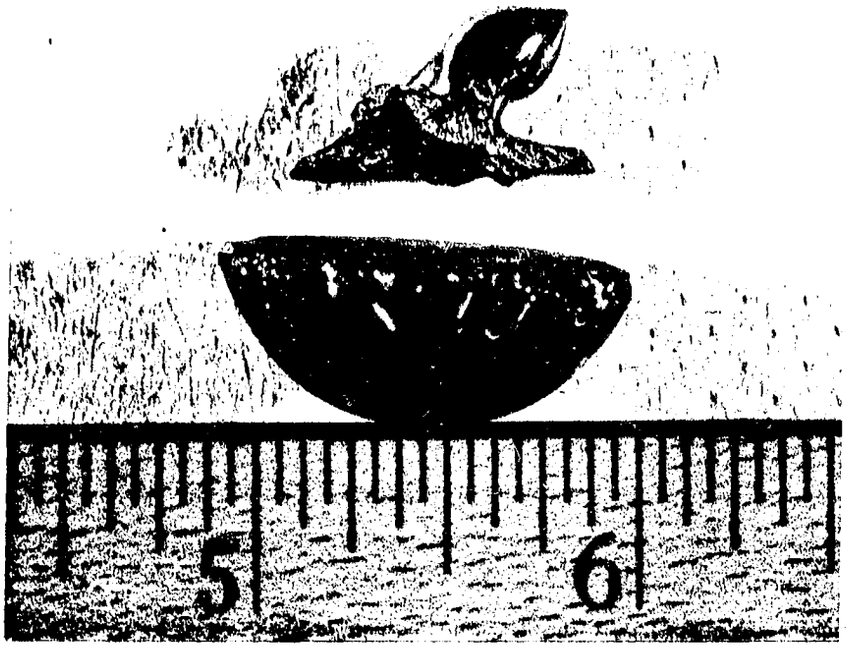

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FIGURE 3 - 25

SECTIONAL, VACUUM-CAST PELLET

3.2.2.5 Comparative Economics of Suction Casting and Rapid Pulling

A comparative economic study of two methods of silicon consolidation, namely suction casting and rapid pulling of polycrystalline ingots, was conducted at a commercial scale of 1000 MT/year. The technique of suction casting is labor intensive and is likely to consume large quantities of expensive quartz tubes. For a commercial plant, large-diameter rods, typically 3 inches in diameter by 3 feet in length, must be cast. With the current technology, the quartz tubes have a tendency to break while the rods are being withdrawn. On the other hand, polycrystalline silicon rods can be rapidly pulled in a standard Czochralski crystal-pulling machine. The pull rate depends primarily on the temperature gradient at the growth interface in the solid crystal. A single crystal 4 inches in diameter can be pulled at a rate of 4 inches/hour, whereas a polycrystalline rod can be pulled at a faster rate.

The process sequence and time requirements were developed for suction casting and rapid pulling assuming that multiple charges can be processed from a single (305 mm diameter) crucible up to a crucible life of 70 hours. Melt rate of free-space pyrolysis powder was taken to be 10 kg/hour, which is the observed rate for polycrystalline rod. The estimated net consolidation rate per melter is approximately 6 kg/hour for suction casting and 2 kg/hour for rapid pulling. For a commercial plant producing 1000 MT/year (135 kg/hour, 85% on-stream) of polycrystalline silicon rods, 23 melters for suction casting and 68 crystal pullers for rapid pulling are required.

The economic model for this study was based on a 15-year project life; 10-year, sum-of-digits depreciation; 46% federal income tax; 3 years of construction time; and 20% DCF rate. The estimated consolidation cost for both suction casting and rapid pulling techniques were approximately in the range of $7 to $8 per kg of silicon. The large operating cost of quartz tube replacement for suction casting is balanced by increased investment charges for the rapid-pulling technique. With the present-day technology, neither of these consolidation techniques are, thus, projected to be cost-effective for meeting the DOE/JPL 1986 goal of $10/kg overall price of

semiconductor-grade silicon suitable for making solar cells. Rapid pulling, however, offers the advantages of less development effort and better-quality product samples.

For meeting the 1986 price objectives, other consolidation methods such as heterogeneous fluid-bed silane pyrolysis, molten silicon shotting, or direct feeding into Czochralski single-crystal units should be evaluated.

3.2.2.6 Melter Development for EPSDU

As discussed in Section 3.2.3.3, the free-space pyrolysis powder can be controllably transferred to a melter and melted continuously with minimum degassing and dusting. Consequently, free-space pyrolysis powder has the potential of being fed directly into a crystal-pulling furnace. Furthermore, convincing discussions with vendors of commercial melting equipment indicate that a commercial Czochralski crystal-growing apparatus can be modified to accept silicon powder as a feed and to produce polycrystalline silicon rods. The melter for the EPSDU will be developed jointly with one or two vendors. For this purpose, Hamco of Rochester, NY, and Siltec of Menlo Park, CA, have indicated their interest in developing suitable melting and consolidation equipment for free-space pyrolysis powder. Hamco has opted to develop rapid pulling of polycrystalline rods as the preferred consolidation scheme. Siltec's preferred approach involves transfer of molten liquid silicon into a semi-continuous, water-cooled, solidification chamber where a semi-crystalline ingot is pulled. Development and design of a melter system for EPSDU is expected to be accomplished in the proposed next phase of JPL-sponsored work.

3.2.3 Fluid-bed Silane Pyrolysis

3.2.3.1 Program Goals

The fluid-bed pyrolysis of silane involves heterogeneous decomposition of silane gas on hot silicon seeds to produce free-flowing particles of silicon. The method offers the potential for converting high-purity

silane into pure silicon that can be directly processed using standard Czochralski technology.

As a result of the Phase I, Mod 6 program, silane has been successfully pyrolyzed in a see-through, fluid-bed reactor at high efficiencies yielding dense, coherent plate on seed particles without generating excessive quantities of fines. Long-term (48-hour), continuous operation of the fluid-bed reactor and gas distributor was demonstrated. Experiments were also conducted in horizontal reaction tubes to better understand and identify the conditions favoring the formation of silicon plate, powder, and fibers.

During Phase II, an analytical model for fluid-bed pyrolysis was developed and direct heating of bed particles by capacitive means was demonstrated. Also, fluidization experiments were conducted using inert gases and a preliminary economic analysis of the fluid-bed system for a commercial-scale operation of 1000 MT/year was developed.

3.2.3.2 Silane Pyrolysis Experiments

3.2.3.2.1 Fluid-Bed Pyrolysis

- Equipment

During the course of this program, see-through reactors were used to study the behavior of spouting beds, spout fluidized beds, and fluidized beds. A water-cooled gas distributor was developed for studying the behavior of fluidized beds. The current reactor consists of a cylindrical 85 mm I.D. glass tube (either quartz or Pyrex) that extended below the gas distributor and the resistant heating elements (Figure 3-26). A graphite seal between the gas distributor and the glass tube prevented the silicon seed-bed particles from falling below the gas distributor. An O-ring seal at the top and bottom of the glass tube kept the reactor pressure tight. A flotation collar filter assembly was positioned at the top of the reactor to trap elutriated fines. Figure 3-27 is a schematic of the gas-flow train. For long-duration experiments, a manifold permitted the exchange of silane cylinders without interrupting the pyrolysis equipment.

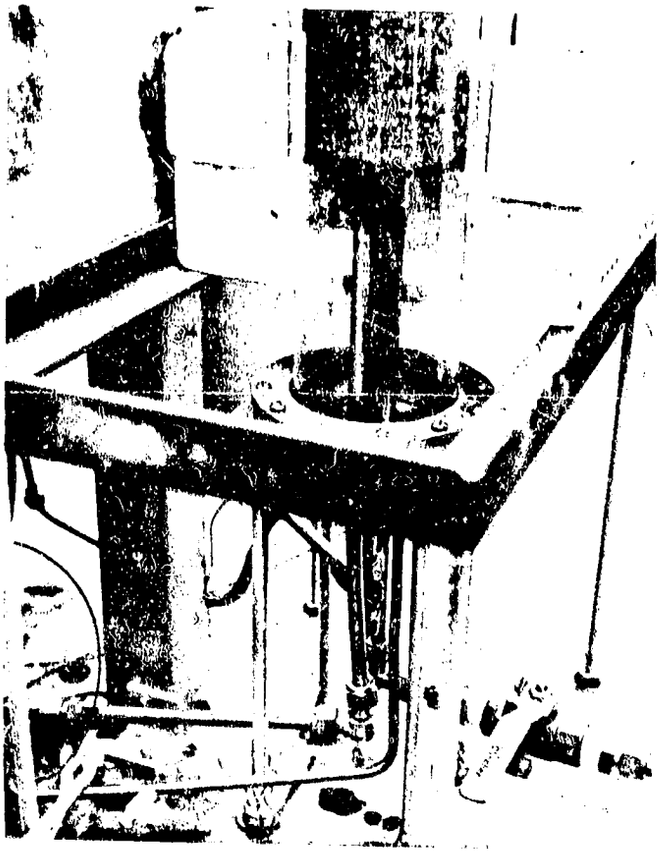

FIGURE 3 - -26

FLUID-BED REACTOR VIEW SHOWING PARTICLES OF SILICON SUPPORTED BY THE GAS DISTRIBUTOR

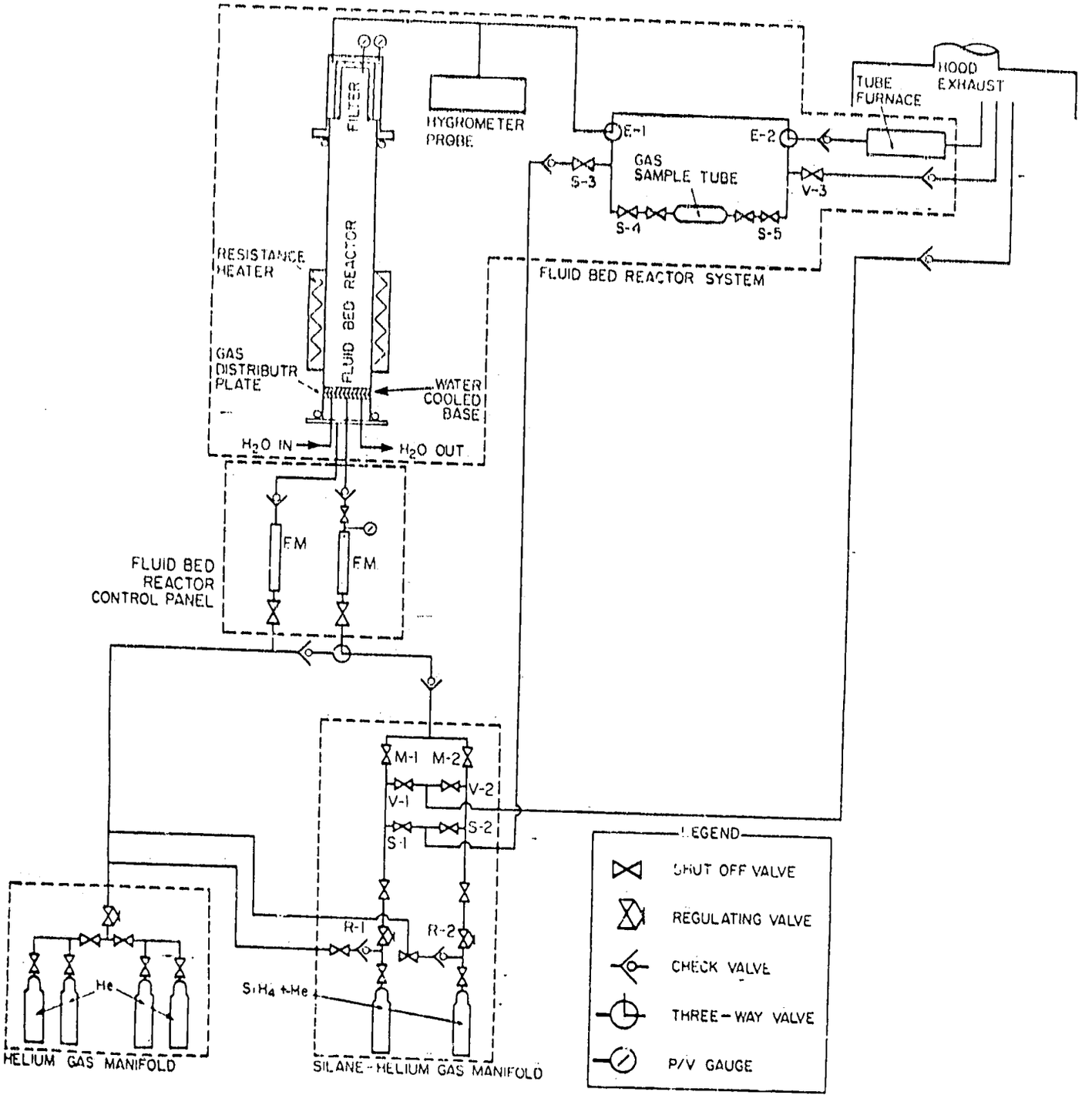

FIGURE 3 - 27

FLUID-BED REACTOR GAS-FLOW DIAGRAM

Early in the program, the conical bottom of the glass reactor contained a single-orifice gas injector. This configuration was unsuitable for elevated temperature studies. Several design modifications ensued until a flat-topped gas distributor was designed. The flat-topped distributor was water-cooled and contained the graphite pressure seal previously described. When spouting or spout fluidized bed behavior was studied, the top of the distributor contained a central 2 mm diameter orifice surrounded by a porous metal plate (30 micron average pore size). Gases could be introduced into the glass reactor through the central orifice, through the porous metal plate, or through both simultaneously. In the final gas distributor design, (Figure 3-28), the top surface consisted of a porous metal plate (30 micron average pore size) without a central orifice. Approximately one half of the porous metal surface was attached directly to the water-cooled base by brazing. With the current design, the temperature of the porous metal surface was below 300°C when the bed of fluidized silicon particles was at 950°C.

To prevent elutriation of silicon fines from the fluid-bed reactor, a porous metal filter assembly was attached to the top of the glass reactor tube. The filter (30 micron average pore size) was contained in a cylindrical stainless steel case. The filter assembly was larger in I.D. than the reactor and fit over the top of the reactor without resting on the glass. It was supported by an overhead cable. The base of the filter assembly was attached to a Viton disk which, in turn, was attached to a collar sealed (by means of an O-ring) to the upper portion of the glass reactor tube. The exhaust gases were directed through a hygrometer probe and to a bubbler to maintain the pressure within the reactor slightly above atmospheric.

- Seed-bed Source

To meet the purity objectives of the program (production of semiconductor-grade silicon), a high-purity source of the seed material must be obtained. Once the fluid-bed reactor is operational, a portion of the product may be crushed and reused as seed material. The initial source of the seed

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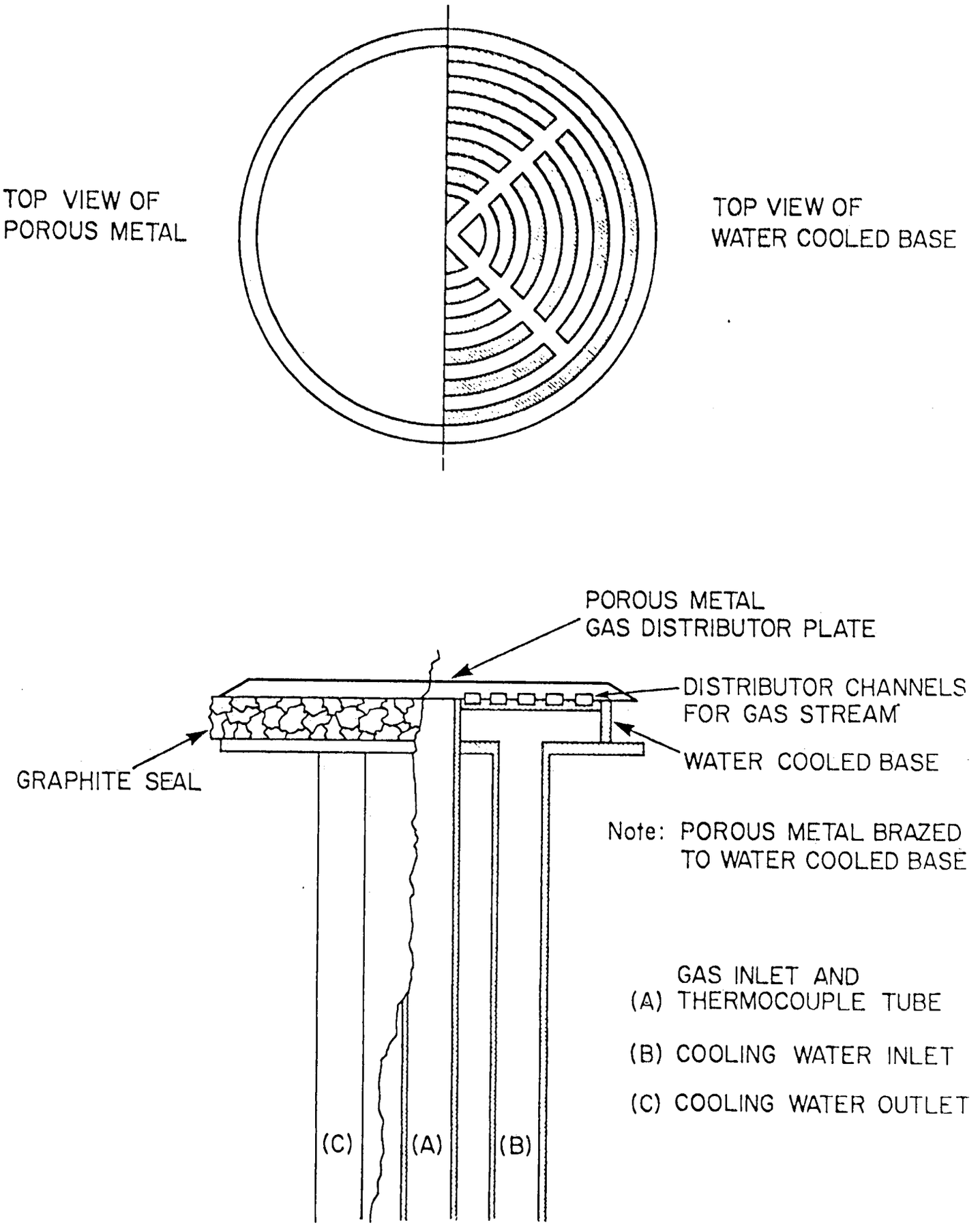

FIGURE 3 - 28

GAS DISTRIBUTOR FOR FLUID-BED REACTOR

material could probably be obtained from a manufacturer of high-purity polycrystalline silicon. An investigation was conducted to determine the practicality of crushing bulk silicon using a hammer mill and cone, jaw, and roller crushers. After the first comminution, the particles were classified by screening into specific size ranges. The particles remaining on the 35 mesh Tyler screen were returned to the same crusher and the process repeated. The data presented in Table III-11 are the cumulative yield after three crushings and classifications. For particles in the -35/+60 mesh size range, a 50% yield was obtained through the combined use of a hammer mill and the roller crusher. The free-flow and tap densities are presented in Table III-12, which lists the average cumulative properties of the silicon particles. Figure 3-29 shows the typical acicular shape of all of the powders examined with a scanning electron microscope (SEM).

Dry and wet tumbling (polishing) of -35/+60 mesh particles were evaluated as a means of converting the acicular particles into a more spherical shape. A 10.2 cm diameter rubber container was used for the polishing experiments, which were of 4, 8, or 24 hours duration. Methanol and distilled water (equal volumes) were added to the powder charge for the wet polishing experiments. There was little change in screen analysis before and after the tumbling experiments. Examination of the particle shape in the scanning electron microscope did not reveal any noticeable decrease in particle acicularity.

- Experiments

Several silane pyrolysis experiments were conducted with the dual gas distributor. Mixtures of silane and helium (from 3.3 to 14.7 volume percent silane) were injected into the fluid bed reactor through the central orifice. An envelope of helium surrounding this gaseous mixture was used to fluidize the silicon particles. Although the intent was to have a spout fluidized bed, no spout was observed when the beds were at temperatures ranging from 840° to 1010°C; very active particle motion with a great deal of slugging was observed. The products of all pyrolysis reactions were powdered silicon and silicon coatings on the seed particles. No deposits were observed on the

TABLE III-11

CUMULATIVE YIELD FOR SEVERAL CRUSHING METHODS

Crushing Method	Feed Stock Size	Cumulative Yield for Mesh Size Listed			
		+35	35/60	60/100	-100
Roller Crusher*	1.3 cm to +35 mesh	1	37	31	31
Hammer Mill	10 cm to +35 mesh	23	43	20	14
Jaw Crusher	10 cm to +35 mesh	81	10	4	5
Cone Crusher	10 cm to +35 mesh	77	12	5	6

*The feed stock had to be reduced (via the jaw crusher) to the size indicated for acceptance through the roller crusher.

TABLE III-12

CUMULATIVE PROPERTY DATA FOR CRUSHED SILICON*

Crushing Method	Tyler Mesh	Density (g/cc)**		Flow Rate sec/50 g***	Surface Area (m^2/g)
		Free Flow	Tap	Si	
Cone Crusher	35/60	1.05	1.25	-	0.03
	60/100	0.91	1.14	156.64	0.06
	100/250	0.85	1.16	142.9	0.11
Roll Crusher	35/60	1.09	1.25	-	0.03
	60/100	0.99	1.27	127.27	0.07
	100/250	0.95	1.31	123.58	0.15
Hammer Mill	35/60	1.14	1.33	-	0.028
	60/100	1.08	1.33	101.64	0.04
	100/250	0.98	1.31	107.9	0.08
Jaw Crusher	35/60	1.08	1.28	-	0.075
	60/100	0.92	1.20	154.3	0.17
	100/250	0.85	1.17	154.7	0.25

*The data are average values obtained after each of the crushing operations.

**The free flow and tap densities were determined using a standard procedure established by the Technology Department at the Parma Technical Center.

***The ASTM Designation B213-48 (Reapproved 1970) was followed in determining the rate of flow of the powders. The 35/60 mesh size particles were too large for the flowmeter funnel.

FIGURE 3 - 29

PHOTOMICROGRAPH OF -60/+100 MESH SILICON PARTICLES (50 X)

wall of the reactor. Figure 3-29 is a photomicrograph of particle cross-sections from a 900°C experiment. The coatings were porous and approximately 60% of the particles examined had coatings (maximum thickness of 60 microns). In all experiments, except one, a small hollow cylinder of silicon grew around the central orifice. Experiments were conducted for up to two hours with no observable silicon deposits on the reactor wall, nor any evidence of particle clustering.

Two series of experiments were conducted using the flat-topped porous metal plate distributor that did not contain the central orifice. In one series of experiments, a 200 mm deep bed was operated in the slugging mode with one percent silane in helium at 500°, 600°, and 950°C. At the lower temperatures, a significant (14%) quantity of the seed bed (-35/+60 mesh) was elutriated from the reactor and remained in the filter assembly. At all temperatures, considerable quantities of silicon powder were produced together with a shiny, mirror-like plated layer of chemically vapor deposited (CVD) silicon on the inside of the quartz reactor tube. Seed-bed particles from the elevated temperature experiments were not examined. Photomicrographs of sectioned particles (Figures 3-30 and 3-31) show that the coatings obtained at 500°C were porous and loosely attached to the seed particles, while dense and more coherent coatings were obtained at 600°C.

In the second series of experiments with the same gas distributor, 400 mm deep beds of -35/+60 mesh silicon particles were operated in the bubbling mode (approximately 1.5 times minimal calculated fluidization velocity) with 1% and 3% silane and helium. The experiments were conducted at temperatures of 500°, 600°, and 650°C. With the higher silane concentration, incomplete conversion to silicon occurred (a silane flame was visible at the vent port). At 600°C, higher pyrolysis efficiencies were obtained in bubbling beds than in the slugging beds. The pyrolysis products consisted of powder, CVD coatings on the inside of the reactor wall, and particle coatings. Scanning electron micrographs of the particles showed a nodular growth indicative of dense coherent plate on the seed particles from all bubbling-bed experiments. In addition, bubbling beds appeared to produce less powder than the slugging beds.

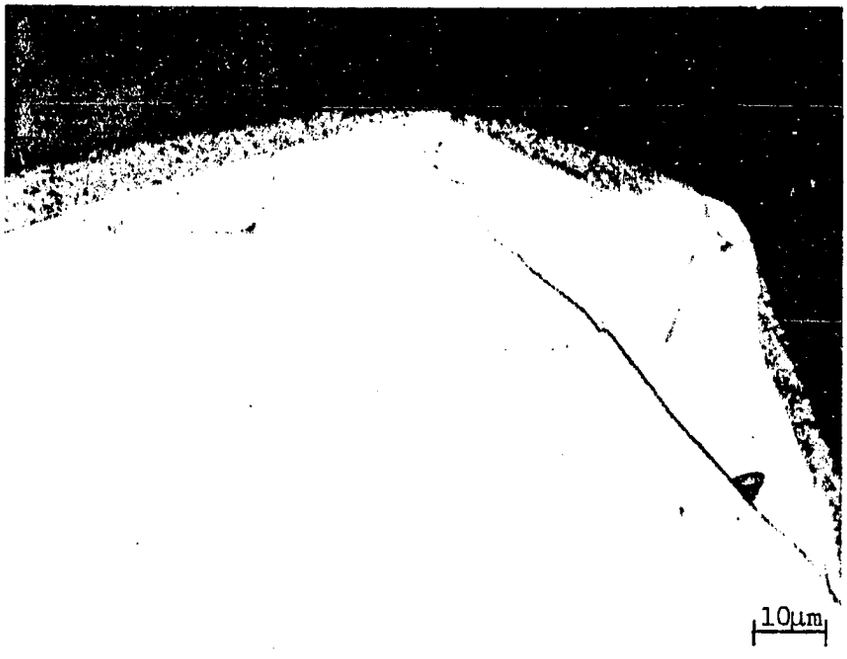

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FIGURE 3 - 30

PHOTOMICROGRAPH OF SECTIONED SILICON PARTICLE COATED AT 500 ^{o}C (1000 X)

FIGURE 3 - 31

PHOTOMICROGRAPH OF SECTIONED SILICON PARTICLES COATED AT 600 °C (1000 X)

One experiment was conducted to demonstrate that the current fluid-bed reactor could operate in the bubbling mode for 48 hours continuously. The reactor was operated with 1% silane in helium as the fluidizing gas for a 400 mm deep bed of -35/+60 mesh silicon particles. After completion of the 48-hour experiment, it was observed that the Pyrex reactor tube had slumped and expanded in diameter from 85 to 100 mm. Beneath the expanded portion, a porous plug of agglomerate particles (approximately 70 mm high) had formed starting 80 mm above the gas distributor. Subsequent experimental data indicated that the gas flow in the plug region was insufficient to maintain a bubbling bed. Consequently, the bed temperature near the distributor was too low for significant pyrolysis to occur and minimal silicon plating occurred below the plug. Above the plug where the seed particles remained fluidized, uniform particle plating occurred. A small quantity (5%) of powdered silicon was produced and some plating occurred on the reactor wall. However, most of the silane-to-silicon conversion occurred in the plug. The overall silane-to-silicon conversion efficiency for the 48-hour experiment was at least 90%. In addition, photomicrographs of cross-sections of particles from above the plug revealed that dense coherent coatings were obtained.

In spite of the undesirable plug formation, demonstration of a continuous 48-hour experiment in the bubbling mode is an important step in fluid-bed pyrolysis development. From the above experiments, it was concluded that the bubbling fluidization mode is better suited for heterogeneous silane pyrolysis than other modes such as spouting and slugging. Problems related to powder and plug formation should be addressed in future experimental work.

3.2.3.2.2 Horizontal Tube Experiments

Experiments were conducted in horizontal pyrolysis reaction tubes to better understand and control the morphology of the silicon produced from silane in fluid-bed reactor experiments. The experiments were conducted by directing silane/helium mixtures both into heated empty transparent tubes and into heated transparent tubes packed with silicon particles.

The experiments with the empty tubes were conducted at temperatures ranging from 440° to 900°C and silane concentrations ranging from

1/2% to 2%. In empty tube experiments conducted at 440° and 490°C, most of the silane passed through the tubes without decomposing. However, the tubes were discolored, indicating that some silicon did deposit. In all other empty tube experiments, (temperatures ranging from 515° to 900°C) gas-phase decomposition into silicon powder occurred together with deposits on the tube that appeared to be dense.

For the packed tube experiments, two particle size cuts of metallurgical-grade silicon particles were used: an average particle size of 335 microns and approximately 1 cm fragments. Experiments were conducted at temperatures ranging from 475° to 800°C and silane concentrations of 1/2% to 10% in helium. By comparison to the open tube experiments under similar conditions, the visual onset of pyrolysis in the packed tubes shifted closer to the gas inlet end of the tubes. Select seed beds were examined microscopically after the pyrolysis experiments. At temperatures of 540° and 600°C, the silicon that deposited on the 335 micron seed particles resembled fibers and no powder was observed. Figure 3-32 is a photomicrograph of typical fibers. Fiber growth was also observed by other investigators (Levin, Ref. 4 and Osada, et al., Ref. 5). Close examination of the fibers, grown at 600°C, revealed that they were extremely long and thin; whereas, the fibers grown at 540°C were much shorter. The length of the fibers also appeared to increase with silane concentration.

In experiments conducted at 540°C, with 1 cm particles, fiber growth was reduced and the primary growth appeared nodular. At 800°C, using 1 cm particles, the product was primarily fine powder. In select experiments, efforts were made to pour the tube contents onto a table for examination For the 475°C experiment, this was easily accomplished and revealed that friable agglomerates had formed. For higher-temperature experiments, (at 525° and 575°C), the agglomerated particles bridged the reaction tubes and blocked the powder from flowing out. Examination of particles from the agglomerated region revealed the presence of nodular and fiber growth on the particle surfaces.

The data generated in the horizontal reactors explained some of the observed behavior in the more complex fluid-bed reactor. It was assumed

FIGURE 3 - 32

PHOTOMICROGRAPH OF SILICON FIBER (900 X)

that silane decomposition in a large bubble was comparable to decomposition in an empty tube. Consequently, the data indicated that more silicon powder should have formed in the slugging bed than in the bubbling bed. This behavior was observed in the fluid-bed reactor both at 500° and 600°C. The horizontal reactor data also suggested that lower fluid-bed reactor temperatures would result in the production of fewer fines but with reduced decomposition efficiency for a given bed depth. The fluid-bed reactor experiments support the contention that lower temperatures result in a lower silane decomposition efficiency. However, insufficient data are available to relate the production of fines to operating temperature. Again, not enough data are available to account for the difference in the morphology of the silicon deposits obtained on fluid-bed seed particles and those obtained on similar sized particles in the packed beds. The fluid-bed reactor particle coatings resembled those obtained in packed beds of substantially larger particles.

3.2.3.3 Fluidization Studies

Pyrolysis studies conducted during this program have indicated that the homogeneous nucleation of silicon fines is minimized when the fluid-bed pyrolysis unit is operated as a bubbling bed. Fluidization tests with inert gas were performed to establish the range of operating conditions under which bubbling bed occurs, and to develop a gas distributor that will evenly spread the feed gas at high temperature, without clogging.

Gas distribution affects the type and quality of fluidization. In addition, the distributor may be designed to segregate particles by size. Inert gas tests of distributors designed to avoid clogging and achieve these goals were performed in 2" and 6" diameter beds.

3.2.3.3.1 Fundamental Bed Behavior

The aim of the inert gas experiments described in this section was to determine the behavior of fluidized beds of silicon particles as a function of bed size and fluidizing gas properties. Bubbling-bed conditions were investigated, with additional experiments of slugging and spouting beds.

- Bubbling-Bed Tests

In each of these tests, the gas distributor was a sintered metal plate which caused the gas to flow uniformly into the bed. In room-temperature, atmospheric tests at the Parma facility in an 85 mm I.D. column, active bubbling beds of -35, +60 mesh silicon were demonstrated with helium and argon fluidizing gas and bed heights between 50 mm and 200 mm. The distributor design in these experiments also allowed spouting bed operation.

Experiments were also conducted at elevated temperatures in which helium was the fluidizing gas in beds ranging in height from 50 mm to 200 mm. Both the dual-gas-injector system (no gas was injected through the central orifice) and a porous-metal, gas-distributor plate were evaluated; no difference in bed behavior was observed between the two gas distributor designs. The experimental data are shown in Figure 3-33. The open data points represent the transition from a static bed to a fluidized bed; the transition was observed for decreasing molar flow rates due to expansion with temperature. The data designating the onset of fluidization are in good agreement with the calculated minimum fluidization velocities. Flow rate hysteresis effects were not observed for the transition from a fluidized-(bubbling) bed to a slugging bed, as shown by the closed data points. Increasing gas flows were used for this determination. Gas flow observation of the transitions in bed from bubbling to slugging were subject to operator judgment. In addition, the transition from bubbling to slugging beds was less clearly defined for the 50 mm and 100 mm beds than for the deeper beds.

The fluidization behavior of -60/+100 mesh silicon particles was also determined as a function of gas velocity and reactor wall temperature for bed depths of 50 mm and 200 mm. Figure 3-34 shows the experimental data. The curves were similar to those in beds of -35/+60 mesh particles. The gas injection velocities at which the bubbling to slugging transition occurred decreased with increasing temperature. The gas flows for incipient fluidization were too low to measure with the flowmeter installed in the system. Minimum fluidization velocity decreases with increasing temperature and increases with increasing particle size.

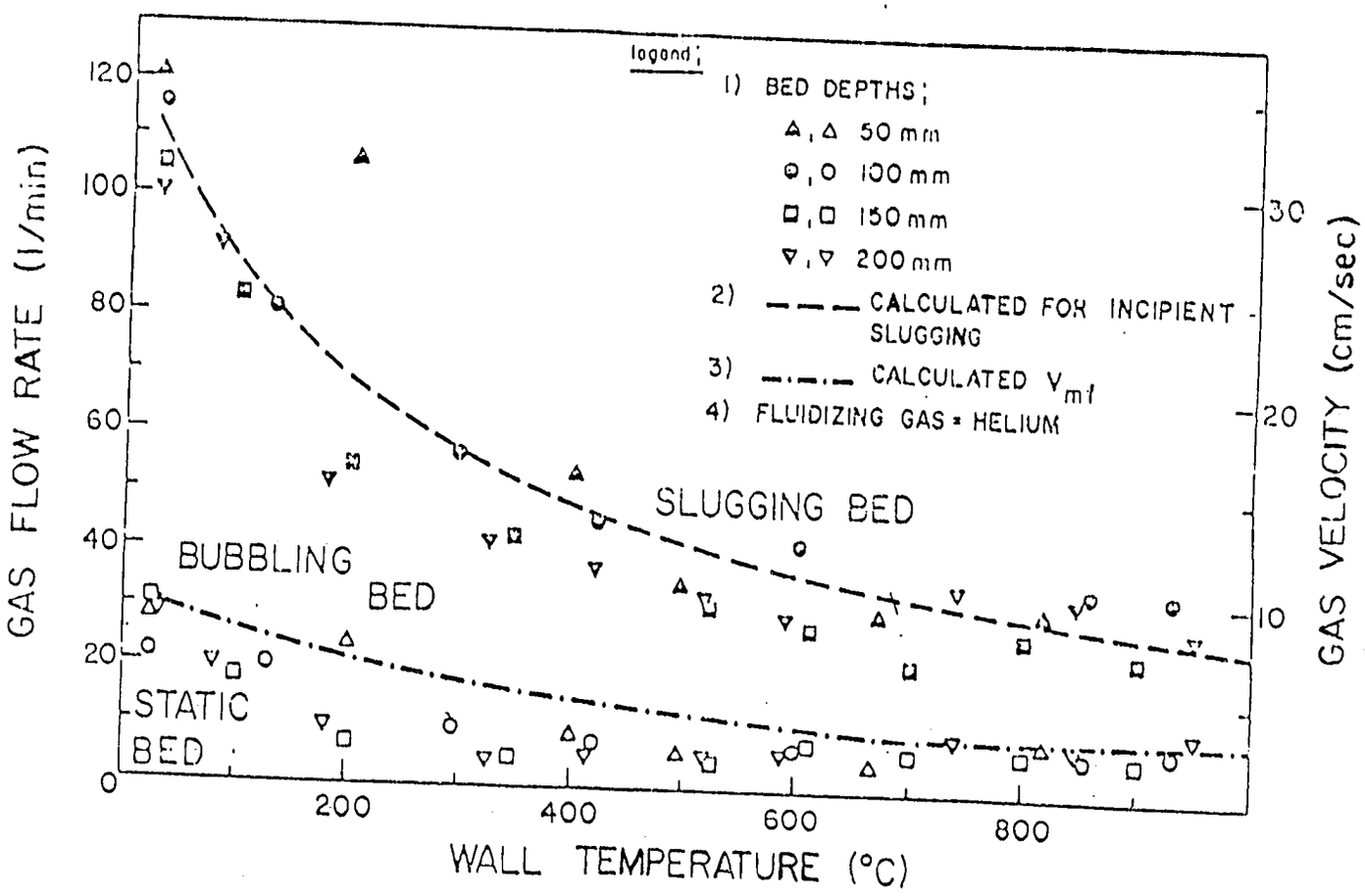


FIGURE 3 - 33

FLUIDIZATION BEHAVIOR OF -35/+60 MESH SILICON PARTICLES

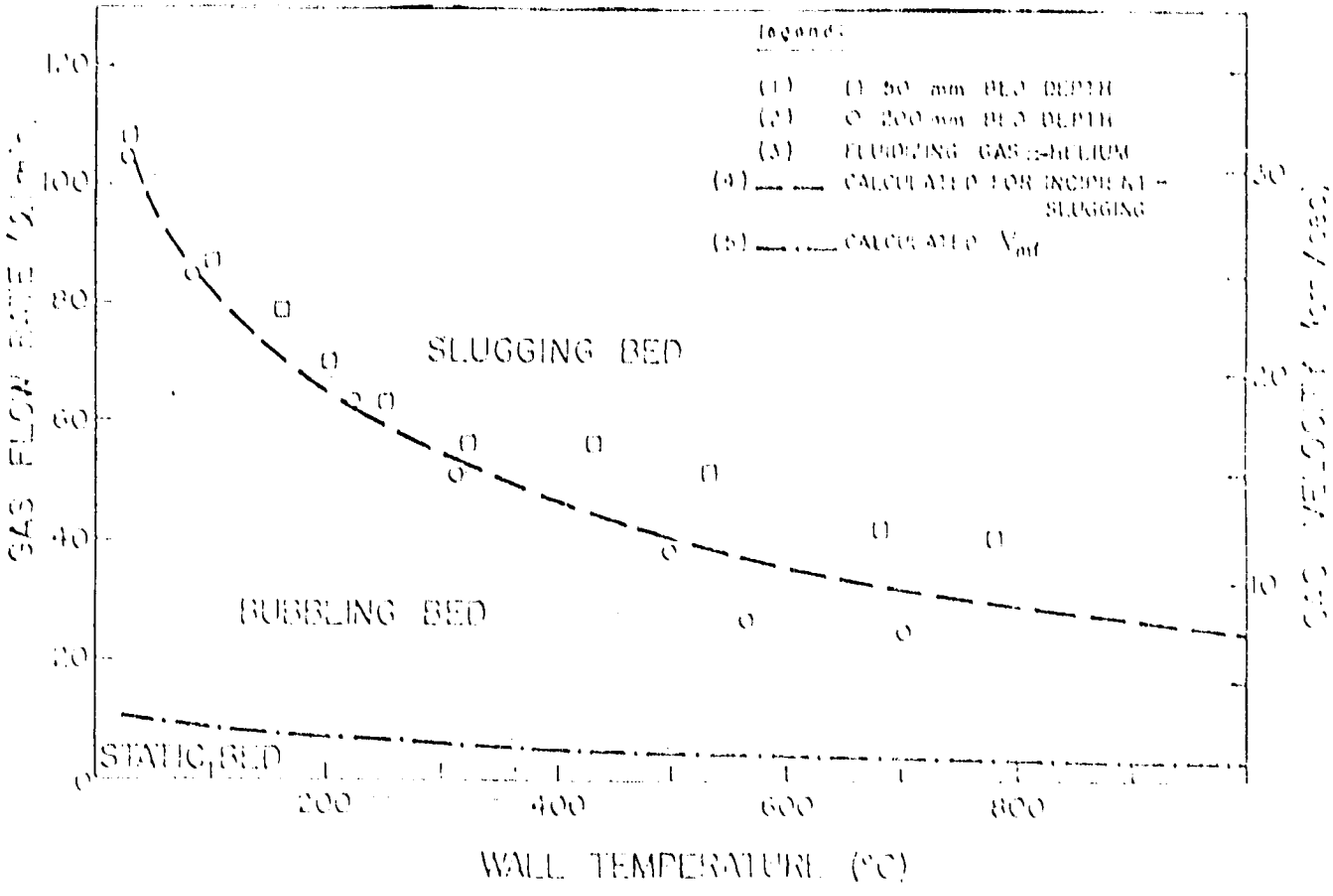


FIGURE 3 - 34

FLUIDIZATION BEHAVIOR OF -60/+100 MESH SILICON PARTICLES

Fluid-bed pyrolysis experiments and inert gas experiments in relatively small (2" to 3" diameter) columns and the analytical model work described later in Section 3.2.3.4 indicate that the required bed height for essentially complete pyrolysis at projected conditions is on the order of one meter. To avoid slugging, and to model realistically larger beds, the current estimate is that the PDU must be 6" in diameter. Inert gas tests were done, therefore, in a 6" diameter column. Since operation with hydrogen and at high temperature was inconvenient, an alternative method was used to fluidize the particles with a gas of the same density and viscosity as hydrogen at elevated temperature. This was done by using helium at room temperature and reduced absolute pressure. By controlling the pressure, the density was controlled to correspond to different fractions of silane. This correspondence between cold-bed test pressure and PDU reactor temperature and composition is shown in Figure 3-35.

It was generally found that for beds up to one meter deep, a wide range of velocities could be used without slugging. These results are shown in Figure 3-36 for -35/+60 mesh particles. This figure shows results under conditions that are relatively unfavorable (low gas density and deep bed). Even so, there is at least a factor of three between the minimum fluidization velocity and the minimum slugging velocity.

These tests confirm that a 6" diameter PDU is large enough to avoid slugging under projected permitting conditions, with results applicable to larger beds.

- <u>Test of Other Fluidization Modes</u>

Room-temperature experiments were conducted with two gas distributor designs to evaluate the seed-bed behavior as a function of particle-size distribution, bed depth, and gas inlet flow velocity in the spouting regime. Helium and argon were used as fluidizing gases. With a single-orifice, conical-base reactor, a spouting bed (without slugging) was only obtainable over a narrow range of operating conditions. Another series of experiments was conducted with a flat-topped, dual-gas distributor. This

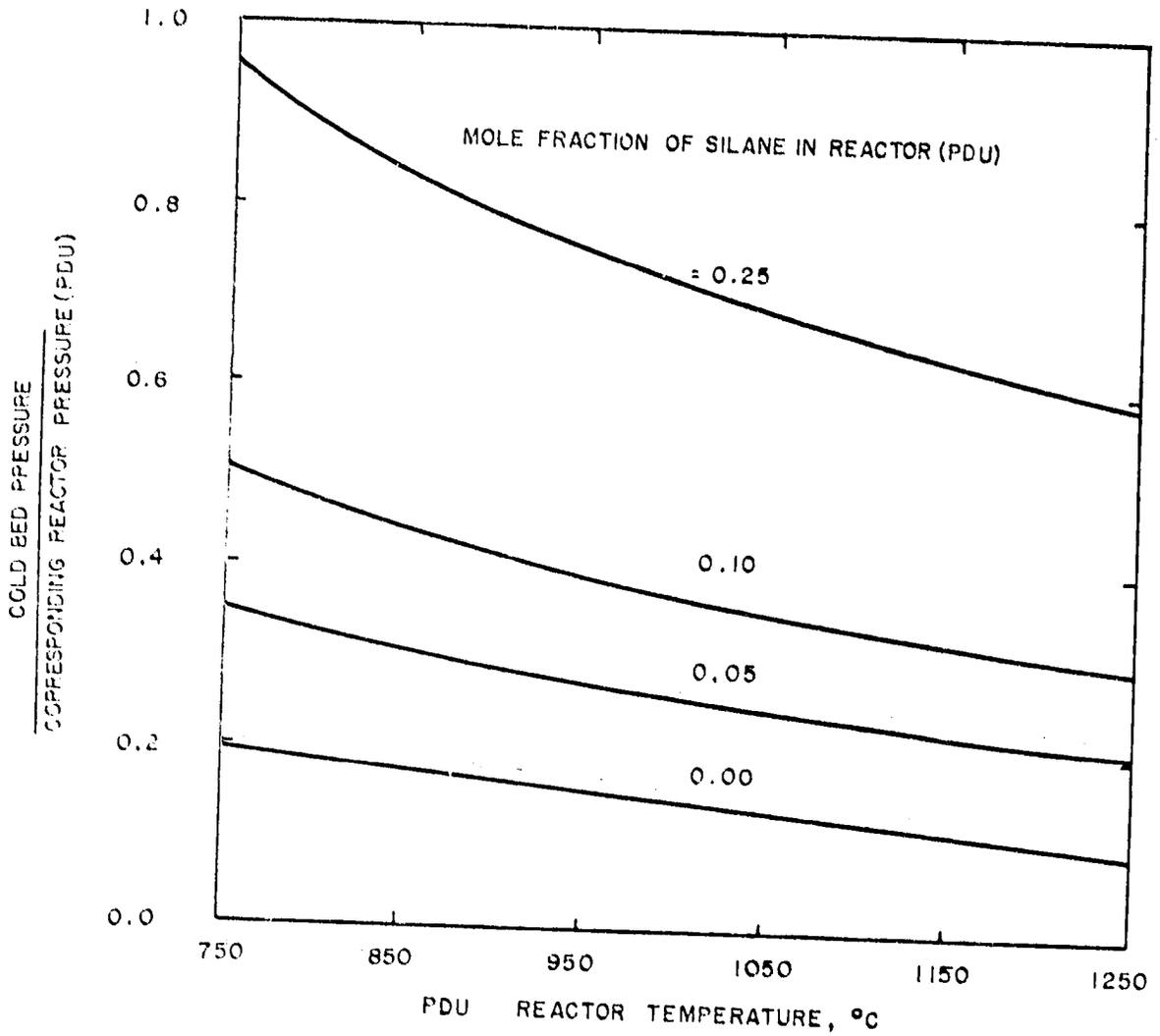


FIGURE 3 - 35

DENSITY MATCH BETWEEN HELIUM IN COLD BED AND SILANE-HYDROGEN MIXTURE IN HOT BED AT VARIOUS SILANE MOLE FRACTIONS AND TEMPERATURES IN HOT BED

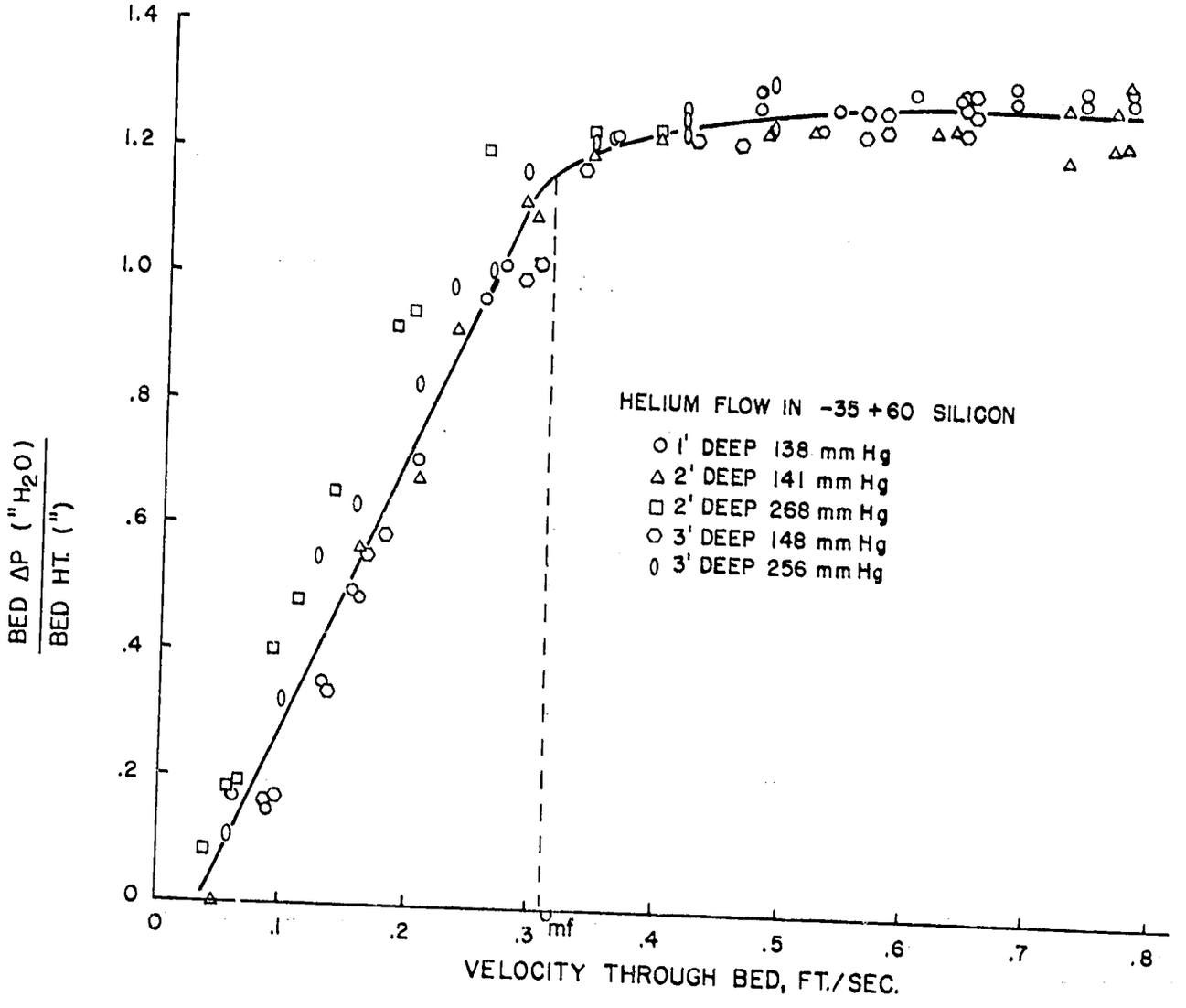


FIGURE 3 - 36

PRESSURE DROP THROUGH BED VS HELIUM
VELOCITY IN BED UNDER PARTIAL VACUUM

distributor contained a centrally located spout orifice (2 mm diameter) surrounded by a porous metal plate. When helium was injected through only the central orifice and the porous metal plate, a stable spout was established while the annulus region was in a fluidized state. It was observed that too high a gas velocity through the porous metal plate would extinguish the spout. When helium was injected solely through the porous metal plate (central injector orifice was not used), active bubbling beds were obtained, as described above.

Other alternative bed modes (fast or recirculating bed, moving bed, or turbulently fluidized bed) were not investigated since it was evident that the bubbling mode of fluidization was well suited for silane pyrolysis.

3.2.3.3.2 Distributor Design

A distributor for silane pyrolysis must meet the following criteria:

1) Uniform distribution of inlet gas. Uneven distribution causes channeling or in extreme cases, spouting or slugging. This leads to poor gas-solid contacting and uneven mixing.

2) Absence of clogging. Silane decomposition can quickly plug the distributor. Temperature control of the distributor is crucial for avoiding this problem.

3) If possible, segregation of particles by size and preferential withdrawal of large particles. This provides a more uniform product.

From the earlier discussion of bed behavior, it is clear that a flat-sintered metal plate can be used to achieve the first criterion; the second was met by integral water cooling of a sintered metal plate. As discussed in Section 3.2.3.2, this distributor operated continuously without

plugging for 48 hours, with no appreciable wear. Thus, the technique has been clearly demonstrated for introducing the gas into a bed of silicon particles.

The third criterion can be addressed by tapering the bed at the bottom into a boot section (as in Figure 3-37), where the superficial gas velocity is raised. This causes finer particles to be excluded from the boot section, thus segregating larger particles in the boot. The boot section of Figure 3-37 is a preliminary design.

Initial tests using the boot showed that segregation can be achieved at a slow rate (Figure 3-38). Further work will be necessary to optimize the parameters.

3.2.3.3.3 Attrition Experiments

Attrition by particle collision results in a loss of product from the bed. The rate of loss clearly depends on the friability of the solids and the violence of mixing in the bed. In these experiments, seed particles of crushed high-purity or metallurgical-grade silicon were used. These particles probably are less friable than those resulting from pyrolysis; the degree of difference is unknown.

Experimental attrition rates for different particle size ranges and degrees of fluidization were tested in a one-inch diameter bed. The results are shown in Figure 3-39. In each case, a brief spurt of rapid attrition occurred, after which the loss rate was less than 0.3%/day, which is negligible.

A separate observation was that high-purity silicon particles, even after thorough washing, discharged a large amount of brown dust after being fluidized at high temperature for 24 to 72 hours. This may be important in evaluating experimental results for two reasons: first, this effluent could be misinterpreted as homogeneous reaction product; and, second, the mode of heterogeneous pyrolysis growth (fibrous, modular, etc.) has been found to depend on the degree of dust on the surface being coated.

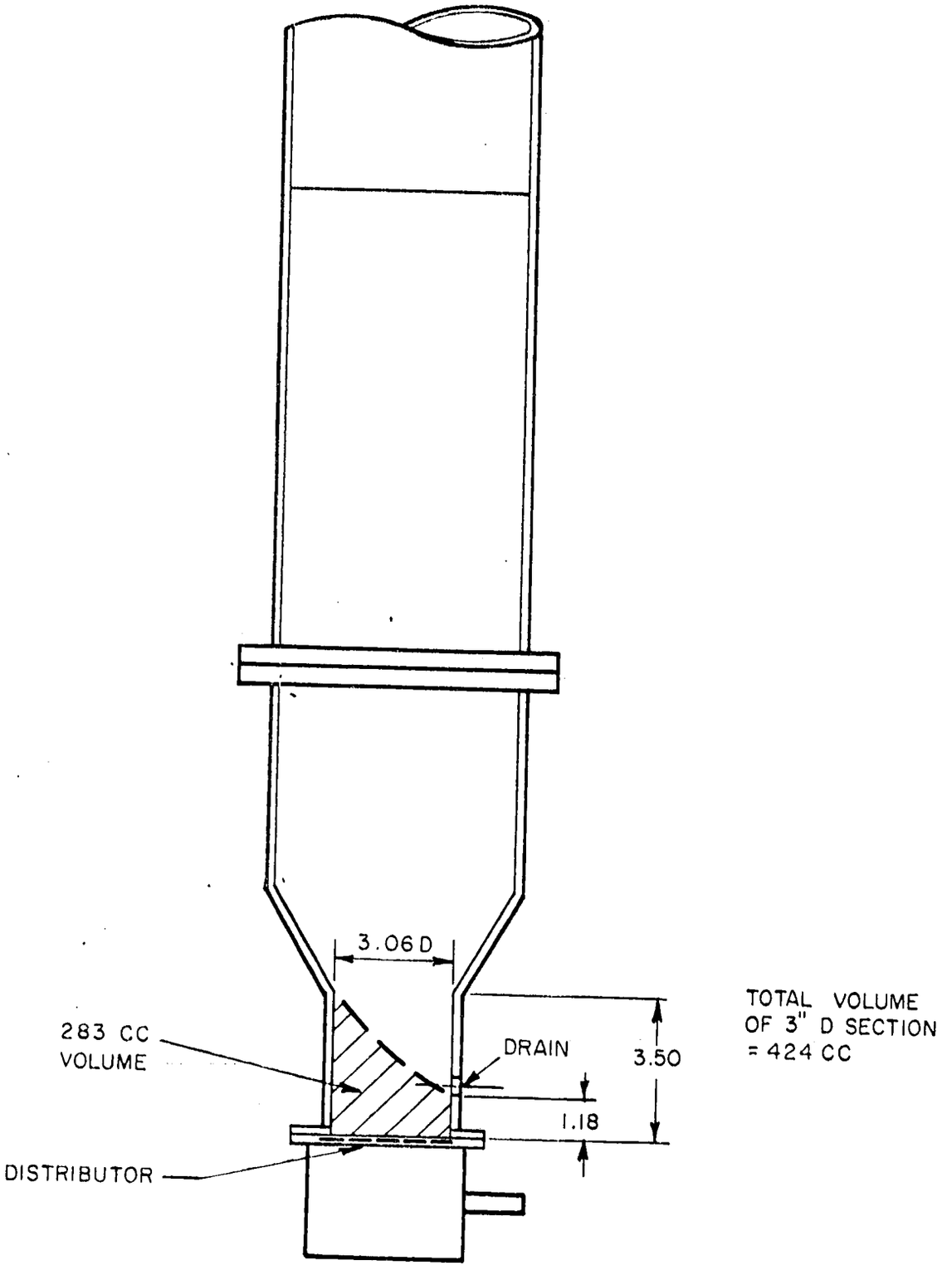


FIGURE 3 - 37

BOOT SECTION FOR PARTICLE SEGREGATION

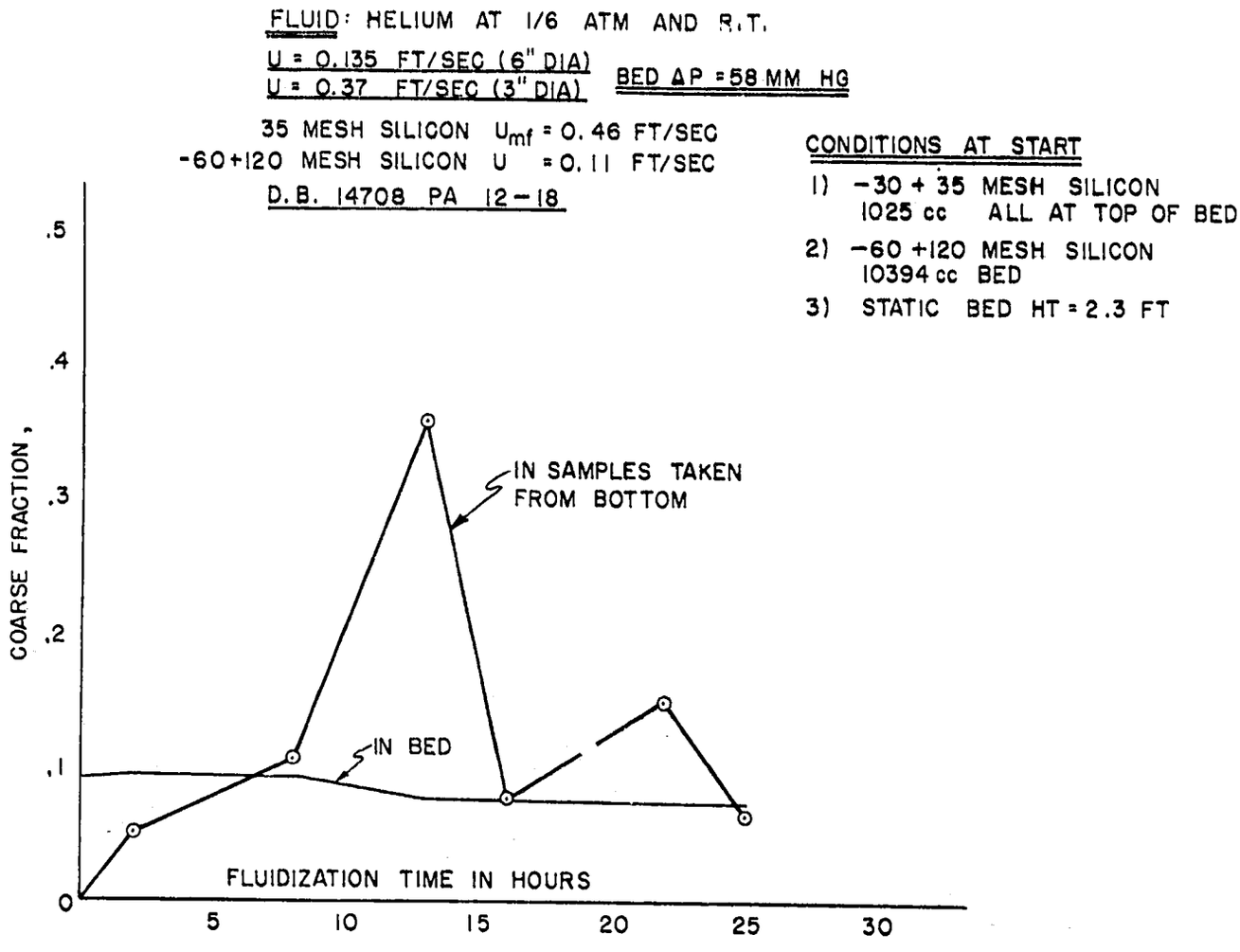


FIGURE 3 - 38

SEGREGATION DATA FROM PRELIMINARY TESTS

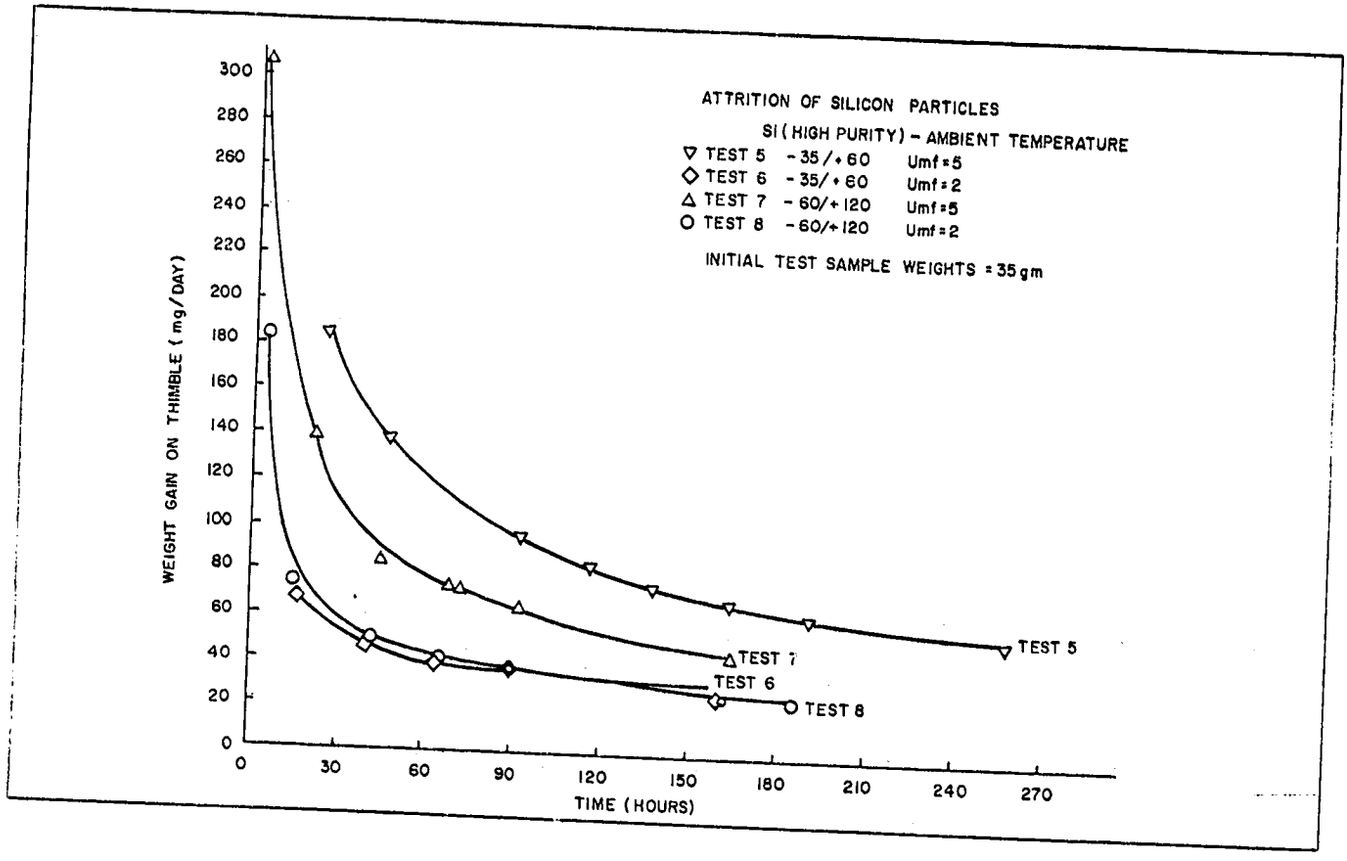


FIGURE 3 - 39

RATE OF FINES GENERATION FOR SEMICONDUCTOR-GRADE SILICON PARTICLES AT U/U_{mf} = 2 and 5

3.2.3.4 Analytical Model

An analytical model of the process of silane pyrolysis in a fluid bed facilitates the integration of experimental results and prediction of system performance. In the overall fluid-bed pyrolysis system, the inlet stream of silane is mixed with hydrogen and introduced at the bottom of the fluid bed. Small silicon seed particles enter the bed at another point. Particles in the bed are coated with additional silicon from the decomposition of the silane, and are withdrawn as product after sufficient growth. At the top of the reactor the gas stream exits as essentially pure hydrogen. A portion of this hydrogen is cooled and recycled to dilute the incoming silane. The remainder is recycled to the STC hydrogenation reactor. Energy is added to the fluid bed to maintain it at the desired temperature. This temperature, the amount of diluting hydrogen needed, the size of the reactor, and the amount of energy required are set by the requirements for complete heterogeneous decomposition of the silane. Heterogeneous decomposition results in the coating of the silicon bed particles; homogeneous decomposition results in the generation of low-density, submicron particulate, which is undesirable.

The key assumptions in the model are concerned with deposition rate data, which determine the necessary fluid-bed height and particle size, and critical concentration data which determine the amount of diluting hydrogen required to avoid significant homogeneous decomposition. The amount of diluting hydrogen primarily determines the energy consumption of the reactor and the reactor diameter for a given production rate.

The critical concentration data, available in the literature, are for high temperatures and low concentrations of silane. In epitaxial reactors (basically hollow tubes with inserts) at these conditions, the transition from heterogeneous to homogeneous decomposition is sharp and well defined. The values used here are extrapolations of this data. There is evidence that this is conservative when applied to the fluid bed. There is also some evidence (in work done at UCC/Parma and JPL) that at low temperatures, the transition between modes of decomposition is not sharp and that

the two modes occur at competing rates as would be expected. In the fluid bed, where the surface area-to-volume ratio is high, heterogeneous decomposition seems to be favored. This factor can be added to the model as further experimental data become available. Existing literature data are shown in Figure 3-40.

The model relates important process variables such as reactor size, conversion efficiency, operating temperature, particle size, energy, and hydrogen recycle requirements.

The amount of energy consumed per kilogram of silicon product is given by:

$$E = \Big\{(1 - f_{o\,SiH_4} + 2\,\eta\, f_{o\,SiH_4})\, h_{H_2}(T) - (1 - f_{o\,SiH_4})\, h_{H_2}(T_o) + (1 - \eta)\, f_{o\,SiH_4}\, h_{SiH_4}(T) - f_{o\,SiH_4}\, h_{SiH_4}(T_o) - \eta\, f_{o\,SiH_4}\, \Delta H_{f\,SiH_4} + \eta\, f_{o\,SiH_4}\, h_{Si}(T)\Big\} \div \Big\{\eta\, f_{o\,SiH_4}\, M_{Si}\Big\}$$

where:

E is the specific energy consumption (J/kg)

$f_{o\,SiH_4}$ is the mole fraction of SiH_4 at inlet (moles/mole)

M_{Si} is the molecular weight of silicon

h_{SiH_4} is the enthalpy of SiH_4 (referenced to 298.15°K) as designated at T or T_o

h_{H_2} is the enthalpy of H_2 (referenced to 298.15°K)

h_{Si} is the enthalpy of Si (referenced to 298.15°K)

$\Delta H_{f\,SiH_4}$ is the heat of formation of silane at 298.15°K

T_o is the temperature of gas prior to the entry into the reactor

T is the temperature of the reactor

η is the conversion efficiency

For complete conversion of silane to silicon, the energy requirement, reactor temperature, and fraction of silane are related as shown in Figure 3-41. The largest contribution to the energy consumption is in

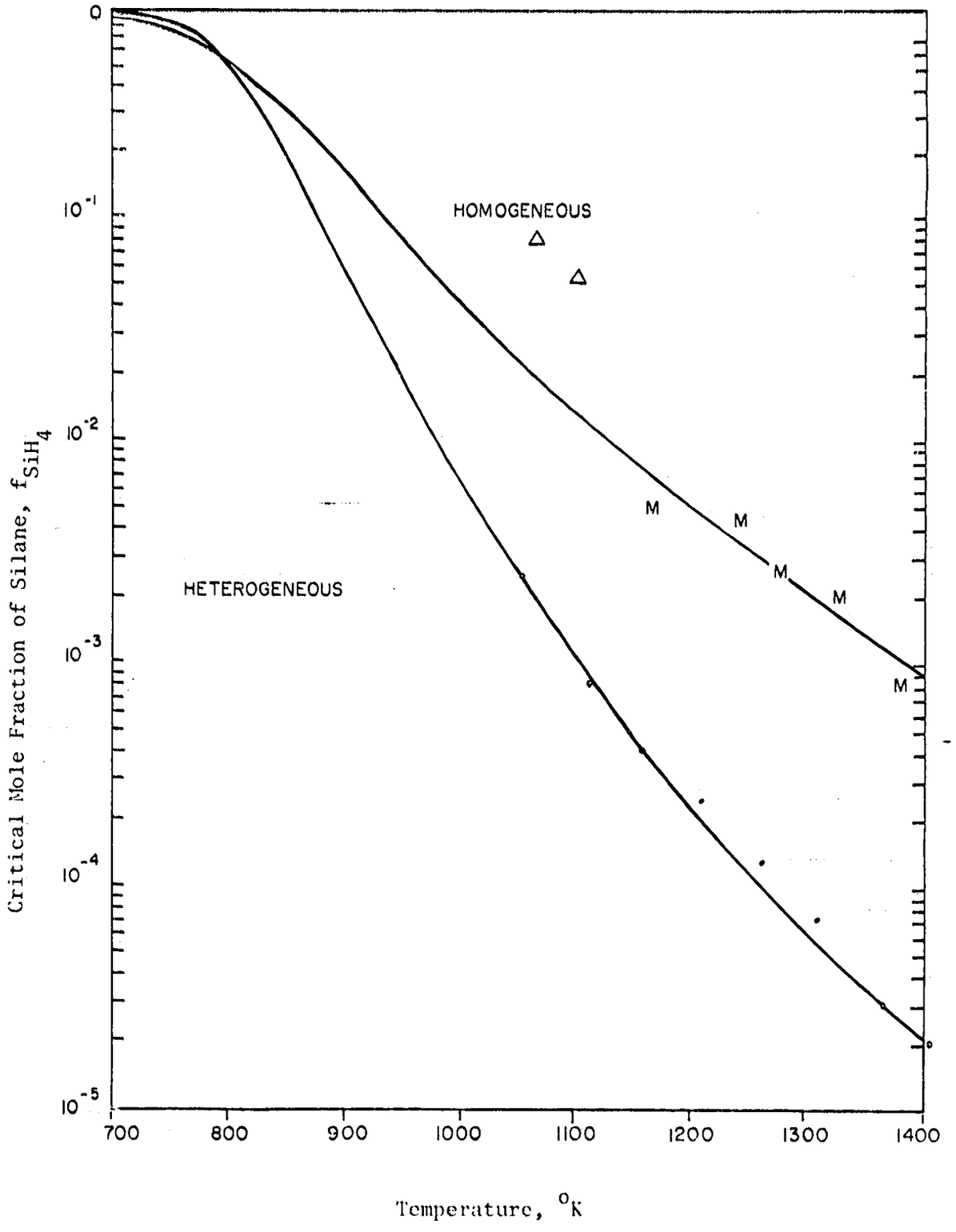


FIGURE 3 - 40

CRITICAL MOLE FRACTION OF SILANE AS A FUNCTION OF TEMPERATURE

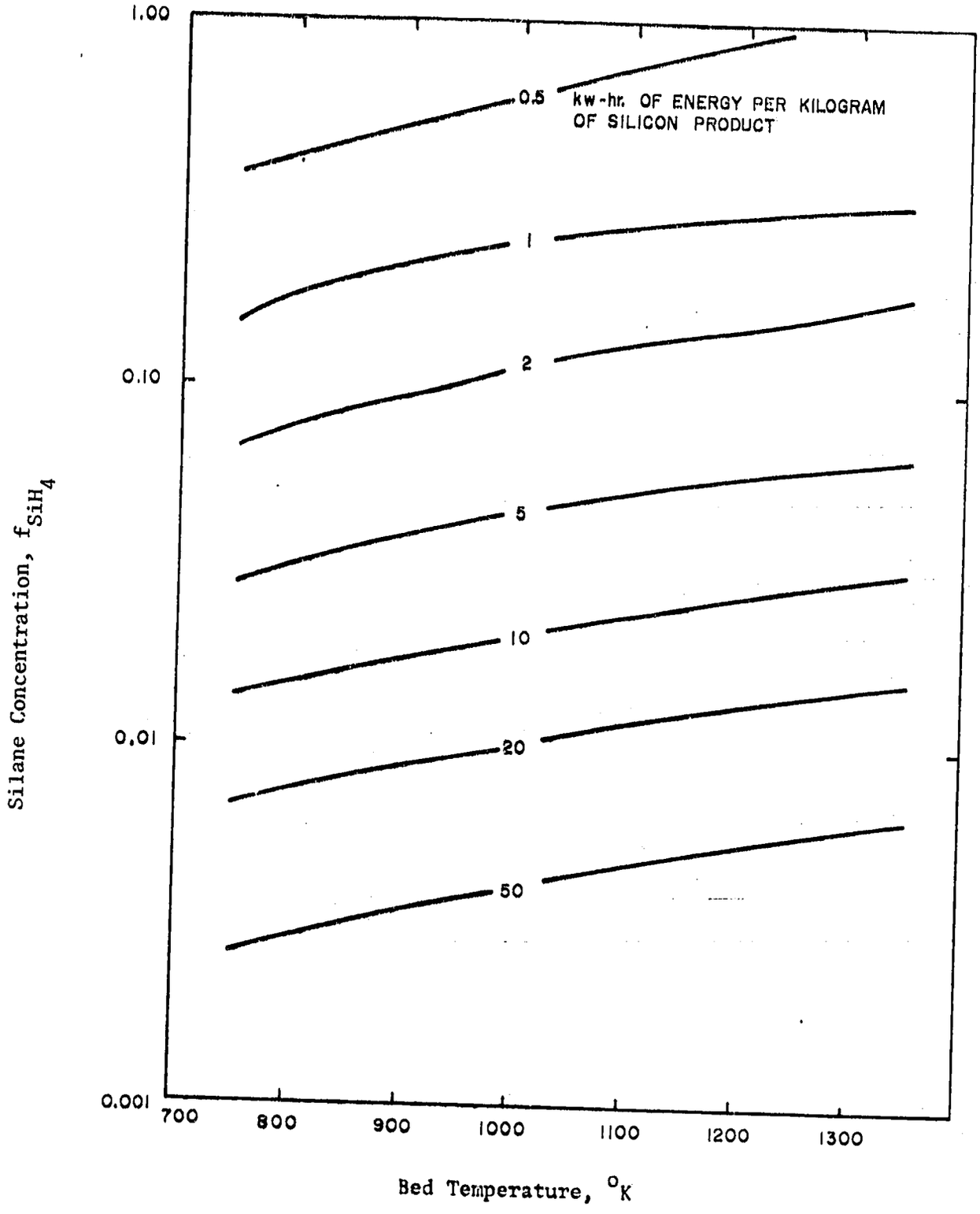


FIGURE 3 - 41

SILANE CONCENTRATION VS ENERGY CONSUMPTION AS A FUNCTION OF BED TEMPERATURE

heating the diluting hydrogen. The larger the feed concentration of silane, the smaller this becomes. This energy is required because the inlet hydrogen and silane must be at a temperature much lower than that at which the reaction occurs. In practice, this difference in sensible heat is greater than the heat of reaction of silane pyrolysis. Thus, even though the pyrolysis reaction is exothermic, additional heat is required.

The reactor dimensions are given by:

$$D = \left(\frac{4\,\tau}{\pi\, M_{Si}\, C_o\, U\, \eta} \right)^{1/2}$$

$$L = -\frac{M_{SiH_4}\, C_o\, U}{R(T)\, a} \left\{ (1 + f_{o\,SiH_4}) \ln (1 - \eta) + 2\, f_{o\,SiH_4}\, \eta \right\}$$

where:

D is reactor diameter (m)

L is bed depth (m)

τ is production rate of silicon (kg/s)

U is the superficial gas velocity at bottom of the reactor (m/s)

C_o is the concentration of silane at reactor inlet ($\frac{\text{moles}}{m^3}$)

$R(T)$ is the rate of decomposition of silane on the surface, per mole fraction of silane ($kg/m^2 s$)

a is surface area of particles per reactor volume (m^2/m^3)

M_{SiH_4} is molecular weight of silane (kg/mole)

Plug flow of the gas through the bed is assumed. This is the most appropriate model because it is probable that the bed will be operated only slightly in excess of U_{mf}, the minimum fluidization velocity. Backmixing of the gas is small, and bubbles disturb plug flow only slightly. The reasons for operating not far above U_{mf} are:

- The bubbles are small, reducing by-passing.
- The bed is not violently agitated. (This may allow the adherence of a loose coating of silicon that would not stick otherwise.)

- The voidage of the bed is not greatly increased, minimizing homogeneous decomposition.

- Internal heat transfer need not be extremely high in this application. Relatively slow solids movement is sufficient.

The minimum fluidization velocity and area per unit volume are taken from standard correlations (Kunii and Levenspiel, Ref. 6).

The reaction rate is experimentally found to be first order:

$$j's = R(T) f_{oSiH_4}$$

$$R(T) = (2.56 \times 10^5) \exp(-1.92 \times 10^4 / T) \quad (kg/m^2 s)$$

where:

j's is the rate of decomposition of SiH_4
P is the absolute reactor pressure (atmosphere)

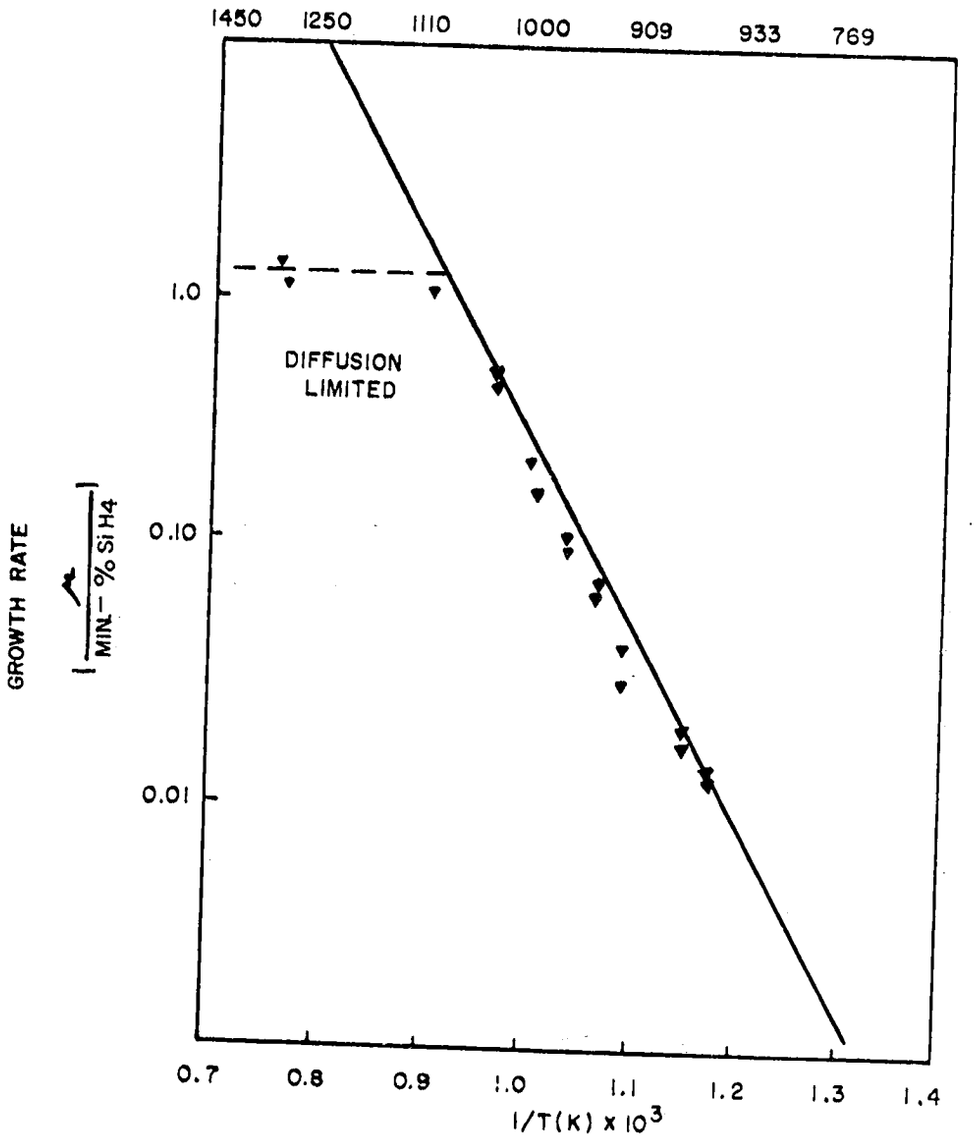
These data are available only at atmospheric pressure. At temperatures of interest, diffusion presents a negligible resistance to decomposition, and the decomposition reaction is the limiting step in the process. This is not true above approximately 1150°K as shown in Figure 3-42. The experimental data are from Eversteyn and Put (Ref. 7).

The reaction rate, as shown, increases rapidly with temperature (doubling approximately every 25°C). The critical mole fraction, however, decreases at about the same rate. This indicates that raising the temperature allows the reactor to be shorter. Since the total gas velocity through the bed is limited by the bed mechanics, higher temperature, implying lower silane feed fraction, in turn implies that the reactor diameter must increase with temperature.

Resulting calculations, showing these trends for reactor dimensions and energy consumption, are shown in Figures 3-43 through 3-45.

The required energy flux through the walls of the reactor is:

$$Q = \tau E / \pi D L$$



(Data Source: Eversteyn and Put, Ref. 7)

FIGURE 3 - 42

SURFACE REACTION RATE VS T^{-1} (K^{-1})

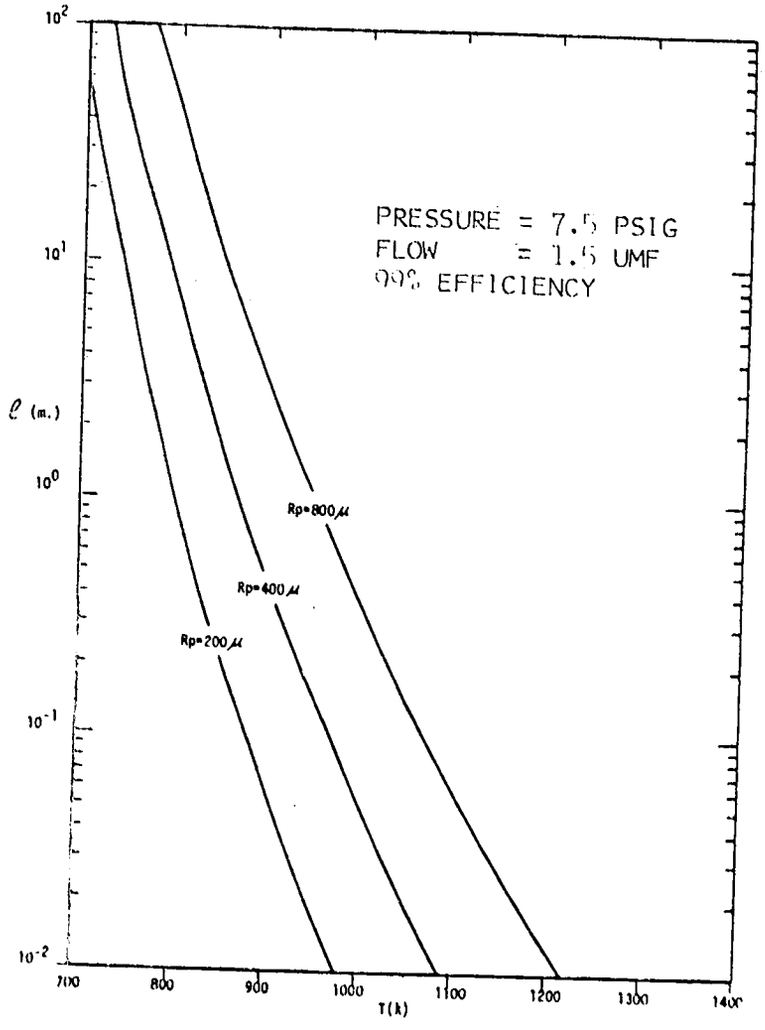


FIGURE 3 - 43

REACTOR LENGTH FOR 99% SILANE CONVERSION VS TEMPERATURE FOR SEVERAL PARTICLE SIZES

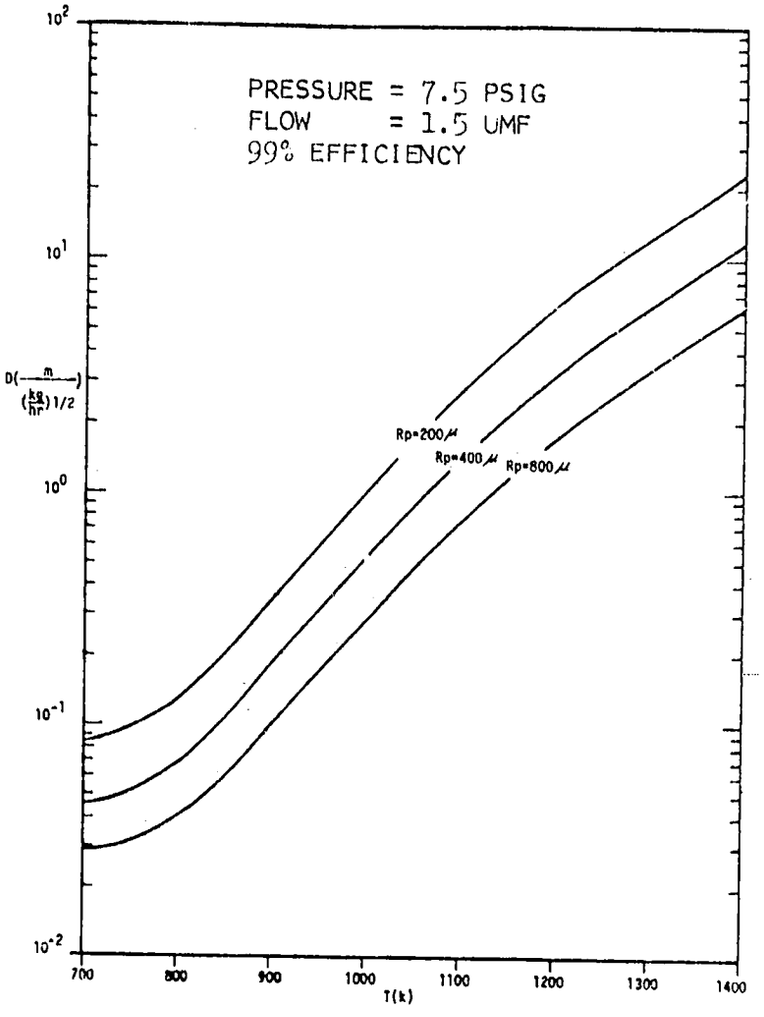


FIGURE 3 - 44

REACTOR DIAMETER FOR 1 KG/HR SILICON PRODUCTION VS TEMPERATURE FOR SEVERAL PARTICLE SIZES

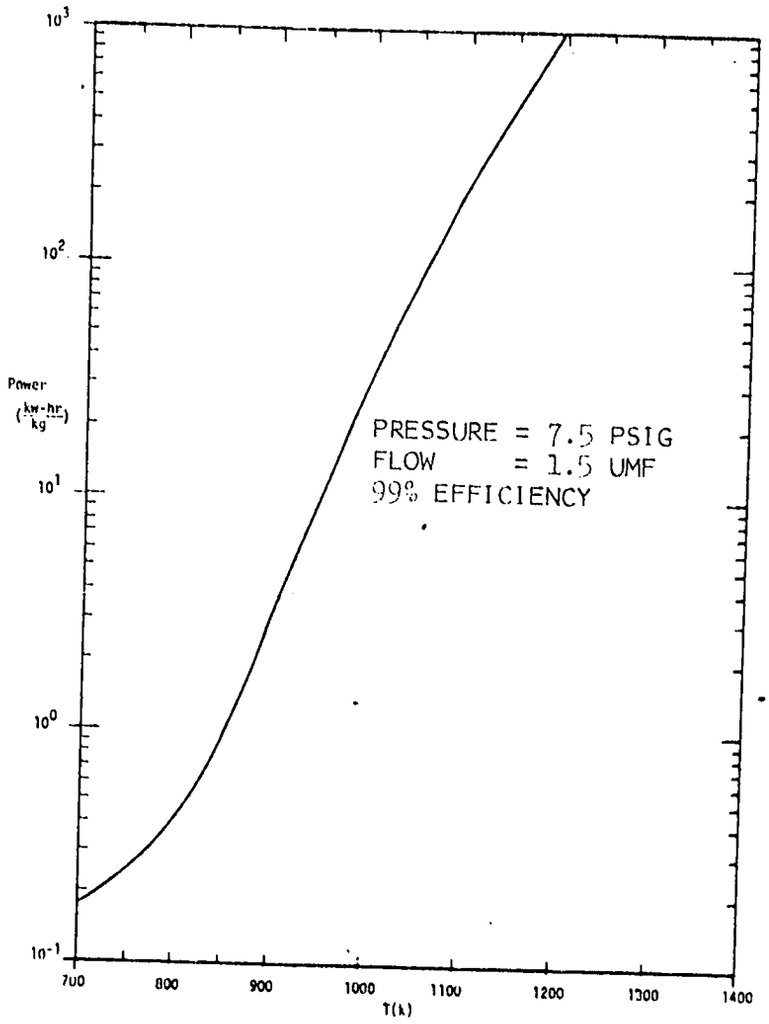


FIGURE 3 - 45

ENERGY CONSUMPTION PER KG OF SILICON PRODUCED VS TEMPERATURE

where:

Q is the energy flux (W/m^2)

This energy flux is shown in Figure 3-46. As the size of the reactor increases, so does the required flux. Typical heat-transfer coefficients for wall-to-bed heat transfer are 200-500W/m^2K. As noted, the reaction rate in this temperature range doubles every 25°C; therefore, the temperature differences shown are very significant. The wall, since it is hotter, coats faster than the particles. The gas near the wall is hotter than the bulk, favoring homogeneous decomposition.

The following results were obtained from the analysis of a single, isothermal bed:

- Based on the available pyrolysis data, a fluid-bed system that is energy-efficient and compact is feasible.

- By heating the particles directly, unfavorable wall reaction (heterogeneous and homogeneous) can be avoided, giving more useful product, increasing efficiency, and preventing reactor deterioration.

3.2.3.5 Capacitive Heating

Having determined that heating the bed particles directly is advantageous, there are different ways to accomplish it. Obvious choices such as radiant heat or laser beam heating are encumbered by severe economic and practical problems. The remaining methods are electrical.

Induction heating of the particles is effective only for very high electrical frequencies and very large particles. In other electrical methods, current is passed through the bed; that is, it is imposed rather than induced. Although direct current has been used, there are disadvantages:

- A continuous, very low impedance metallic conducting path to the particles must be maintained. This precludes the use of quartz or glass lining.

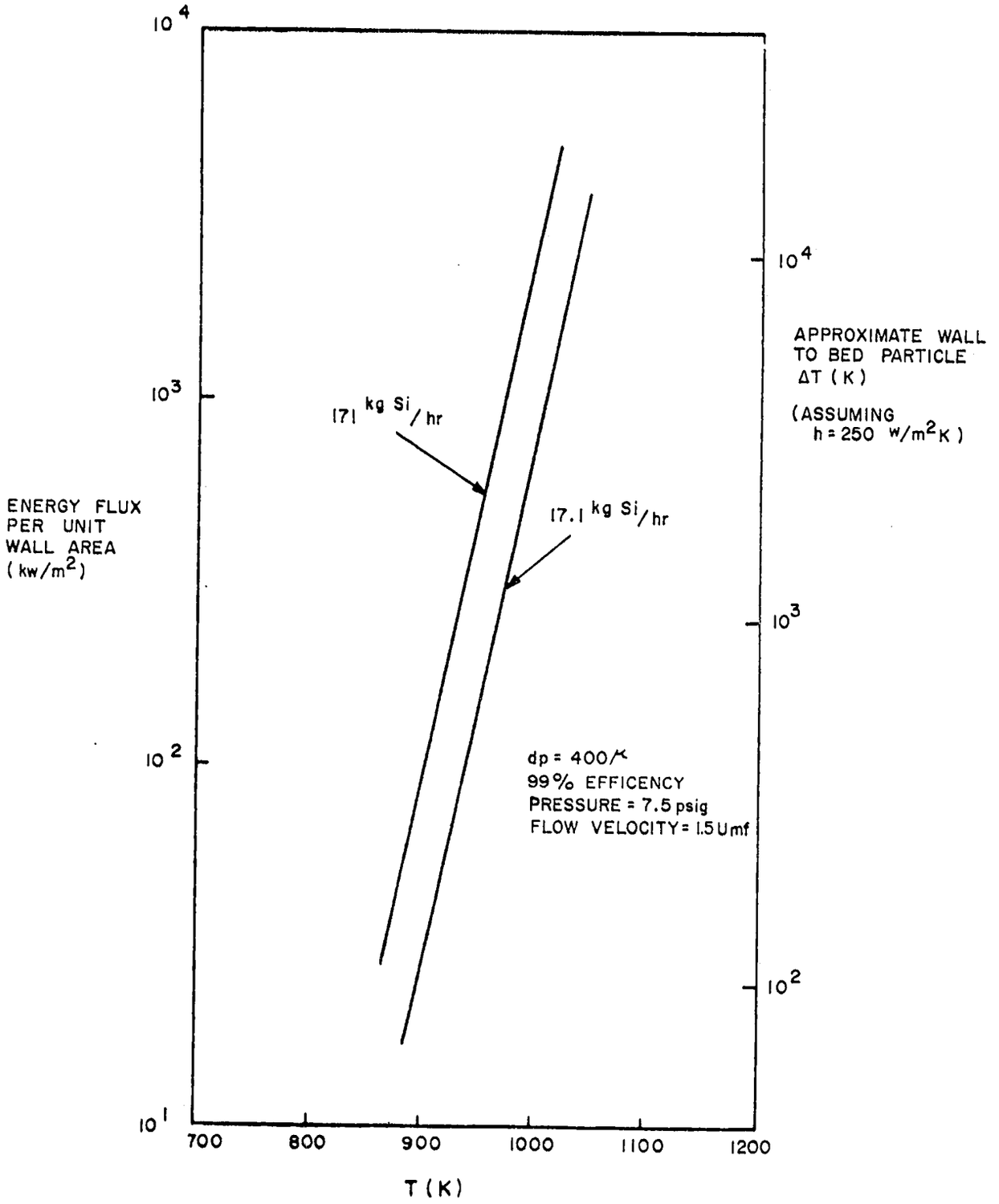


FIGURE 3 - 46

ENERGY FLUX THROUGH THE WALLS VS BED TEMPERATURE

- Direct current encourages arcing relative to high frequencies, which could promote a type of homogeneous decomposition.

The use of high-frequency current to heat the particles is shown in Figure 3-47. Electrical current is passed through the reactor walls and bed particles are coupled capacitively through a thin dielectric coating. The dielectric coating serves two purposes:

1. It acts as a diffusion barrier to impurities.

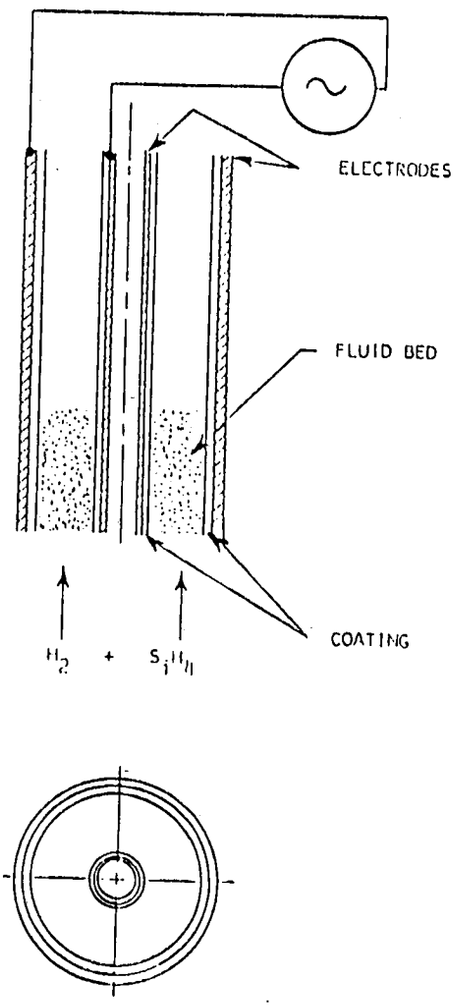
2. It spreads the current evenly through the bed because it has a high impedance to localized current.

Using this type of heating, favorable (particles hotter than wall) temperature gradients of approximately 25°C have been obtained between the particles and the reactor wall.

There are two features here to note. First, a thin coating of quartz on the electrodes does not prevent the flow of current. The quartz acts as the dielectric of a capacitor, with the two capacitor "plates" being the wall and the bed particles. Second, if the contact region between two particles is examined, the same effect is seen. There is a capacitance in parallel with the conductance through the actual region. These phenomena are discussed further below.

3.2.3.5.1 Electrical Behavior

The conduction of electricity in a fluid or packed bed is complicated and not completely understood. The bed conductivity depends on the bulk conductivity of the particles, the electrical properties of the gas, and the shape and size of the particles. A dominant factor is the nature of the contact region between particles. All the current must flow through these regions and, because it is most constricted there, a large portion of the total voltage drop across the bed is at particle junctions.



ESSENTIAL CHARACTERISTICS OF EFB

1. INERT WALL COATING OF HIGH DIELECTRIC MATERIAL-OR-POROUS WALL ELECTRODES WITH PRESSURIZED GAS INTRODUCED.

   RESULT - MINIMIZATION OF PARTICLE CONTAMINATION

2. ELECTRIC CAPACITIVE HEATING OF PARTICLES

   RESULT - FAVORABLE THERMAL GRADIENT FOR PLATING PROCESS

FIGURE 3 - 47

SCHEMATIC DIAGRAM OF CAPACITIVELY COUPLED HEATING OF FLUID BED

If the total impedance of the bed is a constant real impedance, then the effect of adding dielectric (e.g., quartz) coating to the walls is to add two capacitors in series with the bed resistance. At high frequency, the distribution of current near the contact region is modified. The net effect is to add a capacitance effect in the bed itself, leading to a more complicated network model.

Experimental measurements of electrical impedance have uncovered an unexplained phenomenon. There are two bed states. In the first state, H, which occurs primarily at low temperature (<150-200°C), when the voltage across the bed is first applied or when the fluidizing gas is nitrogen, the bed acts as if the particles are coated with a very thin dielectric film. The conductance increases practically linearly with frequency, as shown in Figure 3-48.

As the experiment proceeds the impedance, after a time interval of about 30 minutes, drops abruptly and becomes independent of frequency. The fast transition takes place in less than two seconds. It occurs most easily when the fluidizing gas is inert (argon or helium as opposed to nitrogen). The resulting state, L, is what would have been expected from similar experiments with materials similar in bulk electrical properties to silicon. This behavior is shown in Figure 3-49. The resistance is constant with frequency and voltage. Once this second state is achieved, it persists until the power is interrupted or the gas flow rate is greatly increased; then it reverts to state H. Intuitively, one must believe that state L would continue at higher temperatures.

Adding a ceramic coating to the center electrode increases the bed impedance as expected. By adding a relatively thick coating, the capacitive impedance of the coating is made dominant, as seen in Figure 3-50. At high frequencies (<2MH$_z$) with both coated and uncoated center electrodes, the impedance proportionately decreases or increases with frequency, respectively.

Electrical power is dissipated in the bed in both low and high impedance states, although the frequency required is much higher in the high impedance state. The temperature of the bed increases as the power is applied. The thermal losses are both in the exit gas and through the walls of

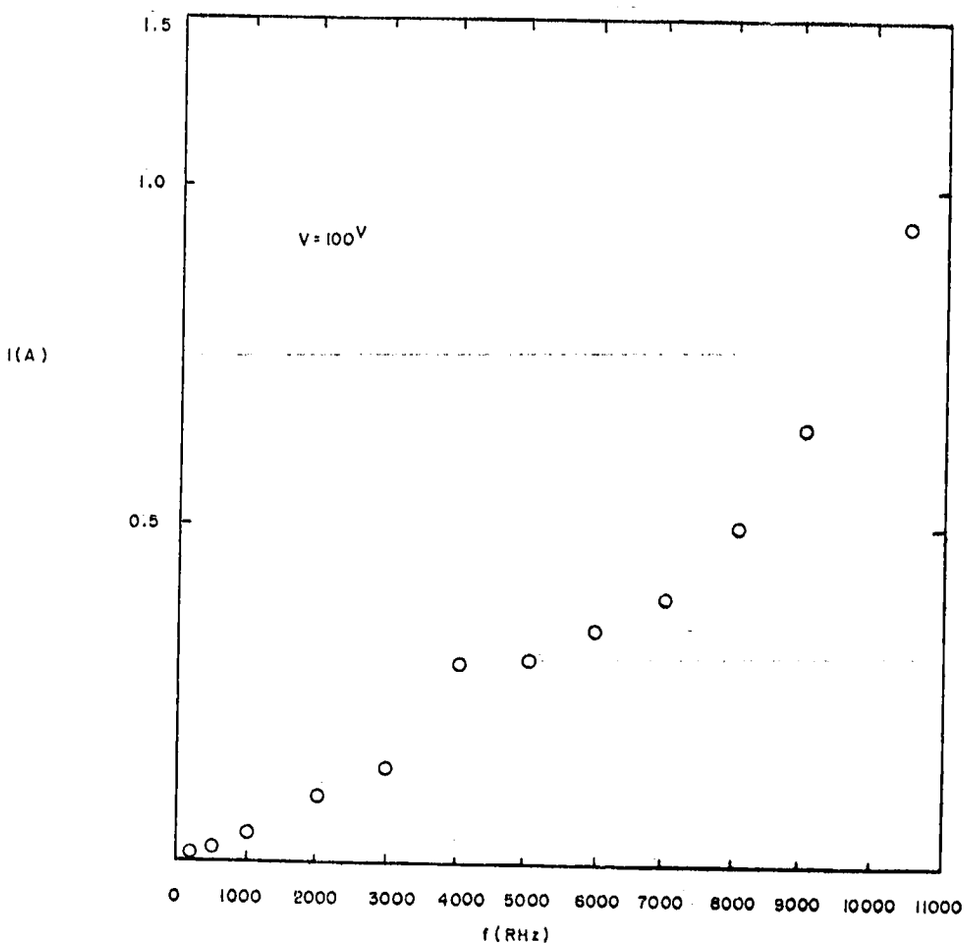


FIGURE 3 - 48

CURRENT VS FREQUENCY OF BED IN STATE H

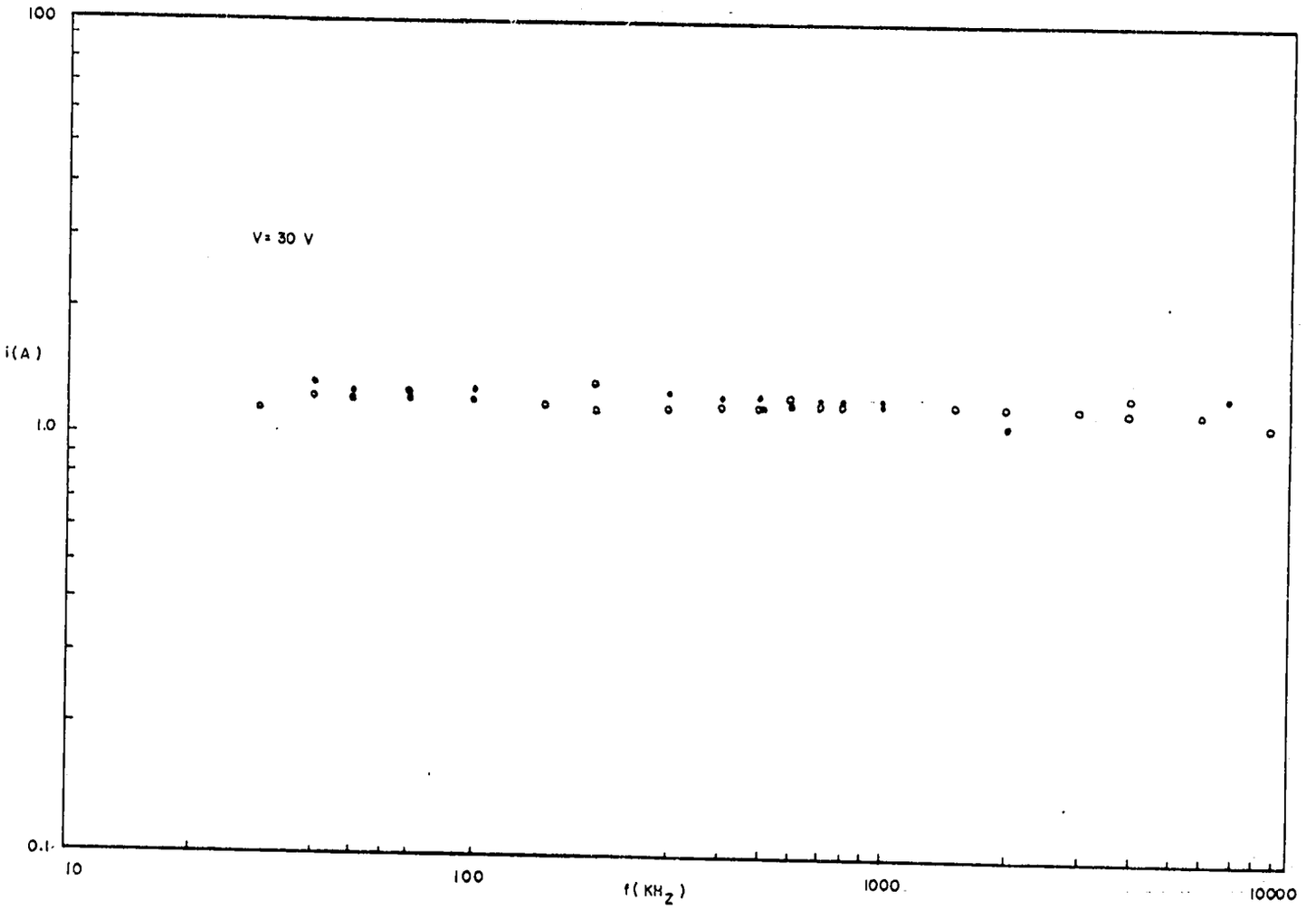


FIGURE 3 - 49

CURRENT VS FREQUENCY OF BED IN STATE L

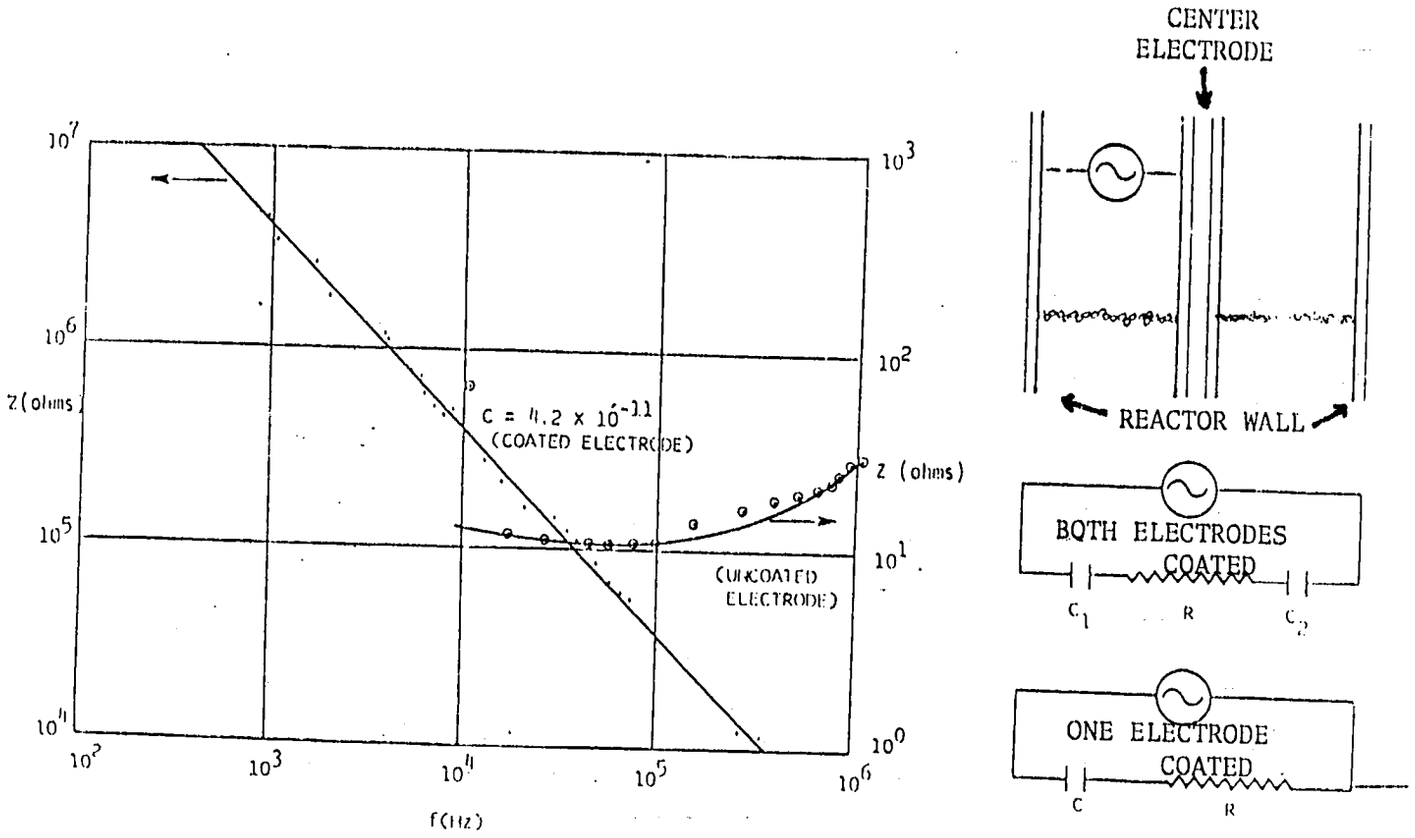


FIGURE 3 - 50

PERFORMANCE OF COATED ELECTRODE

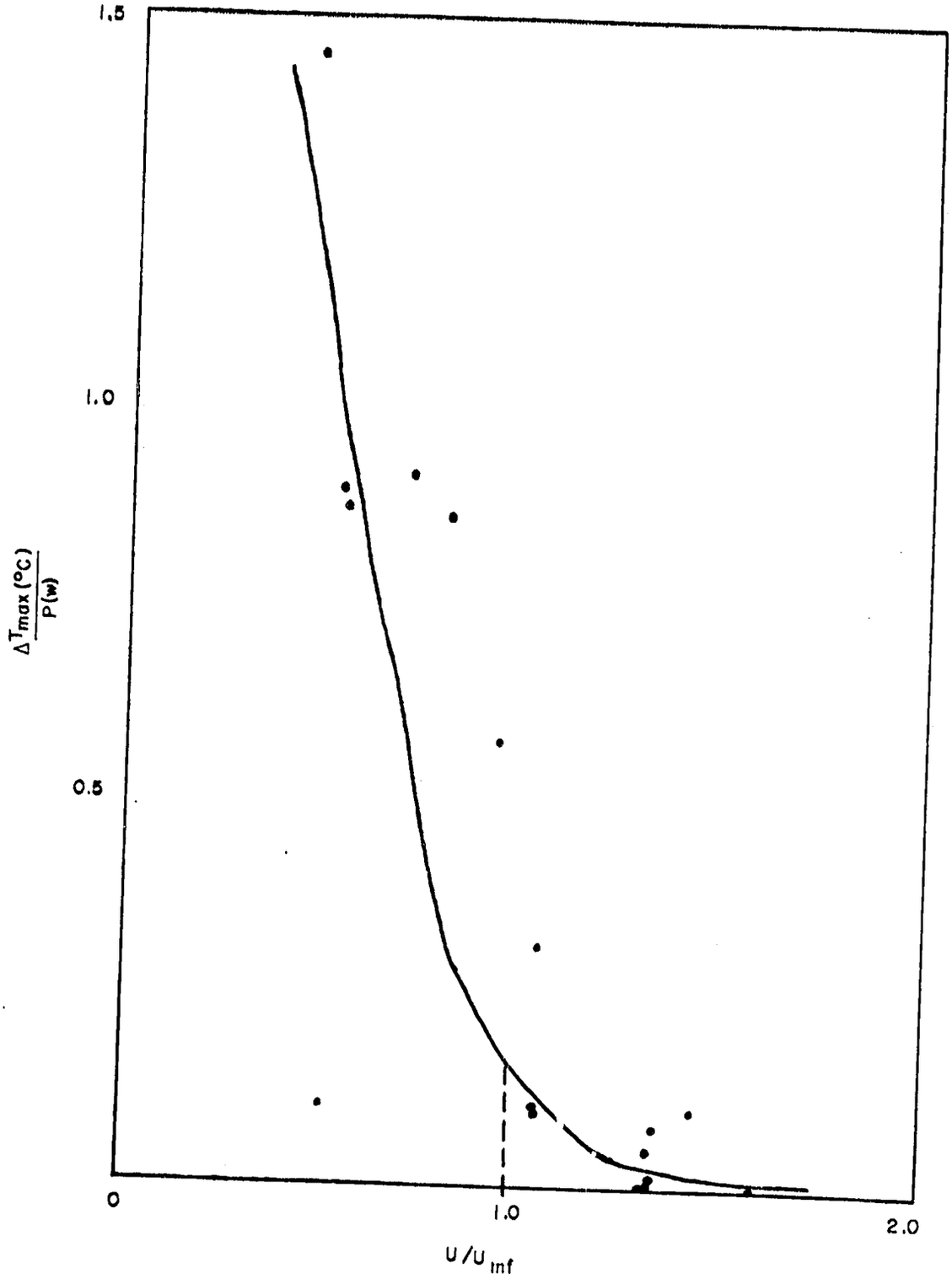


FIGURE 3 - 51

MAXIMUM TEMPERATURE DIFFERENCE IN BED (NORMALIZED TO INPUT POWER) VS FLOW VELOCITY (NORMALIZED TO MINIMUM FLUIDIZATION VELOCITY)

the reactor. The results show that all the electrical power can be accounted for by its being dissipated in the bed and lost by these two mechanisms. When the bed is fluidized, the temperatures inside the bed are very nearly uniform, except in some cases just above the distributor. In Figure 3-51, the maximum internal temperature differences are shown.

Tests demonstrating particle heating at high temperature were performed in the apparatus shown in Figure 3-52. The bed walls are surrounded by guard heaters that are used to control the rate of heat loss through the side walls, and can be used to achieve effectively adiabatic conditions. The inlet gas line was isolated from the bottom of the reactor by insulation to prevent heating of the gas in the chamber below the distributor. Table III-13 shows test results from two experiments; one in which the outer guard heaters (Point E in Figure 3-52) were maintained only 10° - 15° colder than the bed wall (reducing the radial heat flux from the bed), and a second experiment with no guard heating.

In Test 1, to further minimize the heat leak, the lower flange (Point F) was also maintained $15^{o}C$ colder than the bed wall. Under these conditions, heat leak from the bed is controlled to an estimated 70W. The feed gas was preheated by the flow of heat along the tube wall from Point F to Point D. The amount of preheating is accountable by measuring the gas temperature just before the gas enters the bed (Point A). The observed temperature gradients between the wall and the bed indicate a heat-transfer coefficient of 200 $W/m^{2}C$.

Test 2 was a similar experiment except that the guard heating was absent allowing a large radial heat flux. This condition increases the bed particles-to-reactor wall temperature difference to $24^{o}C$, and reduces the attainable bed temperature to $301^{o}C$. By running experiments at higher power, higher wall-to-particle temperature differences can be maintained.

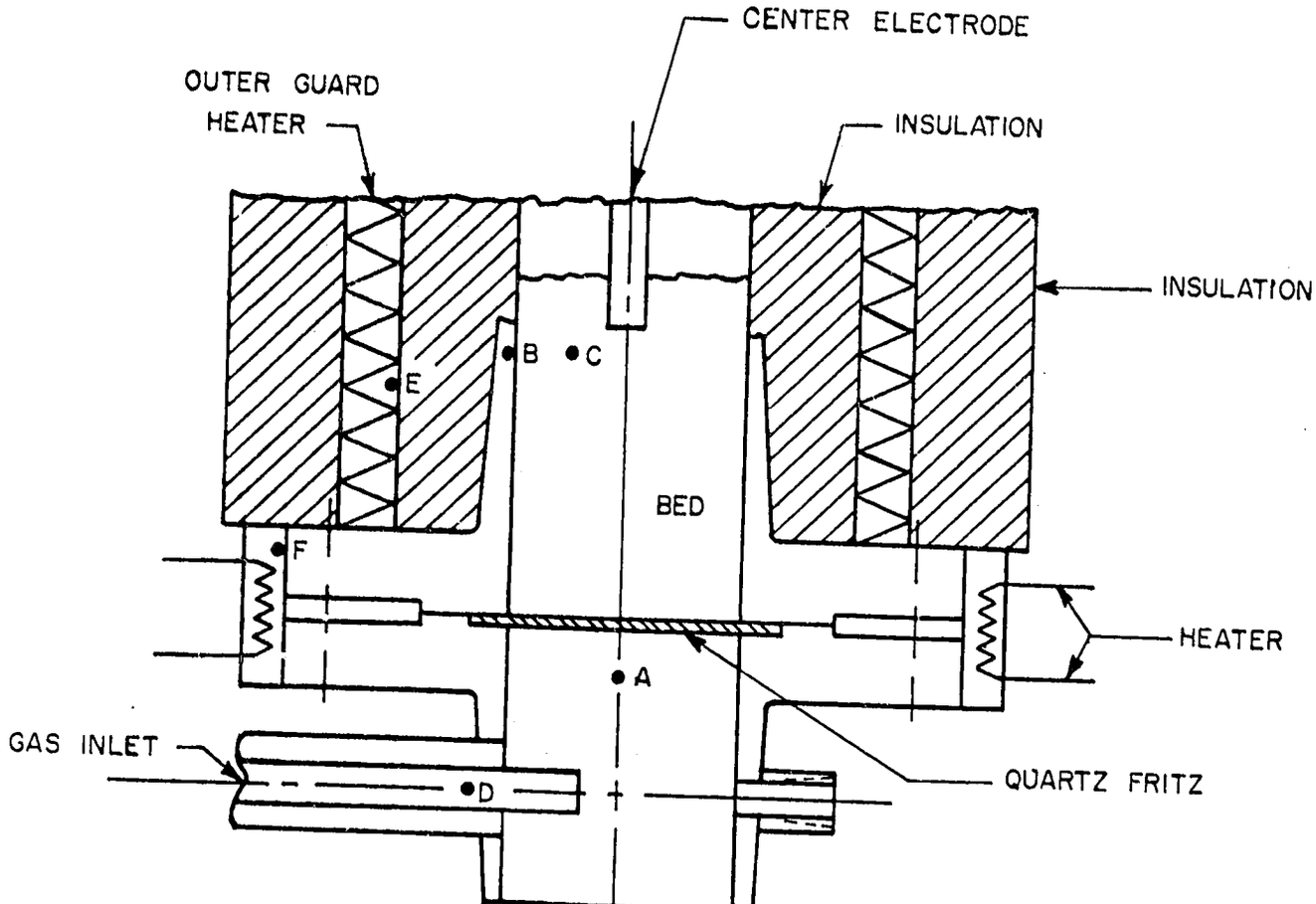


FIGURE 3 - 52

SCHEMATIC OF BED SHOWING POINTS OF TEMPERATURE MEASUREMENT

TABLE III-13

TEMPERATURE DISTRIBUTIONS/RESULTS FOR TESTS 1 AND 2

	Test 1	Test 2
Electrical Dissipation in Bed	250 W	200 W
Electrical Frequency	75 k Hz	15 k Hz
Voltage	44 V	24 V
Current	18 A	18 A
Phase Angle	45°	22°

Temperature Distribution

Point	$T(^{o}C)$	$T(^{o}C)$
A Gas Inlet to Bed	487	210
B Bed Wall	772	277
C Bed Particles	785	301
D Gas Inlet to Apparatus	207	184
E Guard Heater	760	215
F Outer Flange	760	240

Test 1: Heating results with guard heating preventing side heat loss. Note temperatures are maintained so there is still heat loss from bed, not heat addition.

Test 2: No guard heating.

The electrical behavior of the bed is similar at high and low temperatures. There is an initial transient state in which the bed impedance is high ($\sim 50\Omega$), after which it drops to $\sim 1\text{-}3\Omega$. This latter steady impedance is dependent on the position of the electrode, and can be raised by partially removing the electrode from the bed. The lower impedance state also has a reactive component, corresponding to approximately $0.5\mu F$ of capacitance. Although the origin of the transition between states is unknown, the electrical energy can be dissipated readily in the bed, and even when it is confined to only the upper portion of the bed, particle motion quickly distributes the heat evenly.

On this basis, direct electrical heating can be used to maintain a fluidized bed at the temperature required for pyrolysis, with the walls substantially colder.

When high current was passed through the bed, some particles sintered together in loose clumps, shown in Figure 3-53. This is believed to be caused by current concentration and must be investigated further before using this method in a pyrolysis reactor.

3.2.3.6 Commercial-scale Economic Performance

To assess the cost-effectiveness of fluid-bed silane pyrolysis, a preliminary conceptual design and economic analysis of a fluid-bed system was prepared at a commercial scale of 1000 MT/yr silicon. For the purpose of this analysis, the feed silane concentration was taken to be 10% at a reactor operating temperature of 607°C. The estimated fluid-bed diameter and height are 44 inches and 10 feet, respectively. The mean particle diameter in the bed is 700 microns and the operating fluidization velocity is 1.5 times the minimum fluidization velocity. The economic study has indicated that, if technically successful, the cost of pyrolyzing silane in a fluid-bed system could be less than $1/kg, exclusive of the silane cost.

A schematic diagram of 1000 MT/year fluid-bed reactor system is shown in Figure 3-54. The reactor has a boot at the bottom and an expanded

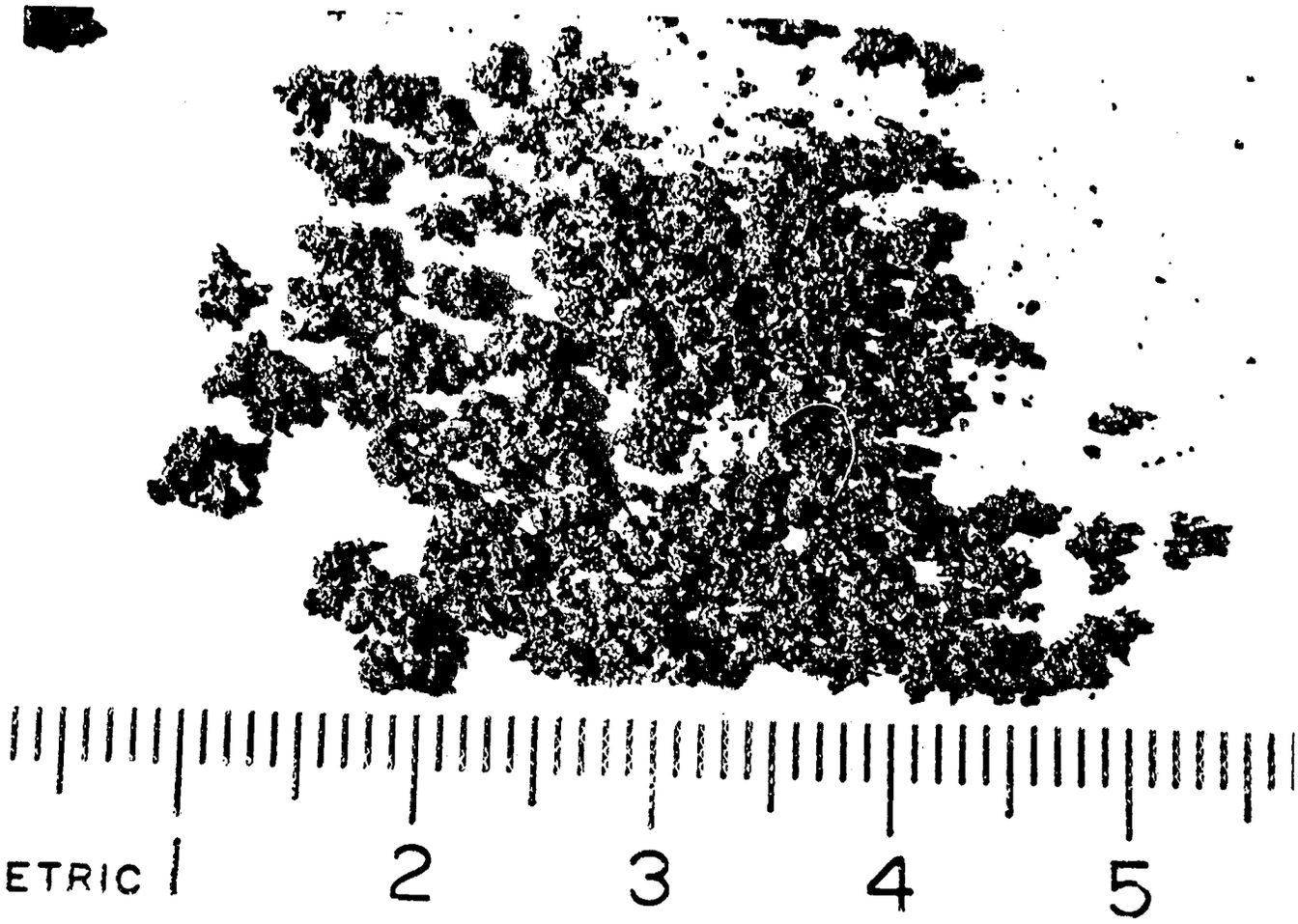


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FIGURE 3 - 53

ELECTRICALLY SINTERED PARTICLES > 10 MESH

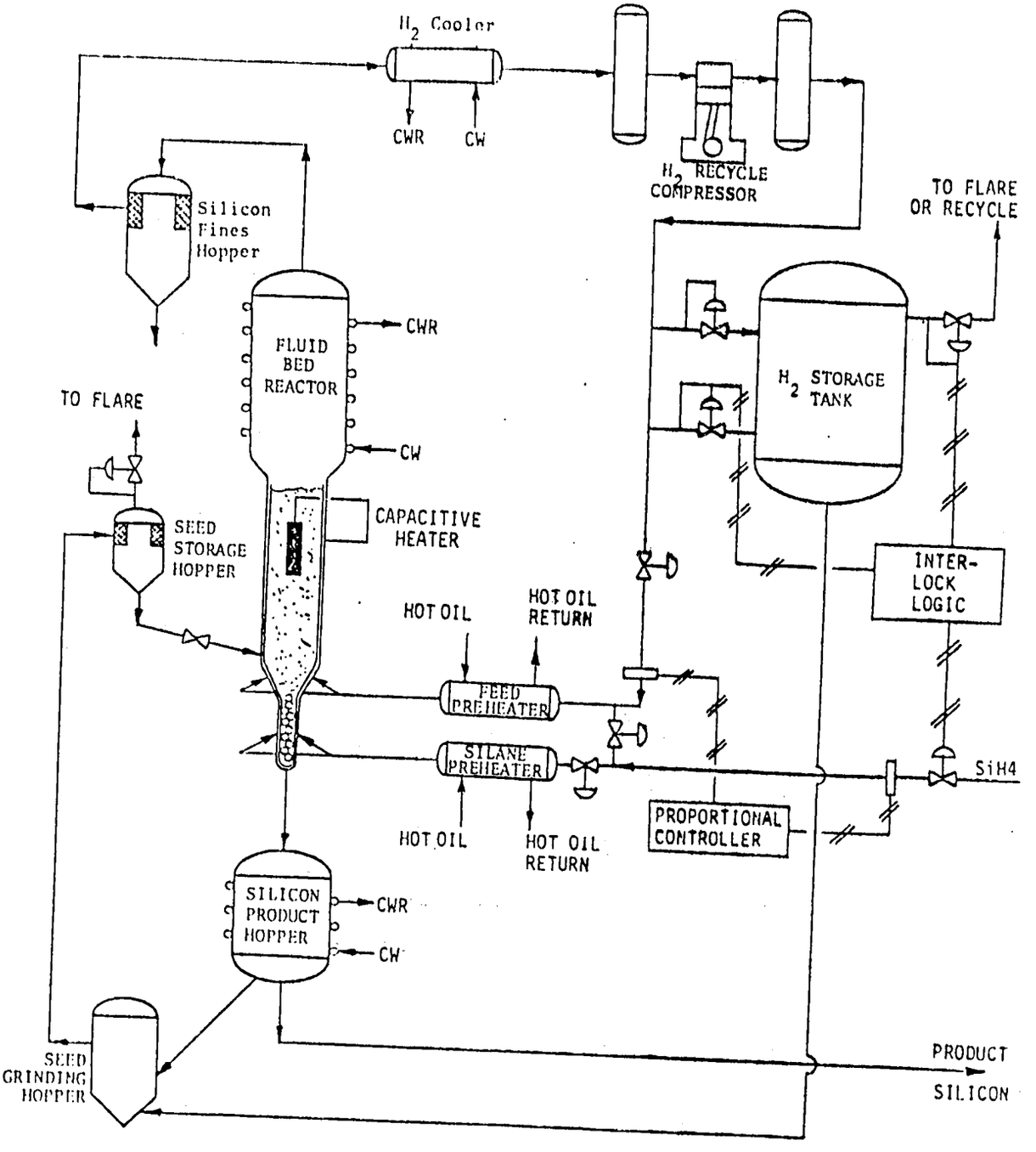

FIGURE 3 - 54

SCHEMATIC DIAGRAM OF FLUID BED PYROLYSIS

section at the top. Feed silane and hydrogen are mixed and preheated to a temperature of 227°C and introduced into the reactor. The bed particles are heated capacitively to maintain the reactor at 607°C. Silane pyrolysis in the reactor coats the bed particles with pure silicon. Larger particles are periodically withdrawn from the bottom. The hydrogen effluent rises into the water-jacketed expanded head and then passes through a porous metal filter into a hopper where the elutriated silicon fines are trapped. The hydrogen is then cooled and compressed by a reciprocating compressor and recycled through the reactor via the hydrogen preheater. The product silicon particles are collected under a blanket of inert gas in a water-cooled storage hopper from which they are transferred to containers for packaging and shipping. The process scheme also includes a seed grinding vessel where large silicon particles are crushed to produce fine seed material, which is stored in a seed hopper for periodic introduction into the reactor.

To estimate the cost of fluid-bed pyrolysis, a preliminary functional design was prepared of the various components in the above process scheme. A list of all the equipment is given in Table III-14. The conceptual design and cost estimate are preliminary at the present time and should be useful only as an overview of the approximate incremental or add-on cost associated with fluid-bed pyrolysis.

Table III-15 presents a summary of the projected economics for fluid-bed pyrolysis. The estimated installed plant cost is $1.81MM. The annual operating costs are estimated to be $0.52 MM. The projected pyrolysis-product cost is $1.00/kg in 1979 dollars or $0.75/kg in 1975 dollars at 20% DCF rate of return.

The above projected cost of fluid-bed pyrolysis is very attractive, particularly when compared with the high estimated cost of consolidating free-space pyrolysis powder by suction-casting or rapid-pulling techniques. It is concluded that if fluid-bed technology for silane pyrolysis can be successfully developed, it has an excellent potential for addressing the JPL/DOE 1986 cost goals for producing polycrystalline silicon for solar cells.

TABLE III-14

1000 MT/YEAR FLUID-BED PYROLYSIS SYSTEM

EQUIPMENT LIST & DESCRIPTION

Equipment	Description
Reactor	Fluid bed reactor vessel composed of 3 sections; bottom section 15" dia. x 3.5' high, mid section 44" dia. x 12' high, top section 72" dia. x 10' high. Lower two sections quartz-lined. Material of construction Incoloy 800.
Product Hopper	6' dia. x 5' high, flanged on both ends, copper construction, cooling coils wrapped on the outside.
Silicon Fines Hopper	6' dia. x 5' high, 45° conical bottom, 316SS construction. Has porous metal filters inside.
Seed Grinding Hopper	4' dia. x 5' high, 45° conical bottom, flanged top, elliptic head, 316SS.
Seed Storage Hopper	3' dia. x 3' high, 45° conical bottom, flanged top, elliptic head, 316SS.
Hydrogen Recycle Storage Tank	9' dia. x 10' high, welded heads, 316SS.
Hydrogen Recycle Compressor	Single-stage, dry-lube reciprocating compressor, 100 HP, 1800 RPM, 660V explosion-proof motor, 28 PSIG outlet pressure. Stainless steel valves & 2'x8' suction & discharge tanks, compressor sized to handle 870 ACFM at inlet.
Hydrogen Cooler	Fin-tube hairpin exchanger, cooling water driven, 430 ft^2 heat transfer area. H_2 on fin side.
Feed Preheater	Fin-tube hairpin exchanger, hydrogen on fin side, heat transfer oil on tube side, 578 $ft.^2$ heat transfer area.
Silane Preheater	Fin-tube hairpin exchanger, silane on fin side, 22 $ft.^2$ heat transfer area.
Capacitive Heater System	200 KW, includes power supply & electrodes.
Porous Metal Filters	30 ft^2 area, 5 micron pore size filters in silicon fines hopper; 18 ft^2 area, 5 micron pore size filters in seed storage hopper.

TABLE III-15

1000 MT/YEAR FLUID-BED PYROLYSIS SYSTEM

PRELIMINARY ECONOMIC ANALYSIS SUMMARY

Plant Investment	$1.81MM
Annual Operating Cost	0.52MM
Working Capital (30% Operating Cost)	0.16MM
Startup Cost (10% Investment)	0.18MM
Start of Project	1979
Start of Production	1981
Years of Operation	15
Sales Volume	10^6 kg/year
Investment Tax Credit	10%
Federal Income Tax	46%
Depreciation Method	10 years sum of digits
Discounted Cash Flow (DCF) Rate of Return	20%
Estimated Cost of Consolidation	$1/kg (1979 dollar)
	$0.75/kg (1975 dollar)

SECTION 4

REACTION KINETICS AND THERMODYNAMIC AND PHYSICAL PROPERTIES

Certain chemical, thermodynamic and physical properties of the key compounds of interest were incomplete and these had to be determined before a detailed process design could be performed. An experimental program was conducted to correct this data deficiency and the data thus collected were correlated in a data bank for use in the computer-aided, facility process design.

A search of the open literature, previous Union Carbide research efforts and an established computer data bank revealed that critical data about the hydrogenation of silicon tetrachloride (STC) and the redistribution reaction of dichlorosilane (DSC) and trichlorosilane (TCS) were incomplete. Deficiencies in the vapor-liquid equilibrium data for the DCS-TCS binary system and gas solubilities in liquid chlorosilanes were also identified.

The status of all these data and the experimentally obtained data are discussed in this section.

4.1 CHEMICAL REACTIONS

The Union Carbide silane process for producing semiconductor-grade silicon from 98%-pure, metallurgical-grade silicon feed contains four chemical reactors. Figure 4-1 graphically depicts the equilibrium constants for these reactions as a function of temperature. The basic chemistry of the entire process can be described by the following six reactions:

$$Si + 2H_2 + 3SiCl_4 \rightleftarrows 4HSiCl_3, \qquad (4\text{-}1)$$

$$2HSiCl_3 \rightleftarrows SiCl_4 + H_2SiCl_2, \qquad (4\text{-}2)$$

$$2H_2SiCl_2 \rightleftarrows HSiCl_3 + H_3SiCl, \qquad (4\text{-}3)$$

$$2H_3SiCl \rightleftarrows H_2SiCl_2 + SiH_4, \qquad (4\text{-}4)$$

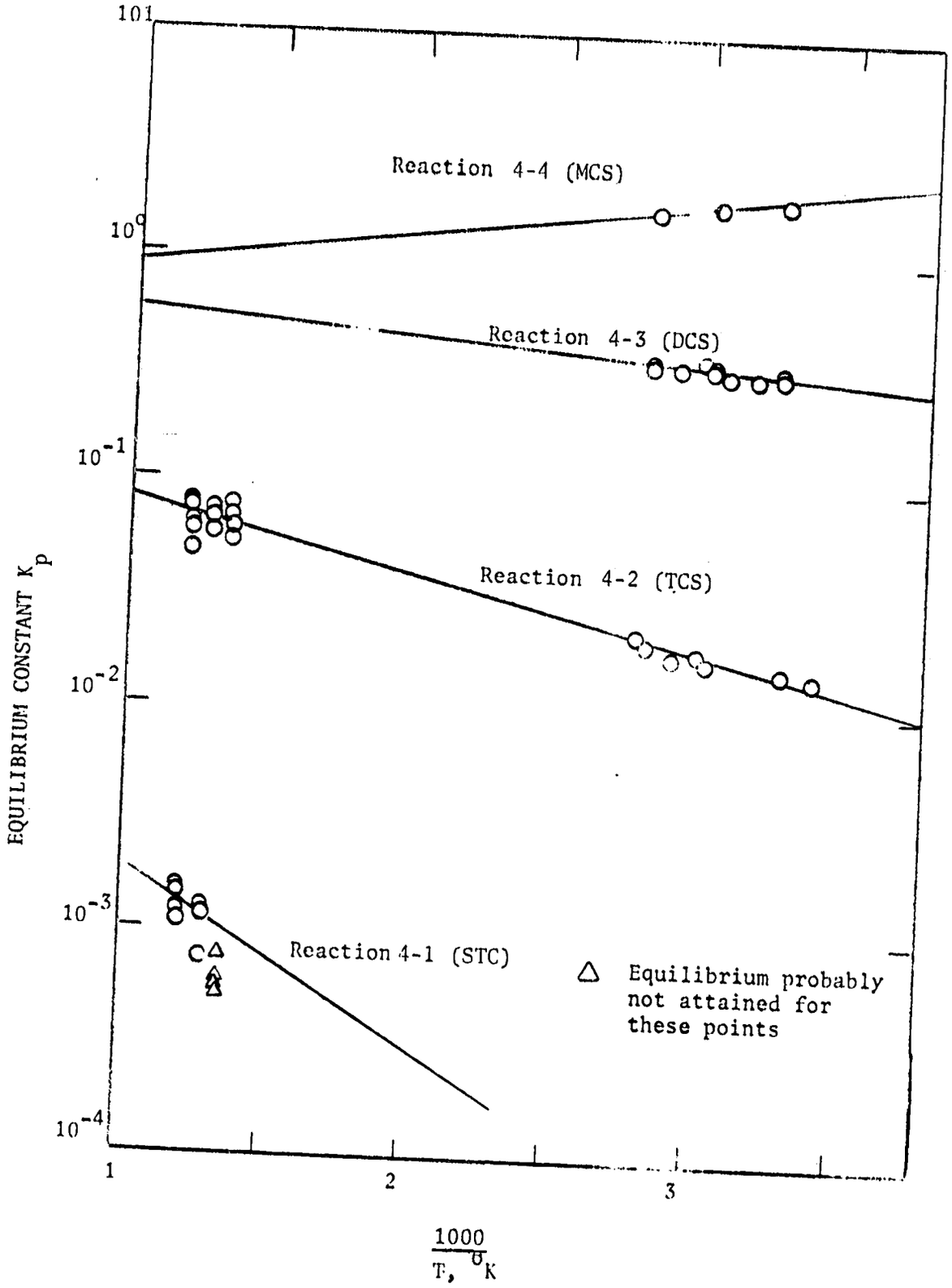

FIGURE 4-1

EQUILIBRIUM CONSTANTS FOR REACTIONS 4-1 THROUGH 4-4 AS A FUNCTION OF TEMPERATURE

$$SiCl_4 + H_2 \rightleftharpoons HSiCl_3 + HCl, \text{ and} \qquad (4\text{-}5)$$

$$SiH_4 \rightarrow Si + 2H_2. \qquad (4\text{-}6)$$

The STC hydrogenation reactor is the first chemical reactor in the processing train (Figure 5-1, 425-02). An equimolar mixture of hot hydrogen and STC is supplied to this fluid-bed reactor that contains metallurgical-grade silicon particles and is operating at 500°C and 515 psia. Equation 4-1 is the dominant reaction and TCS is the desired product of the STC hydrogenation. By reversible reaction 4-1, the amount of TCS in the product stream is about 15 mole %.

The second and third chemical reactors are the TCS and DCS redistribution reactors (Figure 5-1, 435-02, 435-04). In the TCS redistribution reactor, 97 mole % liquid TCS at 70°C is fed into a fixed bed containing Rohm and Haas AMBERLYST® A-21, ion-exchange resin, which is the catalyst for reaction 4-2. This makes about 11 mole % of DCS, the desired product; however, because reactions 4-3 and 4-4 are also occurring, although to a lesser extent, small quantities of silane and monochlorosilane (MCS) are also made.

In the DCS redistribution reactor, 71 mole % liquid DCS at 50°C is fed into a bed containing the same resin as above. In this case, there is no dominant reaction; reactions 4-2, 4-3, and 4-4 are all involved. The product stream has 12 mole % silane, 17 mole % MCS, 39 mole % DCS, 32 mole % TCS and 0.5 mole % STC. However, since the silane is easily separated from the chlorosilanes by the last distillation column in the process train, ultra-high purity silane is produced.

The last chemical reactor is the free-space, silane pyrolysis reactor. Here silane is converted into submicron, silicon powder and hydrogen by irreversible reaction 4-6. This process will go to completion and one mole of silicon is made for every mole of silane.

4.1.1 Equilibrium Constants (K_p) and Heat of Reaction (ΔH)

Chemical equilibrium constants for the reactions described in Section 4.1 were determined from experimental data. If the heat of reaction ΔH is considered

constant in the temperature range of interest, the following relationship is obtained for K_p as a function of temperature:

$$\ln K_p = -\frac{\Delta H}{RT} + C_o , \qquad (4\text{-}7)$$

where R is the gas constant and C_o is a constant.

Upon evaluating all the available experimental data, K_p was calculated at constant temperature and plotted vs 1/T as shown in Figure 4-1. The slope of the straight line is equal to - $\Delta H/R$. These data show that reactions 4-1 through 4-3 are endothermic and reaction 4-4 is exothermic. Table IV-1 gives the values of ΔH, C_o and K_p at 50 and 500°C.

Experimental data were not available for reaction 4-5 and no data were needed for reaction 4-6 since it is known to be irreversible. For reaction 4-5 the heat of reaction was derived from adjusted heat of formation values and (K_p) was calculated at 298°K using the standard Gibbs energy-of-formation values.

4.2 HEAT-OF-FORMATION VALUES

The heat-of-formation values supplied by the JANAF tables (Joint Army, Navy, Air Force; Stull & Prophet, Ref.3) provide a means for calculating the heats of reaction for reactions 4-1 through 4-5. Assuming that the heats of reaction determined from TCS and DCS redistribution experimental data are reliable, the JANAF table heats of formation can be adjusted in a manner that minimizes the sum of squares of deviations from JANAF table values, while maintaining the observed heats of reaction. The results are given in Table IV-2. The amount of adjustment falls within the uncertainty limits given by the JANAF tables for heats of formation.

When the calculated values are compared to the observed values presented in Table IV-1, it is seen that there is fair agreement for reactions 4-2 through 4-4 (Table IV-3). The only discrepancy exists in the observed ΔH for reaction 4-1. Use of the 450, 500, and 550°C data points shown in Figure 4-1 results in a ΔH of 8746 cal/mole. These experimental data are suspect because equilibrium was difficult to obtain, especially in the 450°C data. If the 500

TABLE IV-1

EQUILIBRIUM CONSTANT (K_p) AND HEATS OF REACTION (ΔH)

Equation	ΔH	C_o	Kp 50^oC	Kp 500^oC
1	3554	-4.4804	$4.46(10)^{-5}$	$1.12(10)^{-3}$
2	1486	-1.7540	0.0171	0.0658
3	519	-0.2859	0.335	0.536
4	-601	-0.3596	1.78	1.03
5	18399	4.6933	$3.93(10)^{-11}$	$6.87(10)^{-4}$

ΔH = cal/mole

$$\ln Kp = \frac{-\Delta H}{RT} + C_o$$

TABLE IV-2

HEATS OF FORMATION

	JANAF $\Delta H^o f$	Adjusted $\Delta H^o f$	(JANAF-Adjusted)	% Change to JANAF
SiH_4	8200 ± 500	8135	-65	-0.79
SiH_3Cl	-33900 ± 2000	-33731	+169	+0.50
SiH_2Cl_2	-76600 ± 3000	-76198	+402	+0.52
$SiHCl_3$	-118600 ± 1000	-118146	+454	+0.38
$SiCl_4$	-158400 ± 300	-158608	-208	-0.13

$\Delta H^o f$ = cal/mole at 298°K

The JANAF $\Delta H^o f$ values were adjusted by a least square fit technique, using the following ΔH values taken from Figure 4-1 and Table IV-1.

Equation	ΔH
2	1486
3	519
4	-601

TABLE IV-3

COMPARISON OF HEATS OF REACTION: OBSERVED, CALCULATED FROM JANAF TABLES, CALCULATED FROM ADJUSTED $\Delta H^{o}f$

Reaction Equation No.	ΔH Calculated From JANAF Table $\Delta H^{o}f$	ΔH Calculated From Adjusted $\Delta H^{o}f$	ΔH Observed Values
4-4	-600	-601	-601
4-3	700	519	519
4-2	2200	1486	1486
4-1	800	3240	8746 (450, 500, 550°C Data PTS) 3554 (500, 550°C Data PTS)

ΔH = cal/mole

and 550°C data only are considered, ΔH becomes 3554-cal/mole and agrees with the ΔH found when the adjusted heat of formation values were used.

The adjusted $\Delta H^{o}f$ values given in Table IV-2 and the observed K_p and ΔH values given in Table IV-1 form a consistent set of data based on the latest experimental studies of TCS and DCS redistribution and STC hydrogenation. These data sets provide the best information available at the present time.

4.3 REACTION KINETICS

Three catalytic reactors are used in the silane process for converting metallurgical silicon to high-purity, semiconductor-grade, molten silicon. The metallurgical silicon is first converted to trichlorosilane (TCS) in a hot, copper-catalyzed, STC-hydrogenation, fluid-bed reactor. The trichlorosilane is ultimately converted to pure silane in two catalytic redistribution reactors in conjunction with appropriate distillation separations. The kinetic characteristics of the hydrogenation reactor and both liquid-phase chlorosilane redistribution reactors have been measured. Results are reported below.

4.3.1 Silicon Tetrachloride (STC) Hydrogenation

In the UCC silane process, an equimolar mixture of hot hydrogen and STC is fed to the 500°C, 515-psia, STC-hydrogenation reactor, which contains a fluidized bed of metallurgical silicon and copper-catalyst powder. The gas mixture reacts reversibly with the silicon particulates in the fluid bed to yield a mixture which, at equilibrium conditions, contains about 15% TCS, the sought product. The primary reaction [equation (4-1), Section 4.1].

$$Si + 2H_2 + 3SiCl_4 \rightleftharpoons 4HSiCl_3 \qquad (4\text{-}1)$$

is accomplished via complex gas- and solid-phase reaction mechanisms. In the following paragraphs a description of the experimental apparatus and procedure is provided, and the kinetic data obtained are examined and correlated.

4.3.1.1 Experimental Apparatus and Procedure

The chemical data used to evaluate the kinetics of the hydrogenation of STC were obtained in fixed- and fluid-bed reactors. Hydrogenation runs were made in a 2.5-cm diameter, 30.5-cm high, stainless steel reactor filled with 185 grams of 100-by 200-micron silicon. A schematic of the reactor is shown in Figure 4-2.

The appropriate mass ratio of H_2:STC was achieved by bubbling the H_2 through a thermostated reservoir of STC. The temperature of the reservoir determined the concentration of STC. The feed gas to the reactor was superheated to about 350°C prior to entering the electrically heated reactor tube through a five-orifice distribution grid. The chlorosilane fraction of the reactor effluent was condensed and collected in a -65°C refrigerated condenser, while the hydrogen and noncondensibles were vented to the atmosphere through a back pressure regulator. The condenser was nearly 100% efficient in capturing the chlorosilanes, as indicated by the colorless hydrogen flame at the vent. Condensate samples collected were analyzed chromatographically as described earlier (Section 3.1.2.1). The results are reported on a hydrogen-free basis, i.e., the composition of the condensed chlorosilanes in Table IV-4. Only dichlorosilane, trichlorosilane, and silicon tetrachloride were detected in the samples. No effort was made to analyze for the components formed as intermediate or by-products, since they are present in minute amounts only. The apparatus as originally constructed was capable of operating at up to 118 psia. It was later modified for operation at up to 1000 psia by providing a separate STC feed pump and vaporizer and an enlarged product-collection vessel. Because of the short bed height, the range of gas residence times that could be obtained in a "fluidized" regime were limited to under 15 seconds.

The experimental procedure consisted of charging the reactor with a specified quantity of silicon/copper mass and operating the equipment at 450 and 500°C for three ratios of H_2:STC. Additional silicon was then added to increase the bed height and the runs were repeated. The bed was fluidized at 0.06 ft/sec.; the higher flows were used at the higher H_2:STC

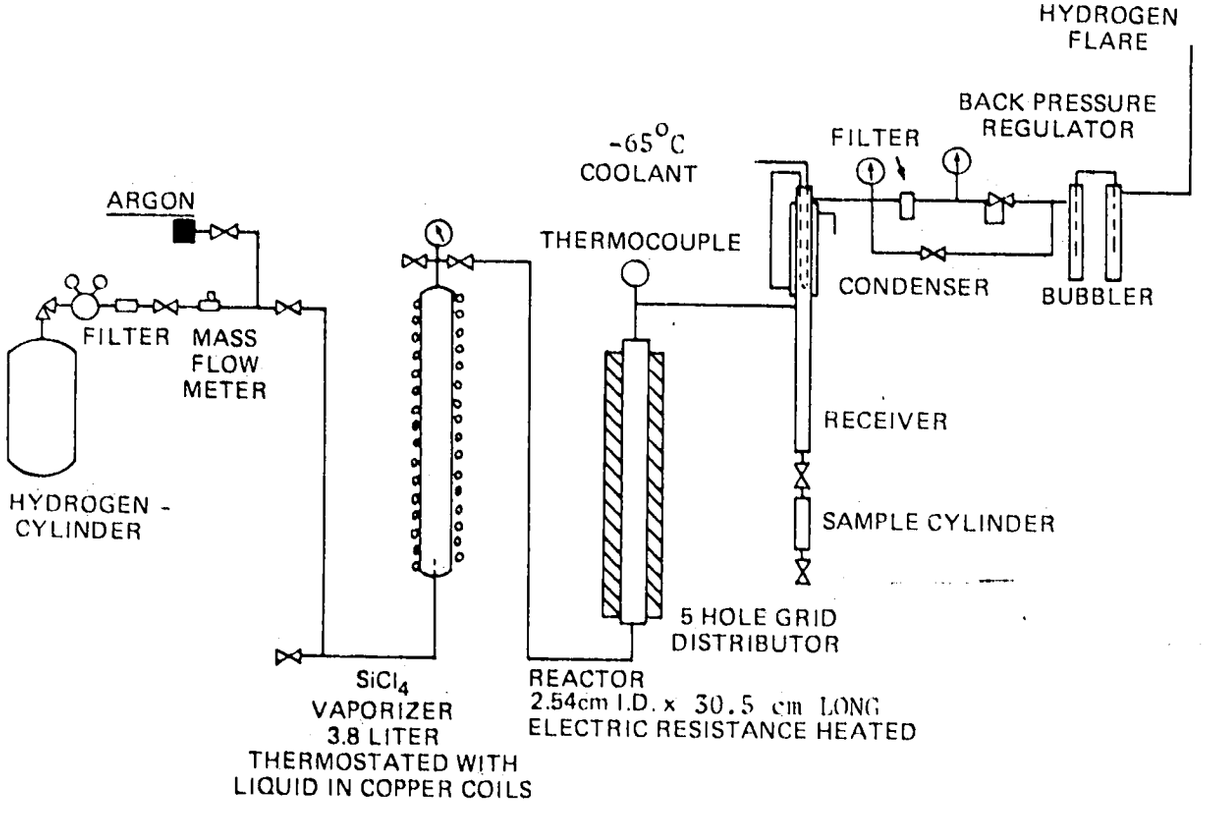

FIGURE 4-2

LABORATORY PRESSURE HYDROGENATION REACTOR

TABLE IV-4

HYDROGENATION OF STC
PRODUCT COMPOSITION DATA

Pressure psia	Temperature °C	H_2:STC Molar Ratio	Reactor Residence Time(1) Sec.	Product Composition, Mole %(2)		
				Mole % H_2SiCl_2	Mole % $HSiCl_3$	Mole % $SiCl_4$
206	500	2.04	10	0.4	9.5	90.10
			21	0.76	18.0	81.24
			34	0.85	22.0	77.15
			45.5	0.95	21.7	77.35
		5.04	10	0.25	5.7	94.05
			21	0.50	12.0	87.50
			34	0.78	18.7	80.52
			45.5	1.05	22.6	76.35
206	450	2.04	10	0.20	4.5	95.30
			21	0.36	9.2	90.44
			34	0.54	14.3	85.16
			45.5	0.67	17.5	81.83
		5.04	10	0.05	4.5	95.45
			21	0.20	9.5	90.30
			34	0.54	15.0	84.46
			45.5	0.80	19.2	80.00
65	500	1.3	5	0.20	13.8	86.00
			9.8	0.24	17.19	82.57
			14.8	0.26	18.86	80.88
			21.2	0.30	18.99	80.71
	450	1.3	39.6	0.184	16.14	83.67
			29.8	0.138	14.26	85.60
			27.4	0.126	13.7	86.17
			13.6	0.095	11.3	88.61

(1) Based on Cu/Si Bed Volume

(2) H_2 Free Basis

ratio to maintain the same quality of fluidization. Chemical data obtained were considered valid after a brief activation or initiation period during which the conversion reached a steady-state value. The residence time was altered by controlling the gas flow rate through the reactor. At residence times higher than 15 seconds, the bed was lightly fluidized.

Kinetic data were also obtained in the hydrogenation reactor of the Process Design Unit (PDU). (See Section 3.1.2.1 for description of the hydrogenation section of the PDU.) Kinetic data were obtained as a function of bed height, temperature, H_2:STC molar ratio and operating pressure. The raw data are presented in Tables IV-5 and IV-6. The fluidization was maintained at 1.5 to 2.0 times the minimum fluidization velocity to avoid a sluggish bed. In all reactions, the copper/silicon contact mass ratio was prepared by blending 2.5 wt % cement copper with metallurgical silicon. These experiments have indicated that metallurgical silicon of ∿98% purity is modestly active for the hydrogenation reaction; however, the time required to achieve a steady-state activity is shortened and the constancy of the activity improved when a small amount of copper (<2%) is present. Higher-purity silicon (99.85%) proves to be less reactive than 97% silicon; in turn, 97% silicon is less active than the 97% silicon plated with 2% copper. It appears that the rate of hydrogenation is greatly increased by the presence of copper or metal impurities in the silicon metal. The increased rate may be ascribed to the catalytic activity of the copper and/or impurities, causing secondary reactions. The nature and/or sequence of these reactions is not obvious at this time.

4.3.1.2 Kinetic Data Evaluation

A preliminary kinetic model of the STC hydrogenation reaction was developed which could be used to design larger scale fluidized bed reactors. Long residence time, fixed-bed laboratory reactor data (Table IV-5) was used to develop the nature and composition of the chemical equilibrium reached in reaction (4-1) as reported in Section 4.1.1. Reaction (4-1) as written presumes gaseous hydrogen and STC reacting with solid silicon (aided by the copper catalyst). One could assume that the mechanism actually involves a gas-phase reaction--not involving silicon--between hydrogen and STC to form TCS and HCl as in reaction (4-5). Partial confirmation for this was that in

TABLE IV-5

HYDROGENATION OF STC AT 112 PSIA WITH 2% Cu/Si

Reaction Temperature °C	$H_2:SiCl_4$ Ratio	Residence Time Sec. (1)	Product Composition, % H_2SiCl_2	% $HSiCl_3$	Mole % (2) $SiCl_4$ %
450	0.83	71.8	0.236	16.34	83.43
450	0.83	75.1	0.306	16.72	82.97
450	0.83	132	0.238	16.87	82.89
450	0.83	135	0.311	17.67	82.02
500	0.83	50.3	0.368	19.34	80.30
500	0.83	48.6	0.368	19.49	80.14
500	0.83	94.2	0.362	19.48	80.16
500	0.83	106	0.379	19.61	80.16
550	0.83	23.5	0.389	19.87	79.74
550	0.83	23.1	0.388	20.18	79.43
550	0.83	41.7	0.394	19.74	79.86
550	0.83	41.9	0.396	19.51	80.10
450	2.5	74.8	0.529	22.95	76.52
450	2.5	74.4	0.512	23.41	76.07
450	2.5	124	0.488	23.57	75.95
500	2.5	51.8	0.675	26.71	72.61
500	2.5	51.7	0.670	26.73	72.60
500	2.5	69.9	0.698	26.70	72.61
550	2.5	16.5	0.684	27.04	72.27
550	2.5	19.3	0.654	27.35	71.99
550	2.5	19.5	0.673	27.13	72.20
550	2.5	39.2	0.684	26.99	72.32
550	2.5	64.5	0.646	26.39	72.96
550	2.5	119	0.591	25.66	73.74

(1) Based on Cu/Si Bed Volume

(2) H_2-Free Basis

TABLE IV-6

HYDROGENATION OF STC IN 5 cm DIA. REACTOR WITH 2% Cu/Si

Bed Height Inches	Ratio, Initial $H_2/SiCl_4$*	T, avg., °C	Pressure psig	Residence Time, sec.	Mole % H_2SiCl_2*	Mole % $HSiCl_3$*
17	2.10	513.7	200	23.4	0.53	20.0
17	2.10	513.7	195	23.0	0.62	22.7
17	2.02	504.0	191	22.7	High	19.4
17	2.02	518.2	195	22.7	0.57	19.0
17	2.02	514.0	195	22.7	0.49	16.5
17	2.02	514.9	195	22.7	0.48	16.3
17	2.02	486.8	191	23.2	0.55	11.3
17	2.02	466.6	191	23.9	0.37	16.3
17	2.02	465.2	191	23.9	0.31	14.2
17	2.02	442.0	191	24.5	0.13	7.6
17	2.02	419.4	192	25.7	0.19	9.7
17	2.02	206.2	168	22.7	0	7.6
17	5.04	537.0	198	11.7	0.45	16.6
17	5.04	509.8	191	11.7	0.30	12.8
17	5.04	500.7	191	11.7	0.24	7.9
17	5.04	497.8	191	11.9	0.32	9.1
17	5.04	461.3	192	12.4	0.31	13.8
17	5.04	465.2	191	12.6	0.18	11.117
17	5.04	420.6	192	13.3	0.17	10.0
17	5.04	414.1	191	13.3	0.13	9.7
27	1.99	463.7	190	38.5	0.66	14.9
27	1.99	465.8	190	38.5	0.70	17.7
27	1.99	479.2	190	37.6	0.76	18.5
27	1.99	496.0	145	28.1	1.01	23.6
27	1.99	428.5	150	31.7	0.26	7.3
27	4.98	485.4	190	19.1	0.74	15.9
27	4.98	485.2	190	19.1	0.91	19.1
27	4.98	494.8	180	18.0	0.99	20.7
27	4.98	458.4	190	20.0	0.45	12.1
27	4.98	395.6	190	21.6	0.22	7.4
36	1.99	419.6	199	55.5	0.98	17.2
36	1.99	425.0	195	54.0	0.86	17.0
36	1.99	481.6	188	48.1	1.16	21.7
36	2.09	377.9	152	43.0	0.21	10.9
36	2.09	388.2	170	47.3	0.29	11.4
36	2.09	401.7	179	48.8	0.38	13.5
36	2.09	438.9	85	22.1	0.33	14.7
36	2.09	436.7	97	25.2	0.32	12.5
36	2.09	452.6	151	38.3	0.24	8.0
36	2.09	487.0	160	38.7	0.52	12.0
36	2.09	473.9	170	41.9	0.65	18.0
36	2.09	474.0	175	43.2	0.69	18.8
36	2.09	478.2	184	48.2	0.73	19.6
36	4.98	432.4	195	28.1	0.80	18.5
36	4.98	432.9	194	28.1	0.48	17.8
36	4.98	485.4	193	25.9	1.18	16.5
36	4.98	481.0	200	27.0	0.64	24.5
36	4.98	481.3	195	26.3	0.69	20.6
36	5.23	488.3	197	25.2	1.53	25.2
36	5.23	485.5	190	24.3	1.27	22.0
36	5.23	488.0	194	24.8	1.34	23.2
36	5.23	503.1	191	24.1	0.76	21.6

* H_2-free basis; balance $SiCl_4$

an "empty-tube" experiment, a small amount of TCS was formed (~1%) which was on the same order of magnitude as predicted by thermodynamics. The rapid reaction of HCl with silicon metal at temperatures as low as 275°C is the well-known commercial route for TCS:

$$SiCl_4 + H_2 \rightleftarrows HSiCl_3 + HCl \qquad (4\text{-}5)$$

$$3\ HCl + Si \rightarrow H\ SiCl_3 + H_2 \qquad (4\text{-}8)$$

This reaction is rapid and quantitative with complete consumption of HCl. Thus the reaction of H_2 and STC in the presence of silicon could likely be a sequence of reaction (4-5) followed by reaction (4-8) in which the silicon acts to scavenge the HCl, shifting the equilibrium of (4-5) toward higher yields of TCS. While there is some experimental evidence to support this reaction path which gives credence to the use of a reversible kinetic model, the actual steps involved in the formation of TCS including the nature and role of the copper catalyst (i.e. the micro-reaction mechanism) are not known at this time.

Assuming that the course of the STC hydrogenation follows a reversible process, it can be generally represented as:

$$n\ SiCl_4 \underset{k_2}{\overset{k_1}{\rightleftarrows}} m\ HSiCl_3 \qquad (4\text{-}9)$$

where n and m are the number of moles of reactant and product respectively and k_1 and k_2 are the kinetic rate constants. At equilibrium, the rates of the forward and reverse reactions are equal, ($k_1/k_2 = k_{equilibrium}$) which leads to an equilibrium partial pressure of the components Pe_i. The experimental data presented in Tables IV-5 and IV-6, representing the major components of the system, were converted to a form suitable for kinetic analysis. Minor components which could be present (HCl, Cu_3Si, $CuCl_2$, etc.) and which could catalytically affect the overall kinetics were assumed to be constant.

The raw mole fraction data from Tables IV-5 and IV-6 were converted to partial pressures and the bed heights and superficial gas velocity converted to residence times as presented in Tables IV-7 through IV-12. The expression of reactant concentration as partial pressure allowed the use of equilibrium and rate constants which were independent of pressure and a function of temperature only.

TABLE IV-7

SILICON TETRACHLORIDE HYDROGENATION
CHEMICAL ANALYSIS DATA

P = 206 psia, T = 500°C,
H_2:STC = 2.04:1

Reaction Time \ Species		H_2	DCS	TCS	STC
0 Sec	Nx	0.6711	0	0	0.3289
	Px	138.25	0	0	67.75
10 Sec	Nx	0.6594	0.0014	0.0324	0.3069
	Px	135.84	0.288	6.674	63.22
	ΔPx	-2.41	+0.29	+6.67	-4.53
21 Sec	Nx	0.6482	0.0027	0.0633	0.2858
	Px	133.53	0.5566	13.040	58.87
	ΔPx	-2.31	+0.27	+6.37	-4.35
34 Sec	Nx	0.6429	0.0030	0.0786	0.2755
	Px	132.44	0.618	16.192	56.75
	ΔPx	-1.09	+0.06	+3.15	-2.12
45.5 Sec	Nx	0.64[illegible]	0.0034	0.0775	0.2761
	Px	132.48	0.700	15.965	56.88
	ΔPx	+0.04	+0.08	-0.23	+0.13

Legend: Nx: Mole Fraction
Px: Partial Pressure, psia
ΔPx: Change in Partial Pressure, psia

TABLE IV-8

SILICON TETRACHLORIDE HYDROGENATION
CHEMICAL ANALYSIS DATA

P = 206 psia, T = 500°C

H_2:STC = 5.04:1

Reaction Time	Species	H_2	DCS	TCS	STC
0 Sec	Nx	0.8344	0	0	0.1656
	Px	171.89	0	0	34.11
10 Sec	Nx	0.8314	0.0104	0.0096	0.1586
	Px	171.27	0.08	1.98	32.67
	ΔPx	-0.62	+0.08	+1.98	-1.44
21 Sec	Nx	0.8279	0.0009	0.0206	0.1506
	Px	170.55	0.19	4.24	31.02
	ΔPx	-0.72	0.11	+2.26	-1.65
34 Sec	Nx	0.8240	0.0014	0.0329	0.1417
	Px	169.74	0.29	6.78	29.19
	ΔPx	-0.81	+0.10	+2.54	-1.83
45.5 Sec	Nx	0.8216	0.0019	0.0403	0.1362
	Px	169.25	0.39	8.30	28.06
	ΔPx	-0.49	+0.10	+1.52	-1.13

Legend: Nx: Mole Fraction

Px: Partial Pressure, psia

ΔPx: Change in Partial Pressure, psia

TABLE IV-9

SILICON TETRACHLORIDE HYDROGENATION
CHEMICAL ANALYSIS DATA

P = 206 psia, T = 450°C,

H_2:STC = 2.04:1

Reaction Time	Species	H_2	DCS	TCS	STC
0 Sec	Nx	0.6711	0	0	0.3289
	Px	138.25	0	0	67.75
10 Sec	Nx	0.6656	0.0007	0.0150	0.3187
	Px	137.11	0.14	3.09	65.65
	ΔPx	-1.14	0.14	3.09	-2.10
21 Sec	Nx	0.6598	0.0012	0.0313	0.3076
	Px	135.92	0.25	6.45	63.37
	ΔPx	-1.19	0.11	3.36	-2.28
34 Sec	Nx	0.6533	0.0019	0.0496	0.2952
	Px	134.58	0.39	10.22	60.81
	ΔPx	-1.34	0.14	3.77	-2.56
45.5 Sec	Nx	0.6491	0.0024	0.0614	0.2872
	Px	133.71	0.49	12.65	59.16
	ΔPx	-0.87	0.10	2.43	-1.65

Legend: Nx: Mole Fraction

Px: Partial Pressure, psia

ΔPx: Change in Partial Pressure, psia

TABLE IV-10

SILICON TETRACHLORIDE HYDROGENATION
CHEMICAL ANALYSIS DATA

P = 206 psia, T = 450°C

H_2:STC = 5.04:1

Reaction Time \ Species		H_2	DCS	TCS	STC
0 Sec	Nx	0.8344	0	0	0.1656
	Px	171.89	0	0	34.11
10 Sec	Nx	0.8322	0.0001	0.0076	0.1602
	Px	171.43	0.02	1.57	33.00
	ΔPx	-0.46	0.02	1.57	-1.11
21 Sec	Nx	0.08295	0.0003	0.0162	0.1539
	Px	170.88	0.06	3.34	31.70
	ΔPx	-0.55	0.04	1.77	-1.30
34 Sec	Nx	0.8263	0.0009	0.0261	0.1467
	Px	170.22	0.19	5.38	30.22
	ΔPx	-0.66	0.13	2.04	-1.49
45.5 Sec	Nx	0.8238	0.0014	0.0338	0.1410
	Px	169.70	0.29	6.96	29.05
	ΔPx	-0.52	0.10	1.58	-1.17

Legend: Nx: —Mole Fraction

Px: Partial Pressure, psia

ΔPx: Change in Partial Pressure, psia

TABLE IV-11

SILICON TETRACHLORIDE HYDROGENATION
CHEMICAL ANALYSIS DATA

P = 65 psia, T = 450°C,
H_2:STC = 1.3:1

Reaction Time	Species	H_2	DCS	TCS	STC
0 Sec	Nx	0.5652	0	0	0.4348
	Px	36.74	0	0	28.26
13.6 Sec	Nx	0.5465	0.0004	0.0512	0.4018
	Px	35.52	0.03	3.33	26.12
	ΔPx	-1.22	0.03	3.33	-2.14
27.4 Sec	Nx	0.5423	0.0006	0.0627	0.3944
	Px	35.25	0.04	4.08	25.64
	ΔPx	-0.27	0.01	0.75	-0.48
29.8 Sec	Nx	0.5413	0.0006	0.0654	0.3927
	Px	35.18	0.04	4.25	25.53
	ΔPx	-0.07	0.00	0.17	-0.11
39.6 Sec	Nx	0.5379	0.0009	0.0746	0.3867
	Px	34.96	0.06	4.85	25.14
	ΔPx	-0.22	0.02	0.60	-0.39

Legend: Nx: Mole Fraction
Px: Partial Pressure, psia
ΔPx: Change in Partial Pressure, psia

TABLE IV-12

SILICON TETRACHLORIDE HYDROGENATION
CHEMICAL ANALYSIS DATA

P = 65 psia, T = 500°C

H_2 :STC = 1.3:1

Reaction Time \ Species		H_2	DCS	TCS	STC
0 Sec	Nx	0.5652	0	0	0.4348
	Px	36.74	0	0	28.26
5 Sec	Nx	0.5419	0.0009	0.0632	0.3940
	Px	35.22	0.06	4.11	25.61
	ΔPx	-1.52	0.06	4.11	-2.65
9.8 Sec	Nx	0.5358	0.0011	0.0798	0.3833
	Px	34.83	0.07	5.19	24.91
	ΔPx	-0.39	0.01	1.08	-0.70
13.8 Sec	Nx	0.5322	0.0012	0.0895	0.3770
	Px	34.59	0.08	5.82	24.51
	ΔPx	-0.24	0.01	0.65	-0.41
21.2 Sec	Nx	0.5324	0.0014	0.0888	0.3774
	Px	34.61	0.09	5.77	24.53
	ΔPx	-0.02	0.02	0.04	-0.04

Legend: Nx: Mole Fraction

Px: Partial Pressure, psia

ΔPx: Change in Partial Pressure, psia

TABLE IV-13

KINETIC DATA CORRELATION

Experimental Runs	$K1 \frac{P_{STC}}{P_{e,TCS}}$ sec^{-1}	$P_{e,\ TCS}$ psia	$K1 \cdot P_{STC}$ sec^{-1}, psia	K1, Specific Rate Constant sec^{-1}
(1) Temp = 500°C P = 206 psia H_2:STC = 2.04	0.0396	21.1	0.836	0.0123
(2) Temp = 500°C P = 206 psia H_2:STC = 5:04	0.0232	14.0	0.325	0.0095
(3) Temp = 450°C P = 206 psia H_2:STC = 2.04	0.0193	20.5	0.396	0.0058
(4) Temp = 450°F P = 206 psia H_2:STC = 5.04	0.0153	12.9	0.198	0.0058
(5) Temp = 450°C P = 65 psia H_2:STC = 1.3	0.0489	5.9	0.289	0.0102
(6) Temp = 500°C P = 65 psia H_2:STC = 2.04	0.1990	6.0	1.194	0.0422

The data was evaluated by testing the correlation to various orders of reversible kinetic models. The boundary conditions assumed that the partial pressure of TCS was initially zero and the partial pressure of STC was at the initial value in the reactant feed stream ($P_{o,TCS} = 0$ $P_{o,STC}$ = initial value). For a first order, reversible reaction, the net rate of production of TCS is given from the stoichiometry of reaction (4-5) as

$$\frac{d\,P_{TCS}}{d\,t} = k_1\,(P_{o,STC} - 3/4\,P_{TCS}) - k_2\,P_{TCS} \qquad (4\text{-}10)$$

The first term represents the formation of TCS by the forward reaction while the second term represents its consumption by the reverse reaction. At equilibrium, ($\frac{dP_{TCS}}{d\,t} = 0$ at $P_{TCS} = P_{e,TCS}$) equation (4-10) becomes

$$k_1\,(P_{o,STC} - 3/4\,P_{e,TCS}) = k_2\,(P_{e,TCS}) \qquad (4\text{-}11)$$

from which

$$k_2 = k_1\,\frac{P_{o,STC} - 3/4\,P_{e,TCS}}{P_{e,TCS}} \qquad (4\text{-}12)$$

Substituting in equation (4-10) and simplifying

$$\frac{d\,P_{TCS}}{P_{e,TCS} - P_{TCS}} = k_1\,\frac{P_{o,STC}}{P_{e,TCS}}\,dt \qquad (4\text{-}13)$$

Integrating with the condition $P_{TCS} = 0$ and $t = 0$ gives

$$\ln\frac{P_{e,TCS}}{P_{e,TCS} - P_{TCS}} = k_1\,\frac{P_{o,STC}}{P_{e,TCS}}\,t \qquad (4\text{-}14)$$

This expression correlated well with the experimental data, Figures 4-3 through 4-8. The slope of the resulting straight lines from each data set was determined and listed in Table IV-13. Variation of k_1 with temperature should follow an Arrenheus relation. However k_1 should not vary with total pressure or hydrogen partial pressure--which it does. This indicates that this pseudo first-order kinetic model does not completely represent the actual reaction, although it fairly represents the system at the experimental conditions. This is not surprising since many of the factors which intuitively would be

presumed to affect the reaction (hydrogen partial pressure, reactive surface area of silicon, copper catalyst concentration and gas-solid contact efficiency, etc.) were not studied over a broad enough range to be incorporated into the model. The empirical kinetic model was used to develop the functional design for the larger scale fluid bed hydrogenation reactor by making conservative assumptions concerning the effects of the unincorporated variables on the reactor design.

The larger scale process design calls for operating the hydrogenation reactor at about 500 psig where the equilibrium conversion to TCS is substantially higher than at lower pressures. The equilibrium compositions can be accurately determined for any temperature and pressure from the discussion in Section 4.1. To determine the specific rate constant, k_1, at 500 psig and 500°C, an extrapolation was made based on the experimental observation at 65 to 200 psig that at 500°C, the reaction rate constant varied directly with the STC partial pressure and inversely with the hydrogen partial pressure. Thus at a 1:1 H_2:STC ratio ($P_{o,STC}$ = 257) at 500 psig, k_1 was calculated to be 0.0065. The design equation (4-14) which relates TCS partial pressure with superficial gas residence time then becomes:

$$\ln \frac{P_{e,TCS}}{P_{e,TCS} - P_{TCS}} = 0.0065 \frac{P_{o,STC}}{P_{e,TCS}} t \qquad (4\text{-}15)$$

or

$$P_{TCS} = P_{e,TCS} \left[1 - \exp \left[-0.0065 \frac{P_{o,STC}}{P_{e,TCS}} t \right] \right] \text{ at } P_{e,TCS} = 75 \qquad (4\text{-}16)$$

thus

$$P_{TCS} = 75 \left[1 - e^{-0.0216t} \right] \qquad (4\text{-}17)$$

When similar silicon particle size distribution and copper catalyst concentration are used as in the experimental studies, equation (4-17) provides a conservative design basis for the hydrogenation reactor.

4.3.2 Catalyst Properties and Reaction Mechanism

The catalyst that has been chosen for the redistribution reaction is AMBERLYST[R] A-21, manufactured by Rohm & Haas Chemical Company. This material is a macroreticular, styrene-divinyl, benzene resin to which has been grafted dimethylamino functional groups. The physical properties of the resin are listed in Table III-8.

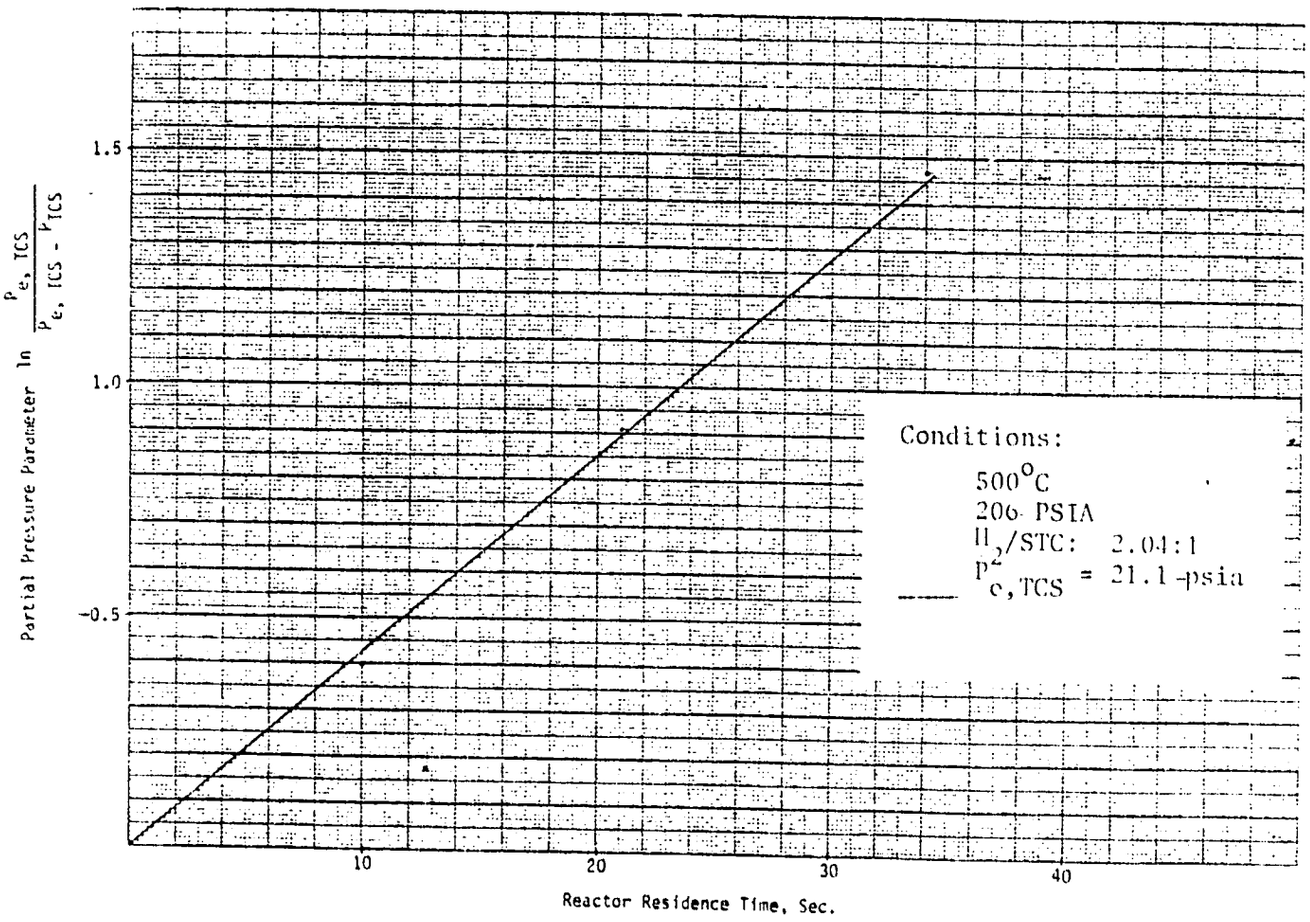

FIGURE 4-3

PLOT OF PARTIAL PRESSURE PARAMETER VS REACTOR RESIDENCE TIME

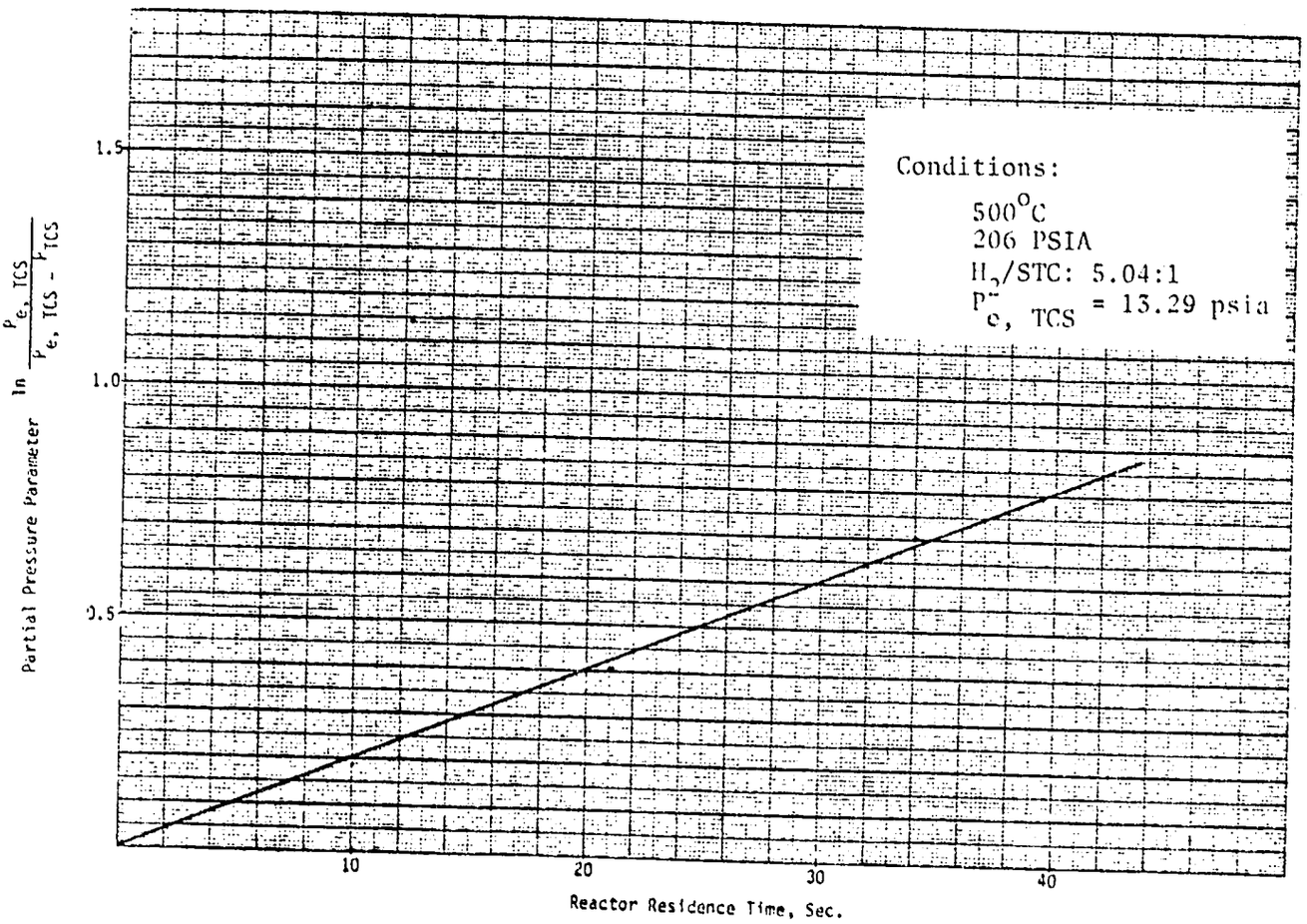

FIGURE 4-4

PLOT OF PARTIAL PRESSURE PARAMETER VS REACTOR RESIDENCE TIME

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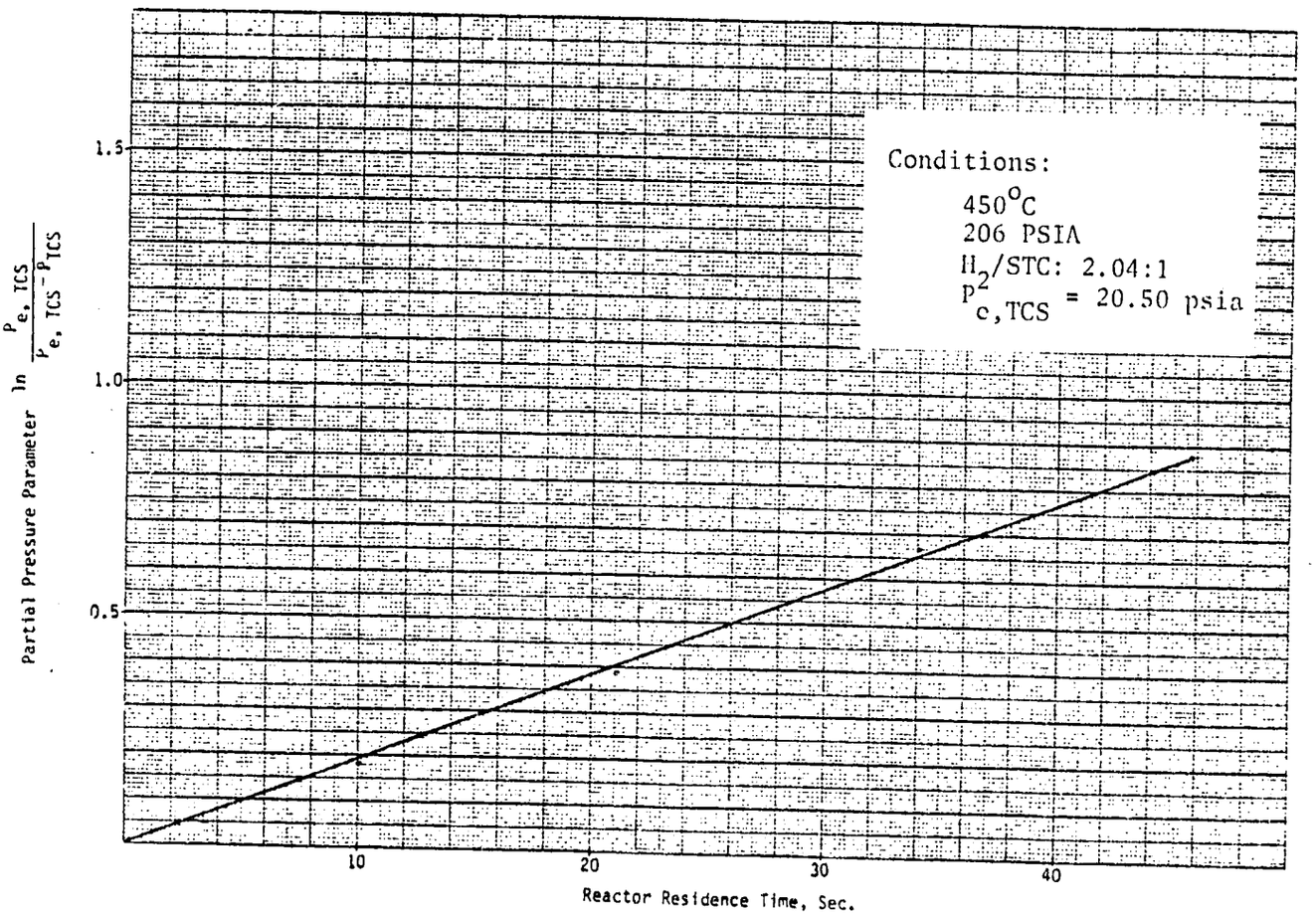

FIGURE 4-5

PLOT OF PARTIAL PRESSURE PARAMETER VS REACTOR RESIDENCE TIME

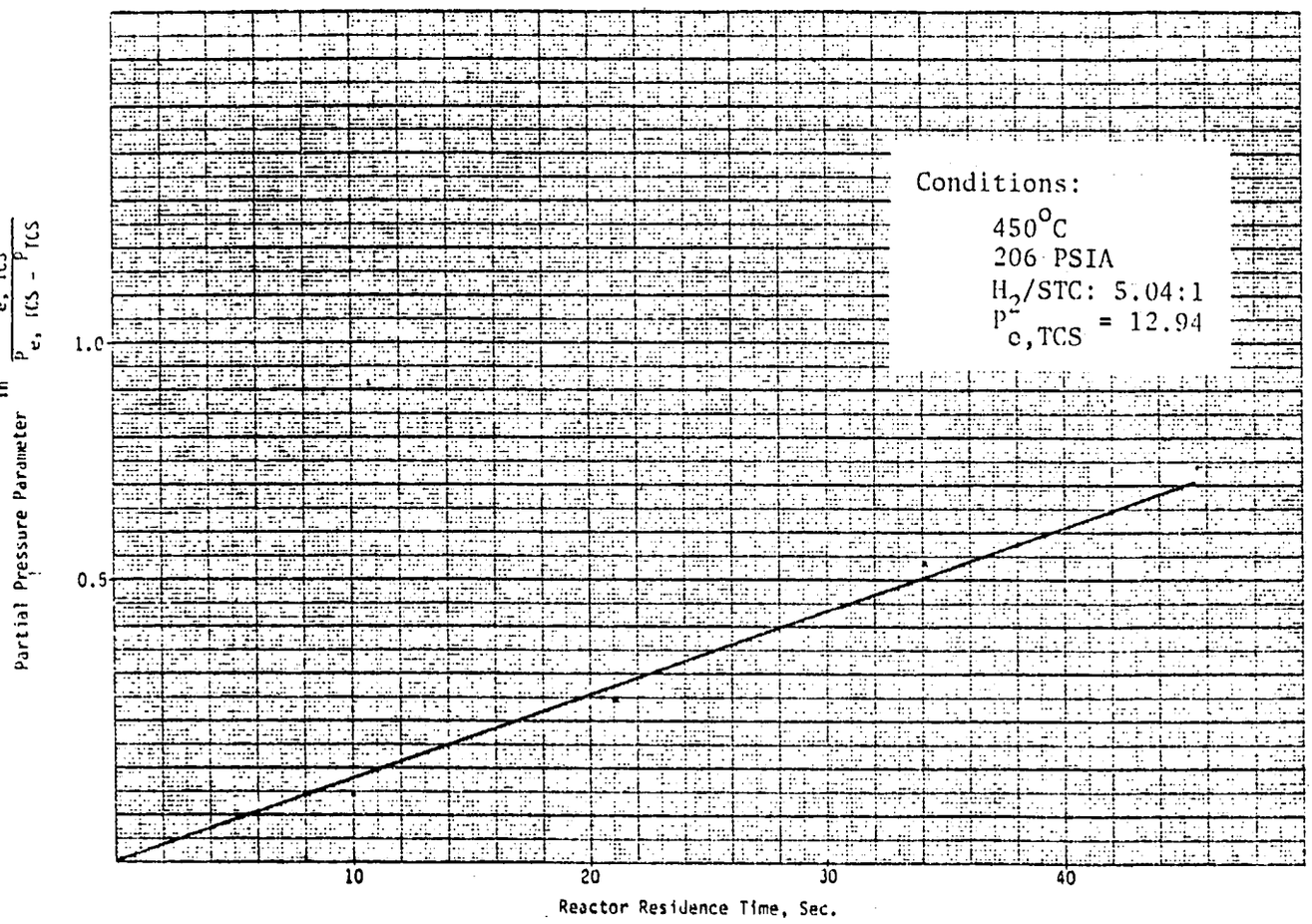

FIGURE 4-6

PLOT OF PARTIAL--PRESSURE PARAMETER VS REACTOR RESIDENCE TIME

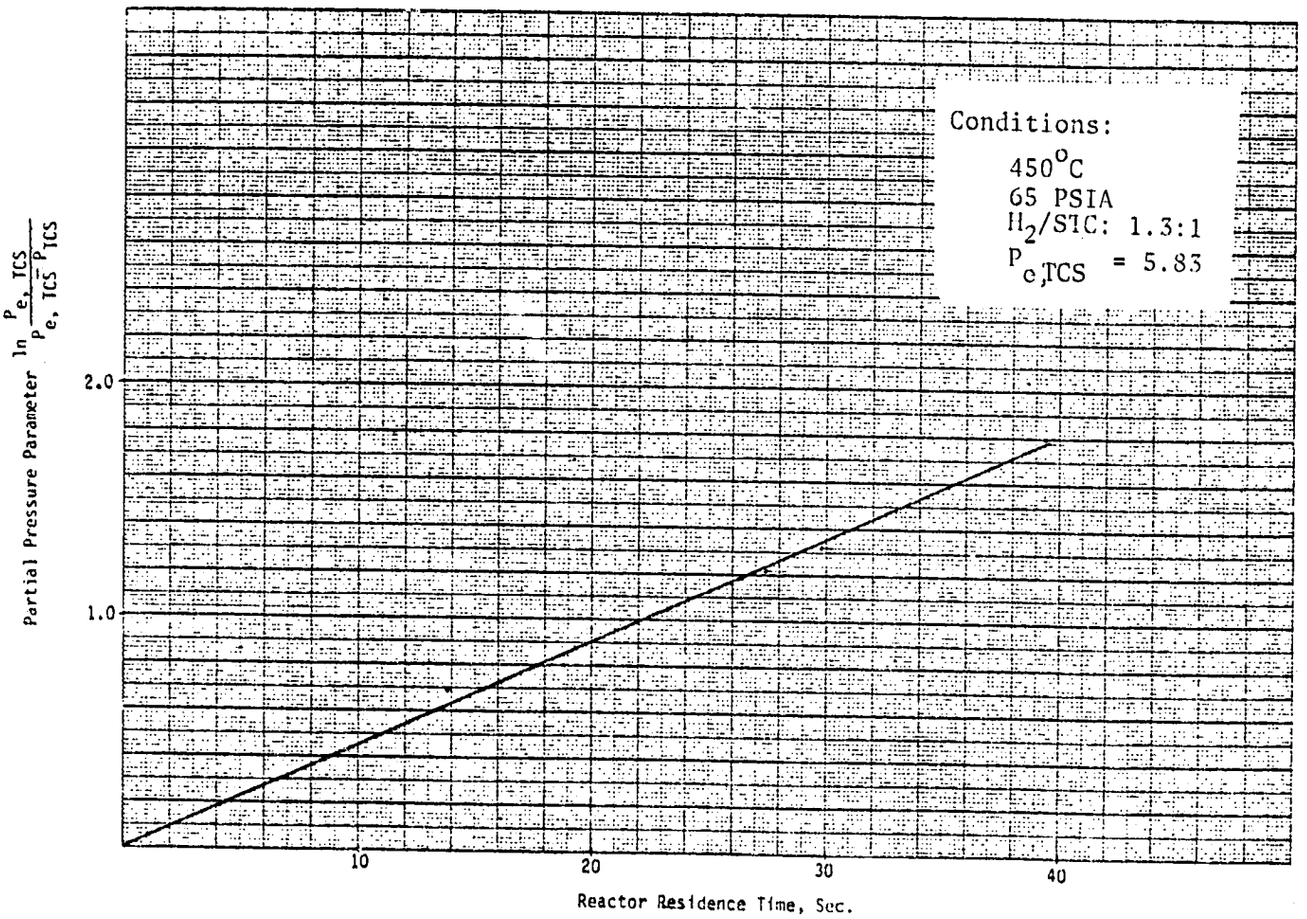

FIGURE 4-7

PLOT OF PARTIAL PRESSURE PARAMETER VS REACTOR RESIDENCE TIME

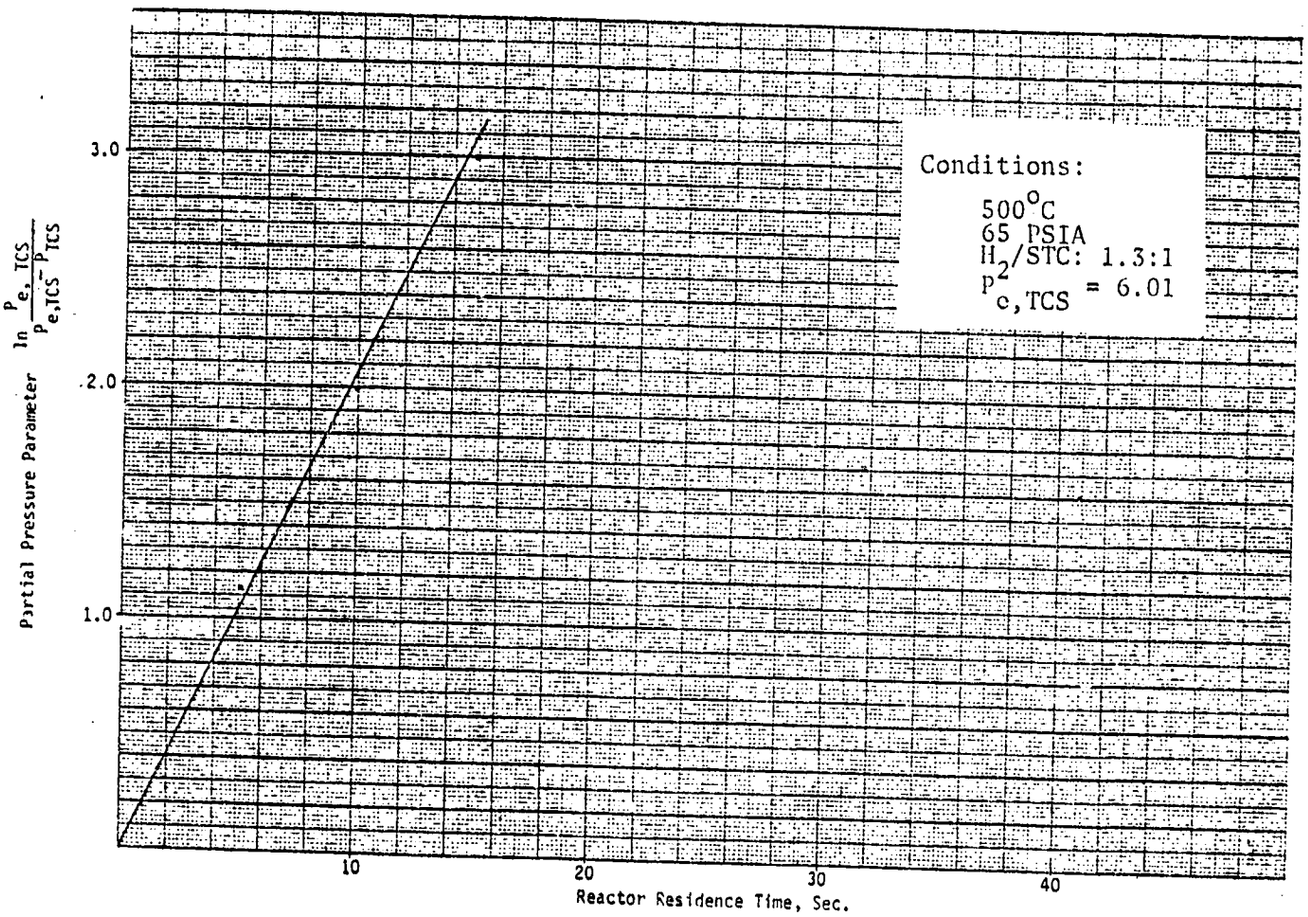

FIGURE 4-8

PLOT OF PARTIAL PRESSURE PARAMETER VS REACTOR RESIDENCE TIME

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Before using this material for the redistribution of chlorosilanes, it was important to determine, in addition to the reaction kinetics and equilibria, the effects that would result from process upsets, changes in inlet feed composition, and HCl addition (as from moisture contamination). A study using deuterium-labeled trichlorosilane and deuterium chloride was performed to help define the reaction mechanism so that the effects of process changes could be qualitatively determined.

It should be appreciated that AMBERYLST® A-21 is functionally a tertiary, aliphatic, amine whose chemical activity parallels other tertiary amines. Its solubility and vapor pressure have been altered by attachment to a polystyrene support. Thus, for the purpose of comparing its catalytic activity, A-21 could be expected to behave chemically like tributylamine or trimethylamine.

A plausible reaction mechanism for the redistribution reaction of chlorosilane is presented below. The hypothesized mechanism involves the reaction of a chlorosilane with the catalyst to form an ionic, amine-chlorosilane salt. This is followed by reaction with a second molecule of chlorosilane, with rearrangement of the H and Cl to form two different chlorosilanes, e.g.,

$$\begin{array}{l} \mathrm{R}\ \mathrm{N}\!:\!\begin{matrix}\mathrm{Me}\\ \mathrm{Me}\end{matrix} + 2\mathrm{HSiCl_3} \rightleftharpoons \left[\begin{matrix}\mathrm{R\text{-}NH}\begin{matrix}\mathrm{Me}\\ \mathrm{Me}\end{matrix} + \mathrm{SiCl_3} + \mathrm{SiCl_3^-}\\ + \mathrm{HSiCl_3}\end{matrix}\right] \rightleftharpoons \left[\mathrm{R\text{-}N.v.H^+...SiCl_3}\ \begin{matrix}\mathrm{Me}\\ \mathrm{Me}\end{matrix}\right] \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \mathrm{Cl_2HSi..Cl} + \mathrm{RN}\!:\!\begin{matrix}\mathrm{Me}\\ \mathrm{Me}\end{matrix} \\ \qquad\qquad \rightarrow \mathrm{H_2SiCl_2} + \mathrm{SiCl_4}, \end{array} \qquad (4\text{-}18)$$

where R = polystyrene support.

In 1970, Reedy (Ref. 9) determined that tributylamine, similar in chemical character to A-21, was an effective catalyst for the redistribution reaction. He further determined that the yield was maximized when the stoichiometric equivalent of HCl was added to the amine. In the same year, Bakay (Ref. 10) found that pretreating A-21 with HCL eliminated the induction period normally observed when TCS was converted to DCS and STC using A-21.

When DCl was added to trichlorosilane feed to which A-21 had been added, a significant amount of isotope exchange took place with the formation of $DSiCl_3$. Large amounts of HD and $SiCl_4$ (Table IV-14) were also formed.

On the basis of these observations, it is possible to conclude that the rate enhancement observed by Bakay (Ref. 10) and Reedy (Ref. 9) derives from the formation of an amine hydrochloride:

$$\begin{matrix} Me \\ RN: \\ Me \end{matrix} + HCl \rightleftarrows \begin{matrix} Me \\ RN\ H^+\ Cl^- . \\ Me \end{matrix} \qquad (4\text{-}19)$$

This reaction would be favored kinetically over the formation of the amine-chlorosilane salt. However, the exchange of Cl^- for $SiCl_3^-$ could be enhanced by the already established $\begin{matrix} Me \\ RN\ H^+ \\ Me \end{matrix}$ ion:

$$\begin{matrix} Me \\ RN\ H^+\ Cl^- \\ Me \end{matrix} = HSiCl_3 \rightleftarrows \begin{matrix} Me \\ RN\ \ H^+\ SiCl_3^- \\ Me \end{matrix} + \underline{HCl.} \qquad (4\text{-}20)$$

This reaction would establish the intermediate complex required above and would also remove excess HCl from the catalyst site. Evidence for the latter is given in Table IV-14, which shows that catalyst performance degraded by a large excess of DCl, returned to normal a short time after the DCl was removed from the $HSiCl_3$ feed.

The isotope tracer experiments also showed the formation of large amounts of HD and $SiCl_4$ when DCl was added in equimolar amounts to $HSiCl_3$ over A-21. This appears to result from the well-known, acid-catalyzed, SiH cleavage by nucleophilic attack of Cl^- on silicon with elimination of hydrogen:

$$\begin{matrix} Me \\ R\text{-}N\ D^+\ Cl^- \\ Me \end{matrix} + HSiCl_3 \rightleftarrows \left[\begin{matrix} Me \\ RN \\ Me \end{matrix} \begin{matrix} D^+ \ldots Cl^- \\ H - - - SiCl_3 \end{matrix} \right] \rightleftarrows HD + SiCl_4 . \qquad (4\text{-}21)$$

TABLE IV-14

DISPROPORTIONATION OF TCS AND DCl GAS IN THE PRESENCE OF A-21 RESIN CATALYST AT 60°C

Expt'l No.	Time Lapse min.	$HSiCl_3$ Feedrate g./min.	DCl Feedrate c.c./min.	$HSiCl_3$ / DCl Ratio	Residence Time sec. (1)	Product Composition, mole % (2)					
						DCl	H_3SiCl	H_2SiCl_2	$HSiCl_3$	$SiCl_4$	Hvs.
-	(Purity of $HSiCl_3$)					-	0	0.2	99.5	0.2	0.1
1	30	0.85	0	-	26	0	0.42	8.75	78.31	12.11	0.42
2	45	0.85	150	1.0	13	10.9	0	0.12	19.31	63.20	6.45
3	60	0.85	150	1.0	13	12.6	0	0	18.28	66.53	2.59
4	75	0.85	75	2.0	9.8	3.8	0	0	43.15	52.48	0.58
	(Stop feeding DCl at 75 min.)										
5	80	0.85	0	-	26	0	0	0.04	60.79	39.11	0.06
6	135	0.85	0	-	26	0	0.32	8.21	80.42	10.76	0.29
7	165	0.85	0	-	26	0	0.40	9.02	79.46	10.86	0.26

(1) Based on void space in A-21 resin, i.e., 65% of bed volume

(2) By gas chromatography: deuteriated compounds were not separated from their hydrogen analogy, i.e., $HSiCl_3$ represented $HSiCl_3$ + $DSiCl_3$.

Further evidence for the presence of the amine-chlorosilane intermediate was presented when the analogous trimethylamine-trichlorosilane was isolated (Ring, Ref. 10).

Thus, in a practical sense, HCl addition can help to achieve a rapid startup of a fresh catalyst charge. Feeding trichlorosilane by itself will achieve the same effect, but with a slightly longer induction time. Adding HCl inadvertantly later on will result in the formation of H_2 and $SiCl_4$ and will result in decreased H_2SiCl_2 output. However, this condition is transient and normal activity will return when the HCl is removed from the feed. Changes in chlorosilane composition in the feed will change the effluent composition according to the kinetics and equilibrium considerations that will be discussed in Section 4.3.2.1. However, no H_2 or HCl will be formed, probably because the redistribution reaction involves exchange between the chlorosilane and an amine-chlorosilane complex and not an amine hydrochloride.

4.3.2.1 —Trichlorosilane Redistribution Kinetics

The reaction path taken by TCS redistribution is governed by reaction (4-2) (Section 4.1). This reaction makes STC and DCS; however, by reaction (4-3) (Section 4.1), DCS in turn produces some TCS and MCS, although the amount of MCS is small (less than 1 mole %). Also, the reaction rate for TCS, reaction (4-2), is much slower than that for DCS, reaction (4-3). Consequently, reaction (4-2) is controlling the rate of conversion. This makes the analysis of the kinetics for TCS redistribution much simpler since only one reaction need be considered.

An examination of Figure 4-9 for TCS redistribution experimental data reveals that the data for the three different bed lengths do not fall on the same curve. At the same residence time for each bed length, the liquid mass velocity is greatest for the 4-inch bed length and the effluent TCS concentration is correspondingly lower. This effect can be considered as a diffusion phenomenon; both liquid velocity and temperature are strongly controlling the amount of conversion from the catalyst surface to the bulk liquid.

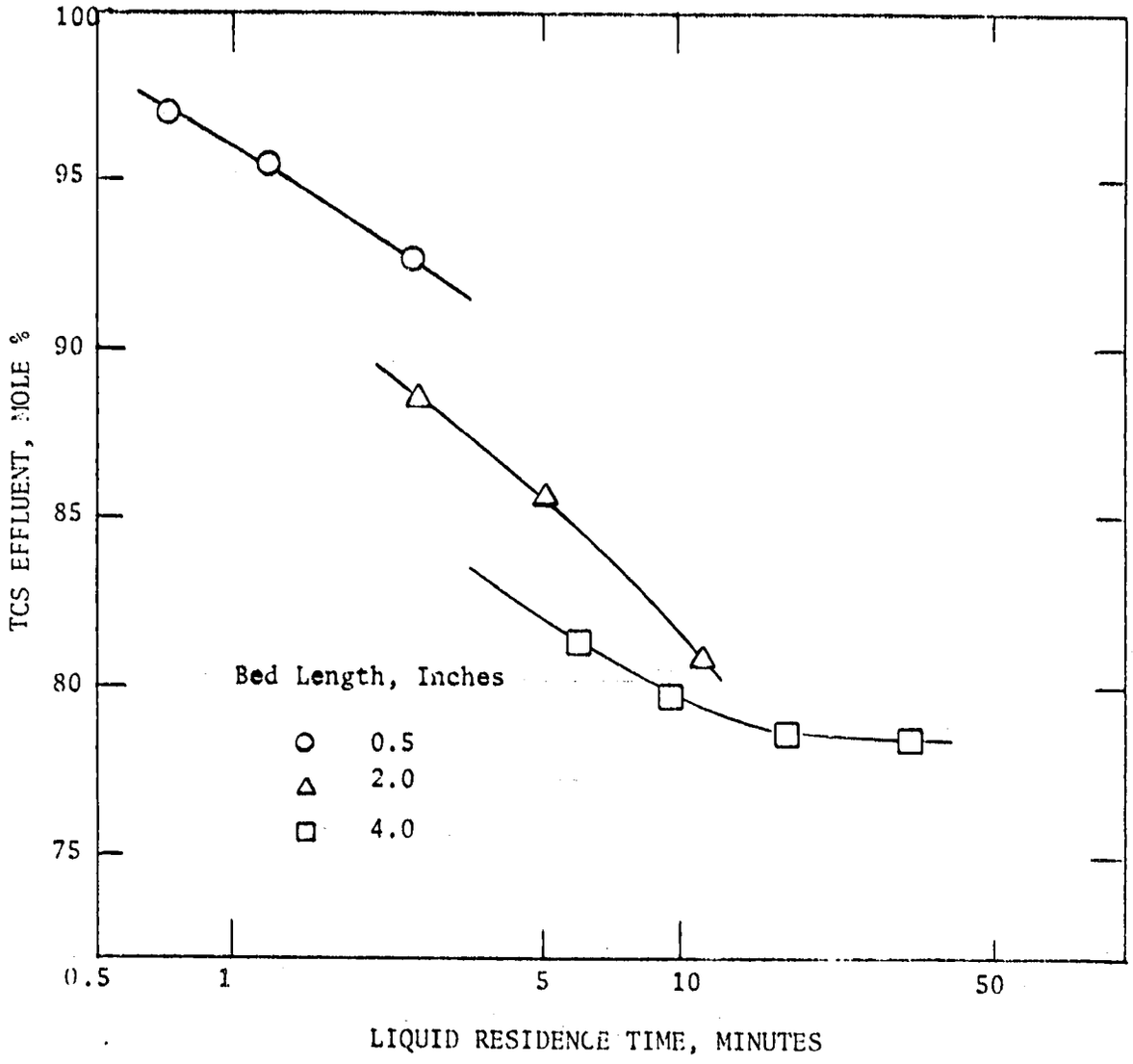


FIGURE 4-9

EFFLUENT PRODUCT COMPOSITION FROM TCS REDISTRIBUTION REACTOR AT 81°C CONTAINING A-21 RESIN CATALYST. BED DIAMETER = 0.43 INCHES

Since there are two molecules of TCS involved in reaction (4-2), the reaction rate is probably second-order. The TCS data was first tested with first-order and second-order, reversible, reaction-rate equations but neither proved satisfactory because of the diffusion effect. A new mathematical model was then developed that takes into consideration the diffusional effect. This model is described below.

The TCS disproportionation reaction is given by reaction (4-2) as follows:

$$2\ HSiCl_3 \rightleftharpoons SiCl_4 + H_2SiCl_2 \qquad (4\text{-}2)$$

For second-order, if diffusional resistance is ignored, the reaction rate is:

$$r_3^* = k_3 \cdot (x_3^2 - x_2 \cdot x_4 / K_3), \qquad (4\text{-}22)$$

where r_3 is the reaction rate; x_2, x_3, and x_4 are mainstream concentrations of DCS, TCS and STC; K_3 is the TCS equilibrium constant for reaction 2; and k_3 is the TCS-reaction-rate constant. When diffusional resistances are included between the mainstream and the active catalyst surface, the reaction-rate expression becomes:

$$r_3 = k_3 \cdot (z_3^2 - z_2\ z_4 / K_3), \qquad (4\text{-}23)$$

where z is a concentration on the catalyst surface that has been isolated from the mainstream by an idealized stagnant film of a certain thickness. This model might be thought of as TCS in the bulk of the mainstream fluid having to diffuse through a stagnant film to reach the catalyst surface and then being redistributed into DCS and STC. The DCS and STC then have to diffuse back through the film before they can reach the mainstream fluid.

To find the component concentrations as a function of time, the following differential-algebraic equations must be solved:

$$\dot{x}_3 = -2k_3 \cdot (z_3^2 - z_2 z_4 / K_3), \qquad (4\text{-}24)$$

$$x_2 = 0.5\ (1 - x_3),$$

$$x_4 = 0.5\ (1 - x_3),$$

where $\dot{x}_3$ is the derivative of x_3 with respect to time. To perform the integration, z_2, z_3, and z_4 must be expressed in terms of x_2, x_3, and x_4. This is accomplished by using a diffusion model that depends on liquid diffusivities of binary pairs for the components TCS, DCS and STC and by assuming that diffusivities are independent of molal concentrations. The reaction-rate constant, k_3, in equation (4-24) accounts for the resistance to conversion at the catalyst surface and for the diffusion resistance through the film to the bulk stream.

An error-squared, minimization numerical analysis was performed on the data to determine the relative proportions of conversion resistance resulting from diffusion and active surface kinetics (k_3). The amount of data available was insufficient to establish this proportionality (the error sums were not strongly dependent on the diffusion/surface kinetics resistance ratio). Therefore, the data have been correlated using superficial fluid velocity as an independent parameter. For this correlation, the diffusion and surface resistance were lumped into the computed, best-rate-constant, k_3, term. TCS concentration as a function of residence time for constant fluid velocities of 1, 2, and 4 ft/hr are presented in Figures 4-10 and 4-11. The experimental points superimposed on the lines of constant velocity show good agreement. In Figure 4-12, the reaction rate constants are shown on an Arrhenius-type plot. The experimental data are listed in Table IV-15.

4.3.2.2 Dichlorosilane Redistribution Kinetics

As stated in Section 4.1, the DCS redistribution is a complex reaction that involves the following three equations:

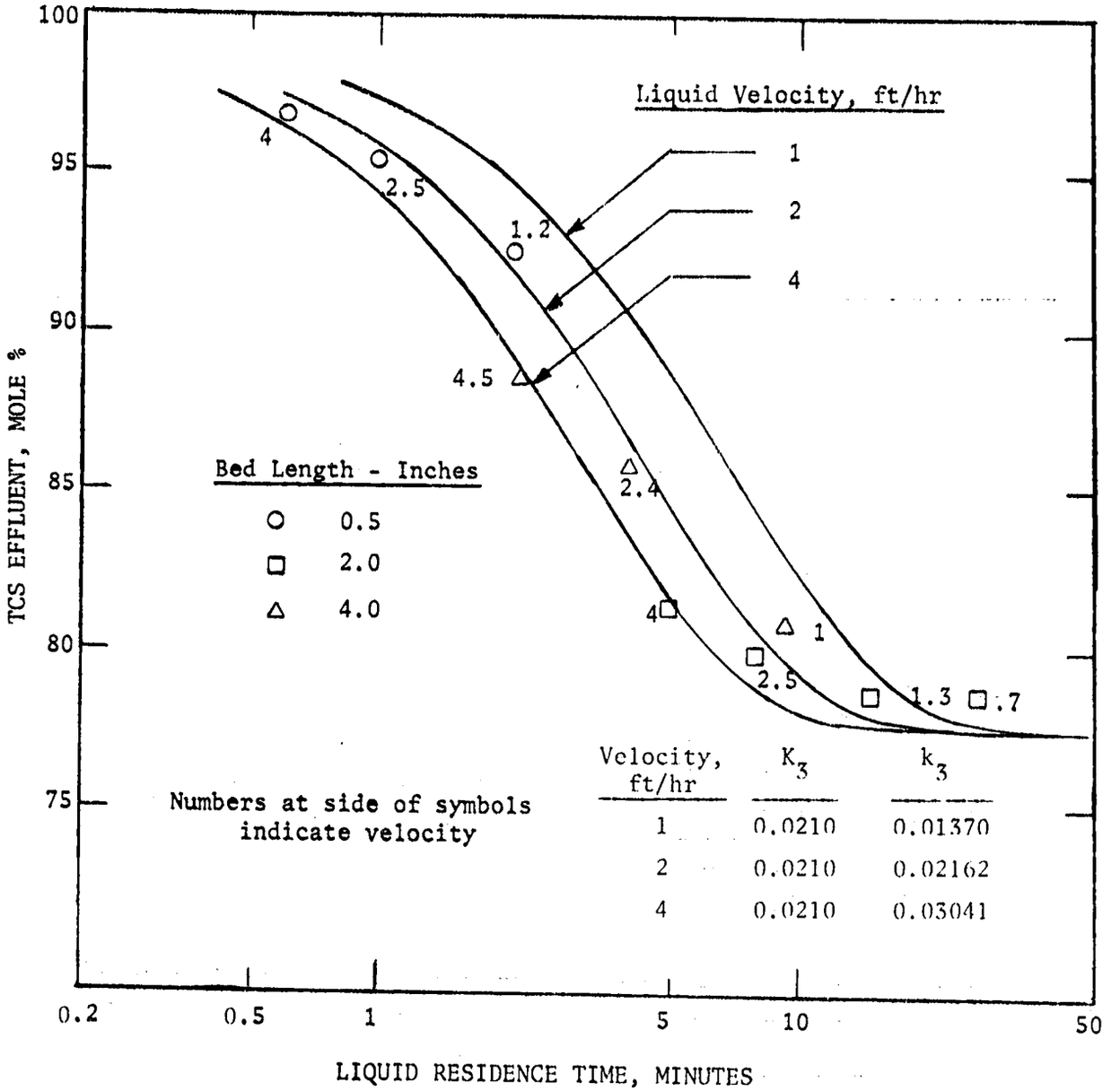
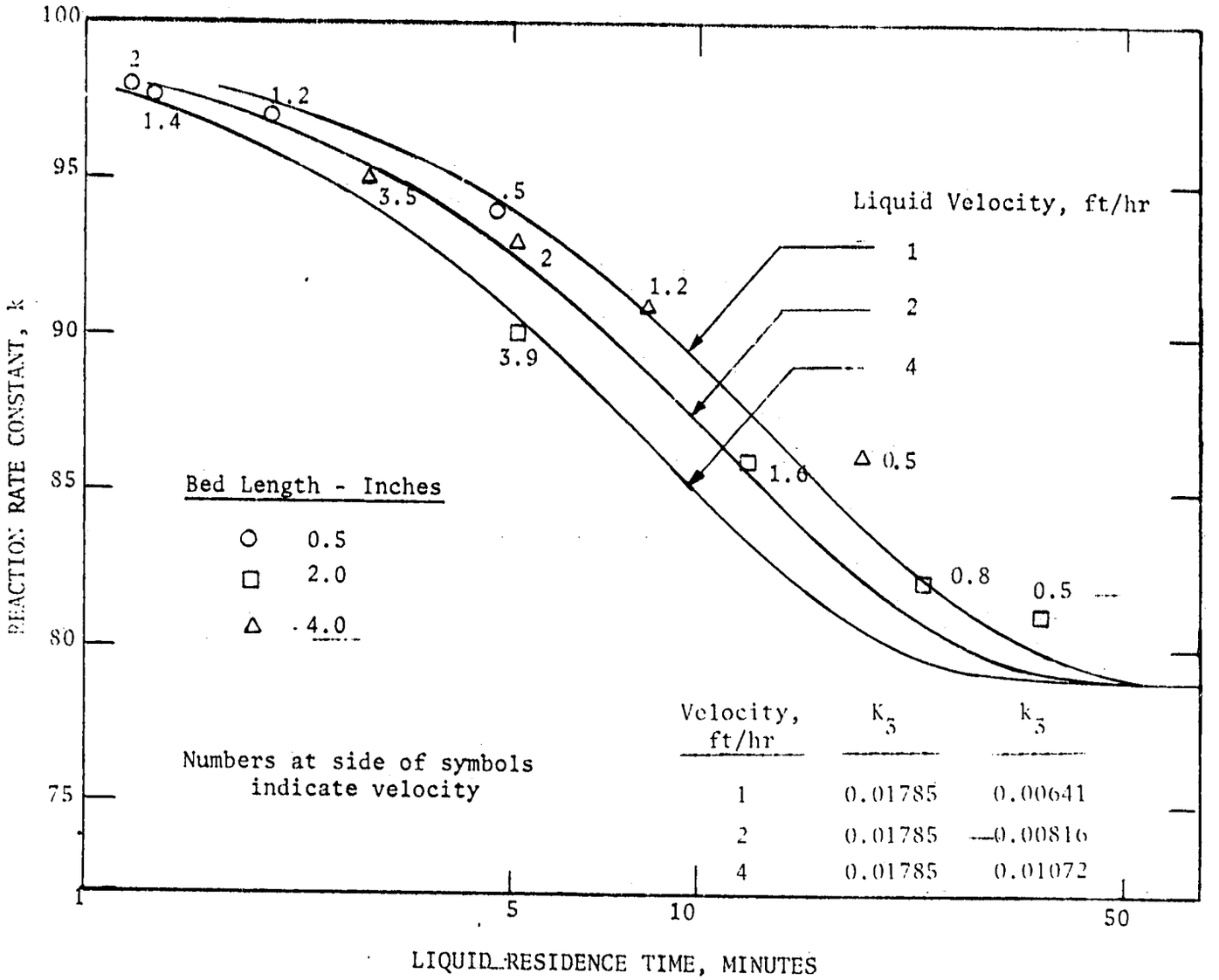


FIGURE 4-10

EFFLUENT PRODUCT COMPOSITION FROM TCS REDISTRIBUTION REACTOR AT 81°C CONTAINING A-21 RESIN CATALYST. BED DIAMETER = 0.43 INCHES



Velocity, ft/hr	K_5	k_5
1	0.01785	0.00641
2	0.01785	0.00816
4	0.01785	0.01072

FIGURE 4-11

EFFLUENT PRODUCT COMPOSITION FROM LIQUID TCS REDISTRIBUTION REACTOR AT 56°C CONTAINING A-21 RESIN CATALYST. BED DIAMETER = 0.43 INCHES

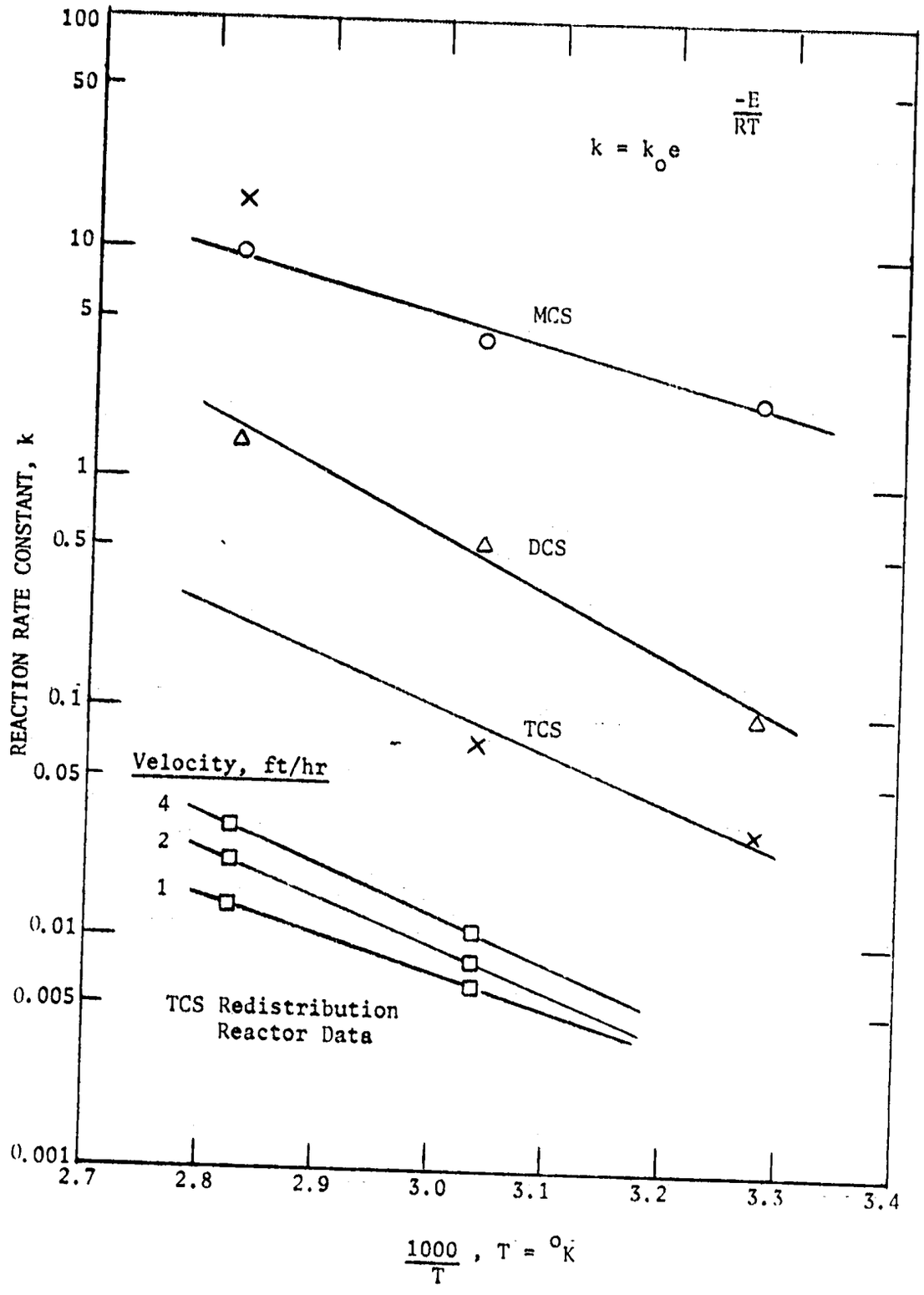


FIGURE 4-12

REACTION RATE CONSTANT AS A FUNCTION OF TEMPERATURE.
TOP THREE CURVES ARE FROM DCS REDISTRIBUTION REACTOR.

TABLE IV-15

CATALYTIC REDISTRIBUTION OF TRICHLOROSILANE

T (°C)	RT (Min)	H_3SiCl*	H_2SiCl_2*	$HSiCl_3$*	$SiCl_4$*	Bed Height (Ins.)
56	4.8	-	4.76	90.64	4.6	0.5
56	4.7	-	3.10	93.87	3.03	"
56	4.7	-	3.03	94.19	2.78	"
56	2.0	-	1.97	96.42	1.61	"
56	2.0	-	1.75	96.74	1.51	"
56	1.3	-	1.26	96.72	1.02	"
56	1.3	-	1.04	98.04	0.92	"
56	2.1	-	1.38	97.29	1.33	"
56	2.1	-	1.37	97.40	1.23	"
56	1.2	-	0.99	98.13	0.88	"
56	1.2	-	0.97	98.16	0.87	"
56	0.63	0.15	0.57	98.79	0.49	"
56	0.63	0.11	0.51	98.92	0.46	"
81	2.1	0.07	3.89	92.65	3.39	"
81	2.1	0.08	3.96	92.52	3.49	"
81	1.0	0.03	2.43	95.41	2.13	"
81	1.0	0.02	2.44	95.44	2.10	"
81	0.61	-	1.77	96.83	1.40	"
81	0.61	-	1.69	96.85	1.46	"
55.5	7.2	0.14	6.25	88.62	4.99	4.0
55.5	7.2	0.18	5.93	88.33	5.56	"
56	12.22	0.22	7.08	86.08	6.62	"
56	12.2	0.21	7.18	86.05	6.56	"
56	5.1	0.18	5.01	90.32	4.49	"
56	5.1	0.15	5.02	90.16	4.67	"
56	23.5	0.25	8.75	82.65	8.34	"
56	23.5	0.23	8.90	82.76	8.11	"
56	23.5	0.22	9.39	82.34	8.05	"
56	36.55	0.43	9.17	81.82	8.58	"
56	36.55	0.34	9.60	81.37	8.69	"

* Mole %

TABLE IV-15

CATALYTIC REDISTRIBUTION OF TRICHLOROSILANE (Con't)

T (°C)	RT (Min)	H_3SiCl*	H_2SiCl_2*	$HSiCl_3$*	$SiCl_4$*	Bed Height (Ins.)
56	36.55	0.25	9.56	81.37	8.82	4.0
56	52.7	0.36	9.58	81.07	8.99	"
56	52.7	0.40	9.62	80.82	9.16	"
81	7.9	0.37	9.81	80.11	9.71	"
81	7.9	0.46	10.16	79.40	9.98	"
81	5.0	0.34	9.06	81.27	9.33	"
81	5.0	0.48	8.99	81.58	8.95	"
81	14.45	0.46	10.64	78.72	10.18	"
81	14.95	0.45	10.66	78.77	10.12	"
81	27.2	0.50	10.63	78.66	10.21	"
81	27.2	0.57	10.72	78.55	10.16	"
180	-	0.66	9.79	80.52	9.03	"
180	-	0.33	9.77	80.74	9.16	"

T (°C)	RT (Min)	SiH_4	H_3SiCl*	H_2SiCl_2*	$HSiCl_3$*	$SiCl_4$*	Bed Height (Ins.)
56	18.5	-	0.13	7.03	86.37	6.47	2.0
56	18.5	-	0.12	6.88	86.57	6.43	"
56	8.2	0.04	0.05	4.60	91.23	4.08	"
56	8.2	0.06	0.06	4.81	90.91	4.16	"
56	5.1	0.16	0.02	3.46	93.32	3.04	"
56	5.1	0.04	0.03	3.45	93.53	2.95	"
56	5.1	-	-	3.38	93.79	2.83	"
56	2.8	-	0.03	2.38	95.62	1.97	"
56	2.8	-	0.03	2.32	95.58	2.04	"
81	9.3	-	0.69	9.42	80.70	9.19	"
81	9.3	0.53	0.44	9.53	80.86	8.64	"
81	4.1	0.03	0.19	7.38	85.81	6.59	"
81	4.1	-	0.22	7.33	85.86	6.59	"
81	2.2	0.21	0.35	5.89	88.58	4.97	"

* Mole %

$$2HSiCl_3 \rightleftarrows SiCl_4 + H_2SiCl_2, \qquad (4\text{-}2)$$

$$2H_2SiCl_2 \rightleftarrows HSiCl_3 + H_3SiCl, \text{ and} \qquad (4\text{-}3)$$

$$2H_3SiCl \rightleftarrows H_2SiCl_2 + SiH_4. \qquad (4\text{-}4)$$

The DCS reaction (4-3) makes TCS and MCS and reaction (4-2) produces STC and DCS. At the same time, the MCS results in more DCS and silane, the desired product. There is considerable conversion of all the chlorosilanes, except for STC. For example, feeding 100% DCS to a redistribution reactor at 80°C and containing A-21 resin catalyst results in the following equilibrium product composition: 10.2 mole % silane, 15.6% MCS, 38.8% DCS, 34.7% TCS and 0.7% STC.

Although the kinetics of the TCS redistribution reaction could be analyzed with a single, second-order rate equation, the kinetics of the DCS redistribution reaction cannot be analyzed so simply. However, assuming for the moment, a second-order rate equation, the reaction rates for equations (4-2), (4-3), and (4-4) are:

$$r_1 = k_1 \, (C_1^2 - C_0 \, C_2/K_1), \qquad (4\text{-}25)$$

$$r_2 = k_2 \, (C_2^2 - C_1 \, C_3/K_2), \text{ and} \qquad (4\text{-}26)$$

$$r_3 = k_3 \, (C_3^2 - C_2 \, C_4/K_3), \qquad (4\text{-}27)$$

where C_0, C_1, C_2, C_3 and C_4 are mole concentrations of silane, MCS, DCS, TCS, and STC, respectively; k is the rate constant; and K is the equilibrium constant. In terms of reaction rates, the rate of change of composition with respect to residence time is given by the equations below:

$$\dot{C}_0 = r_1 \qquad (4\text{-}28)$$

$$\dot{C}_1 = r_2 - 2r_1 \qquad (4\text{-}29)$$

$$\dot{C}_2 = r_1 + r_3 - 2r_2 \qquad (4\text{-}30)$$

$$\dot{C} = r_2 - r_3 \qquad (4\text{-}31)$$

$$\dot{C}_4 = r_3 \qquad (4\text{-}32)$$

The integration of the five differential equations (4-28) through (4-32) produces the values of the chlorosilane concentrations at a specified time.

The calculated concentrations were compared to the experimental points and, when the sum of the squares of the relative differences between the calculated and experimental points were at a minimum, the results were as given in Tables IV-16 through IV-18 for the three temperatures 32, 56, and 81°C. The experimental data is reported in Ref. 12. Figures 4-13 through 4-15 show the excellent agreement between calculated and experimental points. It is apparent that at the highest temperatures reaction rates are the fastest and the time required to reach equilibrium is the shortest. This is graphically illustrated in Figure 4-12, where reaction rate constants are plotted vs 1/T. The only deviation is the TCS rate constant at 81°C. Also, the TCS rate constants derived from the DCS redistribution reactor are higher than the TCS rate constants derived from the TCS redistribution reactor. This can be understood by examining equation (4-27). The TCS rate constant k_3 is calculated using TCS, DCS and STC concentrations. In the DCS reactor the amount of STC in the effluent stream is low, usually about 0.1 to 0.5 mole %. Therefore, it is difficult to measure accurately. The calculated rate constant k includes the effect of diffusion. However, the DCS experimental data does not show the dramatic effect of diffusion (as did TCS, Figure 4-9) and diffusion probably plays a lesser role in the DCS redistribution.

TABLE IV-16

DCS REDISTRIBUTION DATA CALCULATED WITH SECOND-ORDER RATE EQUATIONS AT 32°C

Minutes

C0 EXPMNT	C0 CALCTD	C1 EXPMNT	C1 CALCTD	C2 EXPMNT	C2 CALCTD	C3 EXPMNT	C3 CALCTD	C4 EXPMNT	C4 CALCTD	SPACE TIME
0.002900	0.002900	0.035400	0.035400	0.946100	0.946100	0.012200	0.012200	0.003400	0.003400	0.0
0.004200	0.003227	0.069700	0.054111	0.869100	0.906401	0.054400	0.034158	0.002100	0.002103	0.240000
0.011000	0.004807	0.075500	0.072856	0.828100	0.863267	0.084400	0.057871	0.001000	0.001200	0.540000
0.006500	0.006098	0.077600	0.081039	0.830400	0.842738	0.084600	0.069214	0.000900	0.000910	0.700000
0.006600	0.007231	0.078900	0.086470	0.823600	0.828319	0.089900	0.077229	0.001000	0.000751	0.820000
0.009500	0.009142	0.086500	0.093632	0.801700	0.808090	0.101400	0.088555	0.000900	0.000580	1.000000
0.012100	0.009942	0.082500	0.096134	0.804400	0.800638	0.100400	0.092755	0.000600	0.000531	1.070000
0.013100	0.019151	0.105100	0.115120	0.745400	0.734854	0.135400	0.130529	0.001000	0.000346	1.790000
0.025700	0.020891	0.108300	0.117582	0.712700	0.724711	0.152800	0.136466	0.000500	0.000350	1.920000
0.053400	0.048564	0.139100	0.140361	0.548000	0.596389	0.260300	0.213681	0.000200	0.000904	4.260000
0.047100	0.058728	0.151500	0.144687	0.563300	0.557892	0.232900	0.237442	0.000400	0.001251	5.380000
0.074800	0.070134	0.151500	0.148127	0.494500	0.517275	0.276300	0.262731	0.004200	0.001733	6.990000
0.071200	0.071221	0.151500	0.148395	0.481900	0.513549	0.272400	0.265060	0.001300	0.001784	7.170000

C0 = silane mole fraction
C1 = MCS
C2 = DCS
C3 = TCS
C4 = STC

$K_1 = 1.88$ $k_1 = 2.32$

$K_2 = 0.319$ $k_2 = 0.0945$

$K_3 = 0.0149$ $k_3 = 0.0323$

K = equilibrium constant

k = reaction rate constant

TABLE IV-17

DCS REDISTRIBUTION DATA CALCULATED WITH SECOND-ORDER RATE EQUATIONS AT 56°C

Minutes

C0 EXPMNT	C0 CALCTD	C1 EXPMNT	C1 CALCTD	C2 EXPMNT	C2 CALCTD	C3 EXPMNT	C3 CALCTD	C4 EXPMNT	C4 CALCTD	SPACE TIME
0.002900	0.002900	0.035400	0.035400	0.946100	0.946100	0.012200	0.012200	0.003400	0.003400	0.0
0.002800	0.004269	0.073700	0.086884	0.850300	0.837772	0.071200	0.068928	0.002000	0.002146	0.130000
0.006900	0.007488	0.112600	0.113571	0.775900	0.774191	0.103400	0.103152	0.001200	0.001598	0.230000
0.031700	0.022434	0.135300	0.150396	0.648500	0.655119	0.181900	0.171037	0.002300	0.001013	0.510000
0.042200	0.031385	0.147700	0.157855	0.602600	0.613335	0.205300	0.196426	0.002200	0.000999	0.660000
0.054700	0.047100	0.149700	0.163098	0.551200	0.555934	0.243200	0.232639	0.001200	0.001229	0.950000
0.051000	0.050902	0.139100	0.163527	0.593800	0.543766	0.215700	0.240480	0.000400	0.001325	1.030000
0.069800	0.074413	0.162300	0.162503	0.492100	0.476239	0.275000	0.284559	0.000800	0.002286	1.700000
0.083200	0.077837	0.151400	0.162006	0.477900	0.467162	0.287300	0.290510	0.000200	0.002485	1.840000
0.088400	0.091337	0.160900	0.159493	0.440300	0.432671	0.309800	0.313049	0.000600	0.003459	2.640000
0.085300	0.092606	0.170600	0.159218	0.442100	0.429515	0.301200	0.315092	0.000800	0.003569	2.750000

C0 = silane mole fractic
C1 = MCS
C2 = DCS
C3 = TCS
C4 = STC

$K_1 = 1.75$ $k_1 = 4.21$

$K_2 = 0.340$ $k_2 = 0.532$

$K_3 = 0.01785$ $k_3 = 0.0723$

K = equilibrium constant

k = reaction rate constant

TABLE IV-18

DCS REDISTRIBUTION DATA CALCULATED WITH SECOND-ORDER RATE EQUATIONS AT 80°

Minutes

C0 EXPMNT	C0 CALCTD	C1 EXPMNT	C1 CALCTD	C2 EXPMNT	C2 CALCTD	C3 EXPMNT	C3 CALCTD	C4 EXPMNT	C4 CALCTD	SPACE TIME
0.002900	0.002900	0.035400	0.035400	0.946100	0.946100	0.012200	0.012200	0.003400	0.003400	0.0
0.013500	0.011339	0.113400	0.135293	0.733300	0.718104	0.137000	0.134756	-0.002900	0.000507	0.125000
0.029300	0.025175	0.137100	0.159931	0.648900	0.627937	0.182600	0.185832	0.002100	0.001125	0.220000
0.045700	0.061062	0.201500	0.169600	0.482300	0.502692	0.269600	0.263769	0.001000	0.002877	0.500000
0.073300	0.073376	0.170800	0.167981	0.472100	0.469723	0.283100	0.285308	0.000900	0.003612	0.650000

C0 = silane mole fraction
C1 = MCS
C2 = DCS
C3 = TCS
C4 = STC

$K_1 = 1.64$ $\quad k_1 = 9.58$

$K_2 = 0.3594$ $\quad k_2 = 1.44$

$K_3 = 0.0210$ $\quad k_3 = 16.2$

K = equilibrium constant

k = reaction rate constant

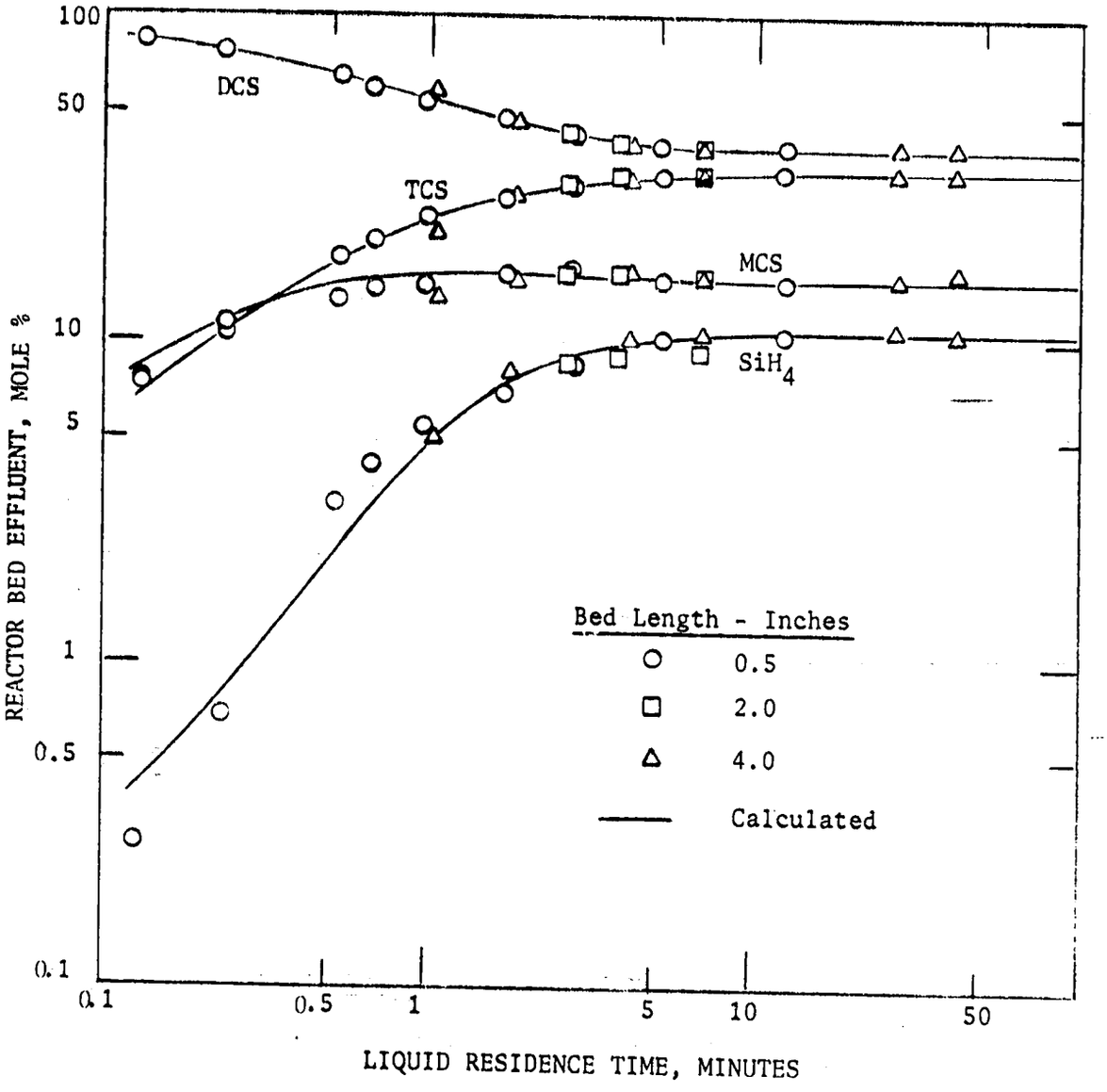


FIGURE 4-13

EFFLUENT PRODUCT COMPOSITION FROM LIQUID DCS REDISTRIBUTION REACTOR AT 56°C CONTAINING A-21 RESIN CATALYST.

BED DIAMETER = 0.43 INCHES

C-3

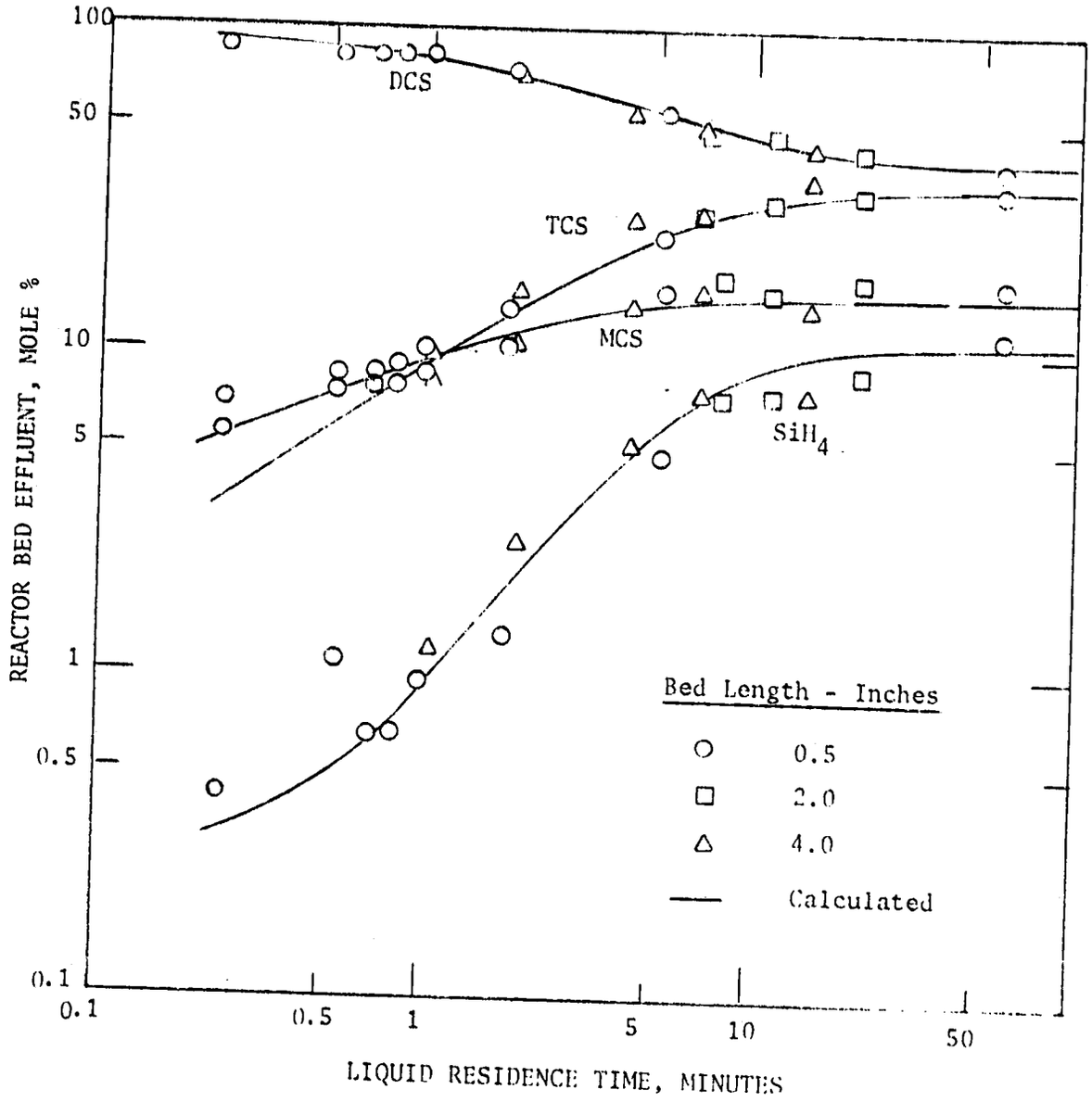


FIGURE 4-14

EFFLUENT PRODUCT COMPOSITION FROM LIQUID DCS REDISTRIBUTION REACTOR AT 32°C CONTAINING A-21 RESIN CATALYST

BED DIAMETER = 0.43 INCHES

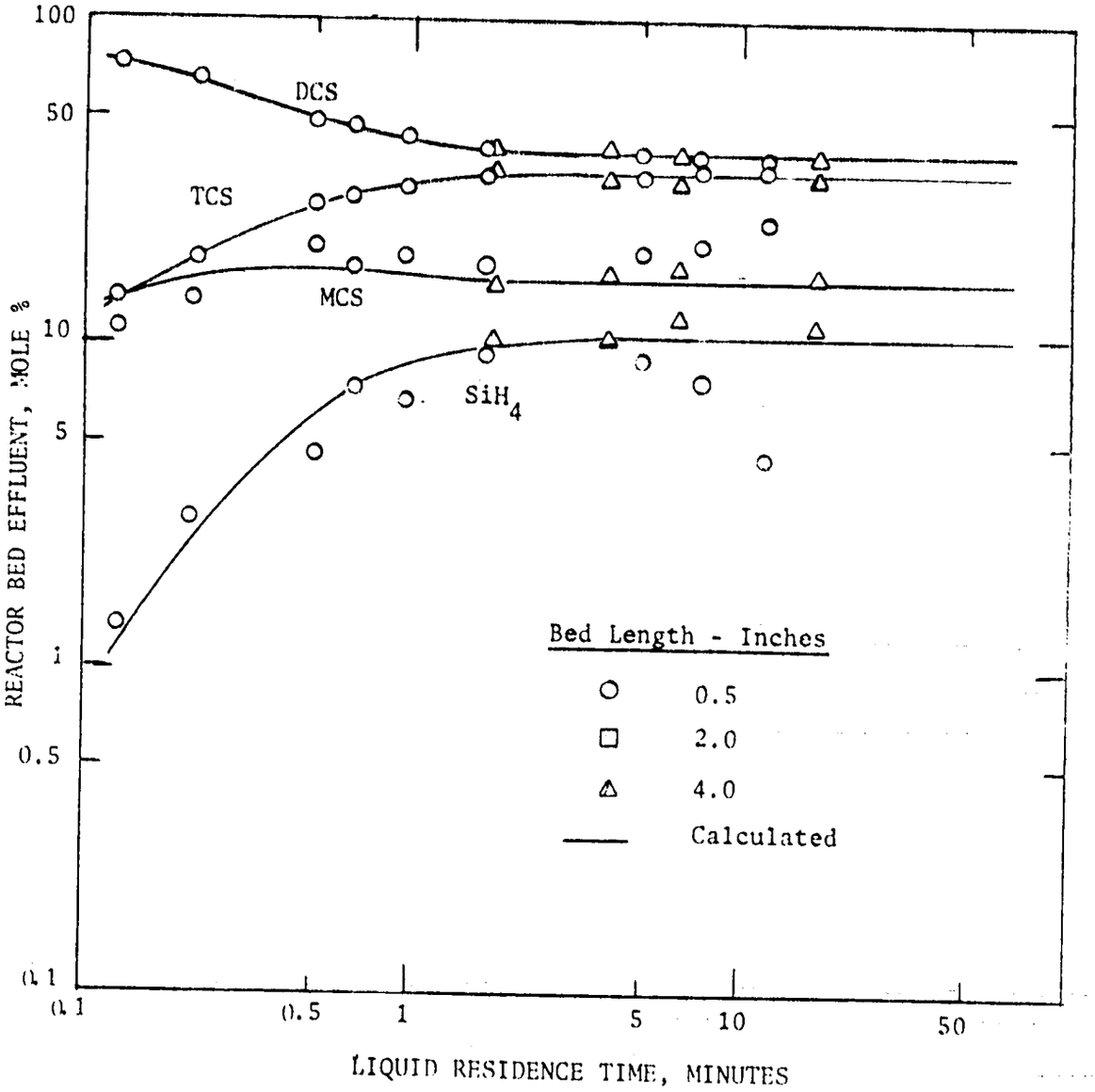


FIGURE 4-15

EFFLUENT PRODUCT COMPOSITION FROM LIQUID DCS REDISTRIBUTION REACTOR AT 81°C CONTAINING A-21 RESIN CATALYST. BED DIAMETER = 0.43 INCHES

4.3.2.3 Experimental Results

The kinetics for the redistribution of chlorosilanes were measured experimentally for both liquid- and vapor-phase reactants at temperatures from 32 to 80°C. The experimental apparatus is illustrated in Figure 4-16. The chlorosilane feed from a pressurized reservoir was fed through a preheat section into the reactor containing the AMBERLYST® A-21 catalyst. The effluent was reduced to atmospheric pressure and vaporized. A portion of the vapor was routed to an on-line gas chromatograph for analysis. The flow rate was monitored by the level in the feed tank or by a flowmeter on the vapor outlet. The liquid-or vapor-residence time in the reactor was varied by changing the reactant flow rate within small limits and by changing the diameter/packed length of the reactor for larger ranges.

The AMBERLYST® A-21 that is commercially available (Table III-8) is saturated with water, which must be removed prior to contact with chlorosilanes. The preferred method is to extract the water with alcohol followed by a non-protic solvent such as toluene or R-113, which can then be evaporated or extracted with $SiCl_4$. Drying the resin with warm, dry air can result in partial oxidation and/or loss of amine functionality. Complete drying of the resin (unless destined for vapor-phase reaction) is avoided since swelling of the resin from the dry state by liquid chlorosilanes (or any other solvent) could result in high internal pressures and physical damage.

In a typical preparation, a column packed with damp catalyst was flushed with three volumes of ethanol (200 proof) at a 20-minute space-time rate. This was followed by a flush with three volumes of toluene, followed by a flush with three volumes of $SiCl_4$. All flushes were performed in a similar manner. The level of residual solvent after each flush was less than 0.01%.

The chromatographic analysis procedure for chlorosilanes was the same as that described in Section 3.1.2.1. The results were reported using a Hewlett-Packard 5831A Reporting Integrator. Duplicate runs were made until the H:Cl ratio of the analyzed product matched that of the feed. This ensured that no errors were injected into the data by sampling errors.

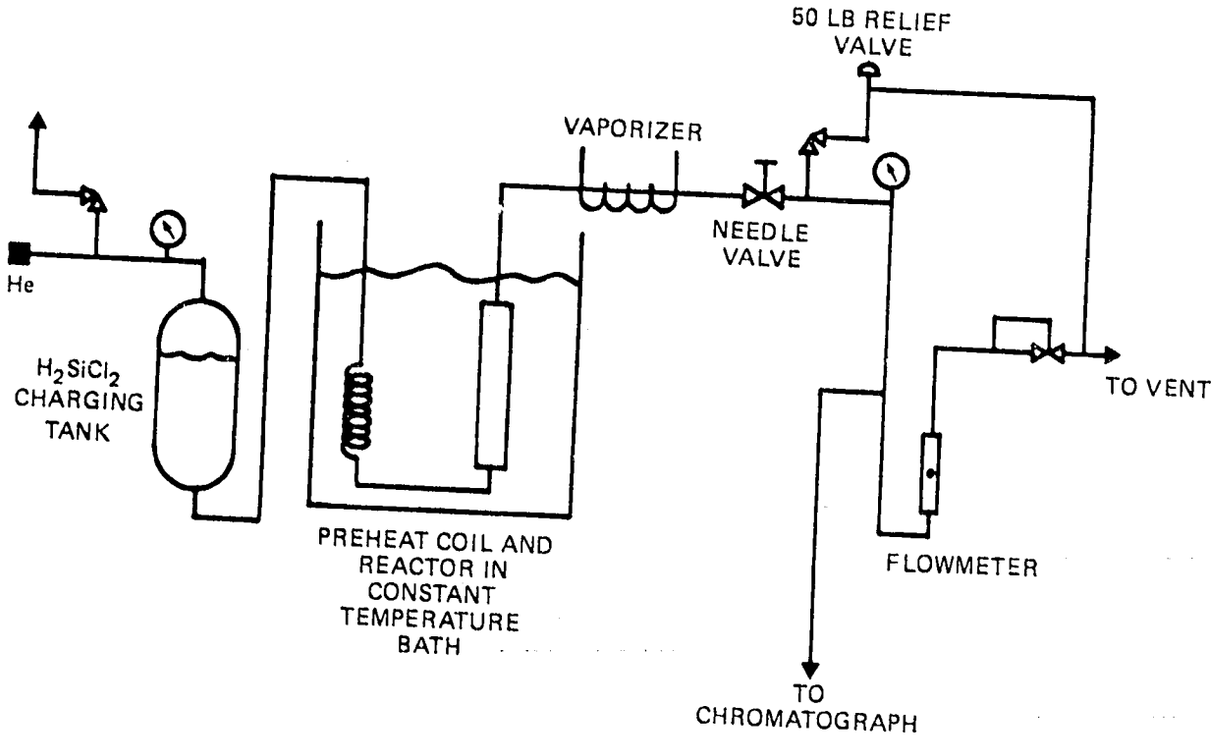


FIGURE 4-16

FLOW DIAGRAM OF DCS REDISTRIBUTION

The equilibrium compositions were obtained by using a 26-foot-long reactor at a reactant flow rate equivalent to a 1-hour residence time. The results of liquid- and vapor-phase sections and equilibria for $HSiCl_3$ (H:Cl = 1:3) and H_2SiCl_2 (H:Cl = 1:1) are listed in Table IV-19.

A series of experiments were made with varying flow rates at each level of catalyst in the reactor for liquid-phase reactants to aid in determining the kinetics profile. The raw data are presented in Table IV-15 and Tables IV-16 through IV-18. Analysis of the data and development of a kinetic model is discussed in Section 4.3.2.2.

TABLE IV-19

CHLOROSILANES REDISTRIBUTION EQUILIBRIA

Feed	DCS			TCS	
Temperature, °C	32	56	81	56	81
Effluent Composition (Mole %)					
Silane	11.50	11.59	11.98	-	-
MCS	15.5	16.10	16.66	0.38	0.50
DCS	40.22	39.53	37.46	9.60	9.78
TCS	32.62	32.69	33.36	80.95	80.63
STC	0.13	0.10	0.54	9.08	9.06

NOTES:
(1) Column dimensions: 0.18 inch I.D., 26 feet long
(2) Catalyst: AMBERLYST® A-21
(3) Residence time: 56 minutes
(4) Resin dried by extraction with ethanol, followed by R-11, and air dried.

4.4 VAPOR-LIQUID EQUILIBRIA

Separation of the chlorosilanes must be made in conjunction with the trichlorosilane and dichlorosilane redistribution reactors. This is accomplished by four distillation columns (Figure 5-1, 432-02, 432-04, 432-06, 432-08). The net effect of this distillation-redistribution train is to move the hydrogen-rich chlorosilanes forward for ultimate production of pure silane and to move the chlorine-rich chlorosilanes, metal chlorides and hydrides backwards by means of distillation separations. The impurities are finally rejected through the settler and stripper sections (Figure 5-1, 421-04, 432-02). To effect accurate design of these distillation columns, the vapor-liquid equilibria (VLE) of the chlorosilanes have to be known.

4.4.1 Binary VLE of Chlorosilane Mixtures

The required data are the binary VLE of the STC-TCS and DCS-TCS systems. The need to acquire these data was recognized early in the program. The STC-TCS binary data were found in the open literature (Zanta, et. al., Ref. 11), and the DCS-TCS binary data were experimentally determined.

4.4.1.1 K Value Model

The vapor and liquid phases in a binary system at equilibrium can be represented (from thermodynamic considerations) by the following relationship:

$$y P\phi = \gamma f x$$

$$K = \frac{y}{x} = \frac{\gamma f}{P\phi} \qquad (4\text{-}33)$$

In the model chosen for chlorosilane mixtures the liquid activity coefficient (γ) is determined by the Wilson equation, the liquid fugacity (f) is calculated at the vapor pressure with the Poynting correction, and the vapor fugacity coefficient (ϕ) is found by the Prausnitz-Chueh-Redlich-Kwong equation of state (Prausnitz, Ref. 13). The advantage of the Wilson equation is that

vapor-liquid equilibria calculations can be made for systems having three or more components using only binary data. The correctness of the chosen K model was verified by the extent to which the experimental vapor-liquid equilibria data were reproduced by it.

4.4.1.2 Silicon Tetrachloride-trichlorosilane, Binary, Vapor-liquid Equilibria

Experimental data for this system at 1 atmosphere pressure are available from the open literature (Ref. 11), and are given in Table IV-20. The Wilson parameters were derived with the aid of a computer program that used the quantities f and Ø given in Section 4.4.1.1. The newly found Wilson parameters were then used in the K model and the K values were calculated at the experimental points. Figure 4-17 shows the good agreement between calculated and observed points. A plot of the liquid activity coefficient (Figure 4-18) indicates that there is a small positive deviation from Raoult's law for this binary system.

4.4.1.3 Dichlorosilane-trichlorosilane, Binary, Vapor-liquid Equilibria

Experimental data were taken at three pressure levels: 100, 200, and 300 psia. As in the case cited above, Wilson parameters were determined and calculated K values were compared with experimental values (Figure 4-19). There is excellent agreement. The smaller numerical values of liquid activity coefficients (Figure 4-20) reveal a smaller positive deviation from Raoult's law for this system than for the STC-TCS binary. This is to be expected since the DCS and TCS molecules are more similar than are the STC and TCS molecules.

The extensive experimental data acquired for this system allow another check on the validity of the K model chosen in Section 4.4.1.1. Using only 100 psia data, the Wilson parameters were found and then used to calculate K values at 300 psia. These were then compared to the experimental 300 psia data. Figure 4-21, presents this comparison and reveals that excellent agreement exists. This example illustrates that the K model, given 100 psia data, can accurately predict data at the higher pressure of 300 psia.

TABLE IV-20

PTxy DATA FOR TRICHLOROSILANE (1) - SILICON TETRACHLORIDE (2)

AT 740 TORR*

Mole Fraction		
Liquid (x1)	Vapor (y1)	°C
0.007	.020	55.75
0.049	0.119	54.0
0.050	0.122	53.45
0.172	0.350	48.3
0.214	0.416	46.85
0.308	0.511	44.8
0.463	0.668	40.9
0.590	0.758	38.2
0.693	0.826	36.6
0.796	0.887	35.05
0.833	0.908	33.10
0.894	0.943	32.5

*Zanta et al., Ref. 11

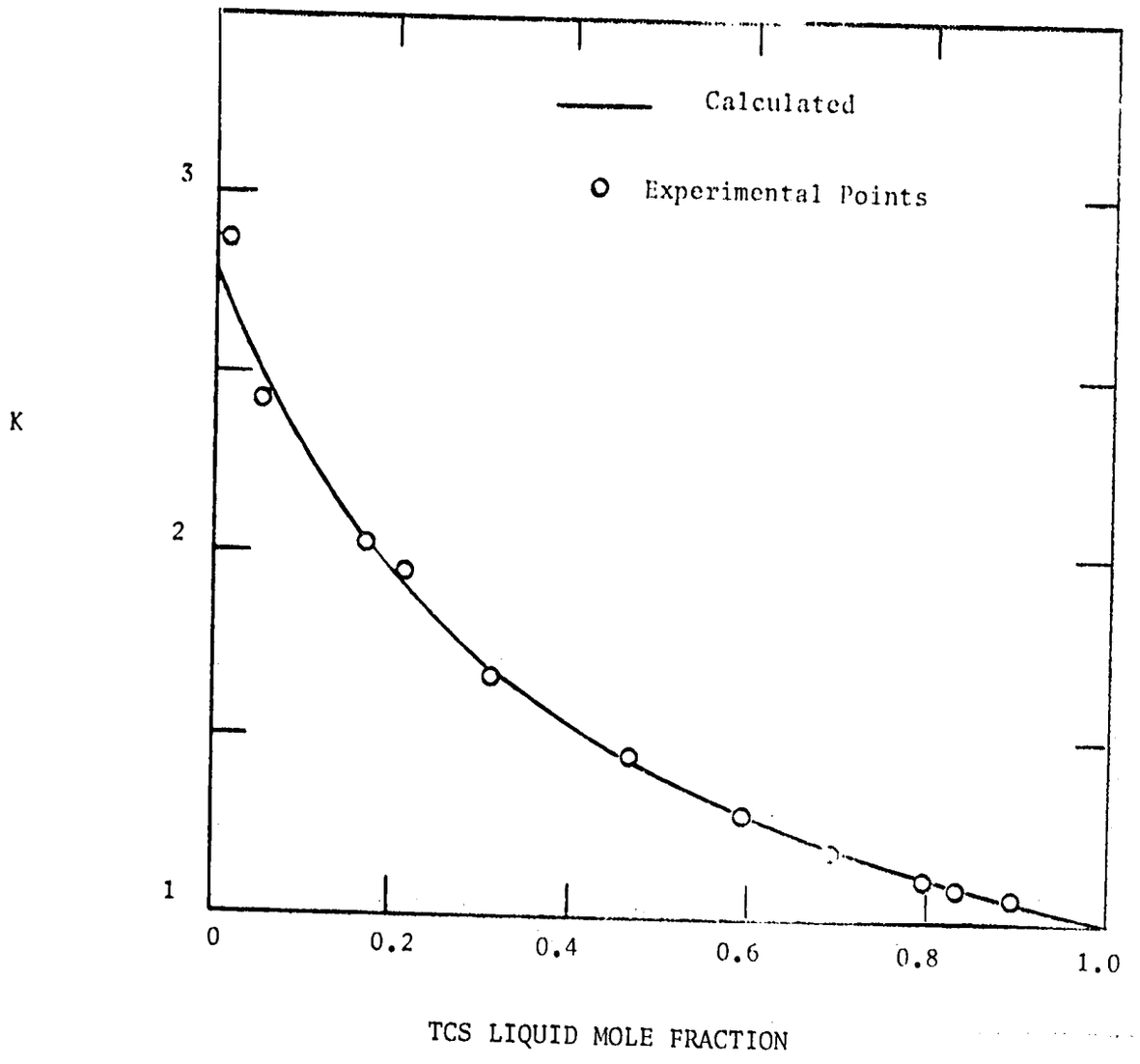


FIGURE 4-17

COMPARISON OF EXPERIMENTAL AND CALCULATED K VALUES FOR STC-TCS BINARY AT 740 TORR.

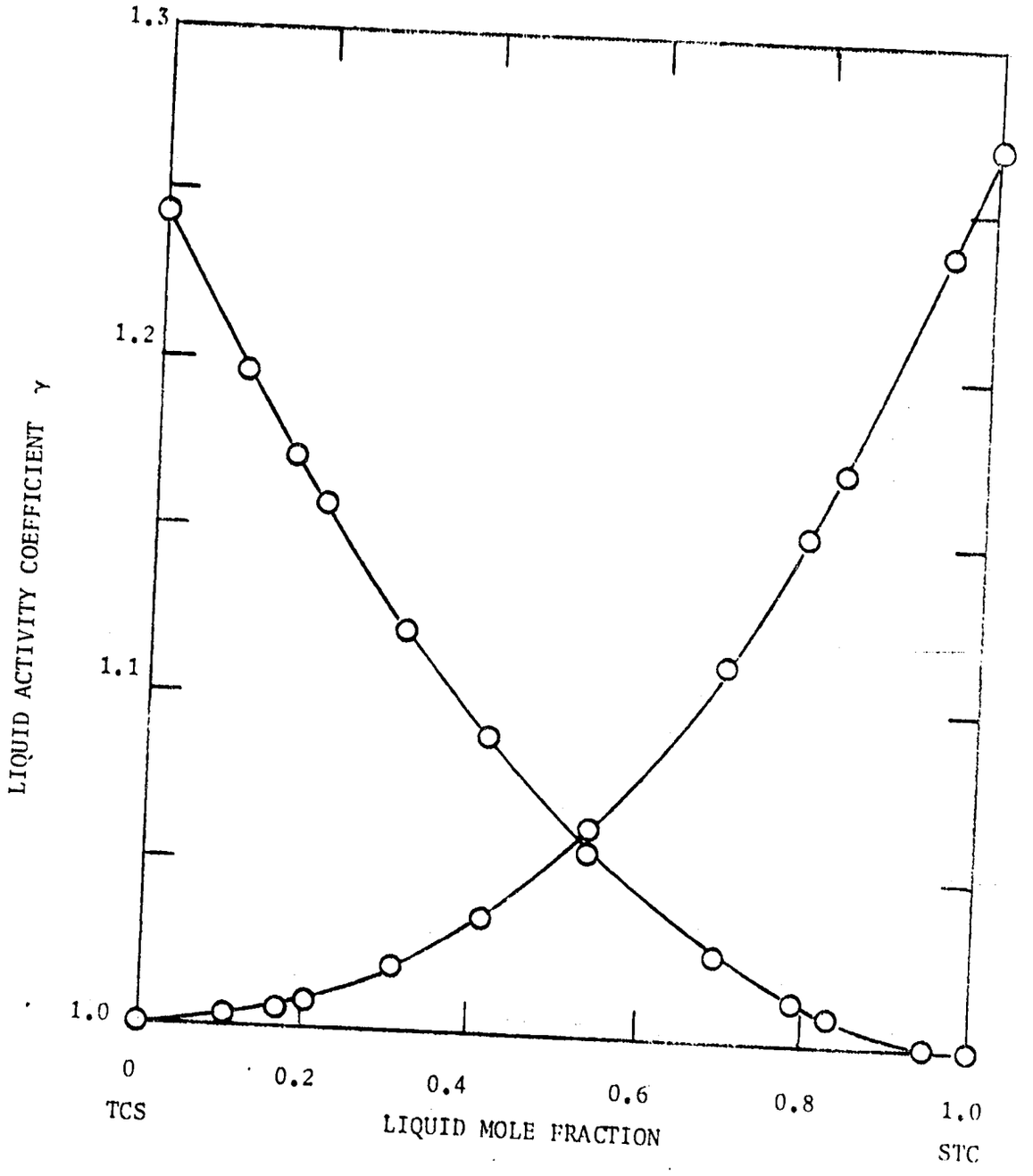


FIGURE 4-18

LIQUID ACTIVITY COEFFICIENT FOR STC-TCS BINARY AT 740 TORR.

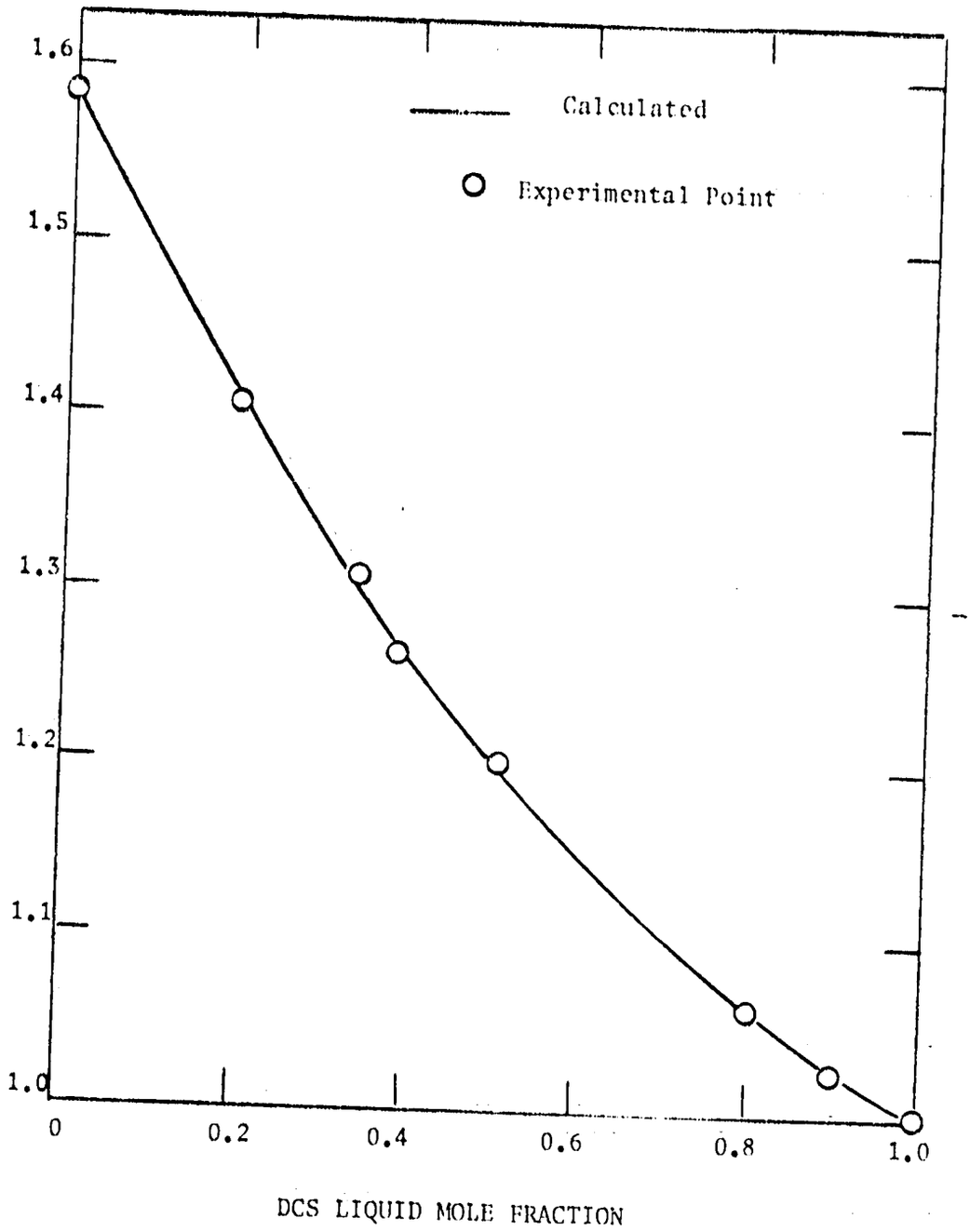


FIGURE 4-19

COMPARISON OF EXPERIMENTAL AND CALCULATED K VALUES FOR DCS-TCS BINARY AT 300 PSIA

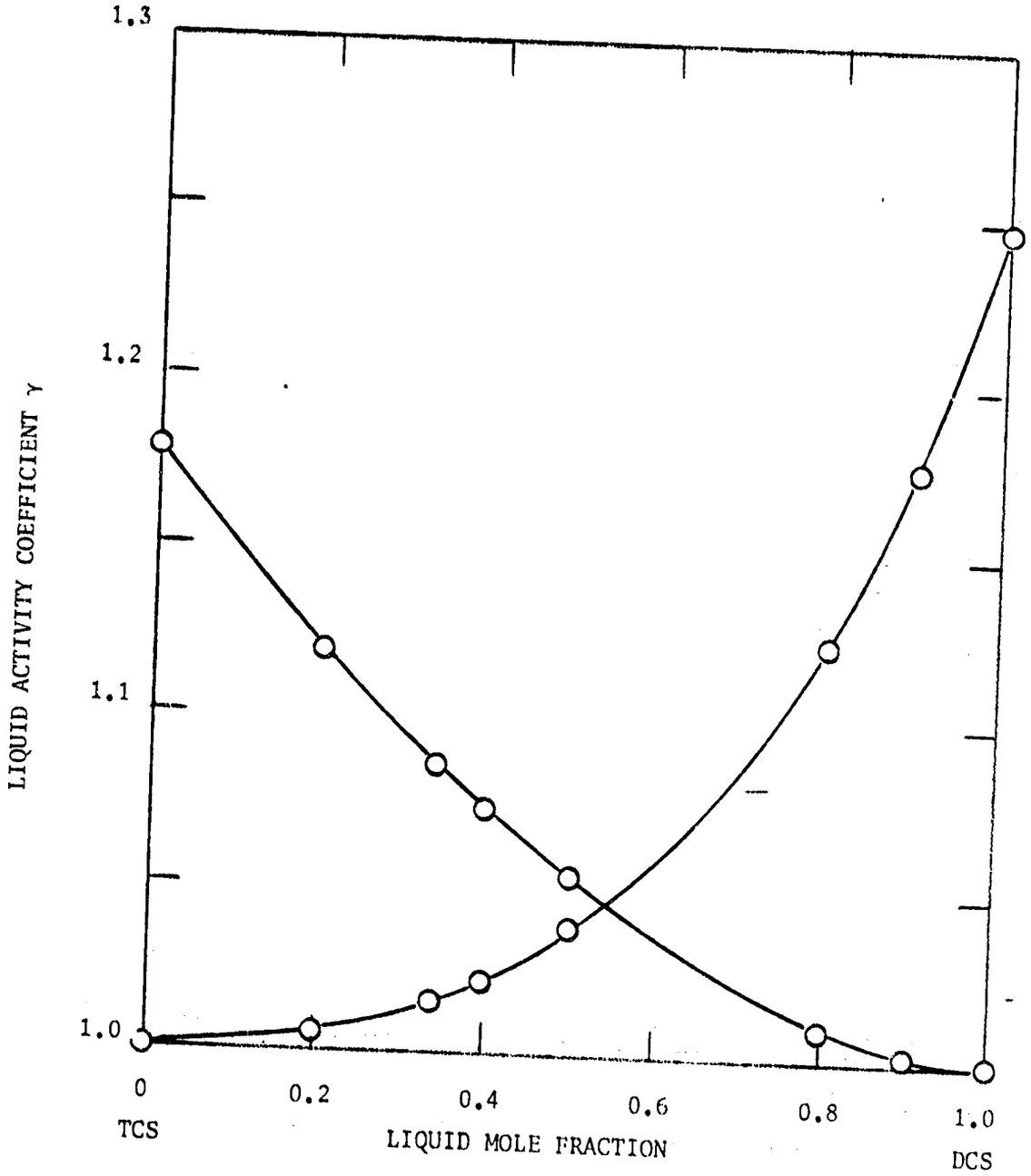


FIGURE 4-20

LIQUID ACTIVITY COEFFICIENT FOR DCS-TCS BINARY
AT 300 PSIA

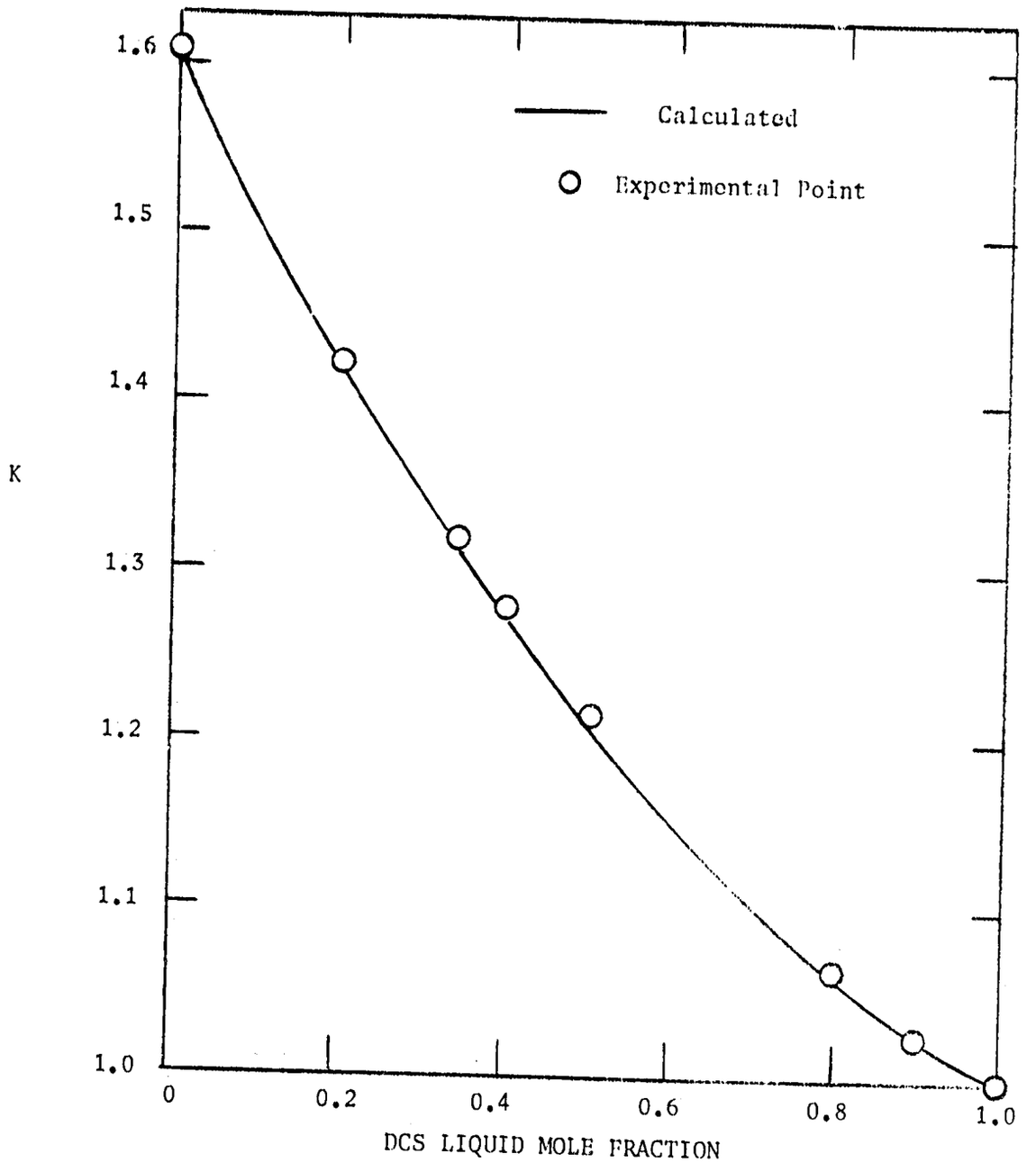


FIGURE 4-21

COMPARISON OF K VALUES CALCULATED WITH WILSON PARAMETERS FROM 100 PSIA DATA WITH EXPERIMENTAL 300 PSIA DATA FOR DCS-TCS BINARY AT 300 PSIA

4.4.2 Vapor-Liquid Equilibria of Chlorosilane, Light-gas Mixtures

The K model in Section 4.4.1.1 cannot be used in the settler and stripper systems because operating temperatures are above the critical temperatures of many of the components and a vapor pressure does not exist for gases such as nitrogen or methane. Therefore, the liquid fugacity in equation (4-33) is indeterminate. In the new K model, as shown below,

$$K = \frac{y_2}{x_2} = \frac{H \exp\left(P - P_1^{sat}\right) \bar{V}_2/RT}{P\phi_2} . \qquad (4\text{-}34)$$

K, for the gaseous component, is expressed in the "pressure-corrected" Henry's law form (Prausnitz, Ref. 13). The Poynting correction and ϕ_2 are assumed to be close to one and equation (3-34) becomes

$$K = \frac{H}{P} . \qquad (4\text{-}35)$$

Equation (4-35) can be compared to equation (4-33), where γ and ϕ are set equal to one. It is seen that Henry's constant is set equal to the psuedo vapor pressure for each component occurring at temperatures above the critical temperature.

4.4.2.1 Henry's Constant

Henry's constant is defined as

$$H = \lim \frac{f_2}{x_2} \text{ as } x_2 \to 0 \qquad (4\text{-}36)$$

Values of H were found by measuring the solubilities of N_2, CH_4, CO_2 and HCl in the chlorosilanes DCS, TCS and STC at 30 and 60°C. Because of the toxic and pyrophoric natures of B_2H_6, PH_3, H_2S and H_2, the solubilities of these gases were estimated by the following procedure (King, Ref. 14). Although gas solubility of one particular gas varies greatly from solvent to solvent,

the ratio of solubilities of two gases remains relatively constant. These ratios were applied to the experimental chlorosilane data to arrive at the estimated solubility values. The measured and estimated Henry's constants are given in Table IV-21.

4.4.3 Experimental Apparatus and Procedure

4.4.3.1 DCS-TCS Vapor-liquid Equilibria

In the past, the classic method of obtaining experimental vapor-liquid equilibria (VLE) consisted of measuring liquid and vapor compositions over the composition range and at either constant temperature or pressure (PTxy data). The fault with this method is that uncertainties can occur because liquid and vapor analyses by sampling are prone to error, especially the latter. The latest state-of-the-art in VLE measurements is to take PTx data and then determine y from appropriate thermodynamic equations (Ref. 13). In this manner, no analysis of liquid or vapor is required.

A prerequisite to this method is that x, the liquid composition, must be determined very accurately. This is accomplished by weighing each component in a stainless-steel vessel with an accurate analytical balance, sensitive to 0.001 gram. A small correction to the liquid-phase composition is made by determining the amount of each component that exists in the vapor space.

Data were collected at the constant pressures of 100, 200, and 300 psia and the boiling point was measured for six different mixture compositions. Detailed procedures are given in Ref. 15. The experimental data are listed in Tables IV-22, IV-23, and IV-24.

4.4.3.2 Vapor Pressure of DCS and TCS

This procedure also necessitates measuring the vapor pressure of each component in the same apparatus that is employed in VLE measurements. Table IV-25 contains the vapor pressure data for the pure components at 100,

TABLE IV-21

GAS SOLUBILITY IN CHLOROSILANES *

HENRY'S CONSTANTS (ATM/MOLE FRACTION)

30°C

	Dichlorosilane	Trichlorosilane	Tetrachlorosilane
N_2	982	899	846
CH_4	247	238	222
CO_2	72.4	76.3	75.8
HCl	53.0	62.4	67.2
B_2H_6**	33.0	31.8	29.8
PH_3 **	25.5	24.5	22.9
H_2 **	-	-	1640
H_2S **	-	-	15.7
Argon **	-	-	406

60°C

	Dichlorosilane	Trichlorosilane	Tetrachlorosilane
N_2	747	794	772
CH_4	253	260	246
CO_2	92.0	98.7	99.9
HCl	69.5	81.2	89.0
B_2H_6**	43.0	42.5	38.5
PH_3 **	32.0	31.8	29.5
H_2S **	-	-	20.5
H_2 **	-	-	1450
Argon**	-	-	360

* Reference 16.

** Estimated Value

TABLE IV-22

PTx DATA FOR DICHLOROSILANE (1)-TRICHLOROSILANE (2)*

z_1	x_1	T(°C)	P(psia)
0.1995	0.1976	94.3	104.0
0.3395	0.3372	88.6	102.0
0.3992	0.3969	85.6	103.0
0.5043	0.5021	83.6	104.0
0.8003	0.7993	75.3	103.0
0.9004	0.9000	73.7	103.0
0.1995	0.1973	126.6	201.0
0.3395	0.3368	121.2	201.0
0.3992	0.3964	119.2	204.0
0.5043	0.5016	114.9	202.0
0.8003	0.7991	107.1	203.0
0.9004	0.8999	104.6	201.0
0.1995	0.1977	150.1	302.4
0.3395	0.3372	143.5	298.4
0.3992	0.3968	141.1	299.4
0.5043	0.5020	137.6	302.4
0.8003	0.7992	128.3	301.4
0.9004	0.8999	125.6	299.4

z_1 = overall mole fraction added to ebulliometer

x_1 = liquid-phase, mole fraction after vapor space correction

*Reference 15.

TABLE IV-23

VAPOR-LIQUID EQUILIBRIUM FOR DICHLOROSILANE (1) - TRICHLOROSILANE (2)*

^{o}C	P(psia)	x_1	y_1	γ_1	γ_2
102.6	102.68	0.0	0.0	1.1572	1.000
94.3	105.51	0.1990	0.3276	1.1163	1.0043
88.6	104.81	0.3395	0.4981	1.0885	1.0141
85.6	102.48	0.3990	0.5601	1.0772	1.0206
83.6	105.28	0.5040	0.6541	1.0575	1.0365
75.3	102.20	0.8003	0.8707	1.0126	1.1318
73.7	102.85	0.9000	0.9347	1.0035	1.1925
71.6	101.78	1.0	1.0	1.0	1.2796
137.0	201.84	0.0	0.0	1.1599	1.0
126.6	201.03	0.1990	0.3007	1.1138	1.0044
121.2	203.14	0.3395	0.4670	1.0849	1.0142
119.2	204.15	0.3990	0.5286	1.0734	1.0206
114.9	201.65	0.5040	0.6280	1.0543	1.0361
107.1	203.21	0.8003	0.8585	1.0115	1.1251
104.6	201.98	0.9000	0.9287	1.0032	1.1803
102.7	202.16	1.0	1.0	1.0	1.2574
159.8	297.71	0.0	0.0	1.1773	1.0
150.1	301.33	0.1990	0.2798	1.1179	1.0049
143.5	299.50	0.3395	0.4431	1.0853	1.0151
141.1	299.44	0.3990	0.5051	1.0730	1.0216
137.6	301.35	0.5040	0.6053	1.0532	1.0372
128.3	299.27	0.8003	0.8483	1.0109	1.1234
125.6	297.59	0.9000	0.9234	1.0030	1.1755
123.6	298.04	1.0	1.0	1.0	1.2472

x = liquid-phase mole fraction

y = vapor-phase mole fraction

γ = liquid-phase activity coefficient

*Reference 15.

TABLE IV-24

VAPOR-LIQUID EQUILIBRIUM FOR DICHLOROSILANE (1) - TRICHLOROSILANE (2)*

°C	P(psia)	x_1	K_1	K_2
102.6	102.68	0.0	1.9852	1.0
94.3	105.51	0.1990	1.6463	0.8394
88.6	104.81	0.3395	1.4671	0.7599
85.6	102.48	0.3990	1.4037	0.7320
83.6	105.28	0.5040	1.2990	0.6962
75.3	102.20	0.8003	1.0881	0.6468
73.7	102.85	0.9000	1.0386	0.6525
71.6	101.78	1.0	1.0	0.6714
137.0	201.84	0.0	1.7364	1.0
126.6	201.03	0.1990	1.5110	0.8731
121.2	203.15	0.3395	1.3756	0.8069
119.2	204.15	0.3990	1.3248	0.7844
114.9	201.65	0.5040	1.2461	0.7499
107.1	203.21	0.8003	1.0727	0.7085
104.6	201.98	0.9000	1.0318	0.7134
102.7	202.16	1.0	1.0	0.7325
159.8	297.71	0.0	1.5811	1.0
150.1	301.33	0.1990	1.4059	0.8992
143.5	299.50	0.3395	1.3052	0.8431
141.1	299.44	0.3990	1.2658	0.8235
137.6	301.35	0.5040	1.2010	0.7958
128.3	299.27	0.8003	1.0600	0.7598
125.6	297.59	0.9000	1.0261	0.7655
123.6	298.04	1.0	1.0	0.7853

x = liquid phase mole fraction

*Reference 15.

TABLE IV-25

PURE COMPONENT VAPOR PRESSURE*

Dichlorosilane

T(°C)	P(psia)
71.8	102.0
71.4	102.0
102.6	202.0
102.7	202.0
123.6	299.4
123.6	299.4

Trichlorosilane

T(°C)	P(psia)
102.4	101.0
102.7	102.0
137.0	201.0
136.9	201.0
159.7	299.4
159.9	299.4

*Reference 15.

200, and 300 psia. These data were added to existing data and new constants were determined in the extended Antoine vapor-pressure equation (Appendix B, Table B-II).

4.4.3.3 Gas Solubility in DCS, TCS and STC

As in the VLE method, no sampling or analysis of the liquid and vapor phases is required. The data are obtained by admitting a known amount of liquid into a calibrated, volume-sample vessel; by adding a weighed amount of gas; and then by shaking the vessel in a thermostated bath until a constant pressure is reached. Gas solubility, as Henry's constant, is found by solving a set of seven-iterative simultaneous equations with the aid of a computer program. More detailed procedures can be found in References 15 and 16.

Henry's constants are listed in Table IV-21 and the experimental data are given in Tables IV-26, IV-27, and IV-28.

4.4.4 Settler Impurity Rejection Performance

Impurity compounds having high boiling points [i.e., those whose atmospheric boiling points are greater than $SiCl_4$ (56.5°C)] are rejected in a scrubber/settler located immediately downstream of the hydrogenation reactor. The fluid-bed, hydrogenation reactor produces a stream consisting of non-condensable gases, H_2, CH_4; condensables such as $HSiCl_3$ and $SiCl_4$; solid dusts of silicon and copper; and vaporized or particulate chlorides of a broad spectrum of compounds such as $AlCl_3$, $FeCl_3$, BCl_3, PCl_5, etc. The character of this stream is such that the volatile salts will precipitate on cool surfaces to form solid agglomerates. Complexing can occur between the various chloride salts to form double salts such as $AlCl_3$-$FeCl_3$. All of the impurity compounds boiling above $SiCl_4$ must be removed from the chlorosilane stream to prevent a buildup and fouling in the subsequent distillation columns.

Removal of the solids by direct filtration was rejected because of fouling that can be caused by the condensed salts and because of the abrasive nature of the silicon. Centrifugal gas/solid separation was rejected because of the abrasive nature of the solids, the small size of the particles,

TABLE IV-26

EXPERIMENTAL DATA
N_2, CH_4, CO_2, AND HCl IN DICHLOROSILANE*

T(°C)	P(atm)	V(cc)	MG(g)	ML(g)	Liquid Mole Fraction X2	
30.00	18.311	337.750	3.331	253.014	0.016478	
30.00	18.253	337.750	3.493	228.324	0.014822	
30.00	18.321	337.750	3.299	250.972	0.015674	
60.00	22.268	337.750	3.331	253.014	0.021738	N_2
60.00	22.064	337.750	3.493	228.324	0.020794	
60.00	22.217	337.750	3.299	250.972	0.021073	
30.00	18.168	337.750	3.779	245.222	0.060637	
30.00	17.692	337.750	3.573	218.017	0.056987	CH_4
60.00	23.102	337.750	3.779	245.222	0.064229	
60.00	22.404	337.750	3.573	218.017	0.060760	
30.00	7.281	337.750	9.184	265.077	0.066832	
30.00	7.417	337.750	8.424	223.479	0.068232	CO_2
60.00	11.942	337.750	9.184	265.077	0.066950	
60.00	12.061	337.750	8.424	223.479	0.067628	
30.00	6.941	337.750	9.526	257.428	0.086335	
30.00	6.907	360.015	9.495	254.011	0.085507	HCl
60.00	11.568	337.750	9.526	257.428	0.086274	
60.00	11.568	360.015	9.495	254.011	0.085034	

* Reference 16.

TABLE IV-27

EXPERIMENTAL DATA
N_2, CH_4, CO_2 AND HCl IN TRICHLOROSILANE*

T(°C)	P(atm)	V(cc)	MG(g)	ML(g)	Liquid Mole Fraction X2	
30.00	21.111	337.750	4.101	282.575	0.022094	N_2
30.00	21.792	337.750	4.284	273.425	0.021496	
60.00	24.194	337.750	4.101	282.575	0.026498	
60.00	24.874	337.750	4.284	273.425	0.026278	
30.00	21.860	337.750	4.583	259.474	0.081187	CH_4
30.00	21.792	337.750	4.535	255.905	0.079914	
60.00	26.130	337.750	4.583	259.474	0.083307	
60.00	25.993	337.750	4.535	255.905	0.082124	
30.00	10.547	337.750	15.279	276.295	0.128983	CO_2
30.00	7.145	337.750	8.780	273.358	0.076992	
60.00	15.446	337.750	15.279	276.295	0.126638	
60.00	10.479	337.750	8.780	273.358	0.075777	
30.00	7.315	337.750	8.779	268.113	0.094962	HCl
30.00	7.315	360.015	9.357	271.300	0.098313	
60.00	10.649	337.750	8.779	268.113	0.093754	
60.00	10.785	360.015	9.357	271.300	0.096486	

* Reference 16.

TABLE IV-28

EXPERIMENTAL DATA

N_2, CH_4, CO_2 AND HCl IN SILICON TETRACHLORIDE *

T(°C)	P(atm)	V(cc)	MG(g)	MG(g)	Liquid Mole Fraction X2	
30.00	20.941	337.750	4.176	316.632	0.024851	N_2
30.00	20.073	360.015	4.329	318.343	0.021036	
60.00	24.054	337.750	4.176	316.632	0.028859	
60.00	22.489	360.015	4.329	318.343	0.026298	
30.00	21.792	337.750	4.543	311.784	0.087788	CH_4
30.00	20.073	360.015	4.543	307.035	0.083263	
60.00	25.585	337.750	4.543	311.784	0.090645	
60.00	23.612	360.015	4.543	307.035	0.085507	
30.00	7.179	337.750	8.951	307.484	0.085539	CO_2
30.00	6.907	360.015	8.784	311.385	0.080963	
60.00	10.003	337.750	8.951	307.484	0.084071	
60.00	9.560	360.015	8.784	311.385	0.079283	
30.00	6.668	337.750	7.630	307.159	0.089344	HCl
30.00	7.247	360.015	8.444	305.158	0.095670	
60.00	9.322	337.750	7.630	307.159	0.088000	
60.00	10.071	360.015	8.444	305.158	0.093631	

* Reference 16.

and the design difficulties associated with maintaining the surface hot enough to prevent condensation of the salts.

A preferable design would use direct, contact heat exchange of the gases with condensed chlorosilane product in a scrubber that would cool the gases, condense and solidify the salt complexes, and scrub out the solid particles all in one step. The amount of scrubbing liquid would be controlled so that the noncondensable gases and the chlorosilanes would leave as a saturated vapor and thus achieve a single-plate distillation separation for the other impurities having higher boiling points.

Ideally, the scrubber would be of the gas venturi type so as to make use of the available pressure drop, achieve high-efficiency scrubbing and, since most designs are of the wetted-wall variety, avoid solids buildup in the unit. Coalescence and separation would be achieved by a flooded tee and centrifugal separator of standard design.

To determine the feasibility of this approach, a crude settler/scrubber was installed as part of the PDU. Hot gas from the hydrogenation reactor tangentially entered a cylindrical vessel with a cone bottom. A level of condensed $HSiCl_3/SiCl_4$ was maintained above the vapor inlet. The cooled, saturated gases left the top of the unit, while solids collected in the liquid phase and settled in the cone bottom for periodic removal.

The efficiency with which the scrubber/settler removed each impurity was also determined (Table IV-29) by calculating (1) the mass of each element that left the reactor, (2) the mass collected in the solid and liquid phases of the settler and (3) the quantity reported in the product. These data show that the simple scrubber/settler depicted in Figure 4-22 works quite well to remove gross amounts of impurities from the chlorosilane stream. Although its efficiency in removing most of the impurities was measured to be quite high, an experimental anomaly was noted for aluminum. This negative efficiency (mass balance indicated a pickup of aluminum) is not reasonable. An analytical error is suspected as, historically in commercial practice, the removal of Al by this method is quite good and limited to entrainment in the vapor product stream of solid $AlCl_3$.

TABLE IV-29

SCRUBBER/SETTLER EFFICIENCIES

	Grams Released in Reactor	Concentration In Product, PPM	Grams In Product	Settler Efficiency
Fe	4.70	0.28	0.04	99.1
Cu	3.29	1.50	0.20	93.9
Al	0.55	7.0	0.93	-69.1
Ca	0.78	0.0093	0.01	98.7
Mn	0.47	0.33	0.04	91.5
Pb	0.01	< 0.02	3×10^{-3}	< 70.0

$$\text{Efficiency} = 1 - \left[\frac{\text{mass of component in product stream}}{\text{mass of component leaving reactor}}\right] \times 100$$

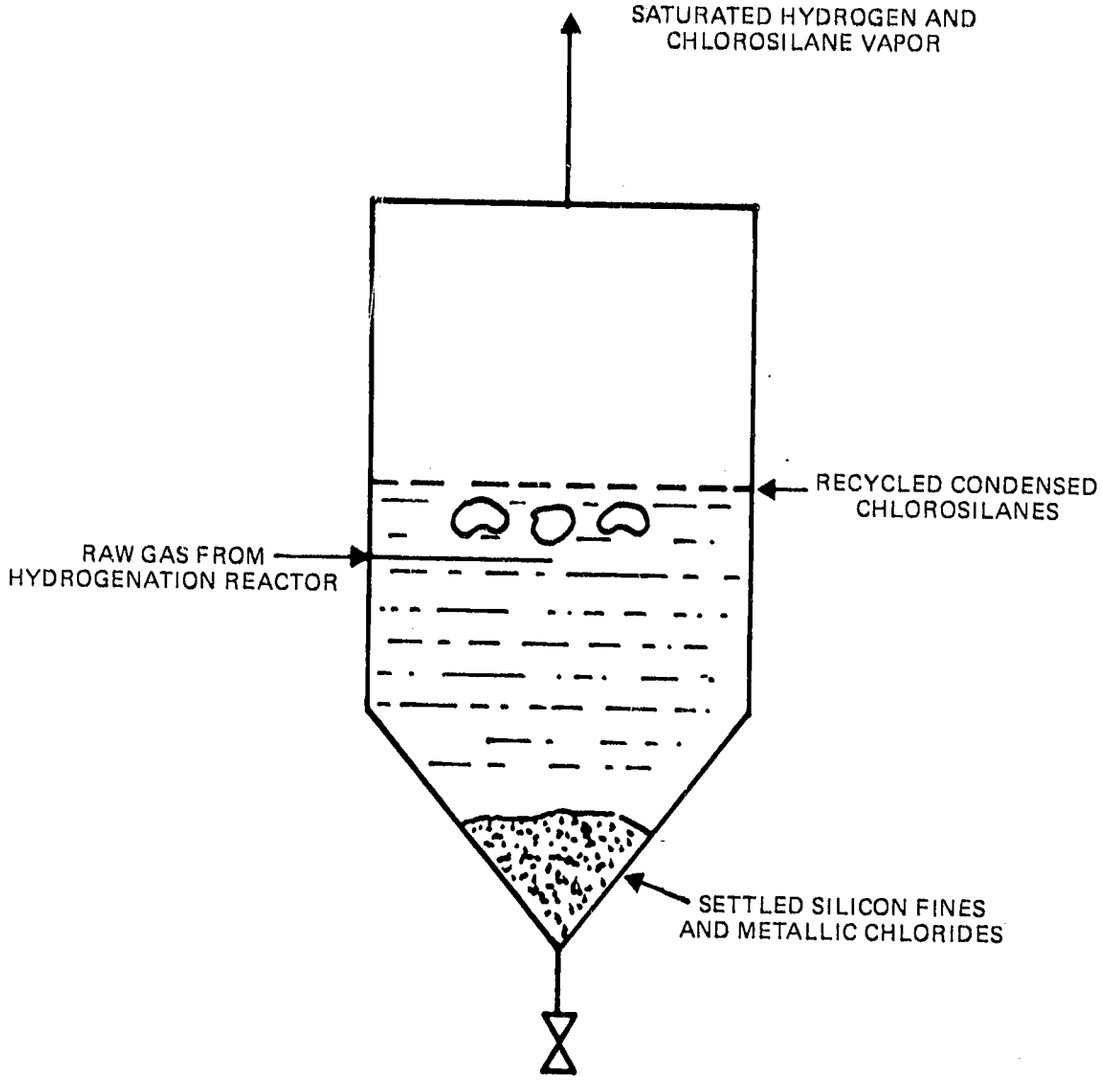


FIGURE 4-22

SCRUBBER/SETTLER FOR THE SILANE PDU

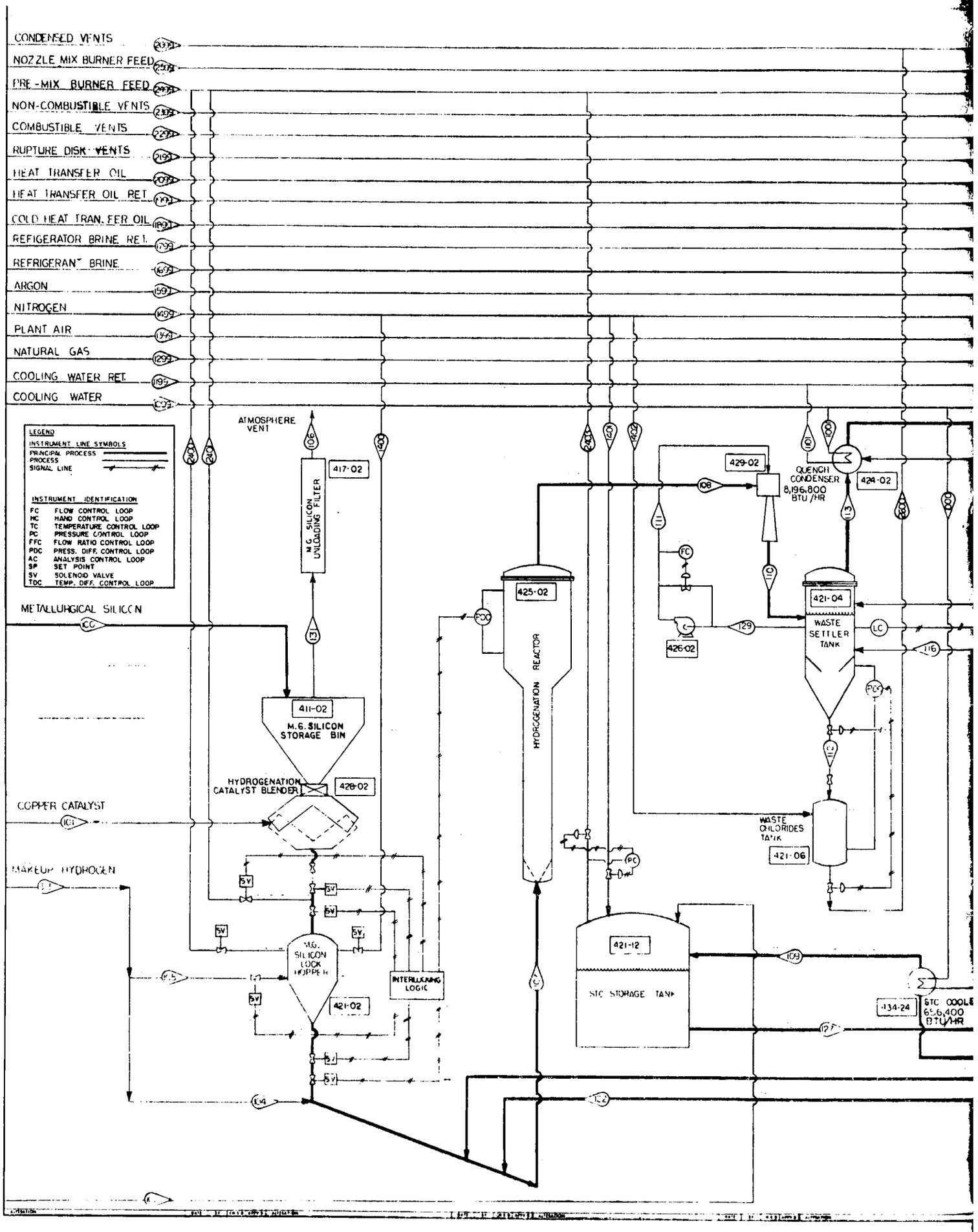
SECTION 5

COMMERCIAL PLANT DESIGNS

Two commercial plant designs yielding semiconductor-grade, molten silicon have been assembled. They are identified by their silicon production capacity; the first is a 1000 MT/Yr (Metric Ton per Year) plant, the second is a 120 MT/Yr plant. The 120 MT/Yr commercial plant is based on the 100 MT/Yr Experimental Process System Development Unit (EPSDU) with some equipment changes. The difference of 20 MT/Yr in silicon production is based solely on the higher on-stream factor, 0.85 versus 0.70 used for the EPSDU design. The 1000 MT/Yr commercial plant uses the same process as the 120 MT/Yr commercial plant, but the equipment used in this design has been resized. The 120 MT/Yr facility is presented to provide insight into the relationship between production capacity and economic performance. The larger, more economically attractive, 1000 MT/Yr plant is also discussed.

The process flow diagram, Figure 5-1, represents the process for both 120 and 1000 MT/Yr commercial plants. The design of the two commercial plants was based on the issue 1 stream catalog (heat/mass balance, Table C-II), and the heat duties found on the process flow diagram (Figure 5-1). The issue 1 stream catalog defines the components and flow quantities for the process streams on the process flow diagram. A list of physical properties for all the process streams can be found in Table C-III. An issue 1 stream summary, Table C-1, supplies temperatures, pressures and decriptions for all streams on the process flow diagram.

An improved heat and mass balance was generated as a result of new kinetic data collected on the hydrogenation reactor. On the basis of this new data, design changes were made to both the TCS redistribution reactor and the DCS redistribution reactor; these changes are within equipment design specifications. A list of improved heat duties can be found in Table E-I, along with equipment names and equipment numbers corresponding to those on the process flow diagram, Figure 5-1. The issue 2 stream catalog (Table E-III) defines the components and improved flow quantities for the process streams. A list of physical properties for the improved process streams can be found in Table E-V. An issue 2 stream summary (Table E-II)



FOLDOUT FRAME

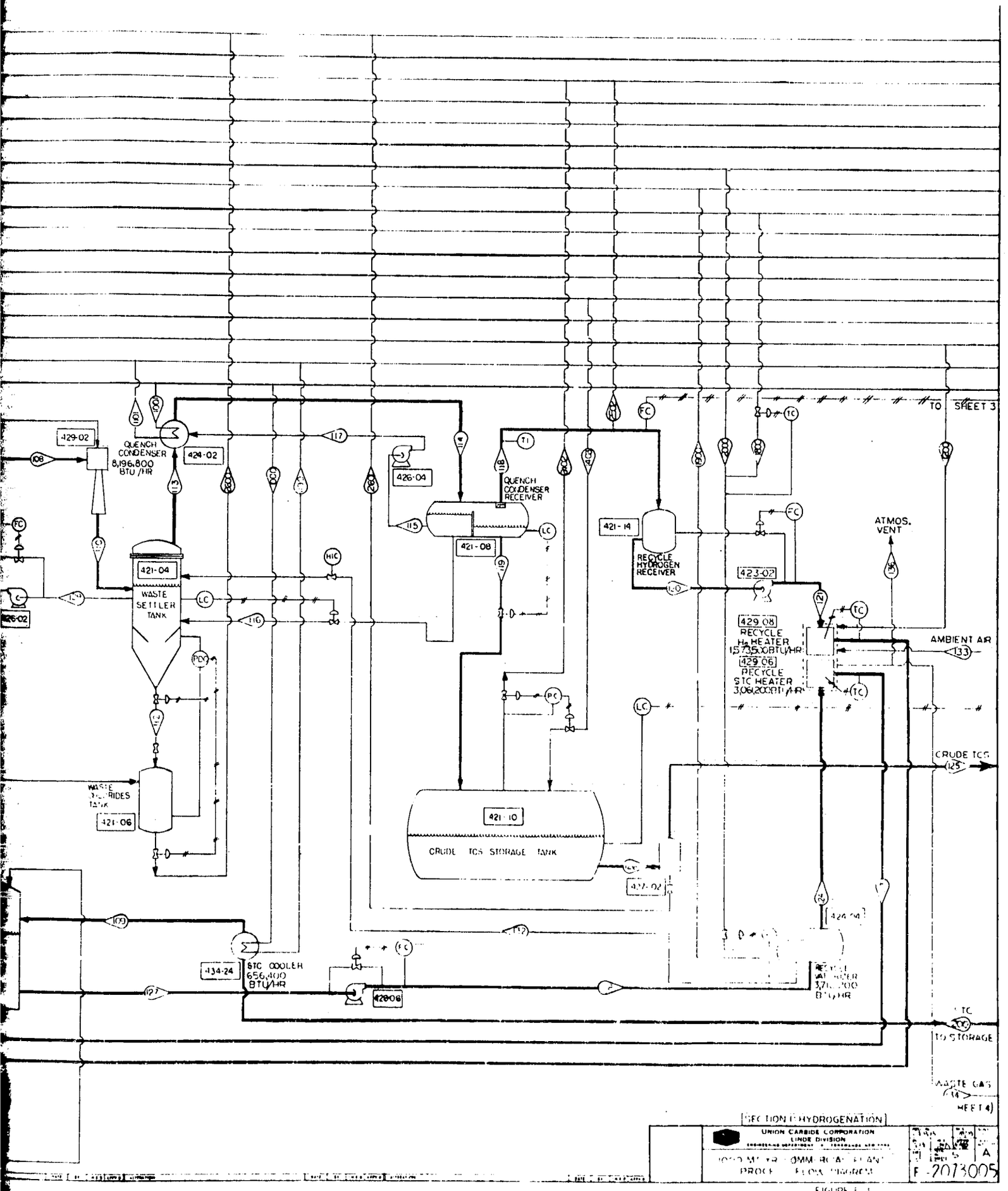
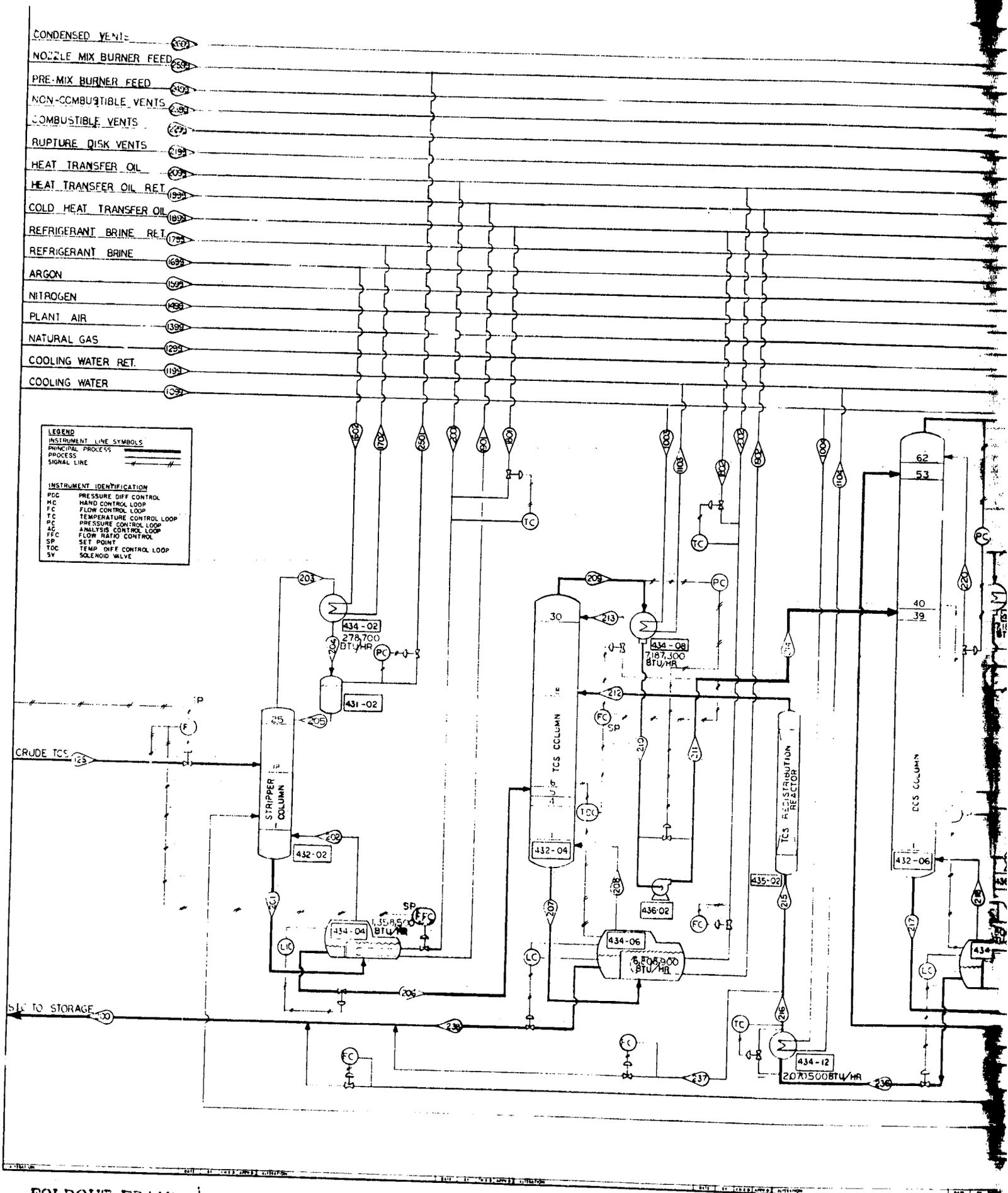


FIGURE 5-1

2 FOLDOUT FRAME



FOLDOUT FRAME

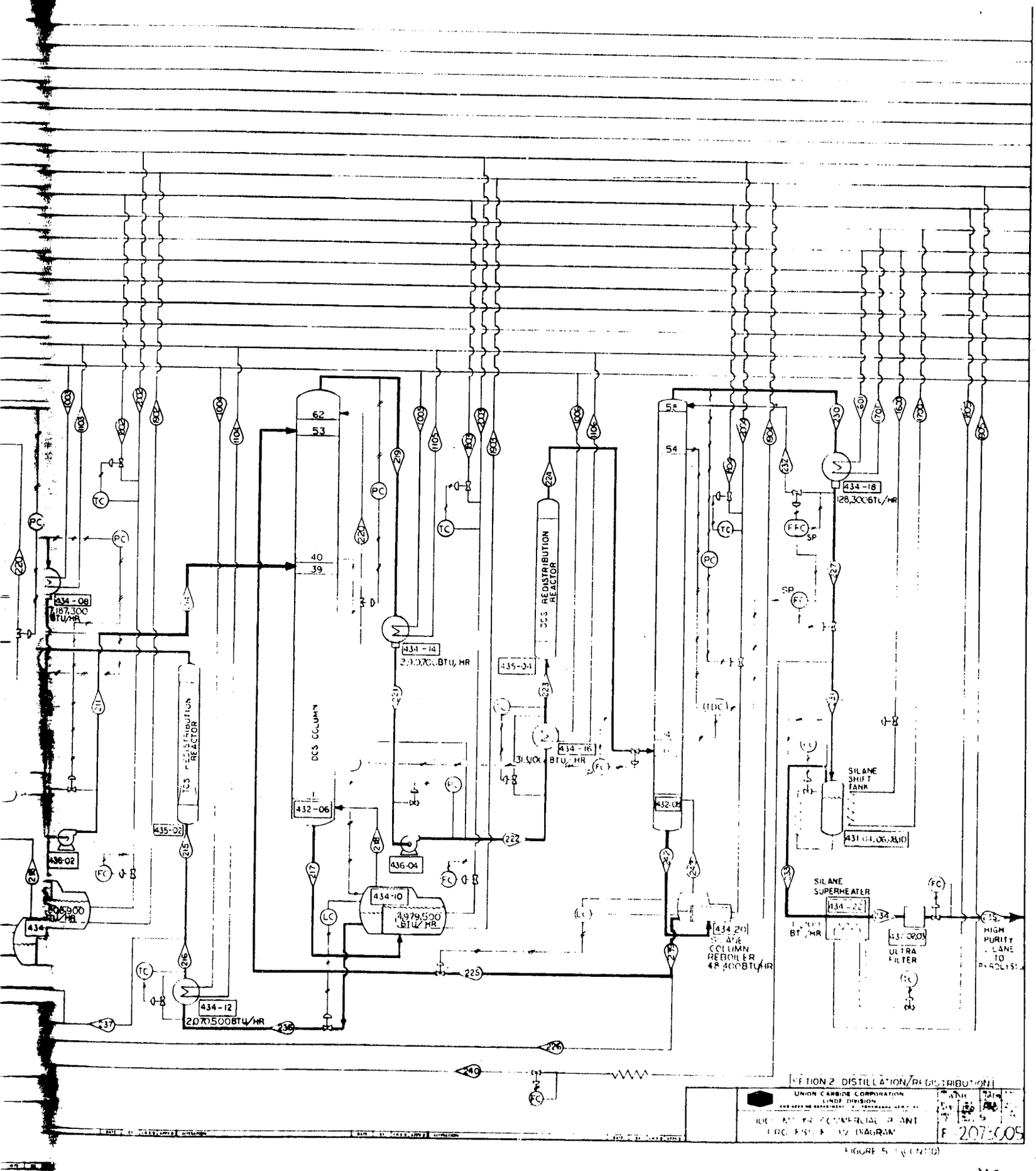
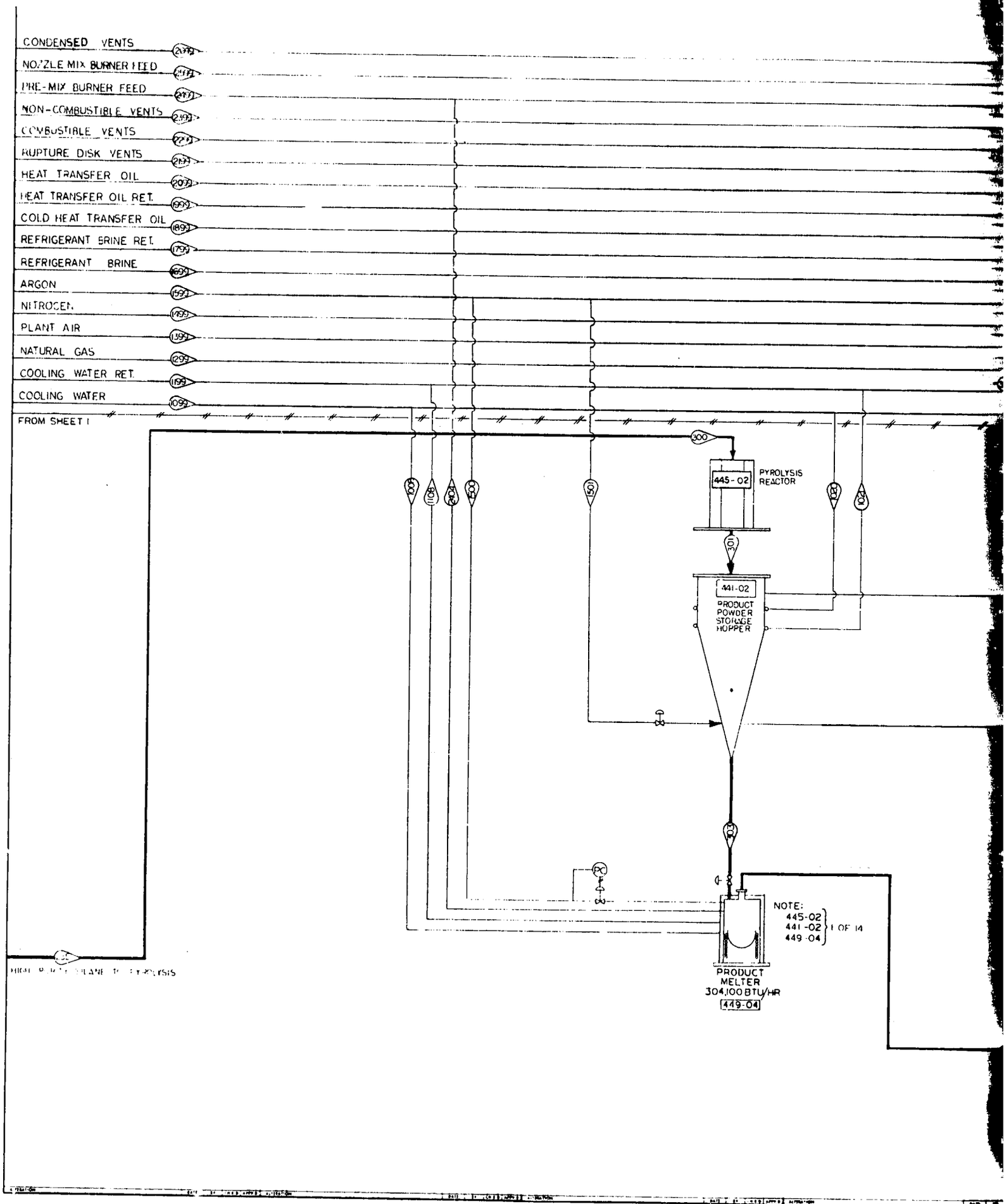


FIGURE 5 (CONTD)


CONDENSED VENTS
NOZZLE MIX BURNER FEED
PRE-MIX BURNER FEED
NON-COMBUSTIBLE VENTS
COMBUSTIBLE VENTS
RUPTURE DISK VENTS
HEAT TRANSFER OIL
HEAT TRANSFER OIL RET.
COLD HEAT TRANSFER OIL
REFRIGERANT BRINE RET.
REFRIGERANT BRINE
ARGON
NITROGEN
PLANT AIR
NATURAL GAS
COOLING WATER RET.
COOLING WATER
FROM SHEET 1
300
445-02
PYROLYSIS REACTOR
101
441-02
PRODUCT POWDER STORAGE HOPPER
PC
NOTE:
445-02
441-02
449-04
1 OF 14
PRODUCT MELTER
304,100 BTU/HR
449-04

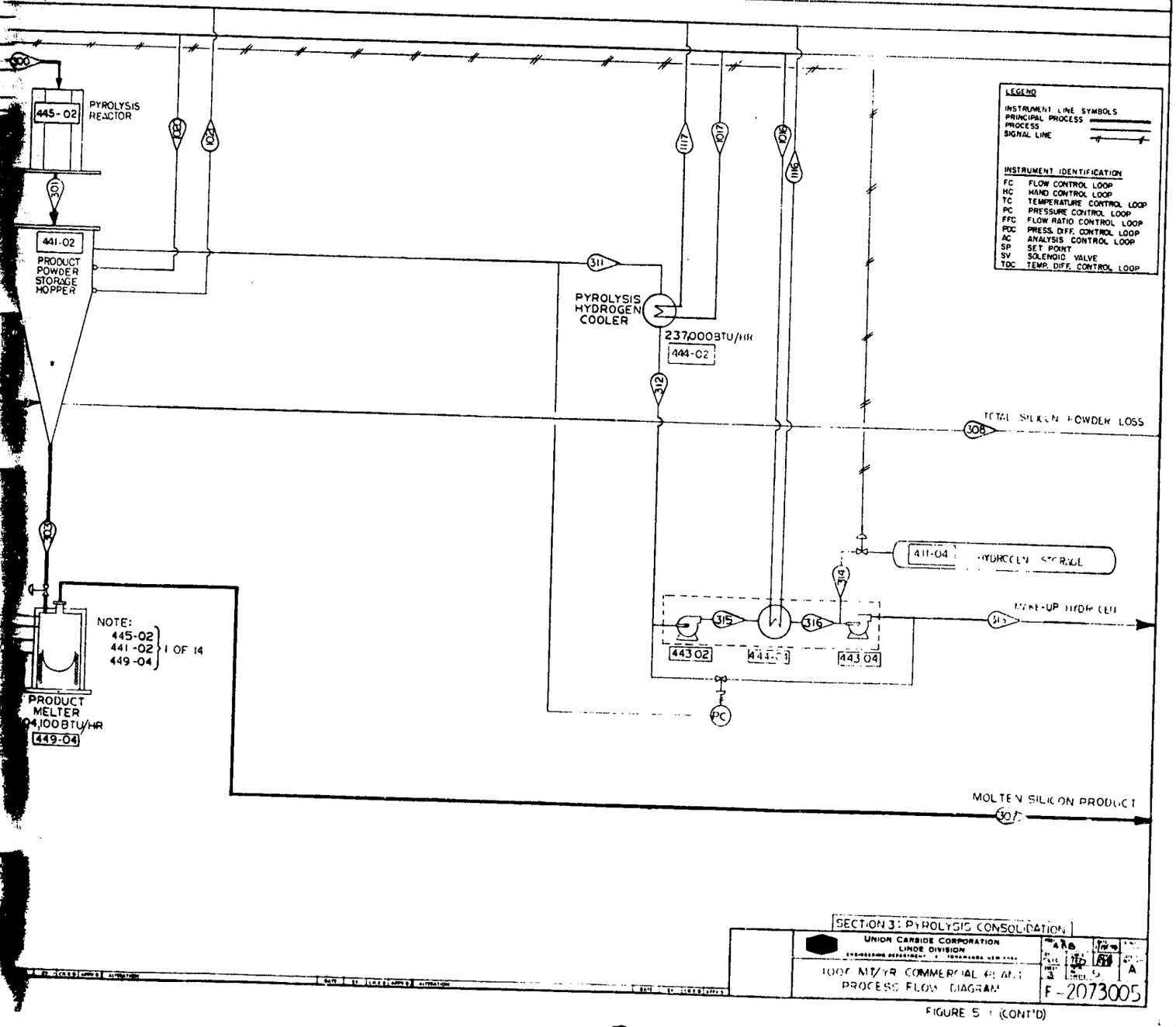
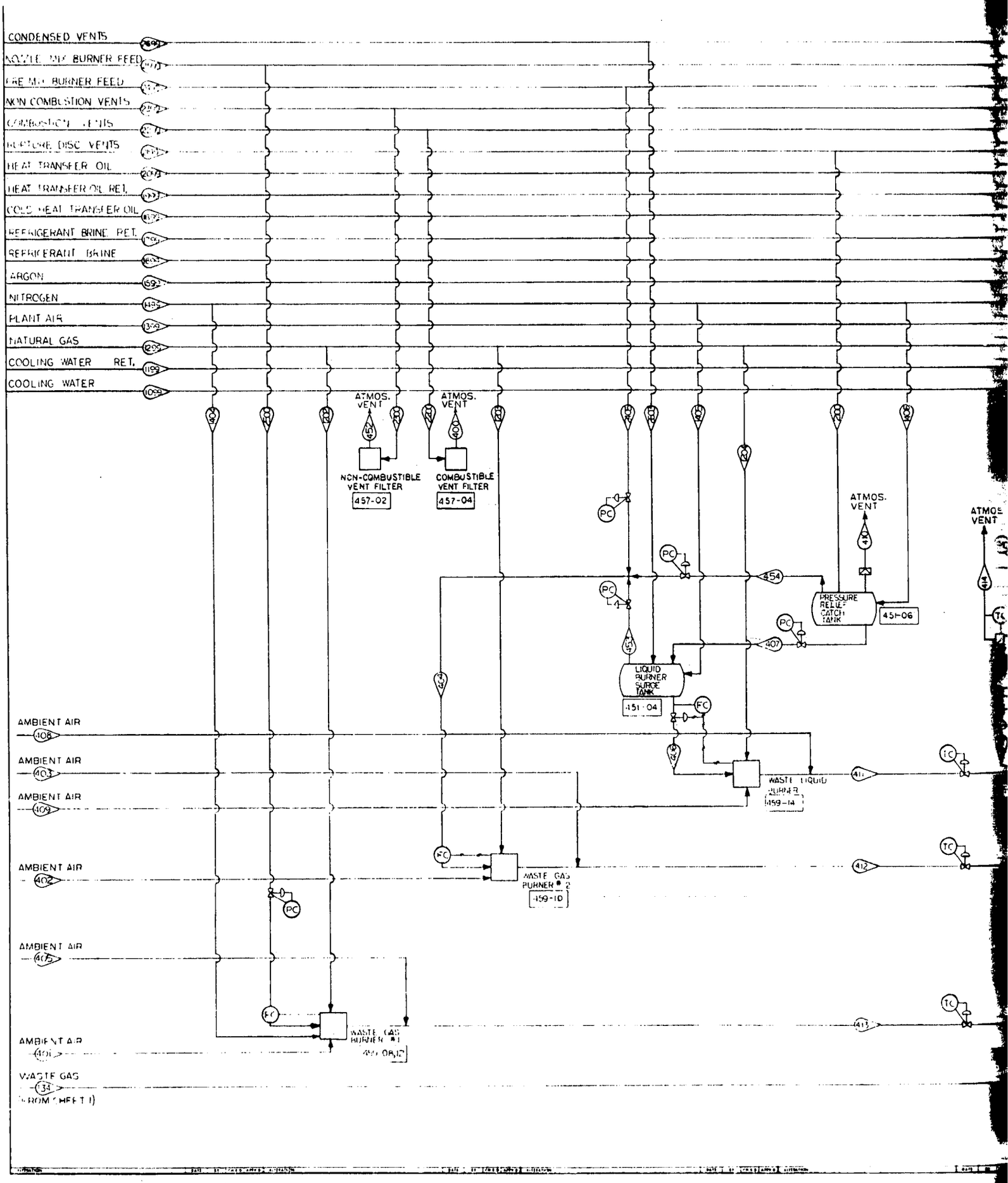
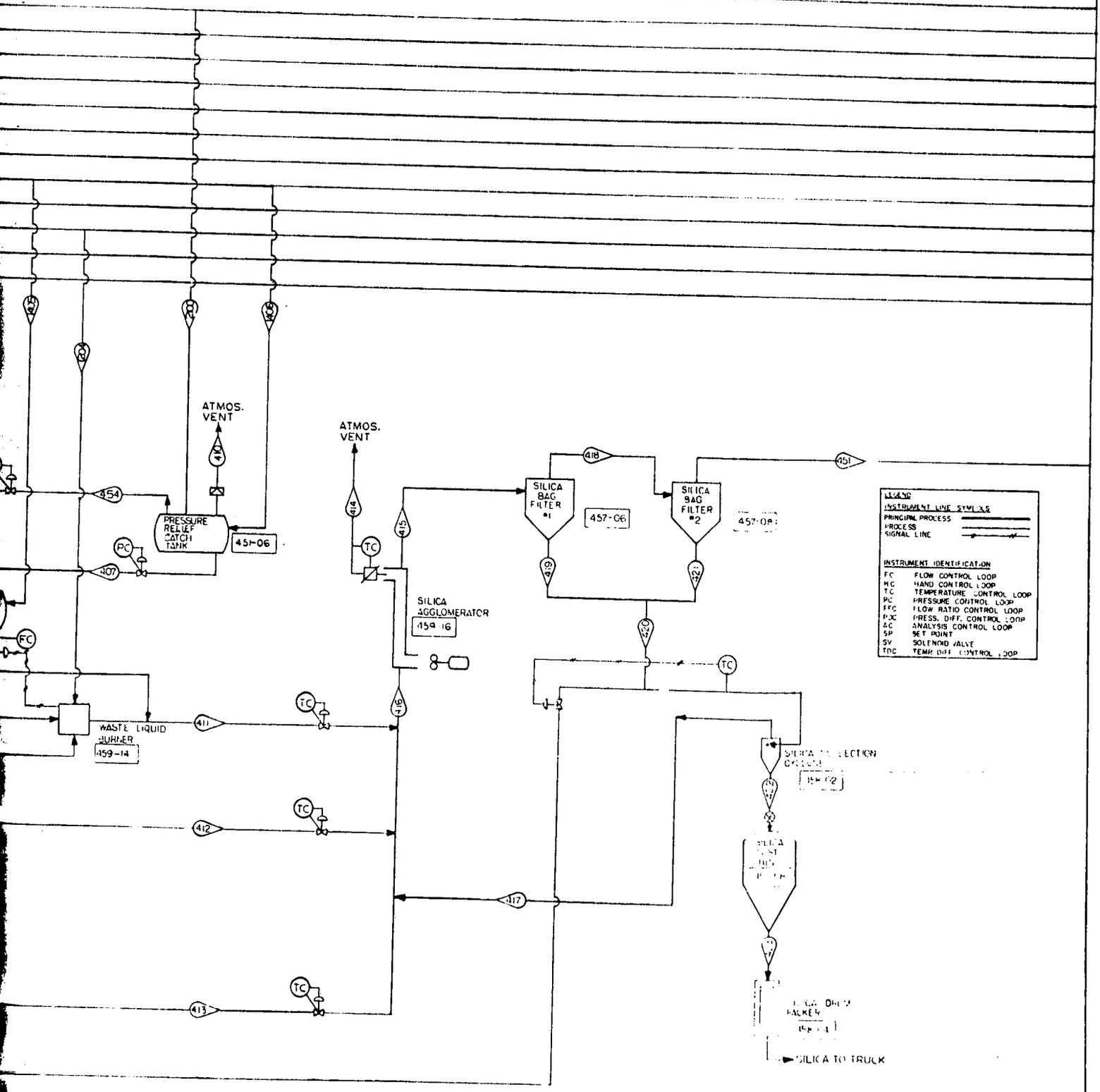


FIGURE 5 (CONT'D)

2 FOLDOUT FRAME


CONDENSED VENTS
NOZZLE MIX BURNER FEED
FREE MIX BURNER FEED
NON COMBUSTION VENTS
COMBUSTION VENTS
RUPTURE DISC VENTS
HEAT TRANSFER OIL
HEAT TRANSFER OIL RET.
COLD HEAT TRANSFER OIL
REFRIGERANT BRINE RET.
REFRIGERANT BRINE
ARGON
NITROGEN
PLANT AIR
NATURAL GAS
COOLING WATER RET.
COOLING WATER
ATMOS. VENT
NON-COMBUSTIBLE VENT FILTER
457-02
COMBUSTIBLE VENT FILTER
457-04
PRESSURE RELIEF CATCH TANK
451-06
LIQUID BURNER SURGE TANK
451-04
WASTE LIQUID BURNER
459-14
WASTE GAS BURNER # 2
459-10
WASTE GAS BURNER # 1
459-08
AMBIENT AIR
WASTE GAS
(FROM SHEET 1)



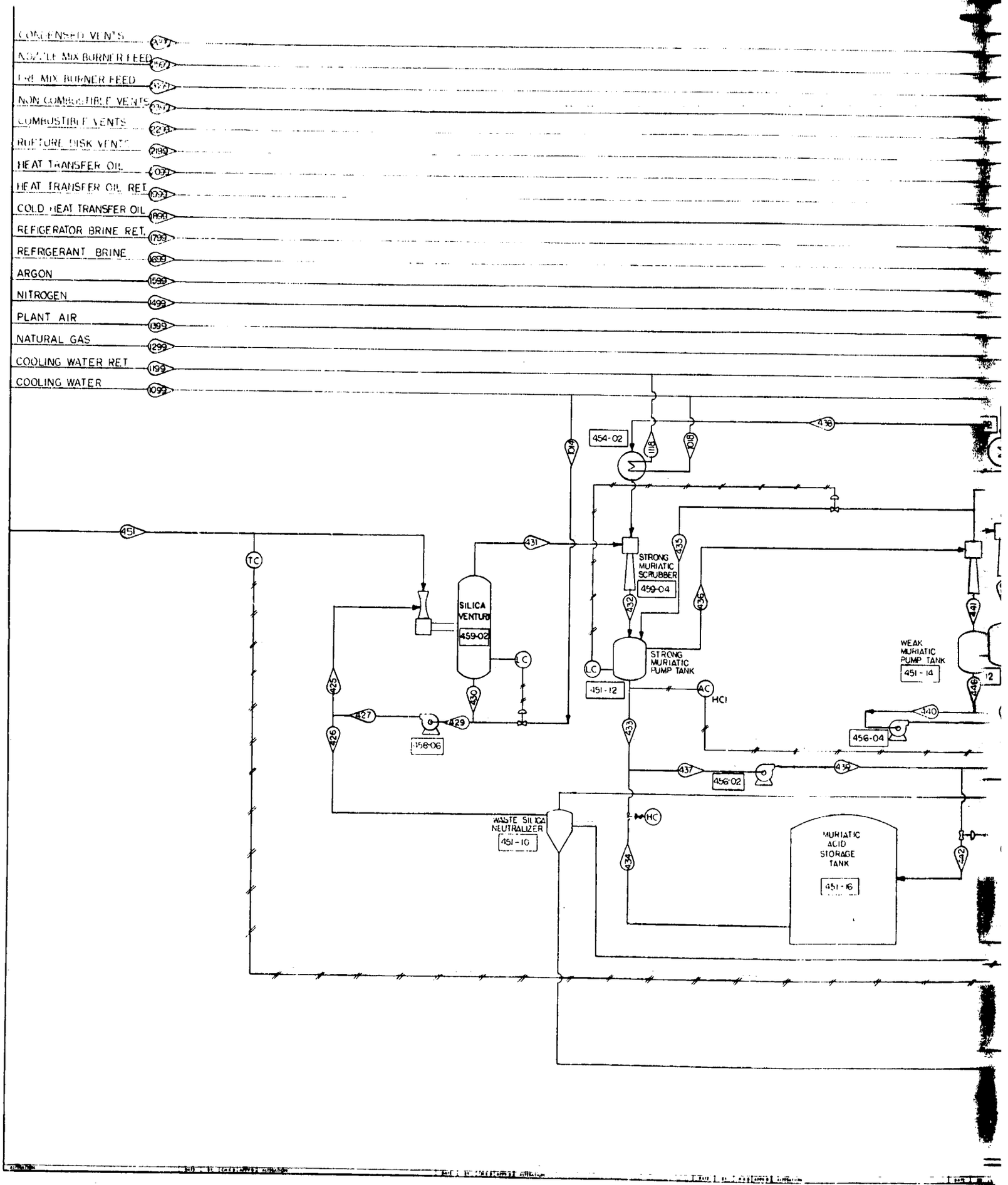
SECTION 4: WASTE DISPOSAL

UNION CARBIDE CORPORATION
LINDE DIVISION

HIGH WATER COMMERCIAL PLANT
PROCESS FLOW DIAGRAM

F-2074005

FIGURE 5 (CONT'D)



FOLDOUT FRAME

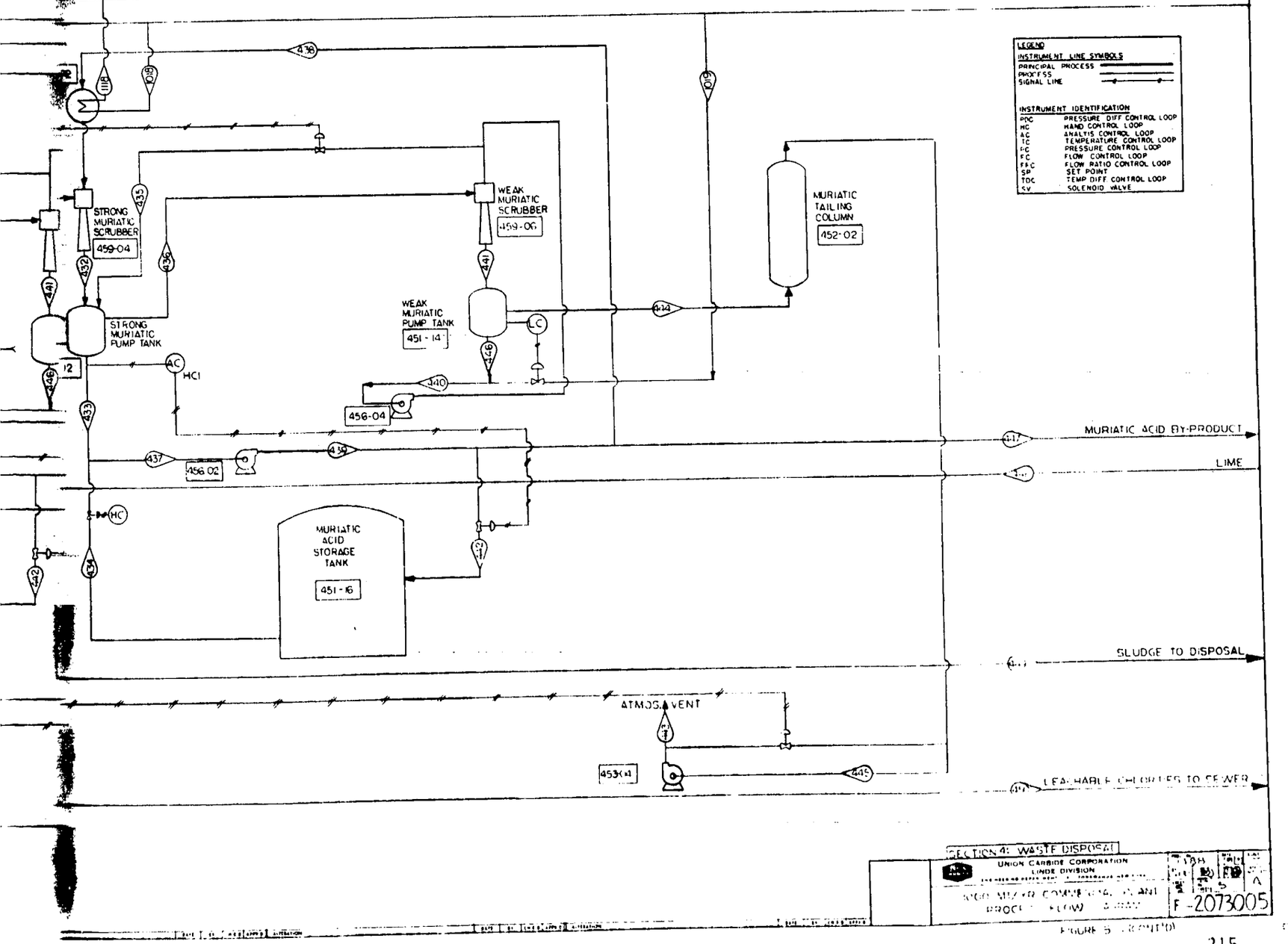


FIGURE 5 (CONT'D)

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supplies adjusted temperatures, pressures and descriptions for all streams based on the issue 2 stream catalog. A trace component analysis (Table E-IV) is provided to present contaminant levels in principal process streams.

5.1 1000 MT/YR COMMERCIAL PLANT

5.1.1 Introduction

The 1000 MT/Yr commercial plant design converts 98%-pure, metallurgical-grade silicon to ultra-high-purity, semiconductor-grade, molten silicon metal. Powdered, metallurgical-grade, silicon metal feed is converted to trichlorosilane by hydrogenation with silicon tetrachloride in a hot, high-pressure, fluid-bed reactor. Through successive purifications by distillation and chlorosilane redistribution, the trichlorosilane is converted to ultra-high-purity silane containing an electronically active metal contaminant concentration below 0.01 PPB. The pure silane is pyrolyzed to form finely divided silicon metal powder, which is electrically melted in enclosed quartz crucibles to yield the molten silicon product. The molten product will be extracted from its containing crucibles and subsequently processed by technology presently being developed by other JPL contractors. The definition and cost of processing the molten silicon is not included in this design study.

The ultimate goal of the DOE/JPL solar program is to produce, by 1986, semiconductor-grade silicon costing no more than $10/kg in 1975 dollars. A facility meeting these goals is described.

5.1.2 Process Design

5.1.2.1 Process Description

The process design converts 98%-pure, commercial, metallurgical-grade silicon into ultra-high-purity silicon metal suitable for solar-cell applications. The feed metallurgical silicon is converted to gaseous trichlorosilane (TCS) in a hot, copper-catalyzed, fluid-bed reactor. Non-

volatile, metal-chloride contaminants are separated from the reactor product stream by removal of a small, liquid fraction at its dewpoint, and hydrogen is subsequently separated as a noncondensable gas from the condensed crude TCS liquid. The crude TCS liquid is stripped free of dissolved volatile impurities in a stripping column. The material is then processed through a series of three conventional distillation columns and two redistribution reactors. This equipment progressively replaces chlorine in the chlorosilane molecules with hydrogen, pushing the heavily chlorinated compounds back to the front of the process and hydrogen-rich molecules forward. Ultimately, silane is produced and subjected to a final distillation in the fourth column that yields an ultra-high-purity, liquid-silane product.

The pure silane is pyrolyzed to form hydrogen gas and high-purity, silicon metal powder. The powder is consolidated by melting and removed from the process.

Reference to the plant process flow diagram, Figure 5-1, is suggested as necessary for following the ensuing detailed process description.

5.1.2.1.1 Hydrogenation

Ninety-eight-percent-pure, powdered, metallurgical-grade silicon, having an average particle size of 200 microns, is received by tank truck or rail car and is transferred pneumatically (100) to the metallurgical-grade silicon storage bin, 411-02 (see Figure 5-1). The conveying air is passed through the metallurgical-grade silicon unloading filter, 417-02, before being exhausted to the atmosphere. Silicon powder from the storage bin is batch fed by a manual slide valve to the hydrogenation catalyst twin shell blender, 428-02, into which a small amount of copper catalyst (101) is also being added. The catalyst/silicon powder blend is transferred through double, block-and-bleed valving into the metallurgical-grade silicon lock hopper, 421-02. Hydrogen gas (105) is used to pressurize the lock hopper to 550 psia after it has been purged free of air with utility nitrogen (1400). Lock hopper outlet valving is then opened and high-pressure hydrogen

gas (104) is used to pneumatically transport the silicon powder into the fluid-bed, hydrogenation reactor, 425-02, operating at 500°C and 515 psia. A recycle stream of hydrogen (122) and silicon tetrachloride (STC) (123), heated to 520°C, is controlled such that the mixed fluidizing stream (107) entering the reactor contains equal molar proportions of hydrogen and STC.

In the hot (500°C), fluid-bed environment of the reactor, the STC is hydrogenated according to the overall reaction,

$$3SiCl_4 + 2H_2 + Si \overset{Cu}{\rightleftarrows} 4HSiCl_3, \qquad (5\text{-}1)$$

which is reversible and which, in the presence of copper catalyst and selected bed dimensions, proceeds nearly to equilibrium to yield a hot, overhead, vapor stream (108) that contains about 15% TCS, 44% unreacted hydrogen and 41% STC. This hot vapor also contains some unreacted silicon dust, copper powder, and all the trace metal contaminants released from the metallurgical silicon in the reactor as metal chlorides. This stream is quenched to its dewpoint, about 180°C, by a large STC/TCS liquid recycle stream (111) in an efficient venturi quench and solids removal contactor 429-02. The two-phase product (110) is delivered to the waste settler tank, 421-04. Liquid STC/TCS from the settler tank is pumped by the quench contactor pump, 426-02, to the venturi quench contactor. Many of the metal contaminants form insoluble complexes with one another in this unit (e.g., aluminum chloride forms a complex with iron chloride) and settle to the bottom of the quiescent settler tank as sludge. Some metal salts remain dissolved in the liquid and a small fraction leave in the vapor phase from the top of the settler. More than 90% of the undesirable metal contaminants remain in the settler either in solution or as insoluble sludge. A small stream (112) of STC/TCS liquid from the settler containing unreacted silicon powder dust, copper catalyst dust, complexed metal salt sludge and dissolved metal salts is rejected through the waste chlorides tank, 421-06, to waste disposal.

The dust-free STC/TCS hydrogen stream, with reduced metal chloride contaminants, flows from the settler through a water-cooled heat exchanger, which condenses the STC/TCS from the noncondensable unreacted hydrogen, to

the quench condenser receiver, 421-08. The hydrogen gas (118) is separated from the STC/TCS condensate, increased in pressure by the recycle hydrogen compressor, 423-02, to 522 psia, and heated to 520°C in the recycle hydrogen superheater, 429-08, before being recycled to the fluid bed STC hydrogenation reactor (122). A small quantity of liquid STC/TCS (115) is circulated from the quench condenser receiver to the quench condenser by the quench condenser wash pump, 426-04. This liquid is sprayed on the tube walls of the quench condenser to wash away any metal chloride contaminants that may have carried over from the settler tank and were deposited. Liquid STC/TCS is also supplied by gravity from the quench condenser receiver to the settler tank (116) as required to maintain a constant liquid level. The latent heat in this stream provides the cooling needed to reduce the temperature of the reactor product from the reactor outlet temperature of 500°C to the settler operating temperature of approximately 180°C. Crude STC/TCS product (119) at ambient temperature is delivered to the large, crude TCS storage tank, 421-10, operating at 100 psia. This nitrogen-pressurized tank provides decoupling between the STC hydrogenation and the distillation/redistribution/purification train. Shutdown of either plant section will not necessitate immediate outage of the other because of this feature.

5.1.2.1.2 Distillation/Redistribution

Crude STC/TCS liquid flows (125) from the crude TCS storage tank 421-10, to the stripping column, 432-02, which operates at 90 psia and is designed to remove the 99% of the possible hydrogen sulfide dissolved in the feed. The stripping column is designed to accomplish two objectives: (1) to remove all volatile contaminant gases lighter than silane to at least 0.01 PPB and (2) to remove 99% of the heaviest of the volatile contaminants. These contaminants are heavier than silane. It is not necessary to drive the stripper when removing the volatile contaminants heavier than silane since they will be rejected in the bottoms of the silane column, 432-08, and purged (226). The reboiler on the stripper, operating at 120°C, is driven by hot oil from a closed-loop hot-oil heating system; heat is extracted from the overhead condenser by a refrigeration system. Overhead distillate vapor containing the rejected light gases is directed to waste

incineration. Since the feed to the column contains significant amounts of DCS, column operating conditions have been selected to minimize overhead losses of this valuable material.

Crude STC/TCS liquid, free of dissolved volatile contaminants, flows (206) from the stripper reboiler, 434-04, to tray 5 in the TCS column, 432-04. The 30-tray TCS column receives a second feed stream (212) containing a mixture of chlorosilanes including STC that has been recycled back from the reboiler, 434-10, of the DCS column. Operating at 55 psia, the TCS column is designed to recover 97% of the total STC in its two feeds in the bottom liquid product, and 97% of the total TCS feed in its overhead distillate product. The STC bottom liquid product (238) is cooled by the STC cooler, 434-24, against cooling water and delivered to a large-atmospheric-pressure, liquid-STC storage tank, 421-12. Liquid STC from this tank (127) is pumped, 426-06, through the recycle STC vaporizer, 424-04; heated to 520°C in the recycle STC superheater, 429-06; and recycled back to the fluid-bed reactor (123). To make up for the small amounts of chlorine that are rejected from the settler tank (112) and the stripper column overheads (2501), technical-grade STC is periodically added (102) to the inventory in the STC storage tank.

Most of the trace-metal contaminants (PCl_3, $AsCl_3$, $FeCl_3$, $NiCl_2$, $CuCl_2$, $CaCl_2$, etc) that enter with the crude STC/TCS liquid fed to this column (206) have a higher boiling point than STC and will, therefore, be rejected with the bottoms product (238) back to the hydrogenation reactor through the STC vaporizer and superheater, and end up as sludge in the settler tank. Some of the contaminants will be rejected directly to the settler tank as vaporizer blowdown (132) and will also end up as sludge in the settler tank. If present, contaminants lighter than STC (B_2H_6, PH_3, AsH_3, BCl_3, etc.) will leave the TCS column with the distillate product.

The TCS column overhead vapor (209), a mixture of MCS, DCS, and TCS, is totally condensed against cooling water in the TCS column condenser, 434-08. This liquid is pumped and divided between column reflux (213) and distillate product (214). The distillate product flows to tray 39 of the subsequent 62-tray DCS column, 432-06. The DCS column, operating

at 320 psia, receives at tray 53 a second feed (225) recycled from the reboiler, 434-20, of the silane column. Both feeds contain mixtures of chlorosilanes. Column operating conditions have been selected to deliver 97% of the total TCS contained in both feeds to the bottom and 97% of the DCS feed to the top of the column as distillate product. The bottom product leaves (236) the hot-oil driven DCS column reboiler, 434-10, and is cooled to 70°C. It is fed (215) liquid-phase through an Amberlyst® A-21, amine base, ion-exchange resin, catalytic-redistribution reactor, 435-02, before being recycled (212) back to the TCS column. The reactor catalyzes the following reactions:

$$2HSiCl_3 \overset{A\text{-}21}{\rightleftarrows} H_2SiCl_2 + SiCl_4 \qquad (5\text{-}2)$$

$$2H_2SiCl_2 \overset{A\text{-}21}{\rightleftarrows} H_3SiCl + HSiCl_3 \qquad (5\text{-}3)$$

$$2H_3SiCl \overset{A\text{-}21}{\rightleftarrows} SiH_4 + H_2SiCl_2 \qquad (5\text{-}4)$$

[These are reactions (4-2), (4-3), and (4-4), respectively, of Section 4-1.]

The reactor is sized to convert its feed, which is predominantly TCS, to 95% of its equilibrium value. The equilibrium of these reactions is such that only small quantities of silane and MCS are formed while substantial quantities of DCS and STC are produced.

Overhead vapor (219) from the DCS column is totally condensed against cooling water in the DCS column condenser, 434-14, before being pumped and divided between reflux (220) and distillate product (222). This distillate product is cooled to 50°C against cooling water by the DCS cooler, 434-16, before being passed liquid-phase through a second redistribution reactor, 435-04, similar to the unit previously described. The feed to this reactor, primarily DCS, is redistributed to form a spectrum of chlorosilanes and silane that is consistent with the equilibrium reactions listed above. Silane, the ultimate product of this distillation/redistribution train, increases from 0.85 to 15.46 mole percent in passing

through the reactor. This redistribution reactor also acts as a trap for residual boron impurities (BCl_3, B_2H_6), which, based on experimental evidence, combine irreversibly with the amine-resin catalyst. The relative level of feed impurities is so low that catalyst life is not materially influenced.

The reactor product (224) is fed directly to tray 11 of the 58-tray silane column, 432-08, operating at 360 psia. Operating conditions have been selected to permit rejection as bottoms product all material except silane. The reboiler, 434-20, is driven by hot oil and heat is removed by the silane column condenser, 434-18, at -31°C by means of a refrigerant unit. Volatile contaminants heavier than silane are not completely removed in the stripping column. These contaminants must be rejected with the bottoms product. The most volatile of the potential contaminants (i.e., the contaminant having the lowest boiling point) is diborane, B_2H_6. It can be formed by chemical reaction between BCl_3 and silane. Its normal boiling point is -93°C, while silane boils at -112°C and MCS at -31°C. Operating conditions for the column have been chosen to separate silane from diborane and all other higher-boiling contaminants. The column has a calculated ability to produce a silane distillate product containing <0.01 PPB diborane when the column feed contains 5 PPB. Ninety-seven percent of the silane contained in the column feed is removed as an ultra-high-purity overhead liquid product (231). This liquid silane is directed to one of three shift tanks. When the selected shift tank is filled, it is isolated and checked for purity and another tank is placed into service. Refrigeration is supplied to these tanks, as required, to compensate for ambient-heat leak and to prevent pressure buildup and loss of contents. When quality checks verify adequate purity, the liquid in the tank is vaporized at a controlled rate in an atmospheric vaporizer to maintain a constant tank pressure while the vapor is removed from the top of the tank (233). The vapor is passed through the silane superheater, 434-22, which is a bath of hot oil, and sent (235) to silane pyrolysis equipment for the production of the final, high-purity, silicon metal product. At any one time, one shift tank is receiving product liquid silane from the silane column, quality control analyses are being made on a second unit, and the third tank is supplying silane to pyrolysis equipment. A fourth tank is available in the event the silane does not pass the quality control analyses; it can

be used to accept product liquid silane while the silane that did not pass the quality check is being drained.

All materials entering the silane column, other than silane, are removed as bottoms liquid product (239) consisting primarily of DCS and TCS with small amounts of MCS and STC. This liquid stream is returned to the DCS column.

The possibility that certain contaminants of intermediate volatility could become trapped in sections of the distillation system has been recognized. For example, BCl_3, whose ABP falls between those of DCS and TCS, will report with the overhead distillate product (214) in the TCS column, enter the DCS column, and be rejected to its bottoms product (236). The bottoms product, however, recycles back to the TCS column. Therefore, conceivably, the concentration of BCl_3 could build in the system to the level necessary either to force it out the top of the DCS column or the bottom of the TCS column (assuming the material is not irreversibly trapped by the TCS redistribution reactor, 435-02). To prevent impurity buildup, provision has been made to recycle a small bleed stream (237) from the bottom of the DCS column back to the STC tank. Similarly, contaminants whose boiling point fall between those of DCS and silane (e.g., B_2H_6. PH_3) could build in the liquid streams (222, 225) traveling between the DCS column and the silane column. To avoid this possibility, provisions have been made to bleed a small quantity of liquid from this system back to the STC tank. There is also the possibility that contaminants heavier than STC are present in the STC storage tank. These contaminants would build up in the STC recycle vaporizer, 424-04, if it were not for a bleed stream (132) removing the contaminants to the settler tank. In all cases, the bleed streams are designed to provide an exit path from the system, either through the settler tank, if the contaminants are heavy-boiling materials, or by way of the stripper overhead product, if the contaminants are light-boiling materials.

Boron is the most undesirable contaminant in the silicon metal used for electronic and semiconductor applications because it is electrically

active and impossible to remove by solid-silicon, zone-refining techniques because of its unfavorable liquid/solid distribution coefficient. Three methods of boron removal have been incorporated into the process design of this plant:

(1) Small amounts of silane (240), which may react with any BCl_3 that is present and form B_2H_6, are fed to the bottom of the stripper. The B_2H_6 will leave with the stripper overhead product as opposed to BCl_3 which leaves with the stripper crude STC/TCS bottoms product.

(2) Passage of product chlorosilanes through catalytic redistribution reactors will result in the trapping of residual boron by this catalyst.

(3) Finally, the silane distillation column is designed and operated to reject from the silane product any or all diborane that may be contained in its feed.

Any of these processing steps are capable of removing boron from the system to acceptable levels. There is conservatism and redundancy built into the process to assure complete boron removal.

5.1.2.1.3 Silane Pyrolysis/Consolidation

Ultra-high-purity silane vapor flows (233) from the top of one of the silane storage tanks, 431-04, into a hot-oil bath, 434-22, to superheat the silane to 52°C. The silane is passed through a micropore filter, 437-02, before being throttled to about 25 psia and injected by a water-cooled nozzle (300) into quartz-lined, free-space, silane-pyrolysis reactors, 445-02. Each reactor is heated by a resistive heater element on the outside of the reactor, and the wall temperature is maintained at 870°C. The gas in the reactor is radiantly heated to about 760°C; it decomposes exothermically to form silicon and hydrogen gas according to the reaction:

$$SiH_4 \rightarrow Si + 2H_2 \qquad (5\text{-}5)$$

The product silicon flows (301) with the hydrogen gas into the product powder-storage hopper, 441-02. The hydrogen gas is separated from the silicon powder; filtered through a 5-micron, metal filter; cooled in the pyrolysis-hydrogen cooler, 444-02; sent (312) to the pyrolysis-hydrogen compressors, 443-02, 443-04; and recycled (313) back to the hydrogenation reactor, 425-02, with make-up hydrogen (314).

The plant will operate with fourteen pyrolysis reactors and each reactor will have its own product powder-storage hopper, 441-02, and melting furnace, 449-04. The silicon powder collected in each product powder-storage hopper will be fed (303) to one of the melting furnaces. The powder will be melted in a quartz crucible by resistive heater elements supplying the consolidated liquid product silicon (307).

5.1.2.1.4 Waste Disposal

Waste streams are disposed in an environmentally acceptable manner by thermal oxidation of chlorosilanes coupled with the use of baghouses to collect solids. Acidic combustion products are scrubbed free of hydrogen chloride, which is recovered as a medium-strength, muriatic acid. Equipment is arranged and controlled to recover as much material as possible in the form of marketable by-products and to produce a minimum of waste products.

Gaseous process wastes are divided into four collection headers: noncombustible gas containing no silane or chlorosilanes (2399); combustible gas containing no silane or chlorosilanes (2299); chlorosilane gases (2499); and silane-hydrogen gases (2599). The first two streams (2300, 2200) are passed separately through bag filters, 457-02 and 457-04, respectively, and vented (452, 400). Similarly, a bag filter, 417-02, is located over the metallurgical-silicon storage bin, 411-02, to collect silicon fines before venting. The fines from these various filters can be reused by dumping them into the metallurgical-silicon storage bin.

Chlorosilane-bearing gases (404) are combusted to yield hydrogen chloride and silica in a pre-mix burner, 459-10. Silane- or hydrogen-

bearing gases (2500) are combusted in a nozzle-mix burner, 459-08. Liquid wastes are collected (406) and combusted in an atomizing, pre-mix burner, 459-14. The various burners all discharge into a vacuum collection system together with enough excess air to quench the flames. To convert all chlorinated material to hydrogen chloride, hydrogen functionality is added, where necessary, in the form of natural gas. To minimize atmospheric venting of chlorosilanes as a result of process upsets, overpressure relief lines are manifolded to a pressure-relief catch tank, 451-06, which phase-separates and feeds material to the appropriate burner for disposal.

Combustion gases from the burners are cooled in the silica agglomerator, 459-16, to about 150-200°C. Silica particles formed in the combustion process agglomerate when cooled in this fashion to form larger, more easily controlled particles. The fumed silica, along with metal oxides formed in the flames, are collected by bag filters, 457-06 and 457-08. Trace submicronic solids remaining in the combustion gases (421) are removed by a high-energy venturi, 459-02, driven by a medium-strength, muriatic solution. As the combustion gases pass through the venturi, they are cooled to near dew-point by humidification. The gases, cleaned of solids, are then scrubbed free of hydrogen chloride with a two-stage venturi ejector, 459-04 and 459-06, producing a nominal 20% muriatic acid solution. The scrubbed gases, cleaned of hydrogen chloride to part per million levels, then pass through the muriatic tailing column, 452-02, which has been packed with a sacrificial metal surface. The gas that is exhausted to the atmosphere (443) by the waste gas induction blower, 453-04, has solid-particulate and hydrogen-chloride levels that are well below regulated limits.

The solids collected by the bag filters, primarily fumed silica, are discharged through a cyclone, 458-02, and an airlock to the silica dust bin, 451-08. The silica dust (432) is packed into 55-gallon drums, as required, using a vibrating table, 458-04, to densify the dust.

The high-energy venturi, 459-02, is purged (426) of collected solids whenever the solids concentration increases to about 2%. Approximately 100 gallons of liquid is purged into a neutralizing tank, 451-10, equipped

with a sand filter where it is neutralized with lime, causing solid precipitation. Leachable calcium chloride is filtered from the solids by gravity percolation through the sand filter and is sewered.

The fumed silica by-product from the bag filters is marketable as a low-performance filler for tires and other rubber products. The medium-strength, muriatic acid is marketable for such applications as pickling metals.

5.1.2.2 Major Process Controls

Major and critical process controls within the 1000 MT/Yr commercial plant processing train are described, and the rationale for their selection is given. Reference is made to the process flow diagram, Figure 5-1, during the following discussion.

The height of the fluidized, metallurgical-silicon, powder bed in the hydrogenation reactor, 425-02, is detected by a differential pressure transmitter spanning the top surface of the bed into the reactor freeboard. This signal is used to effect intermittent transfer of the fresh silicon powder/copper catalyst mixture into the hydrogenation reactor from the feed lock hopper.

The flow rate of the pump-around STC/TCS liquid (129) from the waste settler tank, 421-04, to the venturi quencher is determined by liquid-volume requirements of the venturi for effective entrapment of particulate matter in the liquid phase. A liquid-level controller on the waste settler tank provides it with ambient-temperature TCS/STC liquid (116) from the quench condenser receiver, 421-08. Crude STC/TCS (119) is transferred by a liquid-level controller from the quench condenser receiver to the crude STC/TCS storage tank, 421-10, for delivery to the distillation/redistribution purification train (125).

Recycled hydrogen that has been phase-separated in the quench condenser receiver (118), is flow controlled through a positive displacement compressor, 423-02 back to the hydrogenation reactor. STC (127), pumped

from the STC storage tank, is flow-ratio controlled relative to the hydrogen flow as it is fed to the hydrogenation reactor.

The stripping column, 434-02, is designed to remove dissolved gases from the crude STC/TCS fed to it. This column is designed to achieve two objectives: (1) to remove all volatile contaminant gases lighter than silane to at least 0.01 PPB and (2) to remove 99% of the heaviest of the volatile contaminants. These contaminants are heavier than silane. It is not necessary to drive the stripper in removing the volatile contaminants heavier than silane, since they will be rejected in the bottoms of the silane column, 432-08, and purged (226). The reboiler rate is maintained by a flow-ratio control on the reboiler hot-oil supply, which is linked to the column feed-flow rate. This control maintains a vapor/liquid ratio in the column that is adequate to strip the volatile gases from the incoming liquid. The bottoms liquid product is removed by a liquid-level controller on the stripper reboiler, 434-04. The column operating pressure of 95 psia is maintained by venting (2501) the noncondensables from the column condenser receiver, 431-02. A refrigerated overhead condenser is used to minimize losses of chlorosilanes.

The TCS column, 432-04, is designed to recover 97% of the TCS and STC in the distillate and bottoms product, respectively. Sharpness of separation is controlled by the column's reflux ratio, which is a direct function of reboiler duty for a fixed feed rate. Figure 5-2, which was assembled from data collected in early design study work, gives the computed temperature profile in the column for reboiler duties of 95, 100 and 105% at the design distillate extraction rate. Increased reflux in the column, resulting from increased reboiler duty, provides a sharper separation. A flow control on the hot-oil feed to the column reboiler is used to control the reboiler duty.

Proper control of the TCS column requires that the distillate product (214) be removed from the top of the column at a rate precisely matched by the TCS separated from the feed by the column. The temperature distribution in the column, which was assembled from data collected in early design study work, for distillate draw rates of 95, 100, and 105% of design

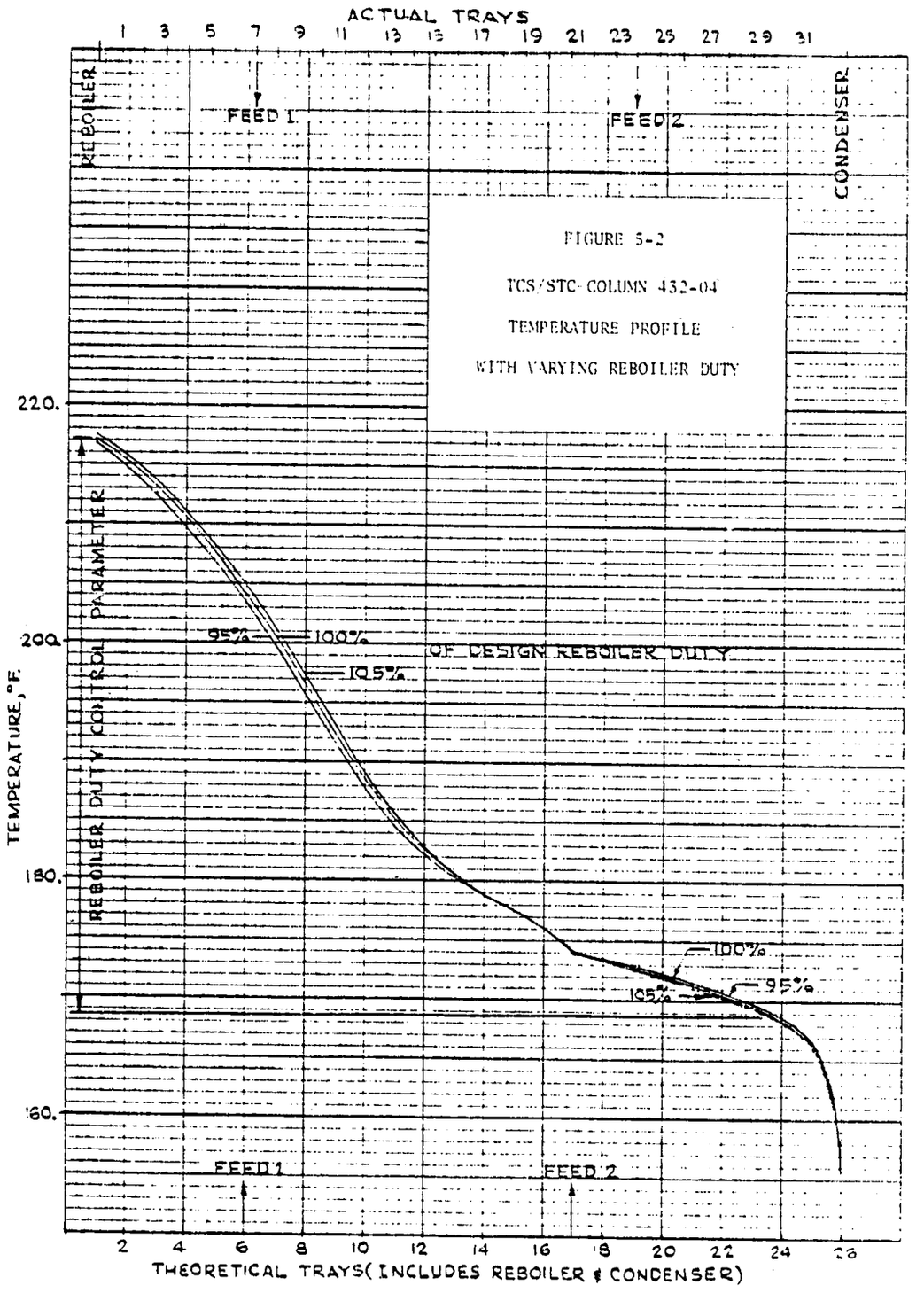

FIGURE 5-2

TCS/STC-COLUMN 432-04

TEMPERATURE PROFILE

WITH VARYING REBOILER DUTY

are given in Figure 5-3. Excessive withdrawal of distillate from the column results in a substantial increase in temperature throughout the column as STC content within the column increases all the way to the top distillate product. The ΔT between reboiler and tray 6 has been selected as a parameter whose value is a direct measure of correct distillate extraction rate and is, therefore, used as a process variable in the distillate feedback control loop. Figure 5-4 presents the process steady-state gain for this loop as determined from the data generated in Figure 5-3.

Column overhead vapor (209) is totally liquefied in the overhead condenser, 434-8. The top portion of the heat exchanger surface is exposed to the condensing vapors, while the remainder is submerged in the condensed liquid, subcooling it. The liquid is extracted from the bottom of the condenser by the reflux pump, 436-02. It is fitted with a bypass valve that has been modulated to control net liquid extraction from the condenser bottom. This action adjusts the level of liquid in the condenser and, therefore, the relative amount of surface area available for condensation. Surface-area modulation affects ΔT requirements to absorb the condensation duty and, therefore, column pressure. Distillate extraction rate is controlled indirectly by modulation of the column reflux supply valve. Adjustment of this valve allows the desired flow of distillate product to pass as feed to the high-pressure DCS column, 432-06.

The three selected control loops--modulating reboiler duty, distillate draw, and column pressure--will be somewhat interactive. In a steady-state situation, a column-pressure variation will affect the process variable value for both temperature controls. The use of ΔT rather than temperature for process variables helps to minimize this effect. It does not eliminate it, however, because the $\partial T/\partial P$ of chlorosilane mixtures is composition-dependent. The controls will permit manipulation of a number of process variables to eliminate interaction of this type in a steady-state situation.

Experience with other systems indicates that controls analogous to those described here work well, are resistant to upsets, and are

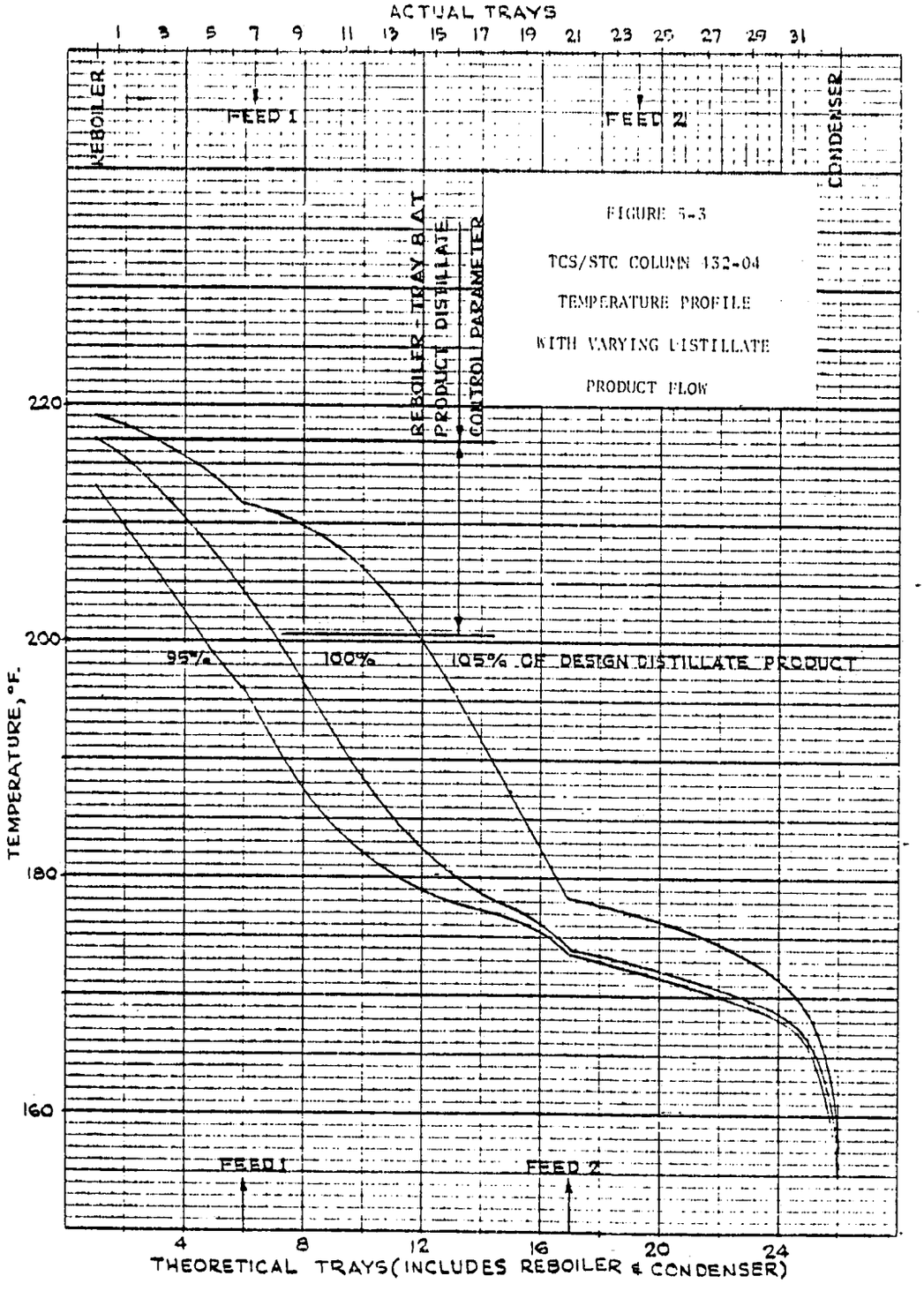

FIGURE 5-3

TCS/STC COLUMN 132-04

TEMPERATURE PROFILE

WITH VARYING DISTILLATE

PRODUCT FLOW

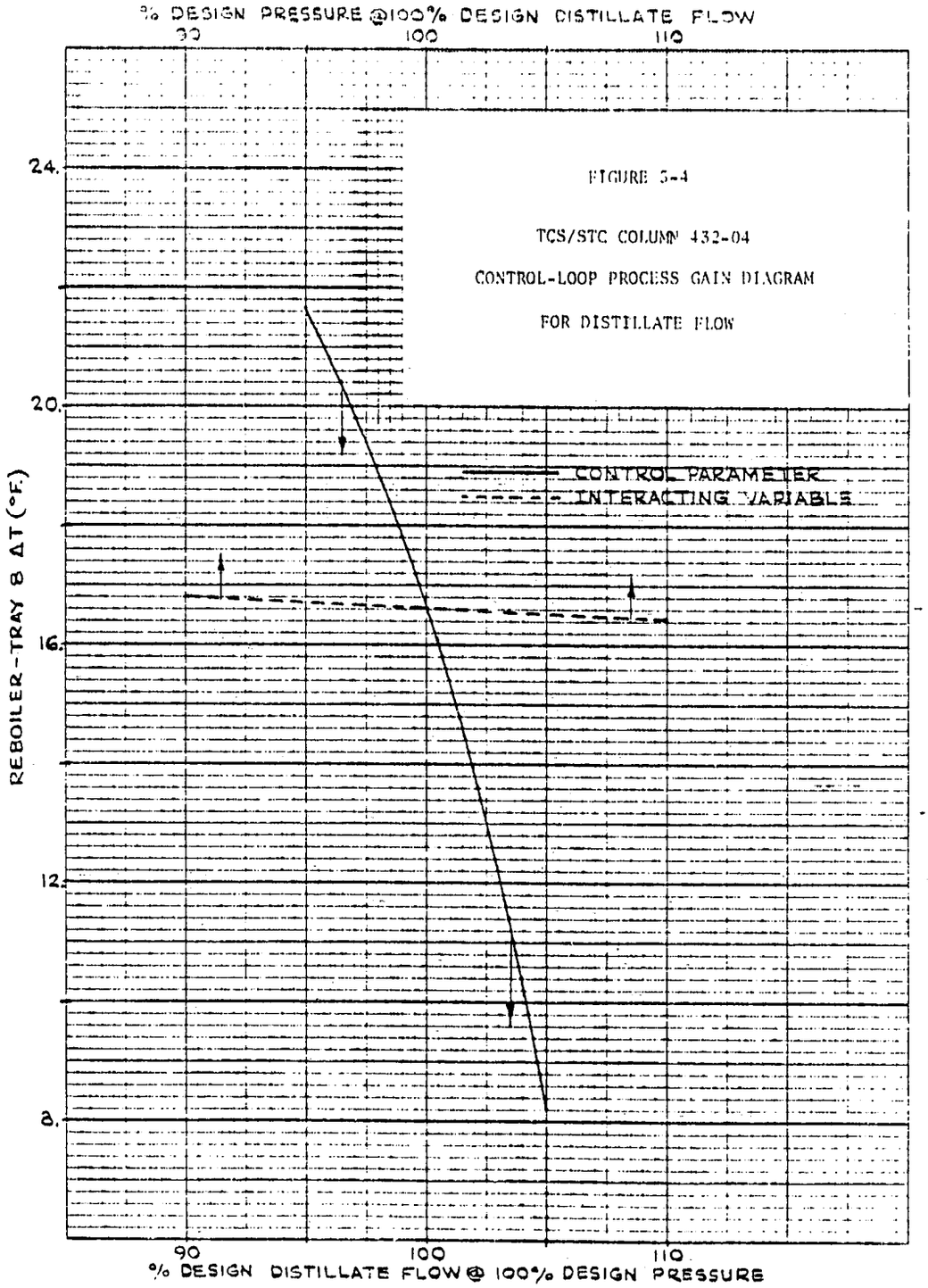

FIGURE 5-4

TCS/STC COLUMN 432-04

CONTROL-LOOP PROCESS GAIN DIAGRAM

FOR DISTILLATE FLOW

able to recover from severe process perturbations. The column contains a large inventory of liquid compared to its throughput rate. Therefore, excursions of purity, flow rate of the feeds, or flows of its products are substantially damped by the mass of the inventory. Also, tray-to-tray purity change rates are relatively low near the ends of the column from which the products are extracted. The situation permits a large, temporary shift in column composition and temperature profile without appreciable effect on product composition.

Control concepts for the DCS column, 432-06, are identical to those selected for the TCS column. Discharge pressure of the reflux pump, 436-04, is 550 psia. This pressure was determined by the requirement to avoid the formation of two phases in the DCS redistribution reactor, 435-04. The pump discharge pressure is maintained by modulation of its bypass valve. The distillate extraction rate is maintained by a reboiler-to-tray-40, ΔT controller, which adjusts the DCS redistribution reactor outlet valve to deliver feed to the silane column, 432-08. The flow control on the hot-oil feed modulates the column reboiler duty. The column reflux valve returns to the column all of the condensed overhead vapor not extracted as distillate product (222). It is modulated to maintain column operating pressure. This is accomplished by exposing the heat-exchange surface in the overhead condenser, as required, by draining the condensate.

In terms of major components, the silane column, 432-08, splits silane from MCS and heavier chlorosilanes. However, operating conditions for the column have been selected to ensure that silane is separated from diborane. Diborane is less volatile than silane, but much more volatile than MCS. The column has been designed to reduce diborane in the distillate to 0.01 PPB from a feed content of 5 PPB. The reflux required to accomplish this separation far exceeds that which would be required to reject MCS. Therefore, the MCS separation is accomplished by the first few trays above the feed. From that point upward, the only major constituent in the column is silane. A temperature profile in the column, which was assembled from the data collected in early design study work, is given in Figure 5-5. Five trays above the feed the temperature profile flattens out at the vapor

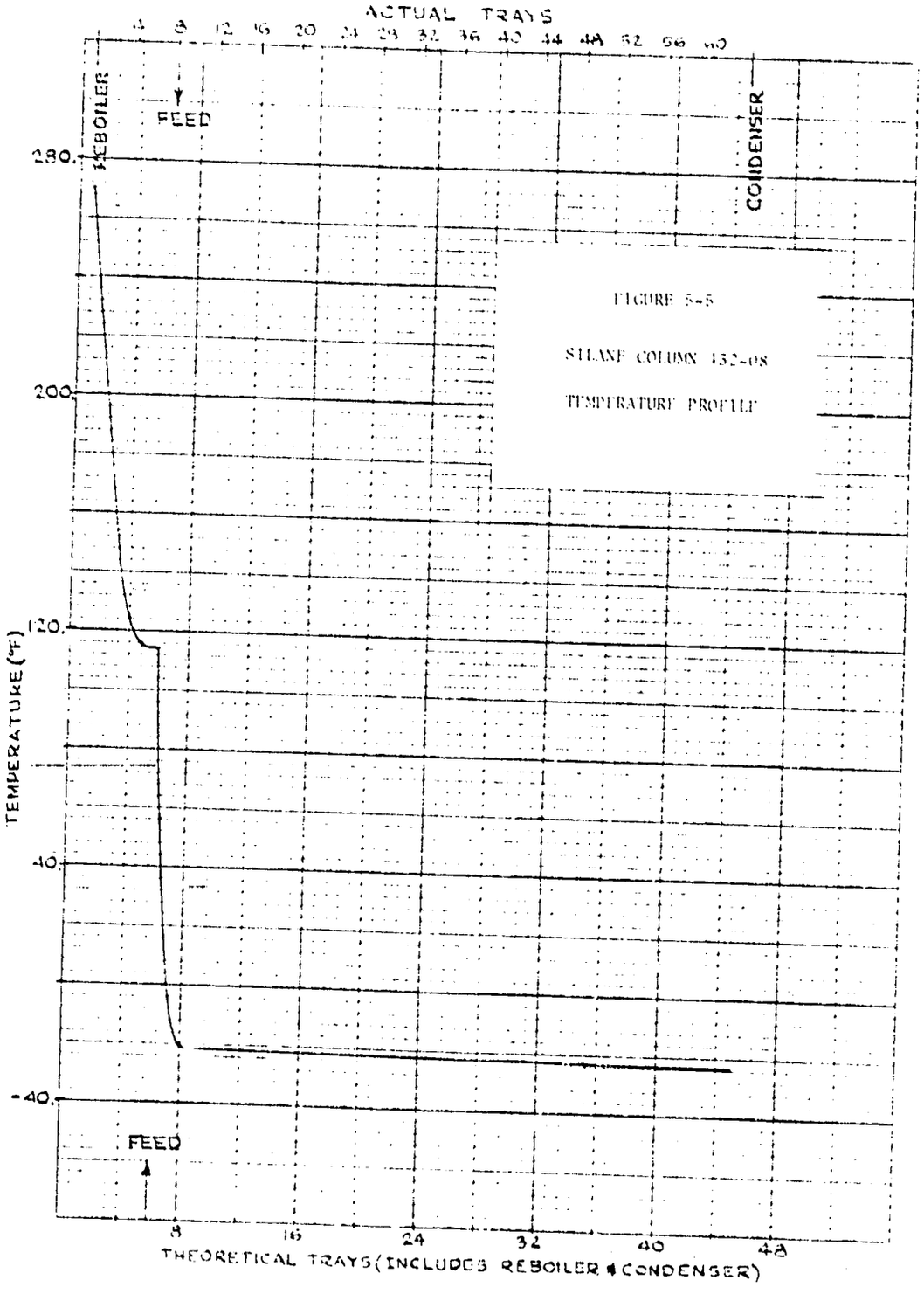

FIGURE 5-5

SILANE COLUMN 132-08

TEMPERATURE PROFILE

temperature of silane and subsequent stages serve only to wash volatile trace impurities from the silane.

When the column is operated at a calculated reflux ratio, the trays above the feed are capable of reducing an assumed diborane content in the feed of 5 PPB down to 0.01 PPB; this is a 500:1 separation factor. Diborane content of the feed is expected to be much less than 5 PPB, possibly as low as 0.04 PPB. Therefore, the 500:1 separation capability will reduce the boron content to a computed 0.00008 PPB. Impurity levels below 0.01 PPB are not accurately measured, so temperatures within this separation zone in the column cannot be used as an indication of separation effectiveness. Maintenance of the reflux ratio at the top of the column will make the unit capable of a feed-to-product diborane content reduction of 500:1. Distillate-extraction rate will be measured and the valve supplying reflux to the column from its overhead total condenser will be modulated by a flow-ratio controller to maintain the reflux ratio.

Separation below the feed has been selected to strip silane from the falling liquid so that 97% of the silane contained in the column feed is extracted in the distillate product. The column is operated such that the silane-distillate-extraction-rate exactly matches its ability to separate silane from the feed. Extraction of distillate silane in excess of its availability will result in the gradual movement of MCS up the column beginning at the feed tray. A column temperature-increase wave starting at the feed tray and moving up the column will simultaneously develop. If excessive distillate extraction occurs for a long period of time, MCS will appear in the distillate product. A ΔT controller measuring between tray 54 and tray 14 (a ΔT sensor rather than a single-tray temperature sensor is used to help minimize interaction with column pressure perturbations) will detect the onset of this MCS "climbing" effect. This control will not be critical and will also be extremely resistant to upsets because transient excursions of MCS high into the upper section of the column will not cause the production of unacceptable silane product. Also, the temporary appearance of substantial quantities of silane in the bottoms has no serious effect.

The column pressure is maintained by the reboiler-heat-input rate. Enough vapor is generated at the column bottom to provide the vapor needed

at the column top to supply the necessary distillate and reflux rates. Adequate heat-exchanger surface is maintained in the overhead condenser, 434-18, by the level of condensate, which blanks excess heat-exchanger surface, as required, to match instantaneous duty and surface-area needs.

Silane distillate product is flow-controlled into one of three refrigerant-cooled shift tanks; a fourth tank is used for backup. Pressure in these tanks is maintained at about 20 psi below the silane column operating pressure by a split-range control that supplies refrigeration to counter a tendency of the pressure to rise as a result of inflowing heat leak. When the tank is filled, it is isolated and various quality control tests are performed on its contents. Its pressure is then increased to about 20 psi above silane column pressure to avoid any possibilty of in-leakage of additional material from the silane column following quality-control testing. Vapor from the top of these tanks is extracted, as required, with a flow controller to the silane pyrolysis reactor. Pressure within the tank is maintained at 20 psi above the silane column pressure by the same split-range pressure controller. It operates the vapor valve on an air-heating coil to generate pressure by extracting liquid from the bottom of the tank, vaporizing it and injecting it back into the top of the tank.

5.1.2.3 Rationale for Selection of Operating Conditions

5.1.2.3.1 Hydrogenation

A reactor operating temperature of 932°F was selected. This is high enough to obtain acceptable first-order reaction rates (Section 4.1) such that near-equilibrium, reactor-effluent composition is approached with modest bed volume. This operating temperature is also low enough to avoid the need for exotic materials of construction. At this temperature, operating data are available to ensure validity of reaction yields used.

The ratio of hydrogen to silicon tetrachloride in the reactor feed and the reactor pressure have been selected as equimolar and 500 psia,

respectively. This feed ratio was selected to provide an optimum yield of trichlorosilane at economic prices. Significant deviation from equimolar ratio will result in one recycle stream or the other being greatly increased, causing the total amount of utilities required to increase. The 500 psia pressure was selected to maximize yield without reaching the point at which equipment availability becomes restricted or component critical pressures are approached.

Vapors coming from the hydrogenation reactor are quenched to their dewpoint by adiabatic humidification with recycle crude TCS/STC mixture in an efficient contactor. Vapors and liquid from the quench are separated efficiently to minimize solids carryover, particularly carryover of aluminum chloride. Vapors pass to a downflow vertical condenser, where they are partially condensed to 100°F. A condensate pump is used to respray a small amount of liquid into the condenser top head, if necessary, to wash the top of the tubes. The best available information indicates that an upflow condenser is not required to maintain sufficiently low aluminum chloride buildup on tubes, if an efficient phase-separator is provided after quenching.

Use of a refrigerated aftercondenser to remove more chlorosilanes from the hydrogen has been examined and found uneconomical at this pressure (500 psia). This is based on a comparison of the condenser total cost vs — the decrease in hydrogenation reactor size resulting from the recycling of less trichlorosilane.

5.1.2.3.2 Distillation Columns

Column pressures have been selected to economically allow component separation without imposing hydraulic difficulties on tray design. For each column, maximum pressures were determined to limit surface tension and vapor-liquid differential density to those values that would give good tray hydraulics. At pressures below the maximum limits, economics were considered to yield the lowest overall cost (amortized capital cost plus utilities) for columns of reasonable height. Based on these considerations, the best ranges of operation were found to be 100 psia for the stripping

column, 50 psia for the TCS column, 300 psia for the DCS column, and 400 psia for the silane column. To maintain proper pressure differentials for flow back and forth between columns, pressures were selected at 95, 55, 320, and 360 psia, respectively. One of the major considerations in this economic evaluation was the use of high-temperature coolant (cooling water) in the condensers. Below ambient temperature cooling is required for only two of the plant's condensers. A small, packaged, -31°C refrigeration system is provided to operate the stripping column and final silane polishing column condensers. Use of this high level refrigeration in the stripping column minimizes chlorosilane losses. The high vapor pressure of silane requires operation of the silane column condenser at below ambient temperature.

Component recoveries were set at 97% of the light key in the overhead products and 97% of the heavy key in the bottom products. This is an estimated optimum recovery, based on experience, to drive the columns enough to reduce recycle streams without excess utility consumption. Rejection of the light gases from the stripping column bottoms and the impurity compounds from the silane column overhead is based on required silane purity, rather than recycle minimization.

5.1.2.3.3 Chlorosilane Redistribution Reactors

The TCS redistribution reactor is positioned between the TCS column and the DCS column. The DCS redistribution reactor is positioned between the DCS column and the silane column. Both are operated with single-phase flow to maintain proper flow profiles through the reactors. To do this, the DCS reactor receives liquid feed at or above 550 psia to avoid the bubble point rise after redistribution and the TCS reactor receives liquid feed at or above 85 psia for the same reason. Immediately following these reactors, the liquids enter the appropriate distillation columns, where they are throttled to column pressure.

Temperatures of 50°C and 70°C were chosen as operating temperatures for the DCS and TCS redistribution reactors, respectively. These

temperatures were chosen to maintain high rate, while avoiding either excessively high pressures (to control bubble point) or thermal breakdown of the catalyst.

5.1.2.3.4 Pyrolysis

Pressure in the pyrolysis reactor is slightly above atmospheric or 5-10 psig. The pressure should be high enough to avoid air in-leakage and provide enough pressure drop for the hydrogen by-product through discharge piping. The pressure should also be low enough to minimize seal requirements and stress on heated members. Temperatures were chosen to produce the rapid breakdown of silane in the reactor, yet avoid semi-solids formation in the unit.

5.1.2.4 Contaminant Removal Summary

Impurities that must be removed from silicon via this process enter in several places. The primary source of impurities is the metallurgical-grade silicon raw material. Other impurities enter with the cement copper catalyst that is used in hydrogenation, with the process make-up hydrogen, and with the process make-up silicon tetrachloride. Nitrogen impurities are contained in the voids of the nitrogen-purged, metallurgical silicon and are dissolved in the liquids that flow through nitrogen-padded storage tanks. Uncertainty exists as to the contribution of impurities by metal surfaces in the silane processing equipment and by materials of construction used in the pyrolysis/consolidation equipment. Sufficient technology exists on surface passivation to reduce the contribution of contamination by metal surfaces to acceptable levels. The impurities levels in pyrolysis/consolidation is somewhat unknown. While use of high-purity quartz and water-cooled metal will minimize impurities, the ultimate impact is unknown. Best indications from experimental work (Ref. 17) show a resistivity similar to semiconductor-grade silicon. This still must be demonstrated on a day-to-day basis in a plant environment.

Table V-1 shows typical impurity levels entering the process and the relative proportions entering with each raw material. These impurities

TABLE V-1

PROCESS IMPURITIES

Element or Compound	Amount Entering per Amount Product	Entry Point, Percentage of Total Compound Entering				Exit Point ('X' indicates compound is present)	
	lb.moles/lb.mole	Metal Grade Silicon	Cement Copper	Hydrogen	STC	Waste Chlorides	Stripper Column
Aluminum	3.25×10^{-3}	96.5%	1.1%	-	2.5%	X	
Antimony	2.63×10^{-6}	81.0	16.2	-	2.8	X	
Argon	6.43×10^{-5}*	0.4	-	99.6	-		X
Arsenic	4.19×10^{-6}	81.0	16.2	-	2.8	X	X
Boron	1.01×10^{-4}	100.0	-	-	<.1	X	X
Calcium	4.68×10^{-4}	100.0	-	-	-	X	
Carbon (C)	1.3×10^{-3}	100.0	-	-	-	X	
Carbon Dioxide	2.42×10^{-6}	0.3	-	99.7	-		X
Chromium	1.20×10^{-4}	100.0	-	-	-	X	
Copper	9.60×10^{-3}	0.6	99.4	-	<.1	X	
Helium	6.05×10^{-5}	-	-	100.0	-		X
Iron	3.10×10^{-3}	99.9	0.1	-	<.1	X	
Lead	4.2961×10^{-6}	25.2	74.0	-	.8	X	
Magnesium	2.16×10^{-4}	99.2	0.8	-	-	X	
Manganese	1.14×10^{-4}	100.0	-	-	<.1	X	
Methane	1.94×10^{-6}	0.7	-	99.3	-		X
Me_2SiCl_2	9.678×10^{-4}**	-	-	-	100.0		X
Nickel	3.96×10^{-5}	100.0	-	-	<.1	X	X
Nitrogen (N_2)	2.01×10^{-2}***	6.2	-	0.2	93.6		X
Oxygen (O_2)	4.18×10^{-3}****	59.7	39.3	0.7	0.3	X	
Phosphorus	2.01×10^{-4}	100.0	-	-	<.1	X	X
Sulfur	7.19×10^{-5}	7.0	93.0	-	-	X	X
Titanium	2.21×10^{-4}	83.9	-	-	16.1	X	
Vanadium	1.22×10^{-4}	99.4	-	-	0.6	X	
Zinc	4.81×10^{-6}	100.0	-	-	-	X	
Zirconium	8.25×10^{-5}	77.7	-	-	22.3	X	

NOTES:
- * Argon does not include pyrolysis purge quantities.
- ** Typical organic-chlorosilane. Decomposes to methane and chlorosilanes.
- *** Includes dissolved nitrogen in inert gas padding on STC storage tanks.
- **** Includes oxygen content of moisture. Reacts to form oxides.

exit the process in two major streams. The complexed and chloride solids are removed through the settler and the light gases are removed by the stripping column. Minor exit points include tank purges, equipment guard filter catches and adsorption by the redistribution reactor catalyst.

Except for light gases, entering impurities are converted to their respective chloride forms in the hydrogenation reactor. These compounds generally have higher boiling points than the chlorosilane mixture exiting the hydrogenation reactor. Rapid quenching of gases to the dew-point results in the formation of a slurry of metal chlorides. Some compounds also react (particularly with boron and phosphorous) to form high-boiling complexes. The uncondensed mixture of hydrogen and chlorosilane is freed of most impurities at this point. Some of the more volatile chlorides, such as aluminum and titanium, however, are still present in significant quantities.

After condensation, the dissolved light gases are removed by the stripping column. All volatile contaminant gases lighter than silane must be removed to at least 0.01 PPB and 99% of the heaviest of the volatile contaminants, which are also heavier than silane, must also be removed. It is not necessary to drive the stripper in removing the volatile contaminants heavier than silane since they will be rejected in the bottoms of the silane column and purged. The bottoms product of the stripping column still contains dissolved impurities, but virtually all impurities (except boron, phosphorus, and arsenic, which pass through as hydrides) are separated from the distillate in the next distillation column. The reaction of boron trichloride to diborane occurs in the second column as trace amounts of silane from the TCS redistribution reactor contact boron trichloride. Similar reactions occur to phosphorus and arsenic chlorides. Essentially all other impurities are removed in the bottoms product of the second column with STC. These compounds are recycled back through hydrogenation and removed from the process in the settler. Depending on volatility, the impurity chlorides will build to fixed concentrations in this loop between hydrogenation and the second distillation column.

The distillate from the second column probably contains measurable amounts of boron, phosphorus and arsenic. Amounts of other materials can be calculated on a theoretical basis but may not be measurable. After this liquid is fed to the third column, little change is made in impurity levels. It is conceivable, however, that certain trace compounds may enter the process and become trapped between the second and third columns. To prevent this, a purge stream is taken from the bottoms product of the third column and sent back to hydrogenation. An example of such a compound would be methyl- or dimethyl-chlorosilane.

The distillate of the third column passes through a redistribution reactor before being fed to the fourth distillation column. Boron present in the third column distillate is further reduced by adsorption onto the redistribution reactor catalyst. The last column is keyed to reject diborane to a level of 0.01 PPB. Since other impurities are heavier, they are removed to even lower concentrations. To prevent a buildup of diborane, phosphine and arsine, a purge from the fourth column bottoms product is sent back to hydrogenation.

In addition to the previously discussed precautions, another scheme is employed to reduce the boron flow to the last column. Small amounts of silane from the silane column distillate are fed to the bottom of the stripping column, which may react with any boron trichloride that is present and form diborane. Diborane will leave with the overhead product as opposed to boron trichloride which leaves with the crude STC/TCS bottoms product.

Because of the redundancy employed in removing impurities, the silane distillate from the last column should be of extremely high purity. Anticipated silane purity is shown in Table V-2 on a theoretically calculated basis, on an expected basis, and on the basis of the probable requirements to make semiconductor-grade product.

TABLE V-2

PRODUCT SILANE IMPURITY ANALYSIS

(In Parts per Billion)

Compounds	Theoretical Mass Balance	Expected	Required For 100+Ω-cm Product
Boron	6.48×10^{-5}	0.01	0.01
Phosphorus	9.687×10^{-13}	<0.01	<0.01
Arsenic	5.260×10^{-23}	<0.01	<0.01
Sulfur	1.566×10^{-12}		
Methyls, dimethyls	10^{-90}		
Ti, V, Zr	2.0518×10^{-30}		
Al	2.051×10^{-30}		
Helium	10^{-90}		
Hydrogen	10^{-90}		<0.01
Nitrogen	8.4695×10^{-8}		
Oxygen	---		
Argon	2.9×10^{-7}		
Methane	3.4647×10^{-12}		
Carbon Dioxide	1.2830×10^{-5}		
Water	---	< 1	1
Chlorosilanes	1.0259×10^{-30}		
Hydrogen Chloride	---	1	1

NOTE: First column is a theoretical calculation and does not reflect any tramp impurities or equipment-related recontamination.

5.1.2.5 Process Performance

5.1.2.5.1 Plant Battery Limits

The 1000 MT/Yr commercial plant requires raw materials, utilities, and consumable items to operate. Raw material consumption consists of 98%-pure, metallurgical-grade silicon, cement copper, technical-grade silicon tetrachloride and commercial-grade hydrogen. Utility inputs are water, fossil fuel, electrical power, inert gases, a hot-oil process heating system and a modest refrigeration system. Consumable items requirements consist of the amine-resin catalyst, quartzware, silicon wafers and various analytical chemicals.

This commercial plant generates a liquid silicon product, by-products and waste. The by-products are fumed silica and muriatic acid, which are actually recovered from plant waste. This reduces volume, cost and time involved in handling the disposal of plant waste.

5.1.2.5.1.1 Raw Materials

Metallurgical-grade silicon will be supplied as nominal 200-micron size powder and will be stored in an atmospheric closed bin. The powder is shipped using cement trailer-type trucks that are commonly used for bulk abrasive solids delivery. The powder will be conveyed from truck to bin using the truck's on-board blower in a positive-pressure mode.

Cement copper will be supplied as commercial-grade material prepackaged into one- or two-gallon metal pails that can be conveniently transported. The cement copper will be loaded manually into the blender.

Silicon tetrachloride will be supplied as 98%-pure, technical-grade liquid, and stored in an atmospheric tank. It will be delivered by tank truck and pumped into storage by pressuring the tank truck with nitrogen.

Commercial-grade hydrogen gas will be supplied and stored on site as a liquid. It will be transported by tank truck.

5.1.2.5.1.2 Utilities

Utilities required by the process will consist of a closed-loop, hot-oil heat source to drive reboilers, cooling water, potable water, electrical power, fossil fuel (natural gas), a modest refrigeration system and inert gas.

The heat to drive process reboilers can be obtained by steam heat or recirculated hot oil. To maintain the simplest, most automatic means of process heating, a heat-transfer oil, such as Therminol-60, at 290°C is preferred over a 600-psig steam system. Although the energy density is lower with a recirculated liquid than with a condensing high-pressure steam, the recirculated liquid offers certain operational and economical advantages. Elimination of the need for boiler-feed water supply and treatment and boiler blowdown, and a reduction in manpower attention are seen as reasons to favor a hot-oil system.

Potable water will be required to provide cooling water make-up and to provide process water for use in waste treatment.

Electrical power will be required to drive electrical motors and pyrolysis heaters.

Fossil fuel will be required to fire the hot-oil heater, a direct-fired process superheater, and the combustion equipment used in waste treatment.

A small refrigeration system will be required to drive the stripping column condenser, and the silane column condenser, and to maintain liquid silane equipment at temperatures below ambient. An R-12 system, with a -43°C condenser temperature is recommended.

Inert gases are required to purge process equipment. Argon will be used in the pyrolysis/consolidation area, and nitrogen will be used in all other areas of the plant.

5.1.2.5.1.3 Consumables

Consumables for the process will consist of Rohm and Haas Amberlyst® A-21, amine-functional resin, quartzware for the pyrolysis/consolidation equipment, silicon wafers for analysis of silane purity and various analytical chemicals.

Amine resin will be required to recharge the two redistribution reactors. While catalyst deactivation rates are uncertain, it has been estimated that approximately one charge per year will be required.

Quartzware will be required for pyrolysis reactor liners and product melter crucibles. Replacement rate will be a function of thermal and mechanical fatigue. It is estimated that each quartz liner will have to be replaced once every three months and that each quartz crucible will have to be replaced once every three days.

Single, crystal, silicon wafers one-inch in diameter will be used for epitaxy. Three wafers per day will be used.

Analysis chemicals will be needed to stock a quality-control laboratory. Cylinder gases will be used for gas chromatography and epitaxy analyses; required cylinder gases include helium, electronic-grade hydrogen, hydrogen chloride and argon. Specialty chemicals needed for concentration and sample preparation of certain chemicals include perchloric acid, hydrofluoric acid, nitric acid, ethyl alcohol, isopropyl alcohol, liquid ammonia, ammonia molybdate, and curcumin polynitrite. Additionally, caustic soda and electronic-grade acetone will be required for cleanup and disposal.

5.1.2.5.1.4 By-products and Wastes

System wastes are processed through a flame-oxidation subsystem to recover silicon as a fumed silica by-product. Chlorine is recovered as a weak muriatic acid solution. Both are marketable as low-value commodities. The fumed silica is used as a filler for such items as rubber products and the muriatic acid is used for such purposes as metal pickling.

5.1.3 Plant Design

5.1.3.1 Process Equipment

A complete process equipment list, which includes pertinent information about each piece of equipment, is provided in Table C-IV for the 1000 MT/Yr commercial plant. More detailed specifications are supplied for the major pieces of equipment (hydrogenation reactor, distillation columns, redistribution reactors, and pyrolysis reactor) in Tables C-V through C-XII. The details and specifications necessary for sizing and designing the equipment are all based on the stream catalog listed in Table C-II.

5.1.3.2 Chemical Handling and Safety

Chlorosilanes and silane are stable compounds at both ambient and process conditions of temperature and pressure. They may be handled safely provided their chemical properties are known and proper provisions taken. These compounds are noncorrosive to both metals and plastics. However, in the presence of moisture, chlorosilanes rapidly react to form silicon hydrates and hydrogen chloride. Because of this reactivity, chlorosilanes should always be handled with care to preclude contact with sources of moisture, even atmospheric air. All chlorosilanes should be treated as potential HCl sources. Silane contains no chlorine, is not reactive with moisture, and, therefore, produces no corrosive by-products.

Flammability of this series increases from silicon tetrachloride, which is nonflammable, to silane, which is pyrophoric (it combusts upon contact with air). The reported flashpoint for trichlorosilane is $-28^{o}C$ with dichlorosilane reported at less than $-28^{o}C$ (tag closed cup) and at less than $-37^{o}C$ (tag open cup).

Volatility and flame temperature also increase through the series. Silicon tetrachloride and trichlorosilane are liquids at normal conditions of temperature and pressure and are heavier than water. Dichlorosilane,

monochlorosilane and silane are gases at normal conditions and are heavier than air. The flame temperature increases with increasing hydrogen content (decreasing chlorine content), ranging from nonflammable silicon tetrachloride to silane, which has a flame temperature slightly less than methane.

Chlorosilanes and silane should be disposed by controlled combustion in the waste-treatment area. However, they may be disposed alternately by reacting with a lime or caustic solution, using copious amounts of solution to keep heat effects to a minimum.

A chlorosilane fire is handled in similar fashion using copious amounts of water in a coarse spray. A silane fire cannot be fought with water since no ignition source is necessary. It is handled similar to a hydrogen fire, by shutting off the source.

5.1.3.3 Instrumentation and Control

The instrumentation for the plant consists of equipment to achieve overall process control and to monitor quality control. While a modern process control system may contain some means of recording control parameters, no special equipment will be installed exclusively for data collection other than some chart recorders. All extensive data collection to evaluate process feasibility and operating characteristics will have been done prior to construction of a commercial plant.

Process control equipment is specified by the temperatures, pressures and mass flows given in the stream catalog, Table C-II, together with the methods of control for individual loops as determined above. Process control equipment will generally consist of field-mounted transmitters and relays, which interface with a central control panel and alarm module. Field-mounted panels will be minimal and only used for troubleshooting. An exception to this will be the stacked pyrolysis reactor/melter units, which will be operated from field-mounted panels with supervisory control at the central control room.

The process will be monitored at the central control room by an operator. An additional roving operator will check the actual operation of the equipment in the field. Because of the requirements of the pyrolysis area, two operators will monitor pyrolysis and equipment locally. A foreman will supervise all control operations on an individual shift.

Quality-control equipment is specified by the requirements of analysis. For composition analysis, a combination of wet chemistry and gas chromatography is used. For silane quality control, a reactor is provided to deposit an epitaxial layer of silicon on a wafer substrate. While this method does not reveal individual contaminant levels, an adequate day-to-day check on silane quality is obtained by observing deposit polarity (p-type vs n-type) and resistivity. Special checks for further quality control will be sent outside or special equipment rented. A laboratory technician will be on duty each shift to operate the quality control equipment; a chemist will oversee the total analytical effort of quality control.

5.2 120 MT/YR COMMERCIAL PLANT

5.2.1 Introduction

The 120 MT/Yr commercial plant design converts 98%-pure, metallurgical-grade silicon to ultra-high-purity, semiconductor-grade, molten silicon metal. The design study and economic analysis for this small commercial facility was made to provide a direct economic comparison with the commercially viable 1000 MT/Yr design.

The UCC silane process converts powdered, metallurgical-grade silicon metal to trichlorosilane by hydrogenation of silicon tetrachloride in a hot, fluid-bed reactor. By successive purification, distillation, and chlorosilane redistribution, the trichlorosilane is converted to ultra-high-purity silane containing total electronically active metal contaminant concentrations below 0.01 PPB.

The pure silane is pyrolyzed to form finely divided silicon metal powder that is electrically melted in quartz crucibles to yield the molten silicon product. The molten product will be extracted from its containing crucibles for subsequent processing by technology presently being developed by other JPL contractors. The definition and cost of this molten silicon processing equipment is not included in this design study.

5.2.2 Process Design

The 120 MT/Yr commercial plant design is the same as the 1000 MT/Yr commercial plant design. The operation of the smaller plant is the same as the operation of the 1000 MT/Yr plant, except for the quantity of ultra-high-purity silicon produced. The same problems of and solutions for contaminant removal still exist. Therefore, process controls and operating pressures and temperatures have not changed. The only process design difference between the 120 MT/Yr plant and 1000 MT/Yr plant is that hydrogen is supplied as a vapor and stored in cylinder banks in the 120 MT/Yr plant while it is supplied and stored as a liquid in the 1000 MT/Yr plant.

5.2.3 Plant Design

The equipment used in the 120 MT/Yr commercial plant differs considerably from the equipment used in the 1000 MT/Yr commercial plant. The reboilers on the stripper and silane columns are coiled tubing in the base of the columns for the smaller plant. The quench contactor pump is a diaphragm in the 120 MT/Yr plant, while it was centrifugal in the 1000 MT/Yr plant. The pyrolysis and consolidation area requires only three reactors and three melters in the small plant as opposed to fourteen reactors and fourteen melters in the large plant. Also, because of the smaller size, most of the plumbing used in the 120 MT/Yr commercial plant will be tubing instead of piping.

SECTION 6
COMMERCIAL PLANT ECONOMICS

Two analyses were performed to assess the economics of producing molten silicon using the UCC silane process. The first evaluated the cost* of silicon produced in a 1000 MT/Yr plant against the 1986 DOE/JPL goal of $10/kg (1975 dollars). The second evaluated the cost of silicon, produced in a 120 MT/Yr facility. The latter analysis provided data about the relationship between product cost and plant capacity.

The economic analyses are based on the best available information as of January 1, 1979, and are in terms of constant first-quarter 1979 dollars. Capital costs, startup costs, and annual operating costs have been estimated. By applying standard financial calculation methods, the product cost has been obtained both in terms of public (or utility) financing and private financing. An annual inflation index of 7% has been assumed for converting 1979 dollars to 1975 dollars for comparison with the JPL/DOE $10/kg cost goal.

6.1 1000 MT/YR COMMERCIAL PLANT ECONOMICS

Based on first-quarter 1979 dollars, using public or utility financing at 9% interest, the silicon product of a 1000 MT/Yr plant would have a cost of $7.55/kg. Assuming an inflation index of 7% per year, this corresponds to a cost of $5.76/kg in 1975 dollars, a figure well under the 1986 goal. The economic analysis will be presented in detail below.

All process equipment costs were obtained with vendor assistance and are given in Appendix Table C-IV. Equipment sizes were scaled from those of the 1000 MT/Yr EPSDU. Costs for freight, mechanical contract, construction field support, and engineering were estimated on the basis of work done in the fourth quarter, 1978, in support of the EPSDU. No detailed engineering design was done for the 1000 MT/Yr plant; the data acquired for the EPSDU is within acceptable accuracy boundaries for budgeting purposes. All capital costs are reported here in constant, first-quarter 1979 dollars.

*In this discussion the term "cost"--in reference to the molten silicon product--represents the cost to the user industries. It includes the expense and return on investment of the producer.

The yearly operating cost was obtained by estimating the cost of all raw materials, utilities, manpower, maintenance materials, analytical services, consumables, property taxes, insurance, period costs and home-office charges. In all cases the plant site was assumed to be at the Union Carbide facility in East Chicago, Indiana, permitting site-specific charges.

The cost of startup was obtained by estimating the cost of manpower training and pre-operation checkout, the cost of preparing operating instructions, the cost of engineering assistance during startup, the cost of startup operations (raw materials, utilities, etc.), and, finally, the cost of reworking equipment during a post-startup period to correct any mechanical deficiencies uncovered during startup.

Working capital requirements were determined by estimating the cash value necessary for the hold-up time of accounts payable, accounts receivable, and inventory value.

The costing elements that served as a basis for estimating plant capital cost, yearly operating cost, startup cost and working capital are summarized in Tables C-XIII through C-XVII.

Assuming 100% public bond or utility financing, product costs were computed on the basis of the following estimates:

Plant Capital Cost	$8,778,600 (3.4% invested in 1979, 36.5% invested in 1980, 60.1% invested in 1981)
Construction Time	2½-3 years (including design time)
Project Life	15 years (1982 to 1997)
Startup Cost	$1,579,900
Working Capital	$461,800 + 11% of sales
Yearly Operating Cost	$5,347,000 + 10% of sales
Depreciation	15 years, straight line

The product costs obtained are as follows:

Interest Rate (Percent)	Silicon Product Cost ($/kg) 1st-Qtr 1979 dollars	1975 dollars
8	$7.44	$5.68
9	7.55	5.76
10	7.66	5.84
11	7.77	5.92
12	7.88	6.01

Assuming 100% private funds, the following estimates were used to compute product costs:

Plant Capital Cost	$8,778,600(3.4% invested in 1979, 36.5% invested in 1980, 60.1% invested in 1981)
Construction Time	2½-3 years (including design time)
Project Life	15 years (1982-1997)
Startup Cost	$1,579,900
Working Capital	$651,000 + 11% of sales
Yearly Operating Cost	$5,347,000 + 10% of sales
Depreciation	10 years SYD (Sum of Years Digits)
Investment Tax Credit	10%
Federal Income Tax	46%

The results, using various discounted cash flow (DCF) rates of return, are as follows:

DCF Rate (Percent)	Silicon Product Cost ($/kg) 1st-Qtr 1979 dollars	1975 dollars
10	$ 7.97	$6.08
15	8.88	6.77
20	9.91	7.56
25	11.07	8.45
30	12.33	9.41

In all cases, working capital was assumed to be recovered at the end of the project life, and the plant was assumed to have no salvage value.

If utility financing at 9% interest is assumed, the silicon product cost is $5.76/kg in 1975 dollars. The distribution of various cost elements in this product cost is given below:

Cost Item	1975 dollars/kg
Raw Materials	$ 1.80
Utilities	0.65
Manpower	0.97
Maintenance Materials	0.21
Analytical Charges	0.03
Consumables	0.26
Property Tax and Insurance	0.08
Period Costs	0.07
Home-Office Charges	0.58
Manufacturing Cost (excluding depreciation)	4.66
Depreciation	0.47
Capital Charges	0.63
Total Product Cost	$ 5.76

6.2 120 MT/YR COMMERCIAL PLANT ECONOMICS

The 120 MT/Yr commercial plant uses the same process as the 1000 MT/Yr plant. It also has the same flow rates as the EPSDU. (The on-stream factor differs, however; the on-stream factor of the 120 MT/Yr plant is 85% and the on-stream factor of the EPSDU is 70%.) Consequently, the bases used for the economic analysis of the 120 MT/Yr commercial plant were quite similar to those used for the 1000 MT/Yr plant.

Again, the analysis was based on the best available information as of January 1, 1979. On the basis of first-quarter 1979 dollars and the assumption of public or utility financing at 9% interest, the silicon product cost of the

120 MT/Yr plant was $24.40/kg. If an inflation index of 7% per year is assumed, this cost is equivalent to $18.61/kg in 1975 dollars.

The investment cost for the 120 MT/Yr commercial plant was obtained from the 100 MT/Yr EPSDU estimate, with certain changes in the instrumentation, waste treatment, pyrolysis and product-consolidation areas. In addition, buildings were used for offices and storage instead of trailers. New equipment costs unique to the 120 MT/Yr plant were obtained using vendor assistance. The cost of each piece of equipment is given in Table D-I.

Yearly operating costs, startup costs, and working capital requirements were estimated similarly to those of the 1000 MT/Yr plant; these costs are broken down in Tables D-II and D-III. Assuming 100% public bond or utility financing, product costs were computed on the basis of the following estimates:

Plant Capital Cost	$4,932,600 (3.4% invested in 1979, 36.5% in 1980, 60.1% in 1981)
Construction Time	2½-3 years (including design time)
Project Life	15 years (1982 to 1997)
Startup Cost	$763,640
Working Capital	$104,710 + 11% of sales
Yearly Operating Cost	$1,861,960 + 10% of sales
Depreciation	15 years, straight line

The product costs obtained are as follows:

Interest Rate (Percent)	Silicon Product Cost ($/kg) 1st-Qtr 1979 dollars	1975 dollars
8	$ 23.94	$ 18.26
9	24.40	18.61
10	24.87	18.97
11	25.35	19.34
12	25.85	19.72

Assuming 100% private funds, the following estimates (in constant, first-quarter 1979 dollars) were used to compute product costs:

Plant Capital Cost	$4,932,600 (3.4% invested in 1979, 36.5% in 1980, 60.1% in 1981)
Construction Time	2½-3 years (including design time)
Project Life	15 years (1982-1997)
Startup Costs	$763,640
Working Capital	$181,900 + 11% of sales
Yearly Operating Costs	$1,861,900 + 10% of sales
Depreciation	10 years SYD
Investment Tax Credit	10%
Federal Income Tax	46%

The results obtained using various discounted cash flow (DCF) rates of return are as follows:

DCF Rate (Percent)	Silicon Product Cost ($/kg) 1st-Qtr 1979 dollars	1975 dollars
10	$ 26.02	$ 19.85
15	30.04	22.92
20	34.63	26.42
25	39.72	30.30
30	45.46	34.68

In all cases, working capital was assumed to be recovered at the end of the project life and the plant was assumed to have no salvage value.

If utility financing at 9% interest is assumed, the silicon product cost is $18.61/kg in 1975 dollars. The distribution of various cost elements contributing to this product cost is given below:

Cost Item	1975 dollars/kg
Raw Materials	$ 1.99
Utilities	.89
Manpower	6.67
Maintenance Materials	.61
Analytical Charges	.29
Consumables	.42
Property Tax and Insurance	.37
Period Cost	.59
Home-Office Charge	1.86
Manufacturing Cost (excluding depreciation)	$ 13.69
Depreciation	2.09
Capital Charges	2.83
Total Product Cost	$ 18.61

A comparison of these costs with the 1000 MT/Yr plant costs will show a small increase in raw materials, utilities and consumables on a per-kg basis resulting from the economics of scale. The manpower requirement is slightly less (eight people) because the 120 MT/Yr plant uses fewer pyrolysis reactor/melter units. Analytical charges and period costs are the same on a total-dollar basis. Maintenance materials, property taxes, and insurance costs are all a function of equipment costs. The home-office charge is 10% of sales.

SECTION 7
RECOMMENDED FUTURE ACTION

To expedite the commercial establishment of the silane-silicon process for producing quality polycrystalline silicon, a number of activities have been proposed, as described below.

7.1 SILANE PYROLYSIS/CONSOLIDATION

No major future improvements either in the configuration or the economics of the process that produces high-purity silane from metallurgical-grade silicon are expected since the process design is relatively mature. However, substantial improvement in the processes that convert the high-purity silane to poly- and single-crystalline silicon are expected. A concentrated R&D effort is needed in three areas to develop technology that is comparable in maturity to the silane-producing technology.

a. Free-Space Pyrolysis - Long term, steady-state tests in the existing PDU and supporting theoretical analysis are required to establish scale-up parameters and determine optimum reactor geometry.

b. Melting/Consolidation - This step is essential for converting free-space reactor silicon powder into a form that can be handled and shipped without introducing contamination. The technology is sound and 3/4-inch rods were produced in an argon atmosphere. For the process to be efficient, the melter should be close-coupled with the pyrolysis reactor and 3-inch rods should be cast in a pyrolysis-released hydrogen atmosphere.

c. Fluid-Bed Pyrolysis - Silicon particles produced in a fluid-bed are automatically in a form that can be handled with a minimum of contamination. Because of the inherent advantages of the fluid bed, a sustained development effort is required to demonstrate technical practicality and obtain scale-up information so that this process can be used as a backup or alternative to free-space pyrolysis.

Future development should build upon recent analytical work performed by JPL and UCC. Details regarding these silane pyrolysis investigations are documented in Hogle, Ref. 18; Praturi, Hsu, Lutwack, Ref. 19; Praturi, Jain, Hsu, Ref. 20; Rexer, Ref. 21; Rexer, Ref. 22; and Timmel & Rexer, Ref. 23.

7.2 ANALYTICAL TECHNIQUES

The silane process promises to deliver silane at a level of impurity several orders of magnitude below detection limits of currently available analytical instruments. Techniques must be developed to detect extremely low levels of impurities in silane. In the process design, the pure silane is homogeneously decomposed into hydrogen and submicron silicon powder, which is melted and converted to solid boules. Zone refining techniques should be developed for evaluating the quality of this final product.

7.3 VAPOR-LIQUID EQUILIBRIUM DATA

The final distillation column, which fractionates silane to very high purity, is designed to separate silane from diborane contaminant whose volatility is only slightly below the value for silane. To final design this column, accurately measured, silane-diborane and silane-phosphine vapor-liquid equilibrium data are needed.

7.4 STC HYDROGENATION KINETICS

Considerable experimental kinetic data are available for silicon tetrachloride hydrogenation. They have been correlated (Section 4.3.2) although the exceedingly complex mechanisms are not thoroughly understood. Copper and metallic contaminants in the metallurgical silicon feed are all believed to catalyze the rate at which the chlorosilanes in the reactor product-mix reach equilibrium. Some experiments have suggested that the addition of copper catalyst to the reactive mass hardly increases the reaction rate. It is suspected that contaminant metals in the feed silicon may have catalyzed the reaction rate in those tests, masking the effect of the copper. To isolate the catalytic effect of copper, kinetic

experiments should be conducted with crushed semiconductor-grade, polysilicon powder (which is contaminant free) both with and without a copper catalyst. In addition, kinetic data are desirable at the 500-psig, process-operating pressure to supplement the 200-psig data currently available.

7.5 WASTE DISPOSAL BURNERS

A system of three burners is provided in the process design to flame oxidize all liquid and gaseous waste. The combustion equipment will be similar to that used by the fumed-silica industry. Some burner design modification and testing are needed to ensure proper burner operation on feeds differing from current commercial practice.

7.6 EXPERIMENTAL PROCESS SYSTEM DEVELOPMENT UNIT (EPSDU)

A sufficient data base is in hand to permit the design, assembly, and operation of a 100 MT/Yr EPSDU to demonstrate all technical and economic aspects of the silane-silicon process. The facility should also be used to amplify and refine the design data base for a large, commercial project.

SECTION 8

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SECTION 9

GLOSSARY

This section includes symbols, notations and abbreviations used in this report.

Notation	Description
a	Particle surface area per unit volume (1/m)
cc	Cubic centimeter
cm	Centimeter
C	Celsius
C_o	In Section 4: Constant
C_o	In Section 3: Inlet Molecular Density ($1/m^3$)
cps	Centi-poise
CVD	Chemical vapor deposited
D	Reactor diameter (m)
DCF	Discounted cash flow
DCS	Dichlorosilane
E	Energy consumption per kilogram of product (J/kg)
EPSDU	Experimental Process System Development Unit
f	Liquid fugacity
ft	Feet
f_{SiH_4}	Molar fraction of silane
f_{oSiH_4}	Inlet molar fraction of silane
gm	Gram
h_{H_2}	Enthalpy of hydrogen (J/mole)
h_{Si}	Enthalpy of silicon (J/mole)
h_{SiH_4}	Enthalpy of silane (J/mole)
H	Henry's constant (atm/mole fraction)
ΔH	Heat of reaction (cal/mole)
ΔHf	Heat of formation (cal/mole)

Notation	Description
I.D.	Inside diameter
J	Joule
JPL	Jet Propulsion Laboratory
k	Reaction rate constant
kg	Kilogram
K	Ratio of y to z
^{o}	Degrees
K_p	Chemical equilibrium constant
l	Liter
L	Bed depth (m)
lb	Pounds
LSA	Low-cost Solar Array
m	Meter
M	A thousand
M_{Si}	Molecular weight of silicon (kg/mole) (28×10^{-3})
mm	Millimeter
MCS	Monochlorosilane
MM	Million
MPa	Mega Pascal
MT	Metric ton
O.D.	Outside diameter
ppb	Parts per billion
ppm	Parts per million
psi	Pounds per square inch
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
P	Pressure (atm)
PDU	Process Development Unit
pts	Points
Q	Heat flux (W/m^2)
R	Gas constant (1.987 cal/mole-^{o}K)
R	In Section 3: Rate of decomposition of silane on surface for silane (kg/m^2-sec)

Notation	Description
sec	Second
SEM	Scanning electron microscope
SS	Stainless steel
STC	Silicon tetrachloride
T	Temperature (^{o}K)
T	In Section 3: Reactor temperature (^{o}K)
T_o	Inlet temperature (^{o}K)
TCS	Trichlorosilane
U	Superficial gas velocity (m/sec)
U_{mf}	Minimum fluidization velocity (m/sec)
UCC	Union Carbide Corporation
$\overline{V}$	Partial molal volume
VLE	Vapor-liquid equilibria
W	Watts
x	Liquid mole fraction
y	Vapor mole fraction
Yr	Year
γ	Liquid activity coefficient
η	Conversion efficiency
ϕ	Vapor fugacity coefficient
τ	Production rate of silicon (kg/sec)

APPENDIX A

SUMMARY OF THE STATEMENT OF WORK AND THE CONTRACT DELIVERABLES

APPENDIX A

SUMMARY OF THE STATEMENT OF WORK AND THE CONTRACT DELIVERABLES

Union Carbide Corporation performed Phases I and II of the total program under JPL/DOE Contract No. 954334. Work performed during Phase I, which was started in October 1975 and completed in January 1979, sought to demonstrate (1) the practicality of a high-volume, low-cost silane production process, including the subsequent pyrolysis of silane to semiconductor-grade silicon; and (2) the feasibility of high-frequency, capacitive heating of a fluidized bed of silicon particles to the silane pyrolysis temperature.

Work performed during Phase II, which commenced in October 1977 and ended in March 1979, aimed to provide: (1) a unified, integrated process design for producing high-quality, semiconductor-grade silicon from metallurgical silicon by assembling a diverse corporate silicon technology base; (2) a preliminary, or if possible, a comprehensive design of an Experimental Process System Development Unit (EPSDU) capable of producing 100 MT/Yr of silicon; and (3) an economic analysis of estimated product price for a high-volume, 1000 MT/Yr plant. The overall goal of the program was to develop technology for producing semiconductor-grade silicon at or below the silicon material task goal of $10 per kilogram (1975 dollars).

The contract technical deliverables and delivery dates were as follows:

Technical Deliverables	Date of Delivery
Phases I & II	
Monthly Technical Reports	Monthly
Quarterly Technical Reports	Quarterly
Final Technical Report	March 31, 1979
Phase I:	
Laboratory Notes, as required by para. (a)(5)	Monthly
Progress sample, as required by para. (a)(4)(A)	Silane shipped to Parma 11/22/77, 2.1 kg
	HPR-626-1-5 powder shipped to JPL 4/19/77, 10 gms.

Progress sample, as required by para. (a)(4)(A)(continued)	HPR-626-1-24-1 powder shipped to JPL 2/14/78, 10 gms. HPR-616-1-24-2 powder shipped to JPL 2/14/78, 10 gms. HPR-626-1-24-3 powder shipped to JPL 2/14/78, 10 gms. HPR-626-6-27-1 powder shipped to JPL 2/14/78, 10 gms. MR-626-8-16-2 melt shipped to JPL 2/14/78, 10 gms. MR-626-8-19B-3 melt shipped to JPL 2/14/78, 10 gms. MR-626-8-19A-4 melt shipped to JPL 2/14/78, 10 gms. MP-626-8-40S melt shipped to JPL 6/14/78, 10 gms.
High-purity silane sample, as required by para (a)(4)(B)	Silane shipped to JPL 7/19/77, 1.1 kg Silane shipped to JPL 7/1978, 3.2 kg
Free-space reactor sample, as required by para. (a)(4)(C)	HPR-626-11-86 powder shipped to JPL 1/16/79, 5086 gms. HPR-626-11-87 powder shipped to JPL 1/16/79, 550 gms.
Fluid-bed reactor sample as required by para. (a)(4)(D)	(See note)
Production sample, as required by para. (a)(4)(E)	MR-626-12-9, powder shipped to Crysteco for crystal pull, 2800 gms., crystal shipped to JPL, 3/23/79, 2500 gms.
Other samples delivered	HPR-626-10-61 powder shipped to JPL 8/29/78, 200 gms. Sample shipped to JPL, 8/17/77, 500 gms Powder shipped to Tarrytown (Analysis) 11/2/77, 400 gms. (4 samples) Powder shipped to Tarrytown (Analysis) 11/3/77, 100 gms. Melt shipped to Tarrytown (Analysis) 12/2/77, 200 gms.

Other samples delivered (continued)	Sample to Siltec 6/13/78, 300 gms. Sample to Linde (Iya) 7/13/78, 2723 gms. Sample to Linde (Iya) 10/5/78, 8000 gms. Sample to Bepex 10/19/78, 300 gms.
Phase II:	
Scale Model of a 1000 MT/Yr Commercial Plant, as required by para. (c)(2)(E)	March 31, 1978
One copy of optimized designs, as required by para. (a)(1)(B)	March 1979 (see note)
One copy of list of equipment and materials directly purchasable, as required by para. (a)(2)(B)	April 28, 1978 (25 MT/Yr) March 1979 (100 MT/Yr)
One copy of detailed flow sheet, as required by para. (a)(2)(A)	April 28, 1978 (25 MT/Yr) March 1979 (100 MT/Yr)
One copy of preliminary plant and equipment design, as required by para. (a)(2)(D)	April 28, 1978 (25 MT/Yr) March 1979 (100 MT/Yr)
One copy of the estimates, overview estimates, integrated design, and overall evaluation and recommendation as required by para (a)(3)	January 1979 (1000 MT/Yr) March 1979 (120 MT/Yr and 1000 MT/Yr)

NOTE: Fluid-bed pyrolysis is not developed sufficiently to be able to design an optimum system at this time. Instead of an optimum design, a report was issued on June 12, 1978 titled "Technical Assessment of Silane Pyrolysis in Fluidized Bed Reactor".

APPENDIX B

CRITICAL PROPERTIES, VAPOR PRESSURE, ENTHALPY AND LATENT HEAT CONSTANTS

CONTENTS OF APPENDIX B

Section No.	Section Title	Page
B-1	Introduction	B-2

Table No.	Table Title	
B-I	Critical Properties	B-4
B-II	Vapor-pressure Constants	B-4
B-III	Vapor Enthalpy	B-5
B-IV	Liquid Enthalpy	B-5

B. 1 INTRODUCTION

A reliable and consistent set of data were needed to perform a heat and mass balance evaluation of the overall UCC silane process. This included such data as the thermodynamic and physical properties of the chlorosilanes and other trace impurity components. These data were acquired through an extensive search of the open literature and in-house UCC research information. When experimental data were found to be missing, the best available estimation procedures were employed (Reid, et al., Ref. 24). These data were stored in a computer data bank for use whenever calculation of a certain property was required. A list of chlorosilane critical properties, vapor pressures, and vapor and liquid enthalpies are given in Tables B-I, B-II, B-III, and B-IV.

The heat of vaporization (ΔH_v) was determined by the use of the Clausius-Clapeyron equation in the following form:

$$\frac{d\ln P}{d\left(\frac{1}{T}\right)} = \frac{-\Delta H_v}{R\Delta Z} \qquad \text{(B-1)}$$

The left-hand side of equation B-1 was calculated from the extended vapor pressure equation (Table B-II) and ΔZ, where ΔZ is the difference between vapor and liquid compressibilities, was determined by an equation of state. The values of H_v were then found as a function of temperature up to the critical point. The factor N in the Watson correlation, which gave the best fit for ΔH_v, was then established:

$$\Delta H_v = \Delta H_{ref} \left[\frac{T_c - T}{T_c - T_{ref}}\right]^N \qquad \text{(B-2)}$$

The N factors are listed in Table B-IV.

Some estimates of the reliability of these physical properties can be made. For example, critical properties and vapor pressures play an important role in K-value calculations (Section 4.4.1.1). Using the critical property and vapor-pressure values given in Tables B-I and B-II resulted in good agreement between experimental and calculated vapor-liquid equilibria data. Replacing these critical constants with those given by Lapidus, et al. (Ref. 25) did not give good agreement. This is an indication of the good reliability of the critical constants presented here. Also, the critical constants presented by Lapidus were not consistent with the vapor-pressure data.

The data presented in Tables B-I through B-IV are the best available information at the present time and should be used in all process calculations. As new information becomes available, it will be evaluated and added to the present data bank.

TABLE B-I

CRITICAL PROPERTIES

	Molecular Weight	Critical Pressure Atm	Critical Temp °C	Critical Compressibilty Zc	Critical Vol cm^3/mole	Pitzer Accentric Factor
SiH_4	32.118	48.00	-3.5	0.2870	132.8	0.0779
H_3SiCl	66.563	47.80	123.5	0.2560	174.0	0.1311
H_2SiCl_2	101.008	44.40	176.3	0.2540	211.0	0.1648
$HSiCl_3$	135.453	40.60	206.0	0.2720	263.0	0.1955
$SiCl_4$	169.898	37.10	233.8	0.2910	325.3	0.2608

TABLE B-II

VAPOR-PRESSURE CONSTANTS

	A	B	C	D
SiH_4	-6.019421	1230.5392	2.881096	-0.006200
H_3SiCl	140.3534	5854.5360	-22.80334	0.03708
H_2SiCl_2	41.7391	4338.0828	- 4.766268	0.001821
$HSiCl_3$	115.4560	6582.2481	-17.57251	0.02179
$SiCl_4$	110.0035	6712.7225	-16.65031	0.02082

$$\ln P = A - \frac{B}{T} + C \ln T + DT$$

$T = {}^{o}K$

$P = atm$

TABLE B-III

VAPOR ENTHALPY

	H_o	A	$Bx10^2$	$Cx10^5$	$Cx10^5$	E
SiH_4	-1099.8755	14.1607	-1.1718	8.149	-12.09	$5.808(10^{-11})$
H_3SiCl	- 436.2637	10.6544	1.326	2.546	- 3.993	$1.914(10^{-11})$
H_2SiCl_2	- 212.4214	11.3693	3.173	-1.568	3.847	$-1.687(10^{-15})$
$HSiCl_3$	822.5439	16.4255	3.821	-3.343	2.099	$-6.812(10^{-12})$
$SiCl_4$	1780.4147	17.9695	6.837	-11.47	11.81	$-5.260(10^{-11})$

$$H_V = H_o + AT + BT^2 + CT^3 + DT^4 + ET^5$$

$T = {}^oK$

H_V = BTU/Lb-mole

TABLE B-IV

LIQUID ENTHALPY

	$T_{ref}(^oK)$	ΔH_{ref}(BTU/Lb-mole)	N
SiH_4	188.90	4703.01	0.313921
H_3SiCl	277.66	7921.16	0.344535
H_2SiCl_2	314.60	9770.96	0.455516
$HSiCl_3$	335.41	10468.96	0.391462
$SiCl_4$	354.90	11449.94	0.338927

$$H_L = H_V - \Delta H_{ref} \left[\frac{T_c - T}{T_c - T_{ref}}\right]^N$$

H_L = Liquid enthalpy, BTU/Lb-mole

H_V = Vapor enthalpy, BTU/Lb-mole (See Table B-III)

T_c = Critical temperature, ^oK

C - 4

APPENDIX C

1000 MT/YR COMMERCIAL PLANT (ISSUE 1)

SECTIONS OF APPENDIX C

Table	Title	Page
C-I	1000 MT/YR Commercial Plant Stream Summary (Issue 1)	C - 2
C-II	1000 MT/YR Commercial Plant Stream Catalog (Issue 1)	C - 5
C-III	1000 MT/YR Commercial Plant Physical Properties for Process Streams (Issue 1)	C - 17
C-IV	Equipment List, 1000 MT/Yr Commercial Plant	C - 24
C-V	Equipment Specification, Hydrogenation Reactor	C - 28
C-VI	Equipment Specification, Stripper Column	C - 29
C-VII	Equipment Specification, TCS Column	C - 30
C-VIII	Equipment Specification, DCS Column	C - 31
C-IX	Equipment Specification, Silane Column	C - 32
C-X	Equipment Specification, TCS Redistribution Reactor	C - 33
C-XI	Equipment Specification, DCS Redistribution Reactor	C - 34
C-XII	Equipment Specification, Pyrolysis Reactor	C - 35
C-XIII	Elements of Plant Capital Cost, 1000 MT/YR	C - 36
C-XIV	Elements of Annual Operating Cost, 1000 MT/YR	C - 37
C-XV	Manpower Staffing, 1000 MT/YR	C - 39
C-XVI	Elements of Start-up Cost, 1000 MT/YR	C - 40
C-XVII	Elements of Working Capital, 1000 MT/Yr	C - 41

TABLE C-I: 1000 MT/YR COMMERCIAL PLANT
STREAM SUMMARY (ISSUE 1)

STREAM NO	INT. NO.	DESCRIPTION	T,F.	P,PSIA	LIQ.FR.
100	1	METALLURGICAL GRADE SILICON POWDER FEED	75.0	15.0	0.0
101	2	COPPER CATALYST FEED	75.0	15.0	0.0
102	3	MAKE-UP STC	75.0	20.0	1.0000
104	5	FLUIDIZATION H2 TO 421-02	150.0	516.7	0.0
105	6	PRESSURIZATION H2 TO HOPPER 421-02	150.0	516.7	0.0
106	7	ATMOSPHERIC VENT FROM CYCLONE 417-02	75.0	14.7	0.0
107	8	FEED TO HYDROGENATION REACTOR 425-02	932.0	516.7	0.0
108	9	PRODUCT FROM REACTOR 425-02	932.0	514.7	0.0
109	10	COOLED RECY. TO STC STORAGE TANK 421-12	120.0	54.0	1.0000
110	11	QUENCHED STC/TCS TO SETTLER 421-04	375.0	513.7	0.5000
111	12	RECYCLE STC/TCS QUENCH STREAM	356.0	574.7	1.0000
112	13	WASTE CHLORIDE SALTS FROM SETTLER	356.0	512.7	1.0000
113	14	SAT. VAPOR H2/TCS/STC TO COND. 424-02	356.0	512.7	0.0
114	15	SAT. LIQ. H2/TCS/STC QUENCH RECVR 421-08	100.0	511.7	0.5000
115	16	SAT. LIQ. TCS/STC TO QUENCH PUMP 426-04	100.0	513.7	1.0000
116	17	LIQUID RECYCLE TO SETTLER 421-04	100.0	513.7	1.0000
117	18	QUENCH STREAM TO CONDENSER 424-02	100.0	572.7	1.0000
118	19	H2 VAPOR FROM 421-08 RECEIVER	100.0	510.7	0.0
119	20	TCS/STC LIQ. PROD. TO CRUDE TANK 421-10	100.0	510.7	1.0000
120	21	H2 FEED TO COMPRESSOR 423-02,03	100.0	510.7	0.0
121	22	COMPRESSED H2 TO H2 HEATER 429-08	100.0	521.7	0.0
122	23	SUPERHEATED H2 TO REACTOR 425-02	961.0	516.7	0.0
123	24	SUPERHEATED STC TO REACTOR 425-02	961.0	516.7	0.0
124	25	SAT. VAPOR STC FROM VAPORIZER 424-04	443.0	521.7	0.0
125	26	CRUDE TCS/STC TO SECTION 2	100.0	95.0	1.0000
126	27	CRUDE TCS/STC TO FILTER 427-02	100.0	100.0	1.0000
127	28	STC FROM STC STORAGE TANK 421-12	75.0	30.0	1.0000
128	100	STC TO STC VAPORIZER 424-04	75.0	526.7	1.0000
129	168	LIQUID TCS/STC TO QUENCH PUMP 426-02,03	356.0	512.7	1.0000
131	170	TRANSPORT AIR TO FILTER 417-02	77.0	14.9	0.0
132	171	RECYCLE STC PURGE STREAM FROM 424-04	443.0	526.7	1.0000
133	104	AIR TO RECYCLE HYDROGEN HEATER 429-08	77.0	14.7	0.0
134	169	ATMOS. VENT FROM RECYCLE HEATER 429-08	1500.0	16.0	0.0
135	181	AIR TO RECYCLE STC HEATER 429-06	75.0	14.7	0.0
136	183	ATMOS. VENT FROM RECYCLE STC HTR. 429-06	1000.0	15.0	0.0
137	242	ATMOSPHERIC VENT FROM 429-06,08	1000.0	15.0	0.0
200	29	STC BOTTOMS PROD. TO STORAGE TANK 421-12	218.0	55.0	1.0000
201	30	432-02 STRIPPER BOTTOMS PRODUCT	240.0	94.6	1.0000
202	31	432-02 STRP. BTMS. VAP. FROM REB. 434-04	244.0	95.0	0.0
203	32	432-02 OVHD PRODUCT	140.0	90.4	0.0
204	33	432-02 CONDENSED OVHD PRODUCT	-21.0	89.4	1.0000
205	34	432-02 STRIPPER REFLUX	-21.0	95.0	1.0000
206	35	432-02 STRIP. BTMS. TO TCS/STC COLUMN	244.0	95.0	1.0000
207	36	432-04 BOTTOMS PRODUCT	214.0	54.8	1.0000
208	37	432-04 BTMS. VAPOR FROM REBOILER 434-06	218.0	55.0	0.0
209	38	432-04 OVHD PRODUCT	159.0	50.2	0.0
210	39	TOTAL 432-04 CONDENSED OVHD PRODUCT	152.4	49.2	1.0000
211	40	PRESSURIZED 432-02 PRODUCT	152.4	320.0	1.0000
212	41	432-06 TCS/STC PRODUCT TO 432-04	158.0	84.0	1.0000
213	42	432-04 REFLUX	152.4	55.0	1.0000
214	43	TCS FEED TO DCS/TCS COLUMN 432-06	152.4	320.0	1.0000
215	44	COOLED TCS FEED TO REDIS. REACTOR 435-02	158.0	85.0	1.0000
216	45	COOLED TCS BOTTOMS FROM 434-12	158.0	85.0	1.0000
217	46	432-06 BOTTOMS PRODUCT	327.0	319.9	1.0000
218	47	432-06 BOTTOMS VAPOR FROM REBOILER	327.5	320.0	0.0
219	48	432-06 OVHD PRODUCT	257.3	315.1	0.0
220	49	432-06 REFLUX	249.8	320.0	1.0000
221	50	432-06 CONDENSED OVHD PRODUCT	249.8	314.0	1.0000
222	51	PRESSURIZED 432-06 OVHD PRODUCT	249.8	550.0	1.0000
223	52	COOLED DCS FEED TO REACTOR 435-04	122.0	549.0	1.0000
224	53	HCS/SIH4 PRODUCT TO COLUMN 432-08	122.0	548.0	1.0000
225	54	432-08 BOTTOMS RECYCLE	267.0	360.0	1.0000
226	55	432-08 BOTTOMS VAPOR	267.0	360.0	1.0000
227	56	TOTAL PROD. SILANE FROM COND. 434-18	-25.7	354.0	0.0
230	59	432-08 VAPOR OVHD TO CONDENSER	-25.7	355.1	0.0
231	60	LIQ. SIH4 TO LIQ. STOR. 431-04,06,08,10	-25.7	354.1	1.0000
232	61	432-08 REFLUX	-25.7	360.0	1.0000
233	62	VAPORIZED SIH4 TO SUPERHEATER 434-22	-25.7	374.1	0.0
234	63	SUPERHEATED SIH4 TO FILTER 437-02,03	126.0	374.1	0.0
235	64	FILTERED SUPERHTD. SIH4 TO SECTION 3	126.0	60.0	0.0
236	65	432-06 TOTAL BOTTOMS PRODUCT	327.5	320.0	1.0000
237	66	TCS RECYCLE FROM 434-12 TO STC REC. STR.	158.0	85.0	1.0000
238	184	432-04 BOTTOMS PRODUCT	218.0	55.0	1.0000
239	197	432-08 BOTTOMS PRODUCT	267.0	360.0	1.0000
240	179	432-08 PURGE SILANE TO 432-02	-25.7	354.1	0.0
242	185	432-08 BOTTOMS TO REBOILER 434-20	267.0	360.0	1.0000
243	186	432-08 BOTTOMS VAPOR TO 432-08	267.0	360.0	0.0
300	67	THROT. SIH4 FEED TO PYROL. REACT. 445-02	77.0	25.0	0.0
301	68	SI POWDER & H2 TO HOPPER 441-02	1502.0	20.0	0.0
303	70	SI POWDER TO MELTER 449-04,06,08	1120.0	20.0	0.0
307	74	TOTAL SI MELTED PRODUCT	2600.0	20.0	0.0
308	75	TOTAL SECT. 3 SI POWDER LOSS	1120.0	20.0	0.0
311	178	H2 FROM PYROLYSIS REACTOR TO 444-02	1562.0	20.0	0.0
312	182	COOLED PYROL. H2 TO COMPRESSOR 443-02,04	100.0	15.8	0.0
313	57	COMPRESSED REC. H2 TO HYDROGENATION	300.0	550.0	0.0
314	58	MAKE-UP H2 FROM STORAGE	77.0	50.0	0.0
400	76	ATMOS. VENT FROM COMBUS. VENT HEADER	100.0	14.0	0.0
401	77	COMBUSTION AIR TO BURNER 459-08	77.0	14.7	0.0
402	78	COMBUSTION AIR TO BURNER 459-10	77.0	14.7	0.0
403	79	COMBUSTION QUENCH AIR TO BURNER 459-10	77.0	14.7	0.0
404	80	TOTAL VAPOR FEED TO PRE-MIX BURN. 459-10	300.0	15.0	0.0

TABLE C-1
(continued)

1000 MT/YR COMMERCIAL PLANT
STREAM SUMMARY (ISSUE 1)

STREAM NO	INT. NO.	DESCRIPTION	T,F.	P,PSIA	LIQ.FR.
405	81	COMBUSTION QUENCH AIR TO BURNER 459-08	77.0	14.7	0.0
406	82	LIQUID BURNER 459-14 FEED	350.0	54.7	1.0000
407	83	LIQUID WASTE FROM CATCH TANK 451-06	350.0	64.7	1.0000
408	84	COMBUSTION QUENCH AIR TO BURNER 459-14	77.0	14.7	0.0
409	85	COMBUSTION AIR TO BURNER 459-14	77.0	14.7	0.0
410	86	ATMOSPHERIC VENT FROM TANK 451-06	350.0	14.7	0.0
411	87	FLUE GAS FROM BURNER 459-14	800.0	14.3	0.0
412	88	FLUE GAS FROM BURNER 459-10	800.0	14.3	0.0
413	89	FLUE GAS FROM BURNER 459-08	800.0	14.3	0.0
414	90	ATMOS. AIR VENT FROM AGGLOM. 459-16	250.0	15.0	0.0
415	91	COOLED FLUE GAS STR. TO FILTER 557-06	300.0	13.8	0.0
416	92	TOTAL FLUE GAS TO AGGLOMERATOR 459-16	800.0	14.0	0.0
417	93	GAS VENT FROM CYCLONE 458-02	800.0	14.2	0.0
418	94	FILTERED FLUE GAS TO FILTER 557-08	300.0	13.8	0.0
419	95	SILICA FROM FILTER 557-06	100.0	14.7	0.0
420	96	TOTAL SILICA FROM FILTERS 557-06,08	100.0	14.7	0.0
421	97	SILICA FROM FILTER 557-08	100.0	14.7	0.0
422	98	SILICA TO DUST BIN 451-08	800.0	14.7	0.0
423	99	SILICA TO DRUM PACKER 458-04	100.0	14.7	0.0
425	215	RECYCLE TO SILICA VENTURI 459-02	105.0	42.0	1.0000
426	227	SLURRY TO SILICA NEUTRALIZER 451-10	105.0	42.0	1.0000
427	103	RECYCLE H2O FROM PUMP 456-06,07	105.0	42.0	1.0000
429	105	MAKE-UP WATER AND 459-02 BOTTOMS	105.0	12.2	1.0000
430	106	BOTTOMS FROM VENTURI 459-02	105.0	12.2	1.0000
431	107	HCL VAPORS TO MURIATIC SCRUBBER 459-04	105.0	12.2	0.0
432	108	MURIATIC SCRUBBER 459-04 EFFLUENT	105.0	12.0	0.5000
433	109	STRONG MURIATIC ACID PRODUCT	105.0	12.0	1.0000
434	110	MURIATIC ACID FROM TANK 451-06	105.0	14.7	1.0000
435	111	WEAK MURIATIC ACID TO TANK 451-12	105.0	12.0	1.0000
436	112	STRONG MURIATIC ACID TO SCRUBBER 459-06	105.0	12.0	0.0
437	113	WEAK MURIATIC ACID TO PUMP 456-02	105.0	12.0	1.0000
438	114	STRONG MURI. ACID RECY. TO COOLER 454-02	105.0	59.0	1.0000
439	115	TOTAL MURI. ACID RECYCLE/PRODUCT	105.0	59.0	1.0000
440	116	WEAK ACID SOLUTION TO PUMP 456-04	105.0	11.7	1.0000
441	117	EFFLUENT FROM SCRUBBER 459-06	105.0	11.7	1.0000
442	118	MURIATIC ACID PRODUCT TO TANK 451-16	105.0	14.7	1.0000
443	119	ATMOS. VENT FROM BLOWER 453-04,05	105.0	14.8	0.0
444	120	HCL LADEN GAS TO TAILING COLUMN 452-02	105.0	11.7	0.0
445	121	STRIPPED GAS FROM TAILING COLUMN 452-02	105.0	11.6	0.0
446	122	WEAK MURIATIC ACID FROM TANK 451-14	105.0	11.7	1.0000
447	123	MURIATIC ACID PRODUCT	77.0	59.0	1.0000
448	124	FINE TO SILICA NEUTRALIZER 451-10	77.0	14.7	0.0
449	125	WASTE SLUDGE TO DISPOSAL	77.0	14.7	1.0000
450	126	WASTE WATER TO DISPOSAL	77.0	14.7	1.0000
451	127	FLUE GAS TO SILICA VENTURI 459-02	300.0	13.6	0.0
452	128	ATMOS. VENT FROM NON-COMBUST. HEADER	100.0	15.0	0.0
453	129	VAPOR FLASH-OFF FROM TANK 451-04	350.0	54.7	0.0
454	130	VAPOR FLASH-OFF FROM TANK 451-06	350.0	64.7	0.0
1000	132	COOLING WATER TO STC COOLER 434-24	85.0	75.0	1.0000
1001	133	COOLING WATER TO QUENCH COND. 424-02	85.0	75.0	1.0000
1003	135	COOLING WATER TO CONDENSER 434-08	85.0	75.0	1.0000
1004	136	COOLING WATER TO COOLER 434-12	85.0	75.0	1.0000
1005	137	COOLING WATER TO CONDENSER 434-12	85.0	75.0	1.0000
1006	138	COOLING WATER TO COOLER 434-16	85.0	75.0	1.0000
1008	140	COOLING WATER TO MELTER 449-04,06,08	85.0	75.0	1.0000
1014	144	COOL. WATER TO MAKE-UP TO VENTURI 459-02	85.0	75.0	1.0000
1016	143	COOL. WTR. TO PYRO. RECY. COMP 443-02,04	85.0	75.0	1.0000
1017	142	COOL. WATER TO RECY. H2 COOLER 442-02	85.0	75.0	1.0000
1018	141	COOL. WTR. TO MURIATIC ACID COOL. 454-02	85.0	75.0	1.0000
1019	139	COOL. WTR. TO MAKE-UP TO SCRUB. 459-06	85.0	75.0	1.0000
1020	134	COOL. WTR. TO PROD. POW.STOR. HOP 441-02	85.0	75.0	1.0000
1099	152	COOLING WATER HEADER	85.0	75.0	1.0000
1100	4	COOLING WATER RET. FROM STC COOL. 434-24	100.0	65.0	1.0000
1101	69	COOLING WATER RET. FROM STC COOLER	100.0	65.0	1.0000
1103	71	COOLING WATER RET. FROM COND. 434-08	100.0	65.0	1.0000
1104	72	COOLING WATER RET. FROM COOLER 434-12	100.0	65.0	1.0000
1105	73	COOLING WATER RET. FROM COND. 434-14	100.0	65.0	1.0000
1106	101	COOLING WATER RET. FROM COOLER 434-16	100.0	65.0	1.0000
1108	102	COOL. WATER RET. FROM MELT. 449-04,06,08	100.0	65.0	1.0000
1116	131	COOL. WATER FROM PYROL. COMP. 433-02,04	100.0	65.0	1.0000
1117	187	COOL. WATER FROM RECY. H2 COOLER 444-02	100.0	65.0	1.0000
1118	188	COOL. WATER FROM MURA. ACID COOL. 454-02	100.0	65.0	1.0000
1120	189	COOL. WATER FROM PROD. HOPPER 441-02	100.0	65.0	1.0000
1199	153	COOLING WATER RETURN HEADER	100.0	65.0	1.0000
1200	196	NATURAL GAS TO RECY. HEATER 429-08	100.0	65.0	1.0000
1202	198	NATURAL GAS TO WASTE BURNER 459-08	75.0	15.0	0.0
1203	199	NATURAL GAS TO WASTE BURNER 459-10	75.0	15.0	0.0
1204	200	NATURAL GAS TO WASTE LIQ. BURNER 459-14	75.0	15.0	0.0
1299	154	NATURAL GAS HEADER	75.0	15.0	0.0
1399	155	PLANT AIR HEADER	75.0	15.0	0.0
1400	172	PRESS. N2 TO M.G. SILICON HOPPER 421-02	75.0	94.7	0.0
1401	173	N2 PAD ON STC STORAGE TANK 421-12	77.0	160.0	0.0
1402	174	PRESS. N2 TO WASTE TANK 421-06	77.0	160.0	0.0
1403	175	N2 PAD ON CRUDE STC TANK 421-10	77.0	160.0	0.0
1404	176	N2 STREAM TO WASTE BURNER 459-08	77.0	160.0	0.0
1405	177	N2 PAD TO SURGE TANK 441-04	77.0	160.0	0.0
1406	167	N2 PURGE TO CATCH TANK 451-06	77.0	160.0	0.0
1499	156	NITROGEN HEADER	77.0	160.0	0.0
1500	201	ARGON TO MELTER 449-04,06,08	77.0	160.0	0.0
1501	202	ARGON TO SILICON HOPPER 441-02	77.0	160.0	0.0
1599	157	ARGON HEADER	77.0	160.0	0.0
1600	203	REF. BRINE TO STOR. 431-04,06,08,10	77.0	160.0	0.0
1601	204	REF. BRINE TO CONDENSER 434-18	-40.0	74.7	1.0000
1602	205	REF. BRINE TO CONDENSER 434-02	-40.0	74.7	1.0000
1699	158	REFRIGERANT BRINE HEADER	-40.0	74.7	1.0000
1700	206	BRINE RET. FROM TANKS 431-04,06,08,10	-40.0	74.7	1.0000
1701	207	BRINE RET. FROM COND. 434-18	-30.0	64.7	1.0000
1702	208	BRINE RET. FROM COND. 434-02	-30.0	64.7	1.0000
1799	159	REFRIGERANT BRINE RETURN HEADER	-30.0	64.7	1.0000
1800	209	COLD HEAT [illegible] DIC TO VAP. 424-04	-30.0	64.7	1.0000
			320.0	30.0	1.0000

TABLE C-I: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM SUMMARY (ISSUE 1)

STREAM NO	INT. NO.	DESCRIPTION	T.F.	P,PSIA	LIQ.FR.
1801	210	COLD HEAT TRANSFER OIL TO REBO. 434-04	320.0	30.0	1.0000
1802	211	COLD HEAT TRANSFER OIL TO REBO. 434-06	320.0	30.0	1.0000
1803	212	COLD HEAT TRANSFER OIL TO REBO. 434-10	320.0	30.0	1.0000
1804	213	COLD HEAT TRANSFER OIL TO REBO. 434-20	320.0	30.0	1.0000
1805	214	COLD HEAT TRANS. OIL TO SIH4 SUP. 434-12	320.0	30.0	1.0000
1899	160	COLD HEAT TRANSFER OIL HEADER	320.0	30.0	1.0000
1900	216	HEAT TRANS. OIL RET. FROM VAP. 424-04	286.0	20.0	1.0000
1901	217	HEAT TRANS. OIL RET. FROM REB. 434-04	286.0	20.0	1.0000
1902	218	HEAT TRANS. OIL RET. FROM REB. 434-06	251.0	20.0	1.0000
1903	219	HEAT TRANS. OIL RET. FROM REB. 434-10	365.0	20.0	1.0000
1904	220	HEAT TRANS. OIL RET. FROM REB. 434-20	308.0	20.0	1.0000
1905	221	HEAT TRANS. OIL FROM SIH4 SUP. 434-22	320.0	20.0	1.0000
1999	161	HEAT TRANSFER OIL RETURN HEADER	320.0	20.0	1.0000
2000	222	HEAT TRANS. OIL TO VAPOR. 424-04	497.0	30.0	1.0000
2001	223	HEAT TRANS. OIL TO REBOILER 434-04	497.0	30.0	1.0000
2002	224	HEAT TRANS. OIL TO REBOILER 434-06	497.0	30.0	1.0000
2003	225	HEAT TRANS. OIL TO REBOILER 434-10	497.0	30.0	1.0000
2004	226	HEAT TRANS. OIL TO REBOILER 434-20	497.0	30.0	1.0000
2099	180	HEAT TRANSFER OIL HEADER	497.0	30.0	1.0000
2100	228	RUPTURE DISK VENTS TO TANK 451-06	497.0	30.0	1.0000
2199	190	RUPTURE DISK VENT HEADER	100.0	20.0	0.0
2200	229	WASTE STR. TO COMB. VENT FILTER 557-04	100.0	20.0	0.0
2299	191	COMBUSTIBLE VENT HEADER	100.0	20.0	0.0
2300	230	NON-COMBUSTIBLE VENTS TO FILTER 557-02	100.0	20.0	0.0
2399	192	NON-COMBUSTIBLE VENTS HEADER	100.0	20.0	0.0
2400	231	N2 PURGE FROM BLENDER 428-02	100.0	20.0	0.0
2401	232	N2 PURGE FROM M.G. SILICON HOP. 421-02	100.0	20.0	0.0
2402	233	N2 PURGE FROM TANK 421-10 TO WASTE HEAD.	100.0	20.0	0.0
2403	234	N2 PURGE FROM 421-12 TO WASTE HEADER	100.0	20.0	0.0
2404	235	MELTER PURGE TO WASTE HEADER	100.0	20.0	0.0
2405	236	WASTE STR. TO PRE-MIX BURNER 459-10	100.0	20.0	0.0
2499	193	PRE-MIX BURNER HEADER	100.0	20.0	0.0
2500	237	NOZZLE MIX WASTE STR. TO BURNER 459-08	100.0	20.0	0.0
2501	238	CONDEN. REC. 431-02 VENT TO WASTE HEADER	100.0	20.0	0.0
2502	145	H2 RECYCLE PURGE	-21.0	90.0	0.0
2599	194	NOZZLE MIX BURNER HEADER	100.0	510.7	0.0
2600	239	WASTE CHLORIDES TO CONDEN. VENTS HEADER	100.0	20.0	0.0
2601	240	FILTERED SLUDGE FROM STC/TCS TANK 421-10	100.0	70.0	1.0000
2603	241	CONDENSED VENTS TO SURGE TANK 451-04	100.0	70.0	1.0000
2699	195	CONDENSED VENTS HEADER	100.0	70.0	1.0000
			100.0	70.0	1.0000

ORIGINAL PAGE IS OF POOR QUALITY

TABLE C-II: 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	100	101	102	104	105	106	107	108
PRESSURE, PSIA	15.00	15.00	20.00	515.70	516.70	14.70	516.70	514.70
TEMPERATURE, DEG F	75.00	75.00	75.00	150.01	150.01	75.00	932.00	932.00
LIQUID FRACTION	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
ENTHALPY + STREAM TEMP, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY + 25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION 25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT = HWT - H25 + HF, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT = HWT - H25 + HF, BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	28.7499	63.5400	169.8980	2.0194	2.0194	28.7932	86.1136	90.9420
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	.0	.0	.2861	28.32	.0	211.6	187.5
2 NITROGEN 28.01	155.4	.0	.0	.0	.0	155.4	.1990	.1990
3 ARGON 39.95	1.854	.0	.0	.0	.0	1.854	.0	.0
4 OXYGEN 32.00	41.68	.0	.0	.0	.0	41.68	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.5961E-01	.0	.0	.0	.0	.5961E-01	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.0	.5083E-02	.7415E-02
9 SILANE 32.12	.0	.0	.0	.0	.0	.0	.6585E-03	.8421E-03
10 MONOCHLOROSILANE 66.56	.0	.0	.0	.0	.0	.0	.8798E-02	.2668E-01
11 DICHLOROSILANE 101.01	.0	.0	.0	.0	.0	.0	.2637	1.471
12 TRICHLOROSILANE 135.45	.0	.0	.0	.0	.0	.0	16.96	62.57
13 SILICON TETRACHLORIDE 169.90	.0	.0	1.741	.0	.0	.0	211.6	176.7
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	3.160	.0	.0	.0	.0	3.160	.0	.0
16 SILICON 28.09	13.16	.0	.0	.0	.0	.0	13.15	1.128
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.1129	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.1129
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 124.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.5961E-01	.0	.0	.0	.0	.5961E-01	.0	.0
72 HYDROGEN (H) 1.01	6.319	.0	.0	.5722	56.65	6.319	440.6	440.6
73 NITROGEN (N) 14.01	310.7	.0	.0	.0	.0	310.7	.3981	.3981
74 OXYGEN (O) 16.00	44.96	.0	.0	.0	.0	44.96	.0	.0
75 SILICON (SI) 28.09	13.16	.0	1.741	.0	.0	.0	241.9	241.9
76 CHLORINE (CL) 35.45	.0	.0	6.965	.0	.0	.0	897.6	897.9
77 ARGON (AR) 39.95	1.854	.0	.0	.0	.0	1.854	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.1129	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.1129
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	215.3	.1129	1.741	.2861	28.32	2824	453.7	453.8

TABLE C-II: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	109	110	111	112	113	114	115	116
PRESSURE, PSIA	54.00	513.70	574.70	512.70	512.70	511.70	513.70	513.70
TEMPERATURE, DEG F	120.00	375.01	356.00	356.00	356.00	100.00	100.00	100.00
LIQUID FRACTION	1.0000	0.5000	1.0000	1.0000	0.0	0.5000	1.0000	1.0000
ENTHALPY @ STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HWT - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HWT - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	168.4590	105.4398	108.8802	109.8526	116.4846	117.8946	157.6698	157.6695
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	198.0	10.53	.1658E-01	192.9	193.4	.5046	5.422
2 NITROGEN 28.01	.0	.2192	.2022E-01	.3185E-04	.2095	.2105	.9810E-03	.1054E-01
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.1041E-01	.2996E-02	.4720E-05	.1018E-01	.1044E-01	.2581E-03	.2772E-02
9 SILANE 32.12	.3657E-04	.9935E-03	.1515E-03	.2386E-06	.1104E-02	.1129E-02	.2438E-04	.2619E-03
10 MONOCHLOROSILANE 66.56	.1055E-02	.4675E-01	.2007E-01	.3162E-04	.4917E-01	.5127E-01	.2096E-02	.2251E-01
11 DICHLOROSILANE 101.01	.2013E-01	5.165	3.694	.5819E-02	2.920	3.055	.1354	1.455
12 TRICHLOROSILANE 135.45	8.503	264.9	202.3	.3187	126.4	132.4	5.964	64.07
13 SILICON TETRACHLORIDE 169.90	196.1	1055.	878.7	1.384	369.8	387.7	17.91	192.5
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	717.0	715.8	1.128	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.1129	.0	.1129	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	8.547	671.4	230.8	.3636	518.3	525.5	7.250	77.90
73 NITROGEN (N) 14.01	.0	.4385	.4044E-01	.6370E-04	.4191	.4210	.1962E-02	.2108E-01
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	204.6	2042.	1801.	2.836	499.2	523.2	24.02	258.0
76 CHLORINE (CL) 35.45	809.8	5027.	4129.	6.730	1864.	1954.	89.82	965.0
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.1129	.0	.1129	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	204.6	2241.	1811.	2.966	692.3	716.9	24.52	263.4

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TABLE C-II (continued) — 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	117	118	119	120	121	122	123	124
PRESSURE, PSIA	572.70	510.70	510.70	510.70	521.70	516.70	516.70	521.70
TEMPERATURE, DEG F	100.00	100.00	100.00	100.00	100.00	961.00	961.00	442.99
LIQUID FRACTION	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
ENTHALPY W STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HBT - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HBT - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	157.6698	20.3661	157.6695	20.3661	20.3661	20.3661	168.4711	168.4711
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.5046	182.9	4.552	182.9	182.9	182.9	.0	.0
2 NITROGEN 28.01	.9810E-03	.1901	.8849E-02	.1901	.1901	.1901	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.2581E-03	.5083E-02	.2328E-02	.5083E-02	.5083E-02	.5083E-02	.0	.0
9 SILANE 32.12	.2438E-04	.6223E-03	.2199E-03	.6223E-03	.6223E-03	.6223E-03	.3621E-04	.3621E-04
10 MONOCHLOROSILANE 66.56	.2096E-02	.7754E-02	.1890E-01	.7754E-02	.7754E-02	.7754E-02	.1044E-02	.1044E-02
11 DICHLOROSILANE 101.01	.1354	.2438	1.221	.2438	.2438	.2438	.1993E-01	.1993E-01
12 TRICHLOROSILANE 135.45	5.964	8.538	53.80	8.538	8.538	8.538	8.418	8.418
13 SILICON TETRACHLORIDE 169.90	17.91	15.73	161.6	15.73	15.73	15.73	195.8	195.8
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.95	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	7.250	375.0	65.40	375.0	375.0	375.0	8.461	8.461
73 NITROGEN (N) 14.01	.1962E-02	.3803	.1770E-01	.3803	.3803	.3803	.0	.0
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	24.02	24.52	216.6	24.52	24.52	24.52	204.3	204.3
76 CHLORINE (CL) 35.45	89.82	89.04	810.2	89.04	89.04	89.04	808.6	808.6
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	24.52	207.7	221.2	207.7	207.7	207.7	204.3	204.3

TABLE C-II: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	125	126	127	128	129	131	132	200
PRESSURE, PSIA	95.60	100.00	30.00	526.70	512.70	14.90	526.70	55.00
TEMPERATURE, DEG F	100.00	100.00	75.00	75.00	356.00	77.00	442.99	217.99
LIQUID FRACTION	1.0000	1.0000	1.0000	1.0000	1.0000	0.0	1.0000	1.0000
ENTHALPY W STREAM TEMPERATURE, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY W 25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HWT + H25 + HF, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HWT + H25 + HF, BTU/HR-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	157.6635	157.6695	168.4711	168.4711	109.0802	28.0859	168.4711	168.4590
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	4.552	4.552	.0	.0	10.53	.0	.0	.0
2 NITROGEN 28.01	.8849E-02	.8849E-02	.0	.0	.2022E-01	.9210E-02	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.2328E-02	.2328E-02	.0	.0	.2996E-02	.0	.0	.0
9 SILANE 32.12	.2199E-03	.2199E-03	.3657E-04	.3657E-04	.1515E-03	.0	.3657E-06	.3657E-04
10 MONOCHLOROSILANE 66.56	.1890E-01	.1890E-01	.1055E-02	.1055E-02	.2007E-01	.0	.1055E-04	.1055E-02
11 DICHLOROSILANE 101.01	1.221	1.221	.2013E-01	.2013E-01	3.694	.0	.2013E-03	.2013E-01
12 TRICHLOROSILANE 135.45	53.80	53.80	8.503	8.503	202.3	.0	.8503E-01	8.503
13 SILICON TETRACHLORIDE 169.90	161.6	161.6	197.8	197.8	878.7	.0	1.978	196.1
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	715.8	13.16	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.13	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.37	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.09	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 85.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.85	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 154.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.43	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	65.40	65.40	8.547	8.547	230.8	.0	.8547E-01	8.547
73 NITROGEN (N) 14.01	.1770E-01	.1770E-01	.0	.0	.4044E-01	.1846E-01	.0	.0
74 OXYGEN (O) 15.99	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	216.6	216.6	206.3	206.3	1801.	13.16	2.063	204.6
76 CHLORINE (CL) 35.45	810.2	810.2	816.8	816.8	4129.	.0	8.168	808.8
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	221.2	221.2	206.3	206.3	1811.	13.17	2.063	204.6

TABLE C-II: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	201	202	203	204	205	206	207	208
PRESSURE, PSIA	94.60	95.00	90.40	89.40	95.00	95.00	54.80	55.00
TEMPERATURE, DEG F	240.01	244.00	140.00	-20.99	-20.99	244.00	214.00	217.99
LIQUID FRACTION	1.0000	0.0	0.0	1.0000	1.0000	1.0000	1.0000	0.0
ENTHALPY @ STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HST - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HST - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	158.6541	154.9733	87.7990	87.7990	109.3012	161.0092	167.3044	166.9236
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	.0	4.580	4.580	.2766E-01	.0	.0	.0
2 NITROGEN 28.01	.0	.0	.8963E-02	.8963E-02	.1136E-03	.0	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.3362E-02	.3362E-02	.1034E-02	.0	.0	.0
9 SILANE 32.12	.8339E-02	.8024E-02	.1818	.1818	.6366E-01	.3154E-03	.0	.0
10 MONOCHLOROSILANE 66.56	.773BE-04	.6212E-04	.2725	.2725	.2536	.1526E-04	.0	.0
11 DICHLOROSILANE 101.01	2.929	1.894	13.51	13.51	13.32	1.035	.1690	.1533
12 TRICHLOROSILANE 135.45	110.0	56.18	4.511	4.511	4.489	53.77	63.64	55.43
13 SILICON TETRACHLORIDE 169.90	242.0	80.39	.1962	.1962	.1958	161.6	785.9	589.9
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	115.8	60.00	42.23	42.23	32.20	55.85	63.98	55.74
73 NITROGEN (N) 14.01	.0	.0	.1793E-01	.1793E-01	.2272E-03	.0	.0	.0
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	354.9	138.5	18.67	18.67	18.32	216.4	849.7	645.4
76 CHLORINE (CL) 35.45	1304.	493.9	41.61	41.61	41.15	809.8	3335.	2526.
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	354.9	138.5	23.26	23.26	18.35	216.4	849.7	645.4

ORIGINAL PAGE IS OF POOR QUALITY

TABLE C-II: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 1)

STREAM NUMBER	209	210	211	212	213	214	215	216
PRESSURE, PSIA	50.20	49.20	320.00	84.00	55.00	320.00	85.00	85.00
TEMPERATURE, DEG F	159.01	152.40	152.40	158.00	152.40	152.40	158.00	158.00
LIQUID FRACTION	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ENTHALPY = STREAM TEMP, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF, BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	132.0257	132.0257	132.0257	136.0456	132.0258	132.0258	136.0458	136.0456
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN 28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE 32.12	.7083	.7083	.7083	.3075	.4005	.3078	.0	.0
10 MONOCHLOROSILANE 66.56	4.129	4.129	4.129	1.794	2.335	1.794	.9419E-02	.9428E-02
11 DICHLOROSILANE 101.01	73.58	73.58	73.58	30.96	41.61	31.97	1.764	1.766
12 TRICHLOROSILANE 135.45	611.3	611.3	611.3	220.1	345.6	265.6	285.0	285.3
13 SILICON TETRACHLORIDE 169.90	13.95	13.95	13.95	40.52	7.890	6.063	6.835	6.842
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	773.6	773.6	773.6	288.6	437.5	336.2	288.6	288.9
73 NITROGEN (N) 14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	703.6	703.6	703.6	293.6	397.9	305.7	293.6	293.9
76 CHLORINE (CL) 35.45	2041.	2041.	2041.	885.9	1154.	886.8	885.9	886.8
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	703.6	703.6	703.6	293.6	397.9	305.7	293.6	293.9

TABLE C-II: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER		217	218	219	220	221	222	223	224
PRESSURE,	PSIA	319.90	320.00	315.10	320.00	314.00	550.00	549.00	548.00
TEMPERATURE,	DEG F	327.00	327.51	257.31	249.80	249.80	249.80	122.00	122.00
LIQUID FRACTION		1.0000	0.0	0.0	1.0000	1.0000	1.0000	1.0000	1.0000
ENTHALPY * STREAM TEMP,	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY * 25C	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF	BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT		135.8623	135.7925	98.9321	98.9321	98.9321	98.9321	98.9321	98.9319
COMPOSITION, LB-MO/HR									
1 HYDROGEN	2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN	28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE	32.12	.0	.0	4.082	3.409	4.082	.6734	.6734	12.19
10 MONOCHLOROSILANE	66.56	.5152E-01	.4210E-01	74.17	61.93	74.17	12.23	12.23	10.45
11 DICHLOROSILANE	101.01	9.056	7.290	346.2	289.1	346.2	57.10	57.10	26.90
12 TRICHLOROSILANE	135.45	1035.	749.8	53.49	44.67	53.49	8.824	8.824	28.52
13 SILICON TETRACHLORIDE	169.90	21.83	14.99	.2079E-01	.1736E-01	.2079E-01	.3429E-02	.3429E-02	.7818
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.13	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR									
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	1053.	764.5	984.6	822.2	984.6	162.4	162.4	162.4
73 NITROGEN (N)	14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	1066.	772.2	477.9	399.1	477.9	78.84	78.84	78.84
76 CHLORINE (CL)	35.45	3211.	2324.	927.0	774.1	927.0	152.9	152.9	152.9
77 ARGON (AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW		1066.	772.2	477.9	399.1	477.9	78.84	78.84	78.84

TABLE C-II: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 1)

STREAM NUMBER		225	226	227	230	231	232	233	234
PRESSURE, PSIA		360.00	360.00	354.00	355.10	354.10	360.00	374.10	374.10
TEMPERATURE, DEG F		267.01	267.01	-25.71	-25.71	-25.71	-25.71	-25.71	126.00
LIQUID FRACTION		1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	0.0
ENTHALPY + STREAM TEMP, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY + 25C, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION +25C, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT + H25 + HF, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF, BTU/HR-MOL		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT		110.7218	110.7222	32.1179	32.1179	32.1179	32.1179	32.1179	32.1179
COMPOSITION, LB-MOL/HR									
1 HYDROGEN	2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN	28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE	32.12	.3657	.3657E-04	11.82	37.84	11.71	26.01	11.82	11.82
10 MONOCHLOROSILANE	66.56	10.45	.1045E-02	.0	.0	.0	.0	.0	.0
11 DICHLOROSILANE	101.01	26.89	.2690E-02	.0	.0	.0	.0	.0	.0
12 TRICHLOROSILANE	135.45	28.51	.2852E-02	.0	.0	.0	.0	.0	.0
13 SILICON TETRACHLORIDE	169.90	.7817	.7818E-04	.0	.0	.0	.0	.0	.0
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MOL/HR									
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	115.1	.1151E-01	47.30	151.4	46.83	104.1	47.30	47.30
73 NITROGEN (N)	14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	67.01	.6701E-02	11.82	37.84	11.71	26.01	11.82	11.82
76 CHLORINE (CL)	35.45	152.9	.1529E-01	.0	.0	.0	.0	.0	.0
77 ARGON (AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW		67.01	.6701E-02	11.82	37.84	11.71	26.01	11.82	11.82

TABLE C-II: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 1)

STREAM NUMBER		235	236	237	238	239	240	242	243
PRESSURE, PSIA		60.00	320.00	86.00	55.00	360.0	354.10	360.00	360.00
TEMPERATURE, DEG F		126.00	327.51	158.00	217.99	267.01	-25.71	267.01	267.01
LIQUID FRACTION		0.0	1.0000	1.0000	1.0000	1.0000	0.0	1.0000	0.0
ENTHALPY W STREAM TEMP,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY W 25C ,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION W25C,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HBT - H25 + HF ,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HBT - H25 + HF ,BTU/LB-MO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT		32.1179	136.0456	136.0456	168.5076	110.7218	32.1179	102.8838	92.0781
COMPOSITION, LB-MO/HR									
1 HYDROGEN	2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN	28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE	32.12	11.82	.0	.0	.0	.3657	.1182	3.666	3.300
10 MONOCHLOROSILANE	66.56	.0	.9428E-02	.9428E-05	.0	10.45	.0	27.07	16.62
11 DICHLOROSILANE	101.01	.0	1.766	.1766E-02	.1568E-01	26.90	.0	45.11	18.21
12 TRICHLOROSILANE	135.45	.0	285.3	.2853	8.215	28.52	.0	38.84	10.32
13 SILICON TETRACHLORIDE	169.90	.0	6.842	.6842E-02	196.1	.7818	.0	.9320	.1501
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR									
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	47.30	288.9	.2889	8.246	115.1	.4730	224.9	109.8
73 NITROGEN (N)	14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	11.82	293.9	.2939	204.3	67.01	.1182	115.6	48.61
76 CHLORINE (CL)	35.45	.0	886.8	.8868	808.9	152.9	.0	237.5	84.61
77 ARGON (AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW		11.82	293.9	.2939	204.3	67.01	.1182	115.6	48.61

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE C-11: (continued)

1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	100	101	102	107	108	111	112	113
PRESSURE, ATM	20.00	20.00	20.00	20.00	20.00	20.00	15.00	550.00
TEMPERATURE, °C	77.00	1562.00	1119.99	2600.01	1119.99	1562.00	100.01	100.01
CLOUDY FRACTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY + STEAM TEMPERATURE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY + 25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION 25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT + HEAT 25°C + HF 25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT + HEAT 25°C + HF 25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT + HEAT 25°C + HF 25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY 25°C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	12.1179	10.7441	27.9945	28.0860	28.0860	2.0196	2.0196	2.0196
COMPOSITION, LB-MOL/HR								
1 HYDROGEN	.0	.0	21.51	.4600E-01	.0	.0	23.48	23.48	28.61
2 NITROGEN	28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE	32.12	11.92	.0	.0	.0	.0	.0	.0	.0
10 MONOCHLOROSILANE	66.56	.0	.591E-01	.591E-01	.0	.0	.0	.0	.0
11 DICHLOROSILANE	101.01	.0	.0	.0	.0	.0	.0	.0	.0
12 TRICHLOROSILANE	135.45	.0	.0	.0	.0	.0	.0	.0	.0
13 SILICON TETRACHLORIDE	169.90	.0	.0	.0	.0	.0	.0	.0	.0
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	11.77	10.42	10.42	1.364	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CHROMIC OXIDE	[illegible]	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS PENTACHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.01	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM TRICHLORIDE	173.35	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.21	.0	.0	.0	.0	.0	.0	.0	.0
49 SILICON DIOXIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN CHLORIDE	36.09	.0	.0	.0	.0	.0	.0	.0	.0
51 HYDRATE	27.97	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHIT	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ASSIM	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	85.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.54	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LEAD OXIDE	56.09	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON MONOXIDE	40.38	.0	.0	.0	.0	.0	.0	.0	.0
65 SILANAL	105.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.19	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLTRICHLOROSILANE	119.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLDICHLOROSILANE	150.99	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MOL/HR								
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	47.10	47.10	.3287	.0	.0	.0	.0	.0
73 NITROGEN (N)	14.01	.0	.0	.0	.0	.0	46.97	46.97	57.22
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	11.92	11.92	10.48	10.42	1.364	.0	.0	.0
76 CHLORINE (CL)	35.45	.0	.0	.0	.0	.0	.0	.0	.0
77 ARGON (AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SILICON (SI)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL MOLES	11.[illegible]	15.16	10.51	10.42	1.364	21.48	21.48	28.61

TABLE C-II: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	114	2400	2401	2403	2404	2600	2601	2602
PRESSURE, PSIA	50.00	20.00	20.00	20.00	20.00	70.00	70.00	20.00
TEMPERATURE, DEG F	77.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LIQUID FRACTION	0.0	0.0	0.0	0.0	0.0	1.0000	1.0000	0.0
ENTHALPY + STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY + 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION +25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = H&T - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = H&T - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	2.0194	28.0134	28.0134	28.0134	39.2603	58.9509	0.0	28.0134
COMPOSITION, LB-MOL/HR								
1 HYDROGEN 2.02	5.126	.0	.0	.0	.4609E-01	.1658E-01	.0	.0
2 NITROGEN 28.01	.0	1.795	.5983	5.009	.0	4.604	.0	4.604
3 ARGON 39.95	.0	.0	.0	.0	3.110	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.4720E-05	.0	.0
9 SILANE 32.12	.0	.0	.0	.0	.5912E-01	.2386E-06	.0	.0
10 MONOCHLOROSILANE 66.56	.0	.0	.0	.0	.0	.3162E-04	.0	.0
11 DICHLOROSILANE 101.01	.0	.0	.0	.0	.0	.5819E-02	.0	.0
12 TRICHLOROSILANE 135.45	.0	.0	.0	.0	.0	.3187	.0	.0
13 SILICON TETRACHLORIDE 169.90	.0	.0	.0	.0	.0	1.384	.0	.0
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	1.128	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.11	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM [illegible] [illegible]	[illegible]	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.13	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MOL/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	10.25	.0	.0	.0	.3287	.3636	.0	.0
73 NITROGEN (N) 14.01	.0	3.590	1.197	10.02	.0	9.209	.0	9.209
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	.0	.0	.0	.0	.5912E-01	2.836	.0	.0
76 CHLORINE (CL) 35.45	.0	.0	.0	.0	.0	6.505	.0	.0
77 ARGON (AR) 39.95	.0	.0	.0	.0	3.110	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	5.126	1.795	.5983	5.009	3.215	7.457	.0	4.604

TABLE C-II: (continued) — 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 1)

STREAM NUMBER	2501	2502	1500	1501
PRESSURE, [illegible]	90.00	510.70	160.00	160.00
TEMPERATURE, [illegible] F	-20.99	100.00	77.00	77.00
LIQUID FRACTION	0.0	0.0	0.0	0.0
ENTHALPY W STREAM TEMP, BTU/HR	0.0	0.0	0.0	0.0
ENTHALPY W 25C, BTU/HR	0.0	0.0	0.0	0.0
HEAT OF FORMATION W 25C, BTU/HR	0.0	0.0	0.0	0.0
HTOT = HGT - H25 + HF, BTU/HR	0.0	0.0	0.0	0.0
HTOT = HGT - H25 + HF, BTU/LB-MOL	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	7.4124	0.0	39.9480	39.9480

COMPOSITION, LB-MOL/HR

1 HYDROGEN	2.02	4.552	.0	.0	.0
2 NITROGEN	28.01	.8849E-02	.0	.0	.0
3 ARGON	39.95	.0	.0	1.064	2.046
4 OXYGEN	32.00	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.2328E-02	.0	.0	.0
9 SILANE	32.12	.1182	.0	.0	.0
10 MONOCHLOROSILANE	66.56	.1889E-01	.0	.0	.0
11 DICHLOROSILANE	101.01	.1865	.0	.0	.0
12 TRICHLOROSILANE	135.45	.2152E-01	.0	.0	.0
13 SILICON TETRACHLORIDE	169.90	.3232E-03	.0	.0	.0
14 CHLORINE	70.91	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.94	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.04	.0	.0	.0	.0
51 DIBORANE	27.67	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	85.01	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.04	.0	.0	.0	.0

ELEMENTAL COMPOSITION, LB-MOL/HR

71 CARBON (C)	12.01	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	10.03	.0	.0	.0
73 NITROGEN (N)	14.01	.1770E-01	.0	.0	.0
74 OXYGEN (O)	15.00	.0	.0	.0	.0
75 SILICON (SI)	28.09	.1454	.0	.0	.0
76 CHLORINE (CL)	35.45	.4601	.0	.0	.0
77 ARGON (AR)	39.95	.0	.0	1.064	2.046
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0
TOTAL FLOW	4.404	.0	.0	1.064	2.046

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TABLE C-III: 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 1)

STREAM NUMBER	100	101	102	104	105	106	107
TEMPERATURE, DEG F.	0.75002E 02	0.75002E 02	0.75002E 02	0.15001E 03	0.15001E 03	0.75002E 02	0.93200E 03
PRESSURE, PSIA	0.15000E 02	0.15000E 02	0.20000E 02	0.51670E 03	0.51670E 03	0.14700E 02	0.51670E 03
LIQUID FRACTION	0.0	0.0	0.10000E 01	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.18385E-01	0.91282E-02	0.45648E 00	0.99447E-02	0.99447E-02	0.18385E-01	0.28920E-01
THER.COND., BTU/HR-FT-F	0.14779E-01	0.10538E 00	0.58240E-01	0.11906E 00	0.11906E 00	0.14779E-01	0.36374E-01
DENSITY, LB-MOLE/FT**3	0.26157E-02	0.26125E-02	0.49871E 00	0.77417E-01	0.77417E-01	0.25634E-02	0.34823E-01
SURFACE TENSION, DYNES/CM	0.0	0.0	0.18946E 02	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.71329E 00	0.72516E 00	0.36201E 01	0.70038E 00	0.70038E 00	0.71322E 00	0.37403E 00
DEW PT. / BUBBLE PT.,F	0.57397E 02	-0.45838E 03	0.15362E 03	-0.45843E 03	-0.45843E 03	0.56838E 02	0.36504E 03
ENTHALPY, BTU/LB-MOLE	0.37072E 04	0.36281E 04	-0.17929E 04	0.41684E 04	0.41684E 04	0.37072E 04	0.20315E 05
SPECIFIC HEAT, BTU/LB-MO-F	0.68255E 01	0.69763E 01	0.32439E 02	0.69878E 01	0.69878E 01	0.68245E 01	0.17083E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.28610E 00	0.28324E 02	0.0	0.21156E 03
2 NITROGEN	0.15536E 03	0.0	0.0	0.0	0.0	0.15535E 03	0.19903E 00
3 ARGON	0.18543E 01	0.0	0.0	0.0	0.0	0.18543E 01	0.0
4 OXYGEN	0.41679E 02	0.0	0.0	0.0	0.0	0.41679E 02	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.59606E-01	0.0	0.0	0.0	0.0	0.59606E-01	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.50829E-02
9 SILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.65350E-03
10 MONOCHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.87984E-02
11 DICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.26371E 00
12 TRICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.16956E 02
13 SILICON TETRACHLORIDE	0.0	0.0	0.17412E 01	0.0	0.0	0.0	0.21156E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.31595E 01	0.0	0.0	0.0	0.0	0.31595E 01	0.0
16 TOTAL MOLES	0.20211E 03	0.0	0.17412E 01	0.28610E 00	0.28324E 02	0.20210E 03	0.44055E 03

STREAM NUMBER	108	109	110	111	112	113	114
TEMPERATURE, DEG F.	0.93200E 03	0.12000E 03	0.37501E 03	0.35600E 03	0.35600E 03	0.35600E 03	0.10000E 03
PRESSURE, PSIA	0.51470E 03	0.54000E 02	0.51370E 03	0.57470E 03	0.51270E 03	0.51270E 03	0.51170E 03
LIQUID FRACTION	0.0	0.10000E 01	0.50000E 00	0.10000E 01	0.10000E 01	0.0	0.50000E 00
VISCOSITY, CENTIPOISE	0.28720E-01	0.36150E 00	0.50418E-01	0.11763E 00	0.11763E 00	0.20712E-01	0.30209E 00
THER.COND., BTU/HR-FT-F	0.33738E-01	0.52514E-01	0.25219E-01	0.38593E-01	0.38593E-01	0.15779E-01	0.56922E-01
DENSITY, LB-MOLE/FT**3	0.34797E-01	0.48798E 00	0.82106E-01	0.37019E 00	0.37019E 00	0.75850E-01	0.51379E 00
SURFACE TENSION, DYNES/CM	0.0	0.15979E 02	0.69388E-01	0.21736E 01	0.23830E 01	0.0	0.16348E 01
PRANDTL NUMBER	0.39906E 00	0.31916E 01	0.89969E 00	0.20448E 01	0.20436E 01	0.23519E 00	0.20399E 01
DEW PT. / BUBBLE PT.,F	0.36381E 03	0.21782E 03	0.37501E 03	-0.45601E 03	-0.45601E 03	0.39221E 03	0.10000E 03
ENTHALPY, BTU/LB-MOLE	0.20678E 05	-0.39573E 03	0.11190E 05	0.77301E 04	0.77313E 04	0.12349E 05	0.44468E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.17654E 02	0.32287E 02	0.35695E 02	0.44520E 02	0.44424E 02	0.22673E 02	0.25171E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.18752E 03	0.0	0.19804E 03	0.10527E 02	0.16583E-01	0.19292E 03	0.19342E 03
2 NITROGEN	0.19903E 00	0.0	0.21924E 00	0.20218E-01	0.31850E-04	0.20953E 00	0.21051E 00
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.74155E-02	0.0	0.10412E-01	0.29961E-02	0.47199E-05	0.10183E-01	0.10341E-01
9 SILANE	0.84208E-03	0.36572E-04	0.99354E-03	0.15145E-03	0.23859E-06	0.11041E-02	0.11286E-02
10 MONOCHLOROSILANE	0.26680E-01	0.10546E-02	0.46751E-01	0.20071E-01	0.31619E-04	0.49173E-01	0.51268E-01
11 DICHLOROSILANE	0.14707E 01	0.20131E-01	0.51645E 01	0.36938E 01	0.58189E-02	0.29198E 01	0.30552E 01
12 TRICHLOROSILANE	0.62568E 02	0.85033E 01	0.26489E 03	0.20233E 03	0.31873E 00	0.12641E 03	0.13237E 03
13 SILICON TETRACHLORIDE	0.17674E 03	0.19606E 03	0.10554E 04	0.87870E 03	0.13842E 01	0.36980E 03	0.38771E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.42853E 03	0.20458E 03	0.15238E 04	0.10953E 04	0.17254E 01	0.69232E 03	0.71683E 03

TABLE C-III: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 1)

STREAM NUMBER	115	116	117	118	119	120	121
TEMPERATURE, DEG F.	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03
PRESSURE, PSIA	0.51370E 03	0.51370E 03	0.57270E 03	0.51070E 03	0.51070E 03	0.51070E 03	0.52170E 03
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.10000E 01	0.0	0.10000E 01	0.0	0.0
VISCOSITY, CENTIPOISE	0.35395E 00	0.35395E 00	0.35395E 00	0.16083E-01	0.35395E 00	0.16083E-01	0.16188E-01
THER.COND., BTU/HR-FT-F	0.54410E-01	0.54410E-01	0.54410E-01	0.62568E-01	0.54410E-01	0.62568E-01	0.62818E-01
DENSITY, LB-MOLE/FT**3	0.51844E 00	0.51844E 00	0.51844E 00	0.84728E-01	0.51844E 00	0.84728E-01	0.86542E-01
SURFACE TENSION, DYNES/CM	0.79927E 01	0.79927E 01	0.72916E 01	0.0	0.80294E 01	0.0	0.0
PRANDTL NUMBER	0.31422E 01	0.31420E 01	0.31422E 01	0.25723E 00	0.31422E 01	0.25723E 00	0.25794E 00
DEW PT. / BUBBLE PT.,F	-0.45403E 03	-0.45403E 03	-0.45403E 03	0.21405E 03	-0.45403E 03	0.21405E 03	0.21567E 03
ENTHALPY, BTU/LB-MOLE	-0.12367E 04	-0.12367E 04	-0.12366E 04	0.45986E 04	-0.12367E 04	0.45986E 04	0.45989E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.31480E 02	0.31480E 02	0.31478E 02	0.96746E 01	0.31482E 02	0.96746E 01	0.96805E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.50464E 00	0.54217E 01	0.50464E 00	0.18295E 03	0.45522E 01	0.18295E 03	0.18295E 03
2 NITROGEN	0.98103E-03	0.10539E-01	0.98103E-03	0.19014E 00	0.88491E-02	0.19014E 00	0.19014E 00
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.25806E-03	0.27724E-02	0.25806E-03	0.50829E-02	0.23278E-02	0.50829E-02	0.50829E-02
10 MONOCHLOROSILANE	0.24380E-04	0.26193E-03	0.24380E-04	0.62229E-03	0.21993E-03	0.62229E-03	0.62229E-03
11 DICHLOROSILANE	0.20956E-02	0.22514E-01	0.20956E-02	0.77544E-02	0.18904E-01	0.77544E-02	0.77544E-02
12 TRICHLOROSILANE	0.13539E 00	0.14546E 01	0.13539E 00	0.24379E 00	0.12213E 01	0.24379E 00	0.24379E 00
13 SILICON TETRACHLORIDE	0.59638E 01	0.64071E 02	0.59638E 01	0.85377E 01	0.53797E 02	0.85377E 01	0.85377E 01
14 CHLORINE	0.17915E 02	0.19246E 03	0.17915E 02	0.15732E 02	0.16160E 03	0.15732E 02	0.15732E 02
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.24522E 02	0.26344E 03	0.24522E 02	0.20767E 03	0.22120E 03	0.20767E 03	0.20767E 03

STREAM NUMBER	122	123	124	125	126	127	128
TEMPERATURE, DEG F.	0.96100E 03	0.96100E 03	0.44299E 03	0.10000E 03	0.10000E 03	0.75002E 02	0.75002E 02
PRESSURE, PSIA	0.51670E 03	0.51670E 03	0.52170E 03	0.95000E 02	0.10000E 03	0.30000E 02	0.52670E 03
LIQUID FRACTION	0.0	0.0	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01
VISCOSITY, CENTIPOISE	0.29038E-01	0.28079E-01	0.28436E-01	0.35395E 00	0.35395E 00	0.45083E 00	0.45083E 00
THER.COND., BTU/HR-FT-F	0.12601E 00	0.12511E-01	0.97780E-02	0.54410E-01	0.54410E-01	0.58133E-01	0.58133E-01
DENSITY, LB-MOLE/FT**3	0.33511E-01	0.36670E-01	0.12862E 00	0.51844E 00	0.51844E 00	0.50368E 00	0.50368E 00
SURFACE TENSION, DYNES/CM	0.0	0.0	0.0	0.14523E 02	0.14427E 02	0.18696E 02	0.87170E 01
PRANDTL NUMBER	0.25388E 00	0.84978E 00	-0.12551E 01	0.31424E 01	0.31422E 01	0.36058E 01	0.36060E 01
DEW PT. / BUBBLE PT.,F	0.21493E 03	0.44404E 03	0.44526E 03	-0.45403E 03	-0.45403E 03	0.17626E 03	0.44536E 03
ENTHALPY, BTU/LB-MOLE	0.12176E 05	0.31123E 05	0.16136E 05	-0.12369E 04	-0.12369E 04	-0.18487E 04	-0.18487E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.92752E 01	0.26369E 02	-0.17148E 02	0.31453E 02	0.31453E 02	0.32381E 02	0.32383E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.18295E 03	0.0	0.0	0.45522E 01	0.45522E 01	0.0	0.0
2 NITROGEN	0.19014E 00	0.0	0.0	0.88491E-02	0.88491E-02	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.50829E-02	0.0	0.0	0.23278E-02	0.23278E-02	0.0	0.0
9 SILANE	0.62229E-03	0.36206E-04	0.36206E-04	0.21993E-03	0.21993E-03	0.36572E-04	0.36572E-04
10 MONOCHLOROSILANE	0.77544E-02	0.10440E-02	0.10440E-02	0.18904E-01	0.18904E-01	0.10546E-02	0.10546E-02
11 DICHLOROSILANE	0.24379E 00	0.19930E-01	0.19930E-01	0.12213E 01	0.12213E 01	0.20131E-01	0.20131E-01
12 TRICHLOROSILANE	0.85377E 01	0.84183E 01	0.84183E 01	0.53797E 02	0.53797E 02	0.85033E 01	0.85033E 01
13 SILICON TETRACHLORIDE	0.15732E 02	0.19582E 03	0.19582E 03	0.16160E 03	0.16160E 03	0.19780E 03	0.19780E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.20767E 03	0.20426E 03	0.20426E 03	0.22120E 03	0.22120E 03	0.20632E 03	0.20632E 03

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TABLE C-III: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 1)

STREAM NUMBER	129	131	132	200	201	202	203
TEMPERATURE, DEG F.	0.35600E 03	0.77000E 02	0.44299E 03	0.21799E 03	0.24001E 03	0.24400E 03	0.14000E 03
PRESSURE, PSIA	0.51270E 03	0.14900E 02	0.52670E 03	0.55000E 02	0.94600E 02	0.95000E 02	0.90400E 02
LIQUID FRACTION	0.10000E 01	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.0	0.0
VISCOSITY, CENTIPOISE	0.11763E 00	0.17845E-01	0.50205E-01	0.24712E 00	0.20622E 00	0.14374E-01	0.12488E-01
THER.COND., BTU/HR-FT-F	0.38593E-01	0.14968E-01	0.38913E-01	0.43484E-01	0.42463E-01	0.60505E-02	0.97906E-02
DENSITY, LB-MOLE/FT**3	0.37019E 00	0.25881E-02	0.25601E 00	0.44802E 00	0.46325E 00	0.14348E-01	0.15243E-01
SURFACE TENSION, DYNES/CM	0.23830E 01	0.0	0.50064E 00	0.11395E 02	0.94373E 01	0.0	0.0
PRANDTL NUMBER	0.20439E 01	0.70090E 00	-0.31757E 00	0.27521E 01	0.26901E 01	0.71510E 00	0.39826E 00
DEW PT. / BUBBLE PT.,F	-0.45601E 03	-0.32022E 03	0.44536E 03	0.21921E 03	0.24346E 03	0.24735E 03	0.15437E 03
ENTHALPY, BTU/LB-MOLE	0.77313E 04	0.37234E 04	0.15573E 05	0.28195E 04	0.31910E 04	0.12915E 05	0.66762E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.44419E 02	0.68084E 01	-0.17142E 02	0.33724E 02	0.36332E 02	0.25961E 02	0.17661E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.10527E 02	0.0	0.0	0.0	0.0	0.0	0.45799E 01
2 NITROGEN	0.20218E-01	0.92296E-02	0.0	0.0	0.0	0.0	0.89627E-02
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.29961E-02	0.0	0.0	0.0	0.0	0.0	0.33619E-02
10 MONOCHLOROSILANE	0.15145E-03	0.0	0.36571E-06	0.36572E-04	0.83391E-02	0.80237E-02	0.18181E 00
11 DICHLOROSILANE	0.20071E-01	0.0	0.10546E-04	0.10546E-02	0.77380E-04	0.62124E-04	0.27250E 00
12 TRICHLOROSILANE	0.36938E 01	0.0	0.20131E-03	0.20131E-01	0.29287E 01	0.18938E 01	0.13507E 02
13 SILICON TETRACHLORIDE	0.20233E 03	0.0	0.85033E-01	0.85033E 01	0.10995E 03	0.56177E 02	0.45109E 01
14 CHLORINE	0.87870E 03	0.0	0.19780E 01	0.19606E 03	0.24199E 03	0.80389E 02	0.19617E 00
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.10953E 04	0.92296E-02	0.20632E 01	0.20458E 03	0.35488E 03	0.13847E 03	0.23261E 02

STREAM NUMBER	204	205	206	207	208	209	210
TEMPERATURE, DEG F.	-0.20992E 02	-0.20992E 02	0.24400E 03	0.21400E 03	0.21799E 03	0.15901E 03	0.15240E 03
PRESSURE, PSIA	0.89400E 02	0.95000E 02	0.95000E 02	0.54800E 02	0.55000E 02	0.50200E 02	0.49200E 02
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.0	0.0	0.10000E 01
VISCOSITY, CENTIPOISE	0.29783E 00	0.50545E 00	0.20757E 00	0.24782E 00	0.13634E-01	0.12553E-01	0.22806E 00
THER.COND., BTU/HR-FT-F	0.68813E-01	0.68999E-01	0.42157E-01	0.43794E-01	0.54681E-02	0.54615E-02	0.47934E-01
DENSITY, LB-MOLE/FT**3	0.74988E 00	0.81799E 00	0.45481E 00	0.45297E 00	0.82479E-02	0.81762E-02	0.60156E 00
SURFACE TENSION, DYNES/CM	0.59011E 01	0.16851E 02	0.93760E 01	0.11539E 02	0.0	0.0	0.12024E 02
PRANDTL NUMBER	0.23854E 01	0.37487E 01	0.26688E 01	0.27635E 01	0.89119E 00	0.66197E 00	0.28002E 01
DEW PT. / BUBBLE PT.,F	-0.45539E 03	-0.45294E 03	0.24835E 03	0.21652E 03	0.21899E 03	0.15998E 03	0.14998E 03
ENTHALPY, BTU/LB-MOLE	-0.40937E 04	-0.58420E 04	0.34226E 04	0.26420E 04	0.13537E 05	0.94035E 04	-0.83738E 03
SPECIFIC HEAT, BTU/LB-MO-F	0.19860E 02	0.23120E 02	0.36079E 02	0.33776E 02	0.26106E 02	0.19428E 02	0.31344E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.45799E 01	0.27664E-01	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.89627E-02	0.11358E-03	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.33619E-02	0.10342E-02	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.18181E 00	0.63659E-01	0.31536E-03	0.0	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.27250E 00	0.25361E 00	0.15256E-04	0.0	0.0	0.70828E 00	0.70828E 00
11 DICHLOROSILANE	0.13507E 02	0.13320E 02	0.10348E 01	0.16901E 00	0.15333E 00	0.41286E 01	0.41286E 01
12 TRICHLOROSILANE	0.45109E 01	0.44894E 01	0.53775E 02	0.63643E 02	0.55429E 02	0.73582E 02	0.73582E 02
13 SILICON TETRACHLORIDE	0.19617E 00	0.19584E 00	0.16160E 03	0.78592E 03	0.58986E 03	0.61125E 03	0.61125E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.13954E 02	0.13954E 02
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.23261E 02	0.18351E 02	0.21641E 03	0.84973E 03	0.84544E 03	0.70362E 03	0.70362E 03

TABLE C-III: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS- (ISSUE 1)

STREAM NUMBER	211	212	213	214	215	216	217
TEMPERATURE, DEG F.	0.15240E 03	0.15800E 03	0.15240E 03	0.15240E 03	0.15800E 03	0.15800E 03	0.32700E 03
PRESSURE, PSIA	0.32000E 03	0.84000E 02	0.55000E 02	0.32000E 03	0.85000E 02	0.85000E 02	0.31990E 03
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01
VISCOSITY, CENTIPOISE	0.22806E 00	0.23166E 00	0.22806E 00	0.22806E 00	0.22948E 00	0.22948E 00	0.99863E-01
THER.COND., BTU/HR-FT-F	0.47934E-01	0.47680E-01	0.47934E-01	0.47934E-01	0.47571E-01	0.47571E-01	0.42541E-01
DENSITY, LB-MOLE/FT**3	0.60156E 00	0.58248E 00	0.60156E 00	0.60156E 00	0.58321E 00	0.58322E 00	0.45138E 00
SURFACE TENSION, DYNES/CM	0.90180E 01	0.11772E 02	0.11953E 02	0.90181E 01	0.11625E 02	0.11626E 02	0.31902E 01
PRANDTL NUMBER	0.27467E 01	0.28013E 01	0.28008E 01	0.27469E 01	0.27084E 01	0.27086E 01	0.17406E 01
DEW PT. / BUBBLE PT.,F	0.31600E 03	0.19339E 03	0.15774E 03	0.31601E 03	0.20199E 03	0.20199E 03	0.32745E 03
ENTHALPY, BTU/LB-MOLE	-0.86084E 03	-0.50363E 03	-0.84007E 03	-0.86084E 03	-0.52852E 03	-0.52852E 03	0.52971E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.31517E 02	0.32433E 02	0.32138E 02	0.31519E 02	0.31586E 02	0.31589E 02	0.41658E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.70828E 00	0.30746E 00	0.40050E 00	0.30777E 00	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.41286E 01	0.17940E 01	0.23345E 01	0.17940E 01	0.94188E-02	0.94278E-02	0.51523E-01
11 DICHLOROSILANE	0.73582E 02	0.30955E 02	0.41608E 02	0.31974E 02	0.17643E 01	0.17661E 01	0.90560E 01
12 TRICHLOROSILANE	0.61125E 03	0.22006E 03	0.34564E 03	0.26561E 03	0.28502E 03	0.28530E 03	0.10351E 04
13 SILICON TETRACHLORIDE	0.13954E 02	0.40517E 02	0.78904E 01	0.60635E 01	0.68349E 01	0.68418E 01	0.21828E 02
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.70362E 03	0.29363E 03	0.39787E 03	0.30575E 03	0.29363E 03	0.29392E 03	0.10660E 04

STREAM NUMBER	218	219	220	221	222	223	224
TEMPERATURE, DEG F.	0.32751E 03	0.25731E 03	0.24980E 03	0.24980E 03	0.24980E 03	0.12200E 03	0.12200E 03
PRESSURE, PSIA	0.32000E 03	0.31510E 03	0.32000E 03	0.31400E 03	0.55000E 03	0.54900E 03	0.54800E 03
LIQUID FRACTION	0.0	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01
VISCOSITY, CENTIPOISE	0.17568E-01	0.15539E-01	0.98611E-01	0.98611E-01	0.98610E-01	0.19842E 00	0.16882E 00
THER.COND., BTU/HR-FT-F	0.82562E-02	0.90002E-02	0.33241E-01	0.33241E-01	0.33241E-01	0.50445E-01	0.51539E-01
DENSITY, LB-MOLE/FT**3	0.54908E-01	0.57277E-01	0.61574E 00	0.61574E 00	0.61574E 00	0.75630E 00	0.70895E 00
SURFACE TENSION, DYNES/CM	0.0	0.0	0.32523E 01	0.32702E 01	0.26196E 01	0.59902E 01	0.57574E 01
PRANDTL NUMBER	0.99505E 00	0.31717E 00	0.24867E 01	0.24858E 01	0.25698E 01	0.28094E 01	0.21352E 01
DEW PT. / BUBBLE PT.,F	0.32841E 03	0.26046E 03	0.23744E 03	0.23548E 03	0.29832E 03	0.29810E 03	0.19129E 03
ENTHALPY, BTU/LB-MOLE	0.11802E 05	0.77634E 04	0.19651E 04	0.19678E 04	0.18349E 04	-0.28526E 04	-0.15984E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.42120E 02	0.13571E 02	0.27549E 02	0.25282E 02	0.35428E 02	0.29210E 02	0.26662E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.0	0.40824E 01	0.34090E 01	0.40824E 01	0.67345E 00	0.67345E 00	0.12191E 02
10 MONOCHLOROSILANE	0.42095E-01	0.74167E 02	0.61932E 02	0.74167E 02	0.12235E 02	0.12235E 02	0.10451E 02
11 DICHLOROSILANE	0.72899E 01	0.34615E 03	0.28905E 03	0.34615E 03	0.57102E 02	0.57102E 02	0.26896E 02
12 TRICHLOROSILANE	0.74984E 03	0.53490E 02	0.44666E 02	0.53490E 02	0.88237E 01	0.88237E 01	0.28517E 02
13 SILICON TETRACHLORIDE	0.14986E 02	0.20789E-01	0.17360E-01	0.20789E-01	0.34294E-02	0.34294E-02	0.78182E 00
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.77216E 03	0.47791E 03	0.39907E 03	0.47791E 03	0.78838E 02	0.78838E 02	0.78837E 02

TABLE C-III: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 1)

STREAM NUMBER	225	226	227	230	231	232	233
TEMPERATURE, DEG F.	0.26701E 03	0.26701E 03	-0.25708E 02	-0.25708E 02	-0.25708E 02	-0.25708E 02	-0.25708E 02
PRESSURE, PSIA	0.36000E 03	0.36000E 03	0.35400E 03	0.35510E 03	0.35410E 03	0.36000E 03	0.37410E 03
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.0	0.0	0.10000E 01	0.10000E 01	0.0
VISCOSITY, CENTIPOISE	0.10088E 00	0.10088E 00	0.10388E-01	0.10396E-01	0.56724E-01	0.56724E-01	0.10560E-01
THER.COND., BTU/HR-FT-F	0.35238E-01	0.35238E-01	0.98706E-02	0.98824E-02	0.46522E-01	0.46522E-01	0.10101E-01
DENSITY, LB-MOLE/FT**3	0.56318E 00	0.56317E 00	0.11008E 00	0.11066E 00	0.90235E 00	0.90235E 00	0.12122E 00
SURFACE TENSION, DYNES/CM	0.35296E 01	0.35296E 01	0.0	0.0	0.30695E 01	0.30507E 01	0.0
PRANDTL NUMBER	0.21057E 01	0.21059E 01	-0.17099E 00	-0.17093E 00	0.20566E 01	0.20566E 01	-0.16986E 00
DEW PT. / BUBBLE PT.,F	0.26769E 03	0.26769E 03	-0.19856E 02	-0.19643E 02	-0.19836E 02	-0.18698E 02	-0.16028E 02
ENTHALPY, BTU/LB-MOLE	0.30489E 04	0.30489E 04	0.14093E 04	0.14093E 04	-0.22003E 04	-0.22003E 04	0.14093E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.33670E 02	0.33672E 02	0.22396E 02	0.22396E 02	0.22396E 02	0.22396E 02	0.22396E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.36568E 00	0.36572E-04	0.11825E 02	0.37840E 02	0.11707E 02	0.26015E 02	0.11824E 02
10 MONOCHLOROSILANE	0.10450E 02	0.10451E-02	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.26894E 02	0.26896E-02	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.28515E 02	0.28518E-02	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.78174E 00	0.78182E-04	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.67006E 02	0.67012E-02	0.11825E 02	0.37840E 02	0.11707E 02	0.26015E 02	0.11824E 02

STREAM NUMBER	234	235	236	237	238	239	240
TEMPERATURE, DEG F.	0.12600E 03	0.12600E 03	0.32751E 03	0.15800E 03	0.21799E 03	0.26701E 03	-0.25708E 02
PRESSURE, PSIA	0.37410E 03	0.60000E 02	0.32000E 03	0.85000E 02	0.55000E 02	0.36000E 03	0.35410E 03
LIQUID FRACTION	0.0	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.0
VISCOSITY, CENTIPOISE	0.12786E-01	0.12262E-01	0.99767E-01	0.22948E 00	0.24723E 00	0.10088E 00	0.10388E-01
THER.COND., BTU/HR-FT-F	0.13768E-01	0.12687E-01	0.42580E-01	0.47571E-01	0.43483E-01	0.35237E-01	0.98717E-02
DENSITY, LB-MOLE/FT**3	0.66750E-01	0.97094E-02	0.45048E 00	0.58321E 00	0.44789E 00	0.56317E 00	0.11013E 00
SURFACE TENSION, DYNES/CM	0.0	0.0	0.31828E 01	0.11625E 02	0.11397E 02	0.35296E 01	0.0
PRANDTL NUMBER	0.69854E 00	0.63836E 00	0.18712E 01	0.27084E 01	0.27518E 01	0.21059E 01	-0.17099E 00
DEW PT. / BUBBLE PT.,F	-0.16028E 02	-0.11544E 03	0.32783E 03	0.20199E 03	0.21932E 03	0.26769E 03	-0.19836E 02
ENTHALPY, BTU/LB-MOLE	0.29548E 04	0.32939E 04	0.53263E 04	-0.52852E 03	0.28212E 04	0.30489E 04	0.14093E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.99875E 01	0.87694E 01	0.44928E 02	0.31586E 02	0.33713E 02	0.33672E 02	0.22396E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.11824E 02	0.11824E 02	0.0	0.0	0.0	0.36572E 00	0.11824E 00
10 MONOCHLOROSILANE	0.0	0.0	0.94278E-02	0.94278E-05	0.0	0.10451E 02	0.0
11 DICHLOROSILANE	0.0	0.0	0.17661E 01	0.17661E-02	0.15675E-01	0.26896E 02	0.0
12 TRICHLOROSILANE	0.0	0.0	0.28530E 03	0.28530E 00	0.82148E 01	0.28517E 02	0.0
13 SILICON TETRACHLORIDE	0.0	0.0	0.68418E 01	0.68418E-02	0.19605E 03	0.78182E 00	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.11824E 02	0.11824E 02	0.29392E 03	0.29392E 00	0.20428E 03	0.67011E 02	0.11824E 00

TABLE C-III: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 1)

STREAM NUMBER	242	243	300	301	303	307	308
TEMPERATURE, DEG F.	0.26701E 03	0.26701E 03	0.77000E 02	0.15621E 04	0.11200E 04	0.26000E 04	0.11200E 04
PRESSURE, PSIA	0.36000E 03	0.36000E 03	0.25000E 02	0.20000E 02	0.20000E 02	0.20000E 02	0.20000E 02
LIQUID FRACTION	0.10000E 01	0.0	0.0	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.87182E-01	0.16048E-01	0.11295E-01	0.23056E-01	0.27579E-01	0.30414E-01	0.19253E-01
THER.COND., BTU/HR-FT-F	0.34648E-01	0.96624E-02	0.10989E-01	0.29363E 00	0.88681E-01	0.39094E 00	0.24771E 00
DENSITY, LB-MOLE/FT**3	0.56309E 00	0.63530E-01	0.43805E-02	0.92157E-03	0.11794E-02	0.60901E-03	0.11794E-02
SURFACE TENSION, DYNES/CM	0.28458E 01	0.0	0.0	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.18684E 01	0.45695E 00	0.65823E 00	0.66165E 00	0.18661E 00	0.74574E 00	0.66508E 00
DEW PT. / BUBBLE PT.,F	0.22698E 03	0.26712E 03	-0.14902E 03	-0.27861E 03	-0.17461E 03	-0.45834E 03	-0.45849E 03
ENTHALPY, BTU/LB-MOLE	0.33272E 04	0.76651E 04	0.29085E 04	0.14134E 05	0.10740E 05	0.22063E 05	0.10952E 05
SPECIFIC HEAT, BTU/LB-MO-F	0.23999E 02	0.10540E 02	0.85034E 01	0.72852E 01	0.46962E 01	0.79883E 01	0.71311E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.23531E 02	0.46089E-01	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.36660E 01	0.33003E 01	0.11824E 02	0.59122E-01	0.59122E-01	0.0	0.0
10 MONOCHLOROSILANE	0.27073E 02	0.16622E 02	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.45109E 02	0.18213E 02	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.38838E 02	0.10321E 02	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.93196E 00	0.15014E 00	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.11562E 03	0.48606E 02	0.11824E 02	0.23590E 02	0.10521E 00	0.0	0.0

STREAM NUMBER	311	312	313	314	2400	2401	2403
TEMPERATURE, DEG F.	0.15621E 04	0.15001E 03	0.15001E 03	0.77000E 02	0.10000E 03	0.10000E 03	0.10000E 03
PRESSURE, PSIA	0.20000E 02	0.15800E 02	0.55000E 03	0.50000E 02	0.20000E 02	0.20000E 02	0.20000E 02
LIQUID FRACTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.22833E-01	0.99894E-02	0.99432E-02	0.91464E-02	0.18380E-01	0.18380E-01	0.18380E-01
THER.COND., BTU/HR-FT-F	0.29541E 00	0.11770E 00	0.11915E 00	0.10581E 00	0.15507E-01	0.15507E-01	0.15507E-01
DENSITY, LB-MOLE/FT**3	0.92157E-03	0.24134E-02	0.82300E-01	0.86632E-02	0.33311E-02	0.33311E-02	0.33311E-02
SURFACE TENSION, DYNES/CM	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.67890E 00	0.70920E 00	0.69996E 00	0.72381E 00	0.69967E 00	0.69967E 00	0.69967E 00
DEW PT. / BUBBLE PT.,F	-0.45847E 03	-0.45841E 03	-0.45843E 03	-0.45838E 03	-0.31554E 03	-0.31554E 03	-0.31554E 03
ENTHALPY, BTU/LB-MOLE	0.14145E 05	0.41508E 04	0.41696E 04	0.36431E 04	0.38794E 04	0.38794E 04	0.38794E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.73199E 01	0.69640E 01	0.69900E 01	0.69785E 01	0.68363E 01	0.68363E 01	0.68363E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.23484E 02	0.23484E 02	0.28610E 02	0.51259E 01	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.17950E 01	0.59833E 00	0.50090E 01
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.23484E 02	0.23484E 02	0.28610E 02	0.51259E 01	0.17950E 01	0.59833E 00	0.50090E 01

TABLE C-III: ... 1000 MT/YR COMMERCIAL PLANT PHYSICAL
(continued) PROPERTIES FOR PROCESS STREAMS (ISSUE 1)

STREAM NUMBER	2404	2600	2601	2402	2501	2502	1500
TEMPERATURE, DEG F.	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	-0.20992E 02	0.10000E 03	0.77000E 02
PRESSURE, PSIA	0.20000E 02	0.70000E 02	0.70000E 02	0.20000E 02	0.90000E 02	0.51070E 03	0.16000E 03
LIQUID FRACTION	0.0	0.10000E 01	0.10000E 01	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.23489E-01	0.57718E-01	0.34805E-02	0.18380E-01	0.98391E-02	0.93727E-02	0.23193E-01
THER.COND., BTU/HR-FT-F	0.11473E-01	0.45892E-01	0.38000E-01	0.15507E-01	0.84090E-01	0.11098E 00	0.10677E-01
DENSITY, LB-MOLE/FT**3	0.33326E-02	0.82605E-01	0.68400E-01	0.33311E-02	0.19072E-01	0.83266E-01	0.27991E-01
SURFACE TENSION, DYNES/CM	0.0	0.82605E-01	0.68400E-01	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.64051E 00	0.64558E 00	0.76643E 00	0.69967E 00	0.36795E 00	0.70929E 00	0.67124E 00
DEW PT. / BUBBLE PT.,F	-0.24779E 03	-0.45853E 03	-0.45831E 03	-0.31554E 03	0.11821E 01	-0.45841E 03	-0.24667E 03
ENTHALPY, BTU/LB-MOLE	0.27972E 04	0.24879E 04	0.38042E 04	0.38794E 04	0.30165E 04	0.38185E 04	0.26299E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.50770E 01	0.12344E 02	0.69733E 01	0.68363E 01	0.75121E 01	0.69988E 01	0.51023E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.46089E-01	0.16583E-01	0.0	0.0	0.45522E 01	0.0	0.0
2 NITROGEN	0.0	0.46044E 01	0.0	0.46044E 01	0.88491E-02	0.0	0.0
3 ARGON	0.31102E 01	0.0	0.0	0.0	0.0	0.0	0.10640E 01
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.47199E-05	0.0	0.0	0.23278E-02	0.0	0.0
9 SILANE	0.59122E-01	0.23859E-06	0.0	0.0	0.11815E 00	0.0	0.0
10 MONOCHLOROSILANE	0.0	0.31619E-04	0.0	0.0	0.18888E-01	0.0	0.0
11 DICHLOROSILANE	0.0	0.58189E-02	0.0	0.0	0.18650E 00	0.0	0.0
12 TRICHLOROSILANE	0.0	0.31873E 00	0.0	0.0	0.21519E-01	0.0	0.0
13 SILICON TETRACHLORIDE	0.0	0.13842E 01	0.0	0.0	0.82320E-03	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.32154E 01	0.63298E 01	0.0	0.46044E 01	0.49088E 01	0.0	0.10640E 01

STREAM NUMBER	1501	
TEMPERATURE, DEG F.	0.77000E 02	0.0
PRESSURE, PSIA	0.16000E 03	0.0
LIQUID FRACTION	0.0	0.0
VISCOSITY, CENTIPOISE	0.23193E-01	0.0
THER.COND., BTU/HR-FT-F	0.10677E-01	0.0
DENSITY, LB-MOLE/FT**3	0.27991E-01	0.0
SURFACE TENSION, DYNES/CM	0.0	0.0
PRANDTL NUMBER	0.67124E 00	0.0
DEW PT. / BUBBLE PT.,F	-0.24667E 03	0.0
ENTHALPY, BTU/LB-MOLE	0.26299E 04	0.0
SPECIFIC HEAT, BTU/LB-MO-F	0.51023E 01	0.0
FLOW * ENTHALPY, BTU/HR	0.0	0.0
COMPOSITION, LB-MOLES/HR		
1 HYDROGEN	0.0	0.0
2 NITROGEN	0.0	0.0
3 ARGON	0.20462E 01	0.0
4 OXYGEN	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0
7 METHANE	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0
9 SILANE	0.0	0.0
10 MONOCHLOROSILANE	0.0	0.0
11 DICHLOROSILANE	0.0	0.0
12 TRICHLOROSILANE	0.0	0.0
13 SILICON TETRACHLORIDE	0.0	0.0
14 CHLORINE	0.0	0.0
15 STEAM/WATER	0.0	0.0
16 TOTAL MOLES	0.20462E 01	0.0

TABLE C-IV: EQUIPMENT LIST, 1000 MT/YR COMMERCIAL PLANT

VESSELS

Equipment No.	Equipment Name	No. Req'd	Type	Capacity	Material Of Construction	Cost (1st Q, '79)
411-02	M.G. Silicon Storage Bin	1	Bin	1750 cu.ft.	Steel	22,500
411-04	Hydrogen Supply Package	1	Tank	18,000 gal.	Steel	Rental*
421-02	M.G. Silicon Lock Hopper	1	Vert. Tank	450 gal.	Steel	13,400
421-04	Waste Settler Tank	1	Vert. Tank	1,700 gal.	304L Stainless	95,000
421-06	Waste Chlorides Tank	1	Vert. Tank	400 gal	Steel	7,100
421-08	Quench Condenser Receiver	1	Horiz. Tank	3,000 gal.	Steel	17,900
421-10	Crude TCS Storage Tank	1	Horiz. Tank	20,000 gal.	Steel	26,300
421-12	STC Storage Tank	1	API Tank	25,000 gal.	Steel	10,000
421-14	Recycle Hydrogen Receiver	1	Vert. Tank	750 gal.	Steel	7,600
421-16	Hydrogen Humidifier Tank	1	Vert. Tank	2.5 gal	Steel	100
431-02	Stripper Condenser Receiver	1	Vert. Tank	70 gal.	304L Stainless	3,500
431-04	Silane Storage Tank	4	Vert. Tank	800 gal.	304L Stainless	27,300 ea.
441-02	Product Powder Storage Hopper	14	Vert. Tank	65 gal.	304L Stainless	14,400 ea.
441-06	Pyrolysis Hydrogen Receiver	1	Vert. Tank	3,400 gal.	Steel	5,800
451-04	Liquid Burner Surge Tank	1	Horiz. Tank	1,300 gal.	Steel	6,300
451-06	Pressure Relief Catch Tank	1	Horiz. Tank	4,000 gal	Steel	11,000
451-08	Silica Dust Bin	1	Bin	2,400 cu.ft.	Steel	21,000
451-10	Waste Silica Neutralizer	1	Bin	200 cu.ft.	Steel	11,400
451-12	Strong Muriatic Pump Tank	1	Vert. Tank	2,500 gal.	Fiberglass	15,000
451-14	Weak Muriatic Pump Tank	1	Vert. Tank	2,500 gal.	Fiberglass	15,000
451-16	Muriatic Acid Storage Tank	1	Vert. Tank	15,000 gal.	Fiberglass	8,700
461-02	Hot Oil Expansion Tank	1	Horiz. Tank	350 gal.	Steel	15,000

*Monthly charge is $2300 for liquid tank and vaporizer coil

REACTORS

Equipment No.	Equipment Name	No. Req'd	Type	Diameter	Height	Material Of Construction	Cost (1st Q, '79)
425-02	Hydrogeneration Reactor	1	Fluid. Bed	2.5 ft.	21 ft.	Incoloy 800	142,500
435-02	TCS Redistribution Reactor	1	Packed	6 ft.	25 ft.	Steel	89,300*
435-04	DCS Redistribution Reactor	1	Packed	2 ft.	25 ft.	Steel	20,700*
445-02	Pyrolysis Reactor	14	Free Space	1.5 ft.	6 ft.	Quartz-lined	23,700 ea.

* includes cost of catalyst

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TABLE C-IV (continued): EQUIPMENT LIST, 1000 MT/YR COMMERCIAL PLANT

PUMPS

Equipment No.	Equipment Name	No. Req'd	Type	Design Flow	Design Head	Material Of Construction	Cost
426-02	Quench Contactor Pump	1	Centrifugal	500 GPM	100 PSI	Cast Iron/304 SS	7,500
426-04	Quench Condenser Wash Pump	1	Diaphragm	6.7 GPM	70 PSI	Steel	7,000
426-06	Recycle STC Pump	1	Diaphragm	60 GPM	550 PSI	Steel	18,000
436-02	TCS Distillate Pump	2	Diaphragm	180 GPM	300 PSI	Steel	33,000 ea.
436-04	DCS Distillate Pump	1	Diaphragm	120 GPM	270 PSI	Steel	38,000
456-02	Muriatic Acid Pump	2	Centrifugal	1000 GPM	60 PSI	Fiberglass	6,600 ea.
456-06	Silica Venturi Pump	1	Centrifugal	330 GPM	40 PSI	Fiberglass	2,300
466-02	Hot Oil Pump	2	Centrifugal	1600 GPM	50 PSI	Ductile Iron	5,500 ea.
466-04	Cooling Water Pump	2	Vert. Turb.	4100 GPM	75 PSI	416 SS	16,700 ea.

FILTERS

Equipment No.	Equipment Name	No. Req'd	Type	Design Capacity	Particle Size	Material Of Construction	Cost
417-02	M.G. Silicon Unloading Filter	1	Bag	500 GPM	1μ	Steel/Polyeth.	600
427-02	Crude TCS Filter	1	Edge	65 GPM	35μ	Steel	500
437-02	Silane Ultra-Filter	2	Micropore	4 ACFM	0.3μ	316 SS	250 ea.
457-02	Non-Combustibles Vent Filter	1	Bag	400 ACFM	1μ	Steel/Polyeth.	900
457-04	Combustibles Vent Filter	1	Bag	150 ACFM	1μ	Steel/Polyeth.	600
457-06	Silica Bag Filter	2	Bag	25,000 ACFM	1μ	Steel/Polyprop.	25,000 ea.

SOLIDS HANDLING

Equipment No.	Equipment Name	No. Req'd	Type	Capacity	Material Of Construction	Cost (1st Q, '79)
428-02	Hydrogeneration Catalyst Blender	1	Twin Shell	50 cu.ft.	Steel	19,100
458-02	Silica Collection Cyclone	1	Standard	2000 ACFM	Steel	1,500
458-04	Silica Drum Packer	1	Vibratory	One drum/minute	Steel	2,900
458-06	Silica Rotary Air Lock	1	Rotary Valve	120 CFM solids	Steel	9,400

COMPRESSORS

Equipment No.	Equipment Name	No. Req'd	Design Flow	Design Head	Material Of Construction	Cost (1st Q, '79)
423-02	Recycle Hydrogen Compressor	1	55 ACFM	90 PSI	Steel	150,000
443-02	Pyrolysis Hydrogen Comp. 1st Stage	1	200 ACFM	550 PSI	Steel	115,000
443-04	Pyrolysis Hydrogen Comp. 2nd Stage	1	-	-	-	443-04*
453-02	Agglomerator Blower	1	65,000 ACFM	10 In. W.C.	Steel	14,000
453-04	Waste Gas Induction Blower	2	25,000 ACFM	100 In. W.C.	Steel	25,000 ea.

*Item cost is included in item cost corresponding to this equipment number.

TABLE C-IV (continued): EQUIPMENT LIST, 1000 MT/YR COMMERCIAL PLANT

COLUMNS

Equipment No.	Equipment Name	No. Req'd	Type	Diameter	Number Of Trays	Material Of Construction	Cost
432-02	Stripper Column	1	Trayed	2.5 ft.	25	Steel	21,300
432-04	TCS Column	1	Trayed	6 ft.	30	Steel	56,700
432-06	DCS Column	1	Trayed	6 ft.	62	Steel	107,500
432-08	Silane Column	1	Trayed	1.5 ft.	58	304L Stainless	54,300
452-02	Muriatic Tailing Column	1	Packed	4 ft.	15 ft. pack	Fiberglass	15,000

HEAT EXCHANGERS

Equipment No.	Equipment Name	No. Req'd	Type	Design Duty (Btu/Hr)	Material Of Construction	Cost (1st Q, '79)
424-02	Quench Condenser	1	Fixed Tbsht	9,840,000	Steel/Cupronickel	77,500
424-04	Recycle STC Vaporizer	1	Kettle	4,450,000	Steel/304 SS	8,400
434-02	Stripper Condenser	1	Fixed Tbsht	350,000	Nickel Steel	4,200
434-04	Stripper Reboiler	1	Kettle	1,630,000	Steel	5,000
434-06	TCS Column Reboiler	1	Kettle	8,180,000	Steel	9,700
434-08	TCS Column Condenser	1	Fixed Tbsht	8,630,000	Steel/Cupronickel	15,600
434-10	DCS Column Reboiler	1	Kettle	5,980,000	Steel	9,700
434-12	TCS Cooler	1	Fixed Tbsht	2,480,000	Steel/Cupronickel	6,100
434-14	DCS Column Condenser	1	Fixed Tbsht	3,500,000	Steel/Cupronickel	5,000
434-16	DCS Cooler	1	Hairpin	380,000	Steel	800
434-18	Silane Column Condenser	1	Fixed Tbsht	160,000	Ni Steel/304 SS	4,400
434-20	Silane Column Reboiler	1	Kettle	580,000	304 SS	5,100
434-22	Silane Superheater	1	Hairpin	23,000	304 SS	2,800
434-24	STC Cooler	1	Hairpin	790,000	Steel	800
434-26	Silane Vaporizer	4	Finned Pipe	60,000	304 SS	5,400 ea
434-28	Silane Storage Cooler	4	Internal Coil	20,000	304 SS	1,250 ea
444-02	Pyrolysis Hydrogen Cooler	1	Fixed Tbsht	320,000	Steel/Cupronickel	5,300
444-04	Pyrolysis H_2 Comp. Intercooler	1	Hairpin	224,000	Steel	443-02*
454-02	Muriatic Acid Cooler	1	Fixed Tbsht	1,230,000	Steel/Hastelloy B	25,000

* Item cost is included in item cost corresponding to this equipment number.

TABLE C-IV (continued): EQUIPMENT LIST, 1000 MT/YR COMMERCIAL PLANT

MISCELLANEOUS

Equipment No.	Equipment Name	No. Req'd	Design Specifications	Material Of Construction	Cost (1st Q, '79)
429-02	Quench & Solids Removal Contactor	1	210 ACFM gas at suction	304 stainless	15,000
429-04	Gas Superheater Furnace	1	5.57 MM Btu/hr fired output	Steel/Firebrick	44,000
429-06	Recycle STC Superheater	1	3,680,000 Btu/hr duty	304 Stainless	429-04*
429-08	Recycle Hydrogen Superheater	1	1,890,000 Btu/hr duty	304 Stainless	429-04*
439-02	DCS Distillate Pump Accumulator	1	1 cu.ft. dry seal accumulator	Steel	1,200
449-02	Storage Hopper Accumulator	1	2 cu.ft. dry seal accumulator	Steel	400
449-04	Product Melter	14	12 in. crucible, 80 KW input	Quartz Crucible	50,000 ea.
459-02	Silica Venturi	1	24,000 ACFM gas at suction	Fiberglass	30,000
459-04	Strong Muriatic Scrubber	1	20,000 ACFM gas at suction	Fiberglass	4,500
459-06	Weak Muriatic Scrubber	1	20,000 ACFM gas at suction	Fiberglass	4,500
459-08	Waste Gas Burner #1	2	32 SCFM waste gas	Steel	10,300
459-10	Waste Gas Burner #2	1	28 SCFM waste gas	Steel	12,600 ea.
459-14	Waste Liquid Burner	1	80 GPH waste liquid	Steel	12,900
459-16	Silica Agglomerator	1	9,160,000 Btu/hr duty	Steel	30,300
469-02	Cooling Tower	1	4100 GPM recirculation, 2 cell	Wood	45,200
469-06	Cooling Tower Make-up	1	93 GPM makeup	Steel	8,200
469-12	Refrigeration System	1	65 tons @ -40°F brine	-	250,000
469-16	Hot Oil Heating Furnace	1	31 MM Btu/hr duty	-	81,000

* Item cost is included in item cost corresponding to this equipment number

TABLE C-V: EQUIPMENT SPECIFICATION, HYDROGENATION REACTOR

Issue Date 3/31/79
Rev MOD IX Report

EQUIPMENT NO. 125-02

EQUIPMENT NAME Hydrogenation Reactor

PROJECT NAME 1000 MT/Yr Commercial Plant

NO. REQD One (1)

Type Reactor: Packed [ ]

Fluidized Bed [X] Free Space [ ]

Reactor Geometry (See Sketch)

Height 30 ft overall

Diameter 2.5 ft x 6 ft

Temperature, Operating 1000°F Design 1100°F

Pressure, Operating 515 psia Design 615 psia

Temperature Control Method Superheater firing rate controls reactor temperature

Heats of Reaction

+8 k cal/g mole (endothermic)

Inlet Streams Chlorosilanes, hydrogen, metallurg. silicon

Effluent Streams Chlorosilanes, hdyrogen, silicon fines

Material of Construction Incoloy 800

REMARKS:

Conical internals are sheet metal and serve to distribute feeds at bottom and reduce eddying near top to reduce carryover of fines.

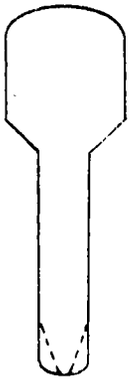

TABLE C-VI: EQUIPMENT SPECIFICATION, STRIPPER COLUMN

Issue Date 3/31/79
Rev MOD IX Report

EQUIPMENT NO. 432-02

EQUIPMENT NAME Stripper Column

PROJECT NAME 1000 MT/Yr Commercial Plant

NO. REQD One (1)

Column Diameter	2.5 ft	No. of Trays	25
Column Height	30 ft	Type of Trays	Single Pass Crossflow
Feed Tray(s)	1 and 18	Tray Spacing	8 inches

Design Duties

Reboiler	1,630,000 Btu/hr	Connections: Feed #1 3", Feed #2 1", Reflux 3", Boilup 4", Bottoms 3", Overheads 3"
Condenser	335,000 Btu/hr	

External Reflux Ratio 1.93

	Column Top	Column Bottom
Liquid Density lb/ft^3	89.4	73.4
Vapor Density lb/ft^3	1.34	2.22
Liquid Viscosity, cp	0.51	0.21
Vapor Viscosity, cp	0.012	0.014
Liq. Sp. Ht., Btu/lb ^oF	0.21	0.229
Vap. Sp. Ht., Btu/lb ^oF	0.201	0.168
Surface Tension, Dynes/cm	5.90	9.44
Relative Volatility	7.36	2.92

Light Key Hydrogen Sulfide Heavy Key Trichlorosilane

Maximum Solid Size 50 microns

Design Temp. 300°F, -50°F

Material of Construction 3½ Nickel steel

Design Press. 115 psia

REMARKS:

TABLE C-VII: EQUIPMENT SPECIFICATION, TCS COLUMN

Issue Date 3/31/79
Rev MOD 1X Report

EQUIPMENT NO. 435-04

EQUIPMENT NAME TCS Column

PROJECT NAME 1000 MT/Yr Commercial Plant

NO. REQD One (1)

Column Diameter	6 ft	No. of Trays	30
Column Height	30 ft	Type of Trays	Single Pass Crossflow
Feed Trays(s)	5 and 18	Tray Spacing	7 inches

Design Duties

Reboiler 8,179,000 Btu/hr

Condenser 8,801,000 Btu/hr

Connections: Feed #1 6", Feed #2 3", Reflux 3", Boilup 6", Bottoms 3", Overheads 6"

External Reflux Ration 1.30

	Column Top	Column Bottom
Liquid Density lb/ft^3	79.5	75.2
Vapor Density lb/ft^3	1.08	1.36
Liquid Viscosity, cp	0.23	0.25
Vapor Viscosity, cp	0.013	0.011
Liq. Sp. Ht., Btu/lb - °F	0.244	0.201
Vap. Sp. Ht., Btu/lb - °F	0.142	0.152
Surface Tension, dynes/cm	12.0	11.6
Relative Volatility	1.75	2.21

Light Key Trichlorosilane Heavy Key Silicon Tetrachloride

Maximum Solid Size 50 microns

Design Temp. 300°F

Material of Construction Steel

Design Press. 90 psia

REMARKS:

TABLE C-VIII: EQUIPMENT SPECIFICATION, DCS COLUMN

Issue Date 3/31/79
Rev MOD IX Report

EQUIPMENT NO. 432-06

EQUIPMENT NAME DCS Column

PROJECT NAME 1000 MT/Yr Commercial Plant

NO. REQD One (1)

Column Diameter	6 ft	No. of Trays	62
Column Height	52 ft	Type of Trays	Single Pass Crossflow
Feed Trays(s)	39 and 53	Tray Spacing	7 inches, 8 inches

Design Duties

Reboiler	5,976,000 Btu/hr	Connections: Feed #1 3", Feed #2 1", Reflux 3", Boilup 6", Bottoms 6", Overheads 6"
Condenser	3,504,000 Btu/hr	

External Reflux Ratio 5.06

	Column Top	Column Bottom
Liquid Density lb/ft^3	60.9	61.5
Vapor Density lb/ft^3	5.67	7.46
Liquid Viscosity, cp	0.086	0.10
Vapor Viscosity, cp	0.016	0.018
Liq. Sp. Ht., Btu/lb °F	0.279	0.307
Vap. Sp. Ht., Btu/lb °F	0.157	0.195
Surface Tension, Dynes/cm	3.25	3.19
Relative Volatility	1.41	1.57

Light Key Dichlorosilane Heavy Key Trichlorosilane

Maximum Solid Size 50 microns Design Temp. 400°F

Material of Construction Steel Design Press. 415 psia

REMARKS:

TABLE C-IX: EQUIPMENT SPECIFICATION, SILANE COLUMN

Issue Date 3/31/79
Rev MOD IX Report

EQUIPMENT NO. 432-08

EQUIPMENT NAME Silane Column

PROJECT NAME 1000 MT/Yr Commercial Plant

NO. REQD One (1)

Column Diameter 1.5 ft

No. of Trays 58

Column Height 45 ft

Type of Trays Single Pass Crossflow

Feed Trays(s) 11

Tray Spacing 7 inches, 8 inches

Design Duties

Reboiler 580,000 Btu/hr

Condenser 160,000 Btu/hr

Connections: Feed 2", Reflux 1", Boilup 3", Bottoms 2", Overheads 1"

External Reflux Ratio 2.20

	Column Top	Column Bottom
Liquid Density lb/ft^3	29.0	62.3
Vapor Density lb/ft^3	3.58	5.11
Liquid Viscosity, cp	0.057	0.10
Vapor Viscosity, cp	0.010	0.017
Liq. Sp. Ht., Btu/lb °F	0.700	0.304
Vap. Sp. Ht., Btu/lb °F	0.695	0.157
Surface Tension, Dynes/cm	3.05	3.52
Relative Volatility	2.131	0.942

Light Key Silane

Heavy Key Diborane

Maximum Solid Size 50 microns

Design Temp. 300°F, -50°F

Material of Construction 304 L Stainless

Design Press. 615 psia

REMARKS:

TABLE C-X: EQUIPMENT SPECIFICATION, TCS REDISTRIBUTION REACTOR

Issue Date 3/31/79
Rev MOD IX Report

EQUIPMENT NO. 435-02

EQUIPMENT NAME TCS Redistribution Reactor PROJECT NAME 1000 MT/YR Commercial Plant

NO. REQD One (1)

Type Reactor: Packed [X]

Fluidized Bed [ ] Free Space [ ]

Reactor Geometry (See Sketch)

Height 25 ft overall

Diameter 6 ft

Temperature, Operating 160°F Design 200°F

Pressure, Operating 310 psia Design 415 psia

Temperature Control Method Pre-cooler with bypass control

Heats of Reaction

None

Flowrates:

Inlet Streams Chlorosilane Liquids

Effluent Streams Chlorosilane Liquids

Material of Construction Steel

REMARKS:

15 ft packed height using amine-based Rohm & Haas A-21 catalyst.

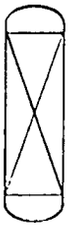

TABLE C-XI: EQUIPMENT SPECIFICATION, DCS REDISTRIBUTION REACTOR

Issue Date 3/31/79
Rev. MON IX Report

EQUIPMENT NO. 435-04

EQUIPMENT NAME DCS Redistribution Reactor

PROJECT NAME 1000 MT/YR Commercial Plant

NO. REQD One (1)

Type Reactor: Packed [X]

Fluidized Bed [ ] Free Space [ ]

Reactor Geometry (See Sketch)

Height 25 ft overall

Diameter 2 ft

Temperature, Operating 120°F Design 200°F

Pressure, Operating 565 psia Design 765 psia

Temperature Control Method Pre-cooler with bypass control

Heats of Reaction

None

Inlet Streams Chlorosilane Liquids

Effluent Streams Chlorosilane Liquids

Material of Construction Steel

REMARKS:

15 ft packed height using amine-based Rohm & Haas A-21 catalyst.

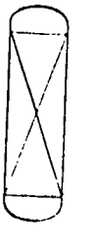

TABLE C-XII: EQUIPMENT SPECIFICATION, PYROLYSIS REACTOR

Issue Date 3/31/79
Rev MOD IX Report

EQUIPMENT NO. 445-02

EQUIPMENT NAME Pyrolysis Reactor

PROJECT NAME 1000 MT/Yr Commercial Plant

NO. REQD Fourteen (14)

Type Reactor: Packed [ ]

Fluidized Bed [ ] Free Space [XX]

Reactor Geometry (See Sketch)

Height 4 ft

Diameter 1.5 ft .id liner x 3 ft od shell

Temperature, Operating 1500°F Design 1800°F

Pressure, Operating 20 psia Design 25 psia

Temperature Control Method Resistance heaters

Heats of Reaction

- 8 k cal/g mole (exothermic)

Inlet Streams Silane gas @ 100°F

Effluent Streams Silicon Powder, hydrogen

Material of Construction Quartz liner, 304 stainless injector

REMARKS:

Reactor is made up of quartz liner in an Incoloy 800 vessel, surrounded by resistance heating elements, insulation and a steel outer shell. Unit is attached to equipment beneath with a water-coolded flange.

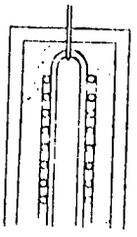

TABLE C-XIII

ELEMENTS OF PLANT CAPITAL COST, 1000 MT/YR

	1979 Dollars
Mechanical Contract	$2,742,400
Process Equipment, Erected	3,813,600
Construction Field Support	149,500
Engineering	1,019,400
Contingency @ 12%	1,053,700
Total Plant Cost	$8,778,600

NOTES:

1. Mechanical contract includes site preparation, foundations, support steel, buildings, piping, electrical and instrumentation.
2. Process equipment, erected include: process equipment, freight, erection and equipment insulation.
3. Contingency percentage is a weighted average of the percentages for various elements from historical experience.

TABLE C-XIV

ELEMENTS OF ANNUAL OPERATING COST, 1000 MT/YR

	1979 Dollars	
RAW MATERIALS		
Metallurgical grade silicon	$1,681,900	
Hydrogen	225,900	
Technical Grade Silicon Tetrachloride	391,900	
Cement Copper	60,000	
Chemical Lime	300	
		$2,360,000
CONSUMABLES		
Redistribution Catalyst	$ 74,000	
Pyrolysis Reactor Liners	89,600	
Melter Crucibles	182,600	
Chromatographs	21,600	
Epitaxial Reactor	18,100	
Wet Chemical Analysis	6,000	
		$ 391,900
UTILITIES		
Electrical Power	$ 487,900	
Natural Gas	290,900	
Potable Water	21,500	
Water Treatment Chemicals	13,500	
Purge Nitrogen	25,900	
Purge Argon	17,400	
Landfill Disposal	400	
		$ 857,500
MANPOWER*		
Labor	$ 582,500	
Maintenance	254,100	
Clerical	43,000	
Analytical	129,100	
Supervision	262,200	
		$1,270,900
MAINTENANCE MATERIALS		
Equipment Parts		$ 269,700
PROPERTY TAXES AND INSURANCE		
Total		$ 103,800

*See Table C-XV for manpower staffing and duty summary.

TABLE C-XIV (Cont'd.)

PERIOD COSTS	1979 Dollars	
Office materials, equipment rental	$ 10,800	
Telephone, postage	8,400	
Service vehicle	3,600	
Guard service	4,800	
Trash removal	2,400	
Supervisory expense account	20,400	
Supervisory relocation expense	26,000	
Miscellaneous	16,800	
		$ 93,200
HOME OFFICE CHARGE		
Total		10% of Sales
TOTAL ANNUAL OPERATING COST		$5,347,000
		+ 10% of Sales

TABLE C-XV

MANPOWER STAFFING, 1000 MT/YR

Staff	Day Workers	Shift Workers 1st	Shift Workers 2nd	Shift Workers 3rd	Total Employed
Silane Area Operators	--	2	2	2	9
Pyrolysis Area Operators	--	2	2	2	9
Silane Area Mechanic	1	--	--	--	1
Pyrolysis Area Mechanics	--	1	1	1	5
Mechanics Helpers	2	--	--	--	2
Instrument Mechanic	1	--	--	--	1
Utility Man	1	--	--	--	1
Lab Technicians	--	1	1	1	4
Secretary	1	--	--	--	1
Accountant	1	--	--	--	1
Foreman	--	1	1	1	5
Chemist	1	--	--	--	1
Plant Engineer	1	--	--	--	1
Plant Superintendent	1	--	--	--	1
Total Employment					42

SUMMARY OF DUTIES:

Silane area operators - oversee main plant, except pyrolysis area. One man is stationed in control room.

Pyrolysis area operators - oversee pyrolysis reactors and melters. One man is stationed at each bank of seven stacked units.

Silane area mechanic - repair plant equipment, except pyrolysis area quartzware.

Pyrolysis area mechanics - rebuild quartzware.

Mechanics helpers - assist mechanics as necessary in all plant areas.

Instrument mechanic - repair plant instrumentation.

Utility man - general area labor, especially around waste treatment equipment to pack out fumed silica.

Lab technicians - operate gas chromatographs, epitaxial reactor and perform wet chemistry.

TABLE C-XVI

ELEMENTS OF START-UP COST, 1000 MT/YR

	(1st Qtr 1979 Dollars)
Wages during pre-hiring and training	
Operating Labor	$ 88,700
Foreman	40,400
Accountant cleric	5,400
Lab Technicians	13,400
Supervisory	50,400
	$ 198,300
Preparation of Operating Instructions	$ 43,000
Engineering Assistance	
Liaison to construction	$ 35,000
Training Assistance	17,000
Checkout Assistance	17,000
Startup Assistance	47,000
	$ 116,000
Operating Costs, including overtime	$ 912,600
Equipment rework costs	$ 310,000
Total start-up costs	$1,579,900

TABLE C-XVII

ELEMENTS OF WORKING CAPITAL, 1000 MT/YR

	Dollars (1st Qtr 1979)
ACCOUNTS PAYABLE	
Raw Materials	$ 194,000
Utilities	82,200
Labor	38,300
Property Taxes	8,500
Income Taxes	189,200
	$ 512,200
ACCOUNTS RECEIVABLE	
Total	11% of sales
INVENTORY	
Raw Materials	$ 90,500
Spares and Consummables	48,300
	$ 138,800
TOTAL WORKING CAPITAL	$ 651,000
	+ 11% of sales

The basis of this table is as follows:

Accounts Payable:	Raw Materials	30 days
	Utilities	35 days
	Labor	11 days
	Taxes (Property & Income)	45 days
Accounts Receivable:		40 days
Inventory:		14 days

APPENDIX D

120 MT/YR COMMERCIAL PLANT (ISSUE 1)

SECTIONS OF APPENDIX D

Table	Title	Page
D-I	Equipment List, 120 MT/Yr Commercial Plant	D - 2
D-II	Elements of Plant Capital Cost, 120 MT/Yr	D - 6
D-III	Elements of Annual Operating Cost, 120 MT/Yr	D - [illegible]

TABLE D-I EQUIPMENT LIST, 120 MT/YR COMMERCIAL PLANT

VESSELS

Equipment No.	Equipment Name	No. Req'd	Type	Capacity	Material Of Construction	Cost (1st Q, '79)
411-02	M.G. Silicon Storage Bin	1	Bin	900 cu ft	Steel	4,790
411-06	Hydrogen Cylinder Bank	1	48 cylinders	3000 SCF	Steel	Rental
421-02	M.G. Silicon Lock Hopper	1	Vert. Tank	55 gal.	Steel	2,270
421-04	Waste Settler Tank	1	Vert. Tank	300 gal.	304L Stainless	10,090
421-06	Waste Chlorides Tank	1	Vert. Tank	59 gal.	Steel	13,760
421-08	Quench Condenser Receiver	1	Horiz. Tank	375 gal.	Steel	6,330
421-10	Crude TCS Storage Tank	1	Horiz. Tank	5000 gal.	Steel	10,260
421-12	STC Storage Tank	1	Vert. Tank	3500 gal.	Steel	8,210
421-14	Recycle Hydrogen Receiver	1	Vert. Tank	140 gal.	Steel	6,840
421-16	Hydrogen Humidifier Tank	1	Vert. Tank	0.3 gal.	Steel	100
431-02	Stripper Condenser Receiver	1	Vert. Tank	10 gal.	304L Stainless	1,030
431-04	Silane Storage Tank	4	Vert. Tank	430 gal.	304L Stainless	15,210 ea
441-02	Product Powder Storage Hopper	3	Vert. Tank	65 gal.	304L Stainless	14,400 ea
441-06	Pyrolysis Hydrogen Receiver	1	Vert. Tank	450 gal.	Steel	5,040
451-04	Liquid Burner Surge Tank	1	Horiz. Tank	160 gal.	Steel	4,170
451-06	Pressure Relief Catch Tank	1	Horiz. Tank	500 gal.	Steel	4,170
451-08	Silica Dust Bin	1	Bin	1410 cu ft.	Steel	9,220
451-10	Waste Silica Neutralizer	1	Bin	200 gal.	Steel	5,700
451-12	Strong Muriatic Pump Tank	1	Vert. Tank	450 gal.	Fiberglass	7,500
451-14	Weak Muriatic Pump Tank	1	Vert. Tank	450 gal.	Fiberglass	7,500
451-16	Muriatic Acid Storage Tank	1	Vert. Tank	3500 gal.	Fiberglass	4,350
461-02	Hot Oil Expansion Tank	1	Horiz. Tank	190 gal.	Steel	469-16*

* Item cost is included in item cost corresponding to this equipment number.

REACTORS

Equipment No.	Equipment Name	No. Req'd	Type	Diameter	Height	Material Of Construction	Cost (1st Q, '79)
425-02	Hydrogenation Reactor	1	Fluidized Bed	20"/34"	24 ft.	Incoloy 800	43,500
435-02	TCS Redistribution Reactor	1	Packed	2 ft.	25 ft.	Steel	20,700*
435-04	DCS Redistribution Reactor	1	Packed	2 ft.	25 ft.	Steel	20,700*
445-02	Pyrolysis Reactor	3	Free Space	3 ft.	9 ft.	Incoloy 800	23,700 ea.

* Includes cost of catalyst

TABLE D-I (continued): EQUIPMENT LIST, 120 MT/YR COMMERCIAL PLANT

PUMPS

Equipment No.	Equipment Name	No. Req'd	Type	Design Flow	Design Head	Material Of Construction	Cost (1st Q, '79)
426-02	Quench Contactor Pump	1	Diaphragm	3600 GPH	100 PSI	304/316SS	7610
426-04	Quench Condenser Wash Pump	1	Diaphragm	45 GPH	70 PSI	Steel	1300
426-06	Recycle STC Pump	1	Diaphragm	450 GPH	550 PSI	Steel	8120
436-02	TCS Distillate Pump	2	Diaphragm	1300 GPH	300 PSI	Steel	14,700 ea.
436-04	DCS Distillate Pump	1	Diaphragm	850 GPH	270 PSI	Steel	9,300
456-02	Muriatic Acid Pump	2	Centrifugal	120 GPM	61 PSI	Fiberglass	3,500 ea.
456-06	Silica Venturi Pump	1	Centrifugal	40 GPM	33 PSI	Fiberglass	2,000 ea.
466-02	Hot Oil Pump	2	Centrifugal	195 GPM	48 PSI	Steel	469-16*
466-04	Cooling Water Pump	2	VertiTurbine	500 GPM	75 PSI	Steel	469-02*

*Item cost is included in item cost corresponding to this equipment number.

FILTERS

Equipment No.	Equipment Name	No. Req'd	Type	Design Capacity	Particle Size	Material Of Construction	Cost (1st Q, '79)
417-02	M.G. Silicon Unloading Filter	1	Bag	500 ACFM	10	Steel/Polyester	470
427-02	Crude TCS Filter	1	Edge	8 GPM	50	Steel	250
437-02	Silane Ultra-Filter	2	Micropore	0.5 ACFM	0.1	304 SS	380 ea.
457-02	Non-Combustibles Vent Filter	1	Bag	50 ACFM	1	Steel	560
457-04	Combustibles Vent Filter	1	Bag	20 ACFM	1	Steel	560
457-06	Silica Bag Filter	2	Bag	3000 ACFM	1	Steel	8150 ea.

SOLIDS HANDLING

Equipment No.	Equipment Name	No. Req'd	Type	Capacity	Material Of Construction	Cost (1st Q, '79)
428-02	Hydrogenation Catalyst Blender	1	Twin Shell	12 CF	Steel	7010
458-02	Silica Collection Cyclone	1	Cyclone	250 ACFM gas	Steel	1000
458-04	Silica Drum Packer	1	Vibratory	One drum/min.	Steel	2900

TABLE D-I (continued): EQUIPMENT LIST, 120 MT/YR COMMERCIAL PLANT

COMPRESSORS

Equipment No.	Equipment Name	No. Req'd	Design Flow	Design Head	Material Of Construction	Cost (1st Q '79)
423-02	Recycle Hydrogen Compressor	1	620 lb/hr	90 psi	Steel	26,500
443-02	Pyrolysis Hydrogen Comp. 1st stage	1	9 lb/hr	550 psi	Steel	63,500
443-04	Pyrolysis Hydrogen Comp. 2nd stage	1	---	---	---	443-02*
453-02	Agglomerator Blower	1	8000 ACFM	10 in W.C.	Steel	2,900
453-04	Waste Gas Induction Blower	1	3000 ACF	100 in W.C.	Cast Iron	14,000

* Item cost is included in item cost corresponding to this equipment number.

COLUMNS

Equipment No.	Equipment Name	No. Req'd	Type	Diameter	Number Of Trays	Material Of Construction	Cost (1st Q '79)
432-02	Stripper Column	1	Trayed	1.0 ft.	25	Steel	16,750
432-04	TCS Column	1	Trayed	2.5 ft.	30	Steel	25,470
432-06	DCS Column	1	Trayed	2.0 ft.	62	Steel	37,090
432-08	Silane Column	1	Trayed	0.33 ft.	58	304L Stainless	44,190
452-02	Muriatic Tailing Column	1	Packed	2.0 ft.	10 ft. pack.	Fiberglass	6,200

HEAT EXCHANGERS

Equipment No.	Equipment Name	No. Req'd	Type	Design Duty Btu/Hr	Material Of Construction	Cost (1st Q '79)
424-02	Quench Condenser	1	Fixed Tbsht	1,205,400	Steel/Cupronickel	32,910
424-04	Recycle STC Vaporizer	1	Kettler	544,700	Steel/304 S.S.	5,170
434-02	Stripper Condenser	1	Fixed Tbsht	40,900	3½ NiSteel	2,800
434-04	Stripper Reboiler	1	Tube coil	199,400	Steel	1,000
434-06	TCS Column Revoiler	1	Kettle	1,000,500	Steel	4,540
434-08	TCS Column Condenser	1	Fixed Tbsht	1,055,200	Steel/Cupronickel	4,670
434-10	DCS Column Reboiler	1	Kettle	731,000	Steel	4,790
434-12	TCS Cooler	1	Hairpin	304,000	Steel/Cupronickel	2,800
434-14	DCS Column Condenser	1	Fixed Tbsht	428,600	Steel/Cupronickel	2,910
434-16	DCS Cooler	1	Hairpin	46,000	Steel/Cupronickel	500
434-18	Silane Column Condenser	1	Fixed Tbsht	18,800	304 S.S.	2,800
434-20	Silane Column Reboiler	1	Tube Coil	70,700	304 S.S.	1,000
434-22	Silane Superheater	1	Tube Coil	28,000	Steel	800
434-24	STC Cooler	1	Hairpin	96,400	Steel/Cupronickel	2,800
434-26	Silane Vaporizer	4	Tube Coil	7,200	304 S.S.	434-04*
434-28	Silane Storage Cooler	1	Tube Coil	2,400	304 S.S.	434-04*
444-02	Pyrolysis Hydrogen Cooler	1	Hairpin	38,700	Steel/Cupronickel	2,900
444-04	Pyrolysis H_2 Comperssor Intercooler	1	Hairpin	---	Cupronickel	443-02*
454-02	Muriatic Acid Cooler	1	Hairpin	150,000	Steel/Hastelloy	5,050

* Item cost is included in item cost corresponding to this equipment number.

TABLE D-1 (continued): EQUIPMENT LIST, 120 MT/YR COMMERCIAL PLANT

MISCELLANEOUS

Equipment No.	Equipment Name	No. Req'd	Specifications	Material Of Construction	Cost (1st Q. 1979)
429-02	Quench & Solids Removal Contactor	1	25.2 ACFM gas at suction	304SS	10,000
429-04	Gas Superheater Furnace	1	680, 400 BTU/hr	Steel	36,500
429-06	Recycle STC Superheater	1	Furnace Tubing 449,400 BUT/hr	304SS	429-04*
429-08	Recycle Hydrogen Superheater	1	Furnace Tubing 544,700 BUT/hr	304SS	429-04*
439-02	DCS Distillate Pump Accumulator	1	1 Gal. Bellows Accumulator	Steel	400
449-02	Storage Hopper Accumulator	1	2 CF Dry Seal Accumulator	Steel	1,200
449-04	Product Metler	3	22 lb/hr Silicon, Resistance Heating	Steel/Quartz	50,000 ea.
459-02	Silica Venturi	1	2400 ACFM gas at suction	Fiberglass	20,000
459-04	Strong Muriatic Scrubber	1	2400 ACFM gas at suction	Fiberglass	2,000
459-06	Weak Muriatic Scrubber	1	2400 ACFM gas at suction	Fiberglass	2,000
459-08	Waste Gas Burner #1	2	4.55 CFM Wste gas	Steel	9,500
459-10	Waste Gas Burner #2	1	15 SCFM Wste gas	Steel	11,600 ea.
459-11	Waste Liquid Burner	1	11 GPH Wasteliquid	Steel	11,900
459-16	Silica Agglomerator	1	954,000 BTU/hr	Steel	8,680
469-02	Cooling Tower	1	500 GPM Recirculation	Aluminum	11,450
469-06	Cooling Tower Make-up	1	12 GPM Makeup	Steel	469-06*
469-12	Refrigeration System	1	8.5 tons (100,000 BUT/hr)	--	86,200
469-16	Hot Oil Heating Furnace	1	61 GPM Therminol, 2,122,000 BTU/hr.	--	80,000

*Item cost is included in item cost corresponding to this equipment number.

TABLE D-II

ELEMENTS OF PLANT CAPITAL COST, 120 MT/YR

Description	$ (1st Quarter 1979)
Mechanical Contract	$ 1,795,200
Process Equipment, Erected	1,436,100
Construction Field Support	149,500
Engineering	1,019,400
Contingency (12%)	532,400
TOTAL PLANT COST	$ 4,932,600

NOTES:

1. Mechanical contract includes site preparation, foundations, support steel, buildings, piping, electrical and instrumentation.

2. Process equipment, erected includes process equipment, freight, erection and equipment insulation.

3. Contingency percentage is a weighted average of the percentages for various elements from historical experience.

TABLE D-III

ELEMENTS OF ANNUAL OPERATING COST, 120 MT/YR

Description	$ (1st Quarter 1979)
Raw Materials	$ 313,290
Utilities	140,670
Manpower	1,048,750
Maintenance Materials	96,700
Analytical Equipment Charges	45,700
Consummable	65,940
Property Taxes and Insurance	57,710
Period Costs	93,200
Home Office Charge	10% of sales
TOTAL YEARLY OPERATING COST (except depreciation and capital charges)	$ 1,861,960 + 10% of sales

NOTE: For typical details, see Table C-XIV.

APPENDIX E

1000 MT/YR COMMERCIAL PLANT (ISSUE 2)

SECTIONS OF APPENDIX E

Table	Title	Page
E-I	Heat Duties	E - 2
E-II	1000 MT/Yr Commercial Plant Stream Summary (Issue 2)	E - 3
E-III	1000 MT/Yr Commercial Plant Stream Catalog (Issue 2)	E - 6
E-IV	Trace Component Analysis	E - 18
E-V	1000 MT/Yr Commercial Plant Physical Properties for Process Streams (Issue 2)	E - 19

TABLE E-I: 1000 MT/YR COMMERCIAL PLANT HEAT DUTIES (ISSUE 2)

Equipment No.	Equipment Name	Heat Duty (Btu/Hr)
424-02	Quench Condenser	8,182,900
424-04	Recycle STC Vaporizer	3,715,000
429-06	Recycle STC Superheater	3,098,700
429-08	Recycle H_2 Superheater	1,575,100
434-02	Stripper Condenser	176,600
434-04	Stripper Reboiler	1,095,300
434-06	TCS Column Reboiler	8,536,000
434-08	TCS Column Condenser	8,623,500
434-10	DCS Column Reboiler	5,852,500
434-12	TCS Cooler	2,483,200
434-14	DCS Column Condenser	3,361,100
434-16	DCS Cooler	522,313
434-18	Silane Column Condenser	174,100
434-20	Silane Column Reboiler	650,600
434-22	Silane Superheater	17,200
434-24	STC Cooler	649,800
444-02	Pyrolysis Hydrogen Cooler	237,000

TABLE E-I: 1000 MT/YR COMMERCIAL PLANT STREAM SUMMARY (ISSUE 2)

STREAM NO	INT. NO.	DESCRIPTION	T,F.	P,PSIA	LIQ.FR.
100	1	METALLURGICAL GRADE SILICON POWDER FEED	75.0	15.0	0.0
101	2	COPPER CATALYST FEED	75.0	15.0	0.0
102	3	MAKE-UP STC	75.0	20.0	1.0000
104	5	FLUIDIZATION H2 TO 421-02	300.0	516.7	0.0
105	6	PRESSURIZATION H2 TO HOPPER 421-02	150.0	516.7	0.0
106	7	ATMOSPHERIC VENT FROM CYCLONE 417-02	75.0	14.7	0.0
107	8	FEED TO HYDROGENATION REACTOR 425-02	944.0	516.7	0.0
108	9	PRODUCT FROM REACTOR 425-02	932.0	514.7	0.0
109	10	COOLED RECY. TO STC STORAGE TANK 421-12	120.0	20.0	1.0000
110	11	QUENCHED STC/TCS TO SETTLER 421-04	375.0	513.7	0.5000
111	12	RECYCLE STC/TCS QUENCH STREAM	350.0	574.7	1.0000
112	13	WASTE CHLORIDE SALTS FROM SETTLER	350.0	512.7	1.0000
113	14	SAT. VAPOR H2/TCS/STC TO COND. 424-02	350.0	512.7	0.0
114	15	SAT. LIQ. H2/TCS/STC QUENCH RECVR 421-08	100.0	511.7	0.5000
115	16	SAT. LIQ. TCS/STC TO QUENCH PUMP 426-04	100.0	513.7	1.0000
116	17	LIQUID RECYCLE TO SETTLER 421-04	100.0	513.7	1.0000
117	18	QUENCH STREAM TO CONDENSER 424-02	100.0	572.7	1.0000
118	19	H2 VAPOR FROM 421-08 RECEIVER	100.0	510.7	0.0
119	20	TCS/STC LIQ. PROD. TO CRUDE TANK 421-10	100.0	510.7	1.0000
120	21	H2 FEED TO COMPRESSOR 423-02,03	100.0	510.7	0.0
121	22	COMPRESSED H2 TO H2 HEATER 429-08	100.0	521.7	0.0
122	23	SUPERHEATED H2 TO REACTOR 425-02	961.0	516.7	0.0
123	24	SUPERHEATED STC TO REACTOR 425-02	969.0	516.7	0.0
124	25	SAT. VAPOR STC FROM VAPORIZER 424-04	443.0	521.7	0.0
125	26	CRUDE TCS/STC TO SECTION 2	100.0	95.0	1.0000
126	27	CRUDE TCS/STC TO FILTER 427-02	100.0	100.0	1.0000
127	28	STC FROM STC STORAGE TANK 421-12	75.0	20.0	1.0000
128	100	STC TO STC VAPORIZER 424-04	75.0	520.7	1.0000
129	168	LIQUID TCS/STC TO QUENCH PUMP 426-02,03	350.0	512.7	1.0000
131	170	TRANSPORT AIR TO FILTER 417-02	77.0	14.9	0.0
132	171	RECYCLE STC PURGE STREAM FROM 424-04	443.0	520.7	1.0000
133	104	AIR TO RECYCLE HYDROGEN HEATER 429-08	77.0	14.7	0.0
134	169	ATMOS. VENT FROM RECYCLE HEATER 429-08	1500.0	16.0	0.0
135	181	AIR TO RECYCLE STC HEATER 429-06	75.0	14.7	0.0
136	183	ATMOS. VENT FROM RECYCLE STC HTR. 429-06	1000.0	15.0	0.0
200	29	STC BOTTOMS PROD. TO STORAGE TANK 421-12	217.0	55.0	1.0000
201	30	432-02 STRIPPER BOTTOMS PRODUCT	214.8	69.6	1.0000
202	31	432-02 STRP. BTMS. VAP. FROM REB. 434-04	219.0	70.0	0.0
203	32	432-02 OVHD PRODUCT	130.2	65.0	0.0
204	33	432-02 CONDENSED OVHD PRODUCT	-25.6	64.6	1.0000
205	34	432-02 STRIPPER REFLUX	-25.6	70.0	1.0000
206	35	432-02 STRIP. BTMS. TO TCS/STC COLUMN	219.0	70.0	1.0000
207	36	432-04 BOTTOMS PRODUCT	213.2	54.8	1.0000
208	37	432-04 BTMS. VAPOR FROM REBOILER 434-06	217.4	55.0	0.0
209	38	432-04 OVHD PRODUCT	159.6	50.2	0.0
210	39	TOTAL 432-04 CONDENSED OVHD PRODUCT	154.4	49.2	1.0000
211	40	PRESSURIZED 432-02 PRODUCT	154.4	320.0	1.0000
212	41	432-06 TCS/STC PRODUCT TO 432-04	156.0	64.0	1.0000
213	42	432-04 REFLUX	154.4	55.0	1.0000
214	43	TCS FEED TO DCS/TCS COLUMN 432-06	154.4	320.0	1.0000
215	44	COOLED TCS FEED TO REDIS. REACTOR 435-02	156.0	85.0	1.0000
216	45	COOLED TCS BOTTOMS FROM 434-12	156.0	85.0	1.0000
217	46	432-06 BOTTOMS PRODUCT	326.9	319.9	1.0000
218	47	432-06 BOTTOMS VAPOR FROM REBOILER	327.3	320.0	0.0
219	48	432-06 OVHD PRODUCT	236.5	315.1	0.0
220	49	432-06 REFLUX	248.8	320.0	1.0000
221	50	432-06 CONDENSED OVHD PRODUCT	248.8	314.1	1.0000
222	51	PRESSURIZED 432-06 OVHD PRODUCT	248.8	530.0	1.0000
223	52	COOLED DCS FEED TO REACTOR 435-04	122.0	549.0	1.0000
224	53	MCS/SIH4 PRODUCT TO COLUMN 432-08	122.0	548.0	1.0000
225	54	432-08 BOTTOMS RECYCLE	267.0	360.0	1.0000
226	55	432-08 BOTTOMS VAPOR	267.0	360.0	1.0000
227	56	TOTAL PROD. SILANE FROM COND. 434-18	-25.7	354.0	0.0
230	59	432-08 VAPOR OVHD TO CONDENSER	-25.7	355.1	0.0
231	60	LIQ. SIH4 TO LIQ. STOR. 431-04,06,08,10	-25.7	354.1	1.0000
232	61	432-08 REFLUX	-25.7	360.0	1.0000
233	62	VAPORIZED SIH4 TO SUPERHEATER 434-22	-25.7	374.1	0.0
234	63	SUPERHEATED SIH4 TO FILTER 437-02,03	126.0	374.1	0.0
235	64	FILTERED SUPERHTD. SIH4 TO SECTION 3	126.0	25.0	0.0
236	65	432-06 TOTAL BOTTOMS PRODUCT	327.5	320.0	1.0000
237	6	TCS RECYCLE FROM 434-12 TO STC REC. STR.	158.0	85.0	1.0000
238	1	432-04 BOTTOMS PRODUCT	217.4	55.0	1.0000
239	1..	432-08 BOTTOMS PRODUCT	267.0	350.0	1.0000
240	179	432-08 PURGE SILANE TO 432-02	-25.7	354.1	0.0
242	185	432-08 BOTTOMS TO REBOILER 434-20	267.0	360.0	1.0000
243	186	432-08 BOTTOMS VAPOR TO 432-08	267.0	360.0	0.0
300	67	THROT. SIH4 FEED TO PYROL. REACT. 445-02	77.0	25.0	0.0
301	68	SI POWDER & H2 TO HOPPER 441-02	1562.0	20.0	0.0
303	70	SI POWDER TO MELTER 449-04,06,08	1120.0	20.0	0.0
307	74	TOTAL SI MELTED PRODUCT	2800.0	20.0	0.0
308	75	TOTAL SECT. 3 SI POWDER LOSS	1120.0	20.0	0.0
311	178	H2 FROM PYROLYSIS REACTOR TO 444-02	1562.0	20.0	0.0
312	182	COOLED PYROL. H2 TO COMPRESSOR 443-02,04	100.0	15.8	0.0
313	57	COMPRESSED REC. H2 TO HYDROGENATION	300.0	550.0	0.0
314	58	MAKE-UP H2 FROM STORAGE	77.0	50.0	0.0
400	76	ATMOS. VENT FROM COM-DS. VENT HEADER	100.0	16.0	0.0
401	77	COMBUSTION AIR TO BURNER 454-08	77.0	14.7	0.0
402	78	COMBUSTION AIR TO BURNER 455-10	77.0	14.7	0.0
403	79	COMBUSTION QUENCH AIR TO BURNER 455-10	77.0	14.7	0.0
404	80	TOTAL VAPOR FEED TO PRE-MIX BURN. 455-10	300.0	15.0	0.0

QUALITY

TABLE E-II: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM SUMMARY (ISSUE 2)

STREAM NO	INT. NO.	DESCRIPTION	T,F.	P,PSIA	LB/HR.
405	81	COMBUSTION QUENCH AIR TO BURNER 459-08	77.0	14.7	0.0
406	82	LIQUID BURNER 459-14 FEED	150.0	54.7	1.0000
407	83	LIQUID WASTE FROM CATCH TANK 451-06	350.0	64.7	1.0000
408	84	COMBUSTION QUENCH AIR TO BURNER 459-14	77.0	14.7	0.0
409	85	COMBUSTION AIR TO BURNER 459-14	77.0	14.7	0.0
410	86	ATMOSPHERIC VENT FROM TANK 451-06	350.0	14.7	0.0
411	87	FLUE GAS FROM BURNER 459-14	800.0	14.3	0.0
412	88	FLUE GAS FROM BURNER 459-10	800.0	14.3	0.0
413	89	FLUE GAS FROM BURNER 459-08	800.0	14.3	0.0
414	90	ATMOS. AIR VENT FROM AGGLOM. 459-16	250.0	15.0	0.0
415	91	COOLED FLUE GAS STM. TO FILTER 557-06	300.0	13.8	0.0
416	92	TOTAL FLUE GAS TO AGGLOMERATOR 459-16	800.0	14.0	0.0
417	93	GAS VENT FROM CYCLONE 458-02	800.0	14.2	0.0
418	94	FILTERED FLUE GAS TO FILTER 557-08	300.0	13.3	0.0
419	95	SILICA FROM FILTER 557-06	100.0	14.7	0.0
420	96	TOTAL SILICA FROM FILTERS 557-06,08	100.0	14.7	0.0
421	97	SILICA FROM FILTER 557-08	100.0	14.7	0.0
422	98	SILICA TO DUST BIN 451-08	800.0	14.7	0.0
423	99	SILICA TO DRUM PACKER 458-04	100.0	14.7	0.0
425	215	RECYCLE TO SILICA VENTURI 459-02	105.0	42.0	1.0000
426	227	SLURRY TO SILICA NEUTRALIZER 451-10	105.0	42.0	1.0000
427	103	RECYCLE H2O FROM PUMP 456-06,07	105.0	42.0	1.0000
429	105	MAKE-UP WATER AND 459-02 BOTTOMS	105.0	12.2	1.0000
430	106	BOTTOMS FROM VENTURI 459-02	105.0	12.2	1.0000
431	107	HCL VAPORS TO MURIATIC SCRUBBER 459-04	105.0	12.2	0.0
432	108	MURIATIC SCRUBBER 459-04 EFFLUENT	105.0	12.0	0.5000
433	109	STRONG MURIATIC ACID PRODUCT	105.0	12.0	1.0000
434	110	MURIATIC ACID FROM TANK 451-06	105.0	14.7	1.0000
435	111	WEAK MURIATIC ACID TO TANK 451-12	105.0	12.0	1.0000
436	112	STRONG MURIATIC ACID TO SCRUBBER 459-06	105.0	12.0	0.0
437	113	WEAK MURIATIC ACID TO PUMP 456-02	105.0	12.0	1.0000
438	114	STRONG MURI. ACID RECY. TO COOLER 454-02	105.0	59.0	1.0000
439	115	TOTAL MURI. ACID RECYCLE/PRODUCT	105.0	59.0	1.0000
440	116	WEAK ACID SOLUTION TO PUMP 456-04	105.0	11.7	1.0000
441	117	EFFLUENT FROM SCRUBBER 459-06	105.0	11.7	1.0000
442	118	MURIATIC ACID PRODUCT TO TANK 451-16	105.0	14.7	1.0000
443	119	ATMOS. VENT FROM BLOWER 453-04,05	105.0	14.5	0.0
444	120	HCL LADEN GAS TO TAILING COLUMN 452-02	105.0	11.7	0.0
445	121	STRIPPED GAS FROM TAILING COLUMN 452-02	105.0	11.6	0.0
446	122	WEAK MURIATIC ACID FROM TANK 451-14	105.0	11.7	1.0000
447	123	MURIATIC ACID PRODUCT	77.0	54.0	1.0000
448	124	FINE TO SILICA NEUTRALIZER 451-10	77.0	14.7	0.0
449	125	WASTE SLUDGE TO DISPOSAL	77.0	14.7	1.0000
450	126	WASTE WATER TO DISPOSAL	77.0	14.7	1.0000
451	127	FLUE GAS TO SILICA VENTURI 459-02	500.0	13.6	0.0
452	128	ATMOS. VENT FROM NON-COMBUST. HEADER	100.0	14.0	0.0
453	129	VAPOR FLASH-OFF FROM TANK 451-04	150.0	54.7	0.0
454	130	VAPOR FLASH-OFF FROM TANK 451-06	350.0	64.7	0.0
1000	132	COOLING WATER TO STC COOLER 434-24	85.0	75.0	1.0000
1001	133	COOLING WATER TO QUENCH COND. 424-02	85.0	75.0	1.0000
1003	135	COOLING WATER TO CONDENSER 434-08	85.0	75.0	1.0000
1004	136	COOLING WATER TO COOLER 434-12	85.0	75.0	1.0000
1005	137	COOLING WATER TO CONDENSER 434-12	85.0	75.0	1.0000
1006	138	COOLING WATER TO COOLER 434-16	85.0	75.0	1.0000
1008	140	COOLING WATER TO MELTER 449-04,06,08	85.0	75.0	1.0000
1014	144	COOL. WATER TO MAKE-UP TO VENTURI 459-02	85.0	75.0	1.0000
1016	143	COOL. WTR. TO PYRO. RECY. COMP 443-02,04	85.0	75.0	1.0000
1017	142	COOL. WATER TO RECY. H2 COOLER 442-02	85.0	75.0	1.0000
1018	141	COOL. WTR. TO MURIATIC ACID COOL. 454-02	85.0	75.0	1.0000
1019	139	COOL. WTR. TO MAKE-UP TO SCRUB. 459-06	85.0	75.0	1.0000
1020	134	COOL. WTR. TO PROD. POW.STOR. HOP 441-02	85.0	75.0	1.0000
1099	152	COOLING WATER HEADER	85.0	75.0	1.0000
1100	4	COOLING WATER RET. FROM STC COOL. 434-24	100.0	65.0	1.0000
1101	69	COOLING WATER RET. FROM STC COOLER	100.0	65.0	1.0000
1103	71	COOLING WATER RET. FROM COND. 434-08	100.0	65.0	1.0000
1104	72	COOLING WATER RET. FROM COOLER 434-12	100.0	65.0	1.0000
1105	73	COOLING WATER RET. FROM COND. 434-14	100.0	65.0	1.0000
1106	101	COOLING WATER RET. FROM COOLER 434-16	100.0	65.0	1.0000
1108	102	COOL. WATER RET. FROM MELT. 449-04,06,08	100.0	65.0	1.0000
1116	131	COOL. WATER FROM PYROL. COMP. 433-02,04	100.0	65.0	1.0000
1117	187	COOL. WATER FROM RECY. H2 COOLER 442-02	100.0	65.0	1.0000
1118	188	COOL. WATER FROM MURIA. ACID COOL. 454-02	100.0	65.0	1.0000
1120	189	COOL. WATER FROM PROD. HOPPER 441-02	100.0	65.0	1.0000
1199	153	COOLING WATER RETURN HEADER	100.0	65.0	1.0000
1200	196	NATURAL GAS TO RECY. HEATER 429-08	75.0	15.0	0.0
1202	198	NATURAL GAS TO WASTE BURNER 459-08	75.0	15.0	0.0
1203	199	NATURAL GAS TO WASTE BURNER 459-10	75.0	15.0	0.0
1204	200	NATURAL GAS TO WASTE LIQ. BURNER 459-14	75.0	15.0	0.0
1299	154	NATURAL GAS HEADER	75.0	15.0	0.0
1399	155	PLANT AIR HEADER	75.0	74.7	0.0

TABLE E-II: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM SUMMARY (ISSUE 2)

STREAM NO	INT. NO.	DESCRIPTION	T,F.	P,PSIA	LB/HR.
1400	172	PRESS. N2 TO M.G. SILICON HOPPER 421-02	77.0	160.0	0.0
1401	173	N2 PAD ON STC STORAGE TANK 421-12	77.0	160.0	0.0
1402	174	PRESS. N2 TO WASTE TANK 421-06	77.0	160.0	0.0
1403	175	N2 PAD ON CRUDE STC TANK 421-10	77.0	160.0	0.0
1404	176	N2 STREAM TO WASTE BURNER 459-08	77.0	160.0	0.0
1405	177	N2 PAD TO SURGE TANK 451-04	77.0	160.0	0.0
1406	167	N2 PURGE TO CATCH TANK 451-06	77.0	160.0	0.0
1499	156	NITROGEN HEADER	77.0	160.0	0.0
1500	201	ARGON TO MELTER 449-04,06,08	77.0	160.0	0.0
1501	202	ARGON TO SILICON HOPPER 441-02	77.0	160.0	0.0
1599	157	ARGON HEADER	77.0	160.0	0.0
1600	203	REF. BRINE TO STOR. 431-04,06,08,10	77.0	160.0	0.0
1601	204	REF. BRINE TO CONDENSER 434-16	-40.0	74.7	1.0000
1602	205	REF. BRINE TO CONDENSER 434-02	-40.0	74.7	1.0000
1699	158	REFRIGERANT BRINE HEADER	-40.0	74.7	1.0000
1700	206	BRINE RET. FROM TANKS 431-04,06,08,10	-40.0	74.7	1.0000
1701	207	BRINE RET. FROM COND. 434-16	-30.0	64.7	1.0000
1702	208	BRINE RET. FROM COND. 434-02	-30.0	64.7	1.0000
1799	159	REFRIGERANT BRINE RETURN HEADER	-30.0	64.7	1.0000
1800	209	COLD HEAT TRANSFER OIL TO VAP. 424-04	-30.0	64.7	1.0000
1801	210	COLD HEAT TRANSFER OIL TO REBO. 434-04	320.0	30.0	1.0000
1802	211	COLD HEAT TRANSFER OIL TO REBO. 434-06	320.0	30.0	1.0000
1803	212	COLD HEAT TRANSFER OIL TO REBO. 434-10	320.0	30.0	1.0000
1804	213	COLD HEAT TRANSFER OIL TO REBO. 434-20	320.0	30.0	1.0000
1805	214	COLD HEAT TRANS. OIL TO SIH4 SUP. 434-12	320.0	30.0	1.0000
1899	160	COLD HEAT TRANSFER OIL HEADER	320.0	30.0	1.0000
1900	216	HEAT TRANS. OIL RET. FROM VAP. 424-04	320.0	30.0	1.0000
1901	217	HEAT TRANS. OIL RET. FROM REB. 434-04	286.0	20.0	1.0000
1902	218	HEAT TRANS. OIL RET. FROM REB. 434-06	286.0	20.0	1.0000
1903	219	HEAT TRANS. OIL RET. FROM REB. 434-10	251.0	20.0	1.0000
1904	220	HEAT TRANS. OIL RET. FROM REB. 434-20	365.0	20.0	1.0000
1905	221	HEAT TRANS. OIL FROM SIH4 SUP. 434-22	308.0	20.0	1.0000
1999	161	HEAT TRANSFER OIL RETURN HEADER	320.0	20.0	1.0000
2000	222	HEAT TRANS. OIL TO VAPOR. 424-04	320.0	20.0	1.0000
2001	223	HEAT TRANS. OIL TO REBOILER 434-04	497.0	30.0	1.0000
2002	224	HEAT TRANS. OIL TO REBOILER 434-06	497.0	30.0	1.0000
2003	225	HEAT TRANS. OIL TO REBOILER 434-10	497.0	30.0	1.0000
2004	226	HEAT TRANS. OIL TO REBOILER 434-20	497.0	30.0	1.0000
2099	180	HEAT TRANSFER OIL HEADER	497.0	30.0	1.0000
2100	228	RUPTURE DISK VENTS TO TANK 451-06	497.0	30.0	1.0000
2199	190	RUPTURE DISK VENT HEADER	100.0	20.0	0.0
2200	229	WASTE STR. TO COMB. VENT FILTER 557-04	100.0	20.0	0.0
2299	191	COMBUSTIBLE VENT HEADER	100.0	20.0	0.0
2300	230	NON-COMBUSTIBLE VENTS TO FILTER 557-02	100.0	20.0	0.0
2399	192	NON-COMBUSTIBLE VENTS HEADER	100.0	20.0	0.0
2400	231	N2 PURGE FROM BLENDER 428-02	100.0	20.0	0.0
2401	232	N2 PURGE FROM M.G. SILICON HOP. 421-02	100.0	20.0	0.0
2402	233	N2 PURGE FROM TANK 421-10 TO WASTE HEAD.	100.0	20.0	0.0
2403	234	N2 PURGE FROM 421-12 TO WASTE HEADER	100.0	20.0	0.0
2404	235	MELTER PURGE TO WASTE HEADER	100.0	20.0	0.0
2405	236	WASTE STR. TO PRE-MIX BURNER 459-10	100.0	20.0	0.0
2499	193	PRE-MIX BURNER HEADER	100.0	20.0	0.0
2500	237	NOZZLE MIX WASTE STR. TO BURNER 459-08	100.0	20.0	0.0
2501	238	CONDEN. REC. 431-02 VENT TO WASTE HEADER	100.0	20.0	0.0
2502	145	H2 RECYCLE PURGE	-21.0	90.0	0.0
2599	194	NOZZLE MIX BURNER HEADER	100.0	510.7	0.0
2600	239	WASTE CHLORIDES TO CONDEN. VENTS HEADER	100.0	20.0	0.0
2601	240	FILTERED SLUDGE FROM STC/TCS TANK 421-10	100.0	70.0	1.0000
2603	241	CONDENSED VENTS TO SURGE TANK 451-04	100.0	70.0	1.0000
2699	195	CONDENSED VENTS HEADER	100.0	70.0	1.0000
			100.0	70.0	1.0000

TABLE E-III: 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER	100	101	102	103	105	106	107	108
PRESSURE, PSIA	15.00	15.00	20.00	516.70	516.70	15.70	516.70	516.70
TEMPERATURE, DEG F	75.00	75.00	75.00	300.00	150.01	75.00	900.00	932.00
LIQUID FRACTION	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ STREAM TEMP, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HST + H25 + HF, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HLIT = HST + H25 + HF, BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	28.7534	63.5400	169.6900	2.0194	2.0194	28.7942	86.4590	91.3[illegible]
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	.0	.0	.2857	28.29	.0	209.6	105.6
2 NITROGEN 28.01	155.4	.0	.0	.0	.0	155.4	.9839E-01	.9839E-01
3 ARGON 39.95	1.854	.0	.0	.0	.0	1.854	.0	.0
4 OXYGEN 32.00	41.68	.0	.0	.0	.0	41.68	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.5961E-01	.0	.0	.0	.0	.5961E-01	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.0	.2374	.3470
9 SILANE 32.12	.0	.0	.0	.0	.0	.0	.2324E-03	.2668E-03
10 MONOCHLOROSILANE 66.56	.0	.0	.0	.0	.0	.0	.7598E-02	.2800E-01
11 DICHLOROSILANE 101.01	.0	.0	.0	.0	.0	.0	.2732	1.549
12 TRICHLOROSILANE 135.45	.0	.0	.0	.0	.0	.0	18.87	64.18
13 SILICON TETRACHLORIDE 169.90	.0	.0	1.718	.0	.0	.0	209.6	174.9
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	3.160	.0	.0	.0	.0	3.160	.0	.0
16 SILICON 28.09	12.02	.0	.0	.0	.0	.0	12.01	.8604E-01
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.1129	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 IRON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.1129
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.5961E-01	.0	.0	.0	.0	.5961E-01	.0	.0
72 HYDROGEN (H) 1.01	6.319	.0	.0	.5715	56.58	6.319	438.9	438.9
73 NITROGEN (N) 14.01	310.7	.0	.0	.0	.0	310.7	.1968	.1968
74 OXYGEN (O) 16.00	44.96	.0	.0	.0	.0	44.96	.0	.0
75 SILICON (SI) 28.09	12.02	.0	1.718	.0	.0	.0	240.8	240.8
76 CHLORINE (CL) 35.45	.0	.0	6.871	.0	.0	.0	895.8	846.0
77 ARGON (AR) 39.95	1.854	.0	.0	.0	.0	1.854	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 IRON (FE) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.1129	.0	.0	.0	.0	.0	.1129
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	214.1	.1129	1.2[illegible]	.2857	24.29	202.1	450.7	4[illegible]

TABLE E-III: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 2)

STREAM NUMBER		109	110	111	112	113	114	115	116
PRESSURE,	PSIA	20.00	513.70	574.70	512.70	512.70	511.30	513.70	513.70
TEMPERATURE,	DEG F	120.00	375.01	356.00	356.00	356.00	100.00	100.00	100.00
LIQUID FRACTION		1.0000	0.5003	1.0000	1.0000	0.0	0.5000	1.0000	1.5000
ENTHALPY @ STREAM TEMP,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = H@T - H25 + HF ,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = H@T - H25 + HF ,BTU/LB-MO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT		168.1566	136.5152	160.1443	155.6416	116.5627	117.9631	157.3650	157.4660
COMPOSITION, LB-MO/HR									
1 HYDROGEN	2.02	.0	196.3	10.79	.1647E-01	191.0	191.5	.5043	5.418
2 NITROGEN	28.01	.0	.1087	.1033E-01	.1561E-04	.1036	.1041	.4894E-03	.5257E-02
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.5498	.2022	.2226E-03	.4782	.4904	.1218E-01	.1308
9 SILANE	32.12	.3657E-04	.3745E-03	.1080E-03	.7548E-07	.3504E-03	.3582E-03	.7781E-05	.8159E-04
10 MONOCHLOROSILANE	66.56	.1644E-02	.4457E-01	.2457E-01	.2383E-04	.3692E-01	.3850E-01	.1576E-02	.1693E-01
11 DICHLOROSILANE	101.01	.1881E-01	5.052	3.503	.6142E-02	3.076	3.219	.1427	1.533
12 TRICHLOROSILANE	135.45	10.31	235.4	171.2	.3286	129.8	135.9	6.125	65.80
13 SILICON TETRACHLORIDE	169.90	194.4	806.0	631.1	1.374	366.1	383.0	17.74	190.5
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.6319E-01	.3149E-02	.6004E-01	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.1129	.0	.1129	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.35	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR									
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	10.35	638.8	199.9	.3741	518.5	525.9	7.438	79.95
73 NITROGEN (N)	14.01	.0	.2174	.2069E-01	.3161E-04	.2073	.2082	.9788E-03	.1051E-01
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	204.7	1047.	805.8	1.755	498.9	522.9	24.01	257.9
76 CHLORINE (CL)	35.45	808.6	3741.	3045.	6.718	1860.	1950.	89.62	962.7
77 ARGON (AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.1129	.0	.1129	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW		204.7	1244.	818.7	1.658	690.5	715.0	24.52	261.4

TABLE E-111: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 2)

STREAM NUMBER	115	116	117	120	121	122	123	124
PRESSURE (PSIA)	512.70	510.70	500.0	514.70	521.70	516.70	516.70	511.70
TEMPERATURE (F)	100.00	150.00	100.00	100.00	100.00	281.30	300.00	300.00
VAPOR FRACTION	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
TOTAL MOLE FLOW (LB-MOL/HR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL MASS FLOW (LB/HR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL VOLUME FLOW (CFH)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL MOLE FLOW (LB-MOL/HR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL MASS FLOW (LB/HR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVG MOLECULAR WEIGHT	152.1656	20.4181	152.1656	20.4181	20.4181	20.4181	160.1711	160.1711
COMPONENTS (LB-MOL/HR)								
1 HYDROGEN	2.02	.5054	181.0	.5551	181.0	181.0	.0	.0
2 NITROGEN	28.01	.9894E-01	.9195E-01	.4410E-02	.9173E-01	.9395E-01	.9395E-01	.0
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.1218E-01	.2374	.1099	.2374	.2374	.0	.0
9 SILANE	32.12	.7781E-05	.1965E-03	.7023E-06	.1966E-03	.1966E-03	.1966E-03	.3621E-06
10 MONOCHLOROSILANE	66.56	.1576E-02	.5773E-02	.1420E-01	.5773E-02	.5773E-02	.5773E-02	.1820E-02
11 DICHLOROSILANE	101.01	.1627	.2546	1.348	.2546	.2546	.2546	.1862E-01
12 TRICHLOROSILANE	135.45	6.135	8.664	55.29	8.664	8.664	8.664	10.20
13 SILICON TETRACHLORIDE	169.90	17.76	15.44	160.1	15.44	15.44	15.44	14.2
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0
15 WATER VAPOR	18.02	.0	.0	.0	.0	.0	.0	.0
16 IRON	55.85	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0
24 SILICA	60.11	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0
26 MONOSODIUM PHOSPHATE	141.94	.0	.0	.0	.0	.0	.0	.0
27 CADMIUM PHOSPHATE	191.38	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM PHOSPHATE	123.22	.0	.0	.0	.0	.0	.0	.0
29 CADMIUM	112.41	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0
33 CHROMIUM OXIDE	98.94	.0	.0	.0	.0	.0	.0	.0
34 MANGANESE MONOXIDE	70.93	.0	.0	.0	.0	.0	.0	.0
35 MONOCHLORO TRICHLOROSILANE	137.11	.0	.0	.0	.0	.0	.0	.0
36 IRON TETRACHLORIDE	211.17	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TETRACHLORIDE	158.15	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0
42 FERROUS CHLORIDE	126.75	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0
44 SILICON CHLORIDE	127.62	.0	.0	.0	.0	.0	.0	.0
45 [illegible] CHLORIDE	119.93	.0	.0	.0	.0	.0	.0	.0
46 TITANIUM TETRACHLORIDE	231.03	.0	.0	.0	.0	.0	.0	.0
47 CHROMIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0
48 MANGANESE CHLORIDE	95.77	.0	.0	.0	.0	.0	.0	.0
49 [illegible] CHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0
51 METHANE	27.67	.0	.0	.0	.0	.0	.0	.0
52 ETHYLENE	34.30	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0
60 SILICA HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0
62 TITANIUM HYDROXIDE	153.95	.0	.0	.0	.0	.0	.0	.0
63 CADMIUM OXIDE	58.08	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0
65 SILANE	106.19	.0	.0	.0	.0	.0	.0	.0
66 MONO SILANE	46.14	.0	.0	.0	.0	.0	.0	.0
67 DISILANE	60.17	.0	.0	.0	.0	.0	.0	.0
68 MONOCHLOROSILANE	115.08	.0	.0	.0	.0	.0	.0	.0
69 DICHLOROSILANE	150.93	.0	.0	.0	.0	.0	.0	.0
70 TRICHLOROSILANE	169.06	.0	.0	.0	.0	.0	.0	.0
COMPONENTS (LB-MOL/HR)								
71 ARGON (C)	1.01	.0	.0	.0	.0	.0	.0	.0
72 NITROGEN (C)	1.01	7.516	171.5	67.12	171.5	171.5	171.5	10.25
73 OXYGEN (C)	1.01	.9788E-01	.1079	.8815E-02	.1079	.1079	.1079	.0
74 METHANE (C)	16.03	.0	.0	.0	.0	.0	.0	.0
75 ETHYLENE (C)	28.02	2.01	24.12	216.1	24.12	24.12	24.12	24.0
76 ETHANE (C)	30.05	88.62	88.52	903.9	88.52	88.52	88.52	80.13
77 ARSINE (C)	77.95	.0	.0	.0	.0	.0	.0	.0
78 HYDROGEN SULFIDE (C)	34.08	.0	.0	.0	.0	.0	.0	.0
79 IRON (C)	55.85	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (C)	52.00	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (C)	54.94	.0	.0	.0	.0	.0	.0	.0
82 [illegible] (C)	40.08	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (C)	26.98	.0	.0	.0	.0	.0	.0	.0
84 LEAD (C)	55.85	.0	.0	.0	.0	.0	.0	.0
85 LEAD (C)	207.19	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (C)	47.90	.0	.0	.0	.0	.0	.0	.0
87 [illegible] (C)	28.71	.0	.0	.0	.0	.0	.0	.0
88 [illegible] (C)	63.54	.0	.0	.0	.0	.0	.0	.0
89 [illegible] (C)	50.34	.0	.0	.0	.0	.0	.0	.0
90 [illegible] (C)	21.22	.0	.0	.0	.0	.0	.0	.0
91 [illegible] (C)	1.01	.0	.0	.0	.0	.0	.0	.0
92 [illegible] (C)	34.02	.0	.0	.0	.0	.0	.0	.0
93 [illegible] (C)	2.01	.0	.0	.0	.0	.0	.0	.0
[illegible]		2.01	2.01	2.01	2.01	.0	.0	.0

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER		125	126	127	128	129	130	131	200
PRESSURE,	PSIA	95.00	100.00	20.00	526.70	512.70	14.90	526.70	95.00
TEMPERATURE,	DEG F	100.00	100.00	75.00	75.00	156.00	77.00	447.00	217.00
LIQUID FRACTION		1.0000	1.0000	1.0000	1.0000	1.0000	0.0	1.0000	1.0000
ENTHALPY # STREAM TEMP,	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY # 25C	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION M25C,	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HMT - H25 + HF	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HMT - H25 + HF	BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY	BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT		157.3649	157.3649	168.1711	168.1711	150.1443	28.0459	168.1713	164.1566
COMPOSITION, LB-MO/HR									
1 HYDROGEN	2.02	4.553	4.553	.0	.0	10.70	.0	.0	.0
2 NITROGEN	28.01	.4418E-02	.4418E-02	.0	.0	.1033E-01	.8337E-02	.0	.0
3 ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.1099	.1099	.0	.0	.2022	.0	.0	.0
9 SILANE	32.12	.7023E-04	.7023E-04	.3657E-04	.3657E-04	.1080E-03	.0	.3657E-04	.3657E-04
10 MONOCHLOROSILANE	66.56	.1422E-01	.1422E-01	.1844E-02	.1844E-02	.2457E-01	.0	.1844E-04	.1844E-02
11 DICHLOROSILANE	101.01	1.288	1.288	.1881E-01	.1881E-01	3.503	.0	.1591E-03	.1881E-01
12 TRICHLOROSILANE	135.45	55.29	55.29	10.31	10.31	171.2	.0	.1031	10.31
13 SILICON TETRACHLORIDE	169.90	160.1	160.1	196.1	196.1	531.1	.0	1.961	196.1
14 CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.3149E-02	12.02	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR									
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	67.12	67.12	10.35	10.35	199.9	.0	.1035	10.35
73 NITROGEN (N)	14.01	.8835E-02	.8835E-02	.0	.0	.2085E-01	.1671E-01	.0	.0
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	216.7	216.7	206.4	206.4	805.8	12.02	2.064	206.7
76 CHLORINE (CL)	35.45	808.4	803.9	815.4	815.4	3045.	.0	8.154	404.0
77 ARGON (AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW		221.4	221.4	206.4	206.4	816.7	12.03	2.064	206.7

TABLE E-III: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 2)

STREAM NUMBER	201	202	203	204	205	206	207	208
PHASE								
TEMPERATURE								
PRESSURE								
FLOW RATE								
FLOW RATE								
FLOW RATE								
FLOW RATE								
FLOW RATE								
TOTAL SOLIDS								
AVERAGE MOLECULAR WEIGHT	190.6816	190.6816	80.0067	80.0067	110.9940	160.2701	166.1690	166.1690
MOLE FRACTIONS								
1 HYDROGEN	2.02	+0	+0	+.576	+.576	+.2168E-01	+0	+0
2 NITROGEN	28.01	+0	+0	+.9966E-02	+.9966E-02	+.3826E-04	+0	+0
3 ARGON	39.95	+0	+0	+0	+0	+0	+0	+0
4 OXYGEN	32.00	+0	+0	+0	+0	+0	+0	+0
5 SODIUM MONOXIDE	38.01	+0	+0	+0	+0	+0	+0	+0
6 CARBON DIOXIDE	44.01	+0	+0	+0	+0	+0	+0	+0
7 METHANE	16.04	+0	+0	+0	+0	+0	+0	+0
8 DIDEUTERIUM OXIDE (D2O)	38.68	+0	+0	+0	+0	+0	+0	+0
9 ETHANE	30.12	+.8526E-02	+.5228E-02	+.1966	+.1966	+.5251E-01	+0	+0
10 MONOCHLOROSILANE	66.56	+.1910E-03	+.1566E-03	+.1770	+.1770	+.9906E-01	+.1708E-01	+0
11 DICHLOROSILANE	101.01	2.838	1.069	+.1981	+.1981	+.1960	+.5571E-04	+0
12 TRICHLOROSILANE	135.45	98.07	47.80	7.312	7.312	7.218	1.109	+.1569
13 SILICON TETRACHLORIDE	169.90	217.8	97.70	3.920	3.920	3.902	55.27	89.26
14 HYDROGEN CHLORIDE	36.91	+0	+0	+.1979	+.1979	+.1975	160.1	887.5
15 WATER STEAM	18.02	+0	+0	+0	+0	+0	+0	+0
16 SILICON	28.09	+0	+0	+0	+0	+0	+0	+0
17 CHROMIUM DIOXIDE	83.99	+0	+0	+0	+0	+0	+0	+0
18 MANGANESE DIOXIDE	86.94	+0	+0	+0	+0	+0	+0	+0
19 CALCIUM	40.08	+0	+0	+0	+0	+0	+0	+0
20 ALUMINUM OXIDE	101.96	+0	+0	+0	+0	+0	+0	+0
21 IRON	55.85	+0	+0	+0	+0	+0	+0	+0
22 LEAD	207.19	+0	+0	+0	+0	+0	+0	+0
23 TITANIUM DIOXIDE	79.90	+0	+0	+0	+0	+0	+0	+0
24 NICKEL	58.71	+0	+0	+0	+0	+0	+0	+0
25 COBALT	58.94	+0	+0	+0	+0	+0	+0	+0
26 PHOSPHORUS PENTOXIDE	141.94	+0	+0	+0	+0	+0	+0	+0
27 VANADIUM PENTOXIDE	181.88	+0	+0	+0	+0	+0	+0	+0
28 ZIRCONIUM DIOXIDE	123.22	+0	+0	+0	+0	+0	+0	+0
29 CARBON	12.01	+0	+0	+0	+0	+0	+0	+0
30 TIN DIOXIDE	89.62	+0	+0	+0	+0	+0	+0	+0
31 ARSENIC PENTOXIDE	229.84	+0	+0	+0	+0	+0	+0	+0
32 IRON SULFATE	151.91	+0	+0	+0	+0	+0	+0	+0
33 CALCIUM CARBONATE	99.09	+0	+0	+0	+0	+0	+0	+0
34 MAGNESIUM OXIDE	40.31	+0	+0	+0	+0	+0	+0	+0
35 CHROMIUM TRICHLORIDE	157.13	+0	+0	+0	+0	+0	+0	+0
36 IRON TRICHLORIDE	162.17	+0	+0	+0	+0	+0	+0	+0
37 ALUMINUM TRICHLORIDE	198.16	+0	+0	+0	+0	+0	+0	+0
38 MANGANESE DICHLORIDE	125.84	+0	+0	+0	+0	+0	+0	+0
39 CALCIUM CHLORIDE	110.99	+0	+0	+0	+0	+0	+0	+0
40 ALUMINUM CHLORIDE	133.34	+0	+0	+0	+0	+0	+0	+0
41 FERRIC CHLORIDE	162.21	+0	+0	+0	+0	+0	+0	+0
42 CHLORIDE CHLORIDE	129.10	+0	+0	+0	+0	+0	+0	+0
43 TITANIUM TETRACHLORIDE	189.73	+0	+0	+0	+0	+0	+0	+0
44 NICKEL CHLORIDE	129.62	+0	+0	+0	+0	+0	+0	+0
45 COBALT CHLORIDE	129.85	+0	+0	+0	+0	+0	+0	+0
46 ZIRCONIUM TETRACHLORIDE	233.03	+0	+0	+0	+0	+0	+0	+0
47 VANADIUM TRICHLORIDE	157.05	+0	+0	+0	+0	+0	+0	+0
48 MAGNESIUM CHLORIDE	95.22	+0	+0	+0	+0	+0	+0	+0
49 SODIUM CHLORIDE	107.97	+0	+0	+0	+0	+0	+0	+0
50 HYDROGEN SULFIDE	34.09	+0	+0	+0	+0	+0	+0	+0
51 ETHANE	27.07	+0	+0	+0	+0	+0	+0	+0
52 ETHYNE	26.04	+0	+0	+0	+0	+0	+0	+0
53 ARSINE	77.95	+0	+0	+0	+0	+0	+0	+0
54 CHROMIUM HYDROXIDE	86.01	+0	+0	+0	+0	+0	+0	+0
55 MANGANESE HYDROXIDE	88.95	+0	+0	+0	+0	+0	+0	+0
56 CALCIUM HYDROXIDE	74.09	+0	+0	+0	+0	+0	+0	+0
57 ALUMINUM HYDROXIDE	78.00	+0	+0	+0	+0	+0	+0	+0
58 IRON HYDROXIDE	89.86	+0	+0	+0	+0	+0	+0	+0
59 LEAD HYDROXIDE	241.20	+0	+0	+0	+0	+0	+0	+0
60 NICKEL HYDROXIDE	92.72	+0	+0	+0	+0	+0	+0	+0
61 COBALT HYDROXIDE	92.95	+0	+0	+0	+0	+0	+0	+0
62 ZIRCONIUM HYDROXIDE	159.25	+0	+0	+0	+0	+0	+0	+0
63 [illegible]	56.08	+0	+0	+0	+0	+0	+0	+0
64 SILICON DIOXIDE	60.08	+0	+0	+0	+0	+0	+0	+0
65 [illegible]	106.19	+0	+0	+0	+0	+0	+0	+0
66 [illegible] SILANE	96.19	+0	+0	+0	+0	+0	+0	+0
67 [illegible] SILANE	60.17	+0	+0	+0	+0	+0	+0	+0
68 [illegible] SILANE	115.04	+0	+0	+0	+0	+0	+0	+0
69 [illegible] SILANE	150.09	+0	+0	+0	+0	+0	+0	+0
70 [illegible] SILANE	124.08	+0	+0	+0	+0	+0	+0	+0
MOLAR COMPOSITIONS								
71 [illegible]	1.01	+0	+0	+0	+0	+0	+0	+0
72 [illegible]	1.01	101.0	46.11	29.18	29.18	14.22	57.05	85.52
73 [illegible]	1.01	+0	+0	+.9913E-02	+.9913E-02	+.9561E-04	+0	+0
74 [illegible]	1.01	18.02	+0	+0	+0	+0	+0	+0
75 [illegible]	1.01	8.09	110.7	11.91	11.91	11.96	21.6	9.6
76 [illegible]	1.01	39.95	11.1	35.25	35.25	27.18	80.5	101.6
77 [illegible]	1.01	39.95	+0	+0	+0	+0	+0	+0
78 [illegible]	1.01	32.00	+0	+0	+0	+0	+0	+0
79 [illegible]	1.01	12.01	+0	+0	+0	+0	+0	+0
80 [illegible]	1.01	52.00	+0	+0	+0	+0	+0	+0
81 [illegible]	1.01	94.94	+0	+0	+0	+0	+0	+0
82 [illegible]	1.01	40.04	+0	+0	+0	+0	+0	+0
83 [illegible]	1.01	26.98	+0	+0	+0	+0	+0	+0
84 [illegible]	1.01	59.85	+0	+0	+0	+0	+0	+0
85 [illegible]	1.01	207.19	+0	+0	+0	+0	+0	+0
86 [illegible]	1.01	47.90	+0	+0	+0	+0	+0	+0
87 [illegible]	1.01	58.71	+0	+0	+0	+0	+0	+0
88 [illegible]	1.01	61.94	+0	+0	+0	+0	+0	+0
89 [illegible]	1.01	90.28	+0	+0	+0	+0	+0	+0
90 [illegible]	1.01	91.22	+0	+0	+0	+0	+0	+0
91 [illegible]	1.01	32.06	+0	+0	+0	+0	+0	+0
92 [illegible]	1.01	26.02	+0	+0	+0	+0	+0	+0
93 [illegible]	1.01	26.01	+0	+0	+0	+0	+0	+0
[illegible]		115.7	16.2	12.6	12.6	11.91	21.6	9.6

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER	209	210	211	212	213	214	215	216
PRESSURE, PSIA	50.20	49.20	320.00	86.00	55.00	320.00	85.00	85.00
TEMPERATURE, DEG F	159.00	159.40	154.40	158.00	154.40	154.40	154.00	158.00
LIQUID FRACTION	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ENTHALPY @ STREAM TEMP, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HRT - H25 + HF, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HRT - H25 + HF, BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	132.4775	132.4775	132.4775	135.8492	132.4776	132.4777	135.8491	135.8491
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN 28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE 32.12	.2209	.2208	.2208	.904HE-01	.1235	.973HE-01	.0	.0
10 MONOCHLOROSILANE 66.56	3.168	3.168	3.168	1.377	1.771	1.397	.6661E-02	.5669E-02
11 DICHLOROSILANE 101.01	77.93	77.93	77.93	33.18	43.57	34.35	2.338	2.341
12 TRICHLOROSILANE 135.45	730.4	730.4	730.4	276.7	408.3	322.0	343.0	343.3
13 SILICON TETRACHLORIDE 169.90	13.64	13.64	13.64	40.31	7.623	6.012	6.400	6.405
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.09	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	896.6	896.6	896.6	347.7	501.3	395.3	347.7	348.0
73 NITROGEN (N) 14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	825.3	825.3	825.3	351.7	461.4	363.9	351.7	352.1
76 CHLORINE (CL) 35.45	2405.	2405.	2405.	1054.	1344.	1060.	1054.	1060.
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	825.3	825.3	825.3	351.7	461.4	363.9	351.7	352.1

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER	217	218	219	220	221	222	223	224
PRESSURE PSIA	419.40	120.00	115.10	326.00	315.10	550.00	[illegible]	[illegible]
TEMPERATURE DEG F	126.09	127.31	256.50	298.77	298.79	298.79	127.00	127.00
LIQUID FRACTION	1.2000	0.0	0.0	1.0000	1.0000	1.0000	1.0000	1.0000
ENTHALPY @ STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HIDE = HST + HPS + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HIDE = HST + HPS + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	135.6775	135.6094	97.7609	97.7609	97.7608	97.7608	97.7608	97.7608
COMPOSITION, LB-MOL/HR								
1 HYDROGEN 2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN 28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE 32.12	.0	.0	.0	.0	.0	.0	.0	.0
10 MONOCHLOROSILANE 66.56	.4525E-01	.3659E-01	2.534	2.071	2.534	.4630	.4630	12.19
11 DICHLOROSILANE 101.01	11.69	9.346	108.0	88.27	108.0	19.74	19.74	19.35
12 TRICHLOROSILANE 135.45	1207.	863.9	414.1	338.5	414.1	75.68	75.68	43.67
13 SILICON TETRACHLORIDE 169.90	14.85	13.44	58.10	47.48	58.10	10.62	10.62	31.38
14 CHLORINE 70.91	.0	.0	.1947E-01	.1591E-01	.1947E-01	.3558E-02	.3558E-02	.3228
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLTRICHLOROSILANE 119.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.99	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.05	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MOL/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	1.31.	862.7	1221.	997.5	1221.	223.1	223.1	223.1
73 NITROGEN (N) 14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	1234.	886.7	582.8	476.3	582.8	106.5	106.5	106.5
76 CHLORINE (CL) 35.45	3725.	2664.	1111.	907.7	1111.	203.0	203.0	203.0
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	1.31.	886.7	582.8	476.3	582.8	106.5	106.5	106.5

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER	225	226	227	230	231	232	233	234
PRESSURE, PSIA	360.00	360.00	354.00	355.10	354.10	360.00	374.10	374.10
TEMPERATURE, DEG F	267.01	267.01	-25.71	-25.71	-25.71	-25.71	-25.71	126.00
LIQUID FRACTION	1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	0.0
ENTHALPY @ STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION H25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HOT - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	105.9568	105.9589	32.1174	32.1174	32.1174	32.1174	32.1174	32.1174
COMPOSITION, LB-MO/HR								
1 HYDROGEN 2.02	.0	.0	.0	.0	.0	.0	.0	.0
2 NITROGEN 28.01	.0	.0	.0	.0	.0	.0	.0	.0
3 ARGON 39.95	.0	.0	.0	.0	.0	.0	.0	.0
4 OXYGEN 32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE 28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE 44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE 16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE 36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE 32.12	.3657	.3657E-04	11.82	37.84	11.71	26.01	11.82	11.82
10 MONOCHLOROSILANE 66.56	18.35	.1835E-02	.0	.0	.0	.0	.0	.0
11 DICHLOROSILANE 101.01	43.66	.4367E-02	.0	.0	.0	.0	.0	.0
12 TRICHLOROSILANE 135.45	31.89	.3190E-02	.0	.0	.0	.0	.0	.0
13 SILICON TETRACHLORIDE 169.90	.3978	.3978E-04	.0	.0	.0	.0	.0	.0
14 CHLORINE 70.91	.0	.0	.0	.0	.0	.0	.0	.0
15 WATER/STEAM 18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON 28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE 83.99	.0	.0	.0	.0	.0	.0	.0	.0
18 MANGANESE DIOXIDE 86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM 40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE 101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON 55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD 207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE 79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL 58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER 63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE 141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE 181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE 123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON 12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 BORON OXIDE 69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE 229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE 151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE 95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE 40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE 137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE 117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE 158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE 125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE 110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE 133.34	0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE 162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE 278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE 189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE 129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE 134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE 233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE 121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE 95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE 102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE 34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 DIBORANE 27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE 34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE 77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE 86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE 88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE 74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE 78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE 89.86	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE 241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE 92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE 97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE 159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO) 56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE 60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE 106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE 46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE 60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE 115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE 150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYLDICHLOROSILANE 129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR								
71 CARBON (C) 12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H) 1.01	175.7	.1756E-01	47.30	151.4	46.83	104.1	47.30	47.30
73 NITROGEN (N) 14.01	.0	.0	.0	.0	.0	.0	.0	.0
74 OXYGEN (O) 16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI) 28.09	94.67	.9468E-02	11.82	37.84	11.71	26.01	11.82	11.82
76 CHLORINE (CL) 35.45	203.0	.2030E-01	.0	.0	.0	.0	.0	.0
77 ARGON (AR) 39.95	.0	.0	.0	.0	.0	.0	.0	.0
78 PHOSPHORUS (P) 30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B) 10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR) 52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN) 54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA) 40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL) 26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE) 55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB) 207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI) 47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI) 58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU) 63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V) 50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR) 91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S) 32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS) 74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG) 24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL FLOW	94.67	.9468E-02	11.82	37.84	11.71	26.01	11.82	11.82

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

[illegible]		235	[illegible]	[illegible]	35.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PSIA		25.00	360.00	[illegible]	217.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		127.00	137.34	159.00	267.01	[illegible]	257.71	[illegible]	[illegible]	[illegible]
[illegible]		0.0	1.0000	1.0000	1.0000	1.0000	0.0	1.0000	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]
[illegible]		32.1179	135.8471	135.8470	168.2152	105.7549	32.1179	98.0541	[illegible]	[illegible]
COMPOSITION LB-MOL/HR										
1 [illegible]	2.02	.0	.0	.0	.0	.0	.0	.0	.0	.0
2 [illegible]	28.01	.0	.0	.0	.0	.0	.0	.0	.0	.0
3 [illegible]	34.03	.0	.0	.0	.0	.0	.0	.0	.0	.0
4 [illegible]	32.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE	32.12	11.92	.0	.0	.0	.0	.0	.0	.0	.0
10 MONO-CHLOROSILANE	66.56	.0	.0	.0	.0	.0	.3657	.1142	3.666	3.6[illegible]
11 DICHLOROSILANE	101.01	.0	.86695E-02	.86695E-05	.0	18.35	.0		47.54	24.19
12 TRICHLOROSILANE	135.45	.0	2.341	.2341E-02	.1210E-01	43.67	.0		73.24	27.57
13 SILICON TETRACHLORIDE	169.90	.0	3.433	.3433	9.960	31.40	.0		43.44	11.54
14 HYDROGEN	70.91	.0	.6406E-02	.6406E-02	176.4	.3478	.0		.4742	.1[illegible]E-01
15 ANTIMONY STEAM	18.02	.0	.0	.0	.0	.0	.0		.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0		.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0		.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0		.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0		.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0		.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0		.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0		.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0		.0	.0
24 [illegible]	58.71	.0	.0	.0	.0	.0	.0		.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0		.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0		.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0		.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0		.0	.0
29 [illegible]	12.01	.0	.0	.0	.0	.0	.0		.0	.0
30 [illegible]	69.62	.0	.0	.0	.0	.0	.0		.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0		.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0		.0	.0
33 [illegible]	95.94	.0	.0	.0	.0	.0	.0		.0	.0
34 [illegible]	90.31	.0	.0	.0	.0	.0	.0		.0	.0
35 [illegible] TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0		.0	.0
36 IRON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0		.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0		.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0		.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0		.0	.0
40 [illegible] CHLORIDE	133.34	.0	.0	.0	.0	.0	.0		.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0		.0	.0
42 [illegible]	274.10	.0	.0	.0	.0	.0	.0		.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0		.0	.0
44 [illegible]	127.62	.0	.0	.0	.0	.0	.0		.0	.0
45 COPPER CHLORIDE	134.45	.0	.0	.0	.0	.0	.0		.0	.0
46 TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0		.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0		.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0		.0	.0
49 [illegible] DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0		.0	.0
50 [illegible] SULFIDE	34.08	.0	.0	.0	.0	.0	.0		.0	.0
51 [illegible]	27.67	.0	.0	.0	.0	.0	.0		.0	.0
52 [illegible]	34.00	.0	.0	.0	.0	.0	.0		.0	.0
53 [illegible]	77.95	.0	.0	.0	.0	.0	.0		.0	.0
54 [illegible] HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0		.0	.0
55 [illegible] HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0		.0	.0
56 [illegible] HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0		.0	.0
57 [illegible] HYDROXIDE	79.00	.0	.0	.0	.0	.0	.0		.0	.0
58 [illegible] HYDROXIDE	89.85	.0	.0	.0	.0	.0	.0		.0	.0
59 [illegible] HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0		.0	.0
60 [illegible] HYDROXIDE	92.32	.0	.0	.0	.0	.0	.0		.0	.0
61 [illegible] HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0		.0	.0
62 [illegible] HYDROXIDE	159.35	.0	.0	.0	.0	.0	.0		.0	.0
63 [illegible]	55.08	.0	.0	.0	.0	.0	.0		.0	.0
64 [illegible]	60.05	.0	.0	.0	.0	.0	.0		.0	.0
65 [illegible]	106.19	.0	.0	.0	.0	.0	.0		.0	.0
66 [illegible] SILANE	66.14	.0	.0	.0	.0	.0	.0		.0	.0
67 [illegible] SILANE	60.17	.0	.0	.0	.0	.0	.0		.0	.0
68 [illegible] SILANE	115.06	.0	.0	.0	.0	.0	.0		.0	.0
69 [illegible] SILANE	159.49	.0	.0	.0	.0	.0	.0		.0	.0
70 [illegible] SILANE	1[illegible].35	.0	.0	.0	.0	.0	.0		.0	.0
ELEMENTAL COMPOSITION LB-MOL/HR										
71 [illegible]	12.01	.0	.0	.0	.0	.0	.0		.0	.0
72 [illegible]	1.01	47.40	34.40	.3480	9.984	175.8	.4730		3.7[illegible]	[illegible]
73 [illegible]	14.01	.0	.0	.0	.0	.0	.0		.0	.0
74 [illegible]	15.00	.0	.0	.0	.0	.0	.0		.0	.0
75 [illegible]	[illegible]	11.92	12.01	35.1	20[illegible]	[illegible]	.1142		1[illegible]	[illegible]
76 [illegible]	[illegible]	.0	1[illegible]	1.063	81.65	203.0	.0		42[illegible]	[illegible]
77 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
78 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
79 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
80 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
81 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
82 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
83 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
84 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
85 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
86 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
87 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
88 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
89 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
90 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
91 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
92 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
93 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
94 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
95 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
96 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
97 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
98 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
99 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
100 [illegible]	[illegible]	.0	.0	.0	.0	.0	.0		.0	.0
		11.92	[illegible]	[illegible]	20[illegible]	[illegible]	.1142		[illegible]	[illegible]

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER	300	301	304	307	308	311	312	313
PRESSURE, PSIA	25.00	20.00	20.00	20.00	20.00	20.00	15.00	550.00
TEMPERATURE, DEG F	77.00	1562.00	1119.99	2600.01	1119.99	1562.00	100.00	100.00
LIQUID FRACTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ STREAM TEMP,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HHT - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTOT = HHT - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	32.1179	10.7441	27.9945	28.0860	28.0860	2.0194	2.0194	2.0194

COMPOSITION, LB-MO/HR

1	HYDROGEN	2.02	.0	23.53	.4609E-01	.0	.0	23.48	23.48	28.57
2	NITROGEN	28.01	.0	.0	.0	.0	.0	.0	.0	.0
3	ARGON	39.95	.0	.0	.0	.0	.0	.0	.0	.0
4	OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5	CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6	CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7	METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8	HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0
9	SILANE	32.12	11.82	.5912E-01	.5912E-01	.0	.0	.0	.0	.0
10	MONOCHLOROSILANE	66.56	.0	.0	.0	.0	.0	.0	.0	.0
11	DICHLOROSILANE	101.01	.0	.0	.0	.0	.0	.0	.0	.0
12	TRICHLOROSILANE	135.45	.0	.0	.0	.0	.0	.0	.0	.0
13	SILICON TETRACHLORIDE	169.90	.0	.0	.0	.0	.0	.0	.0	.0
14	CHLORINE	70.91	.0	.0	.0	.0	.0	.0	.0	.0
15	WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16	SILICON	28.09	.0	11.77	10.42	10.42	1.344	.0	.0	.0
17	CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.0	.0	.0
18	MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19	CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20	ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21	IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22	LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23	TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24	NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25	COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26	PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27	VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28	ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29	CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30	BORON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31	ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32	IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33	CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34	MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35	PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36	BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37	CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38	MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39	CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40	ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41	FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42	LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43	TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	[illegible]	134.45	.0	.0	.0	.0	.0	.0	[illegible]	[illegible]
46	ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47	VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0	.0
48	MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49	SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50	HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51	DIBORANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52	PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53	ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54	CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55	MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56	CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57	ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58	IRON HYDROXIDE	89.86	.0	.0	.0	.0	.0	.0	.0	.0
59	LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60	NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61	COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62	ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63	LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64	SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65	SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66	METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67	DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68	METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69	METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70	DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0

ELEMENTAL COMPOSITION, LB-MO/HR

71	CARBON	(C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72	HYDROGEN	(H)	1.01	47.30	47.30	.3287	.0	.0	46.97	46.97	57.15
73	NITROGEN	(N)	14.01	.0	.0	.0	.0	.0	.0	.0	.0
74	OXYGEN	(O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75	SILICON	(SI)	28.09	11.82	11.82	10.46	10.42	1.344	.0	.0	.0
76	CHLORINE	(CL)	35.45	.0	.0	.0	.0	.0	.0	.0	.0
77	ARGON	(AR)	39.95	.0	.0	.0	.0	.0	.0	.0	.0
78	PHOSPHORUS	(P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79	BORON	(B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80	CHROMIUM	(CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81	MANGANESE	(MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82	CALCIUM	(CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83	ALUMINUM	(AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84	IRON	(FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85	LEAD	(PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86	TITANIUM	(TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87	NICKEL	(NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88	COPPER	(CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89	VANADIUM	(V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90	ZIRCONIUM	(ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91	SULFUR	(S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92	ARSENIC	(AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93	MAGNESIUM	(MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
	TOTAL FLOW			11.82	35.35	10.53	10.42	1.344	23.48	23.48	28.57

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE E-III: 1000 MT/YR COMMERCIAL PLANT
(continued) STREAM CATALOG (ISSUE 2)

STREAM NUMBER		314	2600	2601	2603	2604	2605	2611	2612
PRESSURE, PSIA		50.00	20.00	20.00	20.00	20.00	70.00	[illegible]	[illegible]
TEMPERATURE, DEG F		77.00	100.00	100.00	100.00	100.00	100.00	[illegible]	[illegible]
LIQUID FRACTION		0.0	0.0	0.0	0.0	0.0	1.0000	1.0000	[illegible]
ENTHALPY @ STREAM TEMP, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENTHALPY @ 25C, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT OF FORMATION H25C, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT = HOT - H25 + HF, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT = HOT - H25 + HF, BTU/LB-MO		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY, BTU/HR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT		2.0194	28.0134	28.0134	28.0134	35.2603	64.0447	0.0	28.0134
COMPOSITION, LB-MO/HR									
1 HYDROGEN	2.02	5.089	.0	.0	.0	.6609E-01	.1647E-01	.0	.0
2 NITROGEN	28.01	.0	1.795	.5983	5.007	.0	4.604	.0	4.604
3 ARGON	39.95	.0	.0	.0	.0	3.110	.0	.0	.0
4 OXYGEN	32.00	.0	.0	.0	.0	.0	.0	.0	.0
5 CARBON MONOXIDE	28.01	.0	.0	.0	.0	.0	.0	.0	.0
6 CARBON DIOXIDE	44.01	.0	.0	.0	.0	.0	.0	.0	.0
7 METHANE	16.04	.0	.0	.0	.0	.0	.0	.0	.0
8 HYDROGEN CHLORIDE	36.46	.0	.0	.0	.0	.0	.0	.0	.0
9 SILANE	32.12	.0	.0	.0	.0	.0	.2226E-03	.0	.0
10 MONOCHLOROSILANE	66.56	.0	.0	.0	.0	.5912E-01	.7598E-07	.0	.0
11 DICHLOROSILANE	101.01	.0	.0	.0	.0	.0	.2383E-04	.0	.0
12 TRICHLOROSILANE	135.45	.0	.0	.0	.0	.0	.6142E-02	.0	.0
13 SILICON TETRACHLORIDE	169.90	.0	.0	.0	.0	.0	.3286	.0	.0
14 CHLORINE	70.91	.0	.0	.0	.0	.0	1.374	.0	.0
15 WATER/STEAM	18.02	.0	.0	.0	.0	.0	.0	.0	.0
16 SILICON	28.09	.0	.0	.0	.0	.0	.0	.0	.0
17 CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0	.0	.6004E-01	.0	.0
18 MANGANESE DIOXIDE	86.94	.0	.0	.0	.0	.0	.0	.0	.0
19 CALCIUM	40.08	.0	.0	.0	.0	.0	.0	.0	.0
20 ALUMINUM OXIDE	101.96	.0	.0	.0	.0	.0	.0	.0	.0
21 IRON	55.85	.0	.0	.0	.0	.0	.0	.0	.0
22 LEAD	207.19	.0	.0	.0	.0	.0	.0	.0	.0
23 TITANIUM DIOXIDE	79.90	.0	.0	.0	.0	.0	.0	.0	.0
24 NICKEL	58.71	.0	.0	.0	.0	.0	.0	.0	.0
25 COPPER	63.54	.0	.0	.0	.0	.0	.0	.0	.0
26 PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0	.0	.0	.0	.0
27 VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0	.0	.0	.0	.0
28 ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0	.0	.0	.0	.0
29 CARBON	12.01	.0	.0	.0	.0	.0	.0	.0	.0
30 IRON OXIDE	69.62	.0	.0	.0	.0	.0	.0	.0	.0
31 ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0	.0	.0	.0	.0
32 IRON SULFATE	151.91	.0	.0	.0	.0	.0	.0	.0	.0
33 CUPROUS OXIDE	95.54	.0	.0	.0	.0	.0	.0	.0	.0
34 MAGNESIUM OXIDE	40.31	.0	.0	.0	.0	.0	.0	.0	.0
35 PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0	.0	.0	.0	.0
36 BORON TRICHLORIDE	117.17	.0	.0	.0	.0	.0	.0	.0	.0
37 CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0	.0	.0	.0	.0
38 MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0	.0	.0	.0	.0
39 CALCIUM CHLORIDE	110.99	.0	.0	.0	.0	.0	.0	.0	.0
40 ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0	.0	.0	.0	.0
41 FERRIC CHLORIDE	162.21	.0	.0	.0	.0	.0	.0	.0	.0
42 LEAD DICHLORIDE	278.10	.0	.0	.0	.0	.0	.0	.0	.0
43 TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0	.0	.0	.0	.0
44 NICKEL CHLORIDE	129.62	.0	.0	.0	.0	.0	.0	.0	.0
45 CUPRIC CHLORIDE	134.45	.0	.0	.0	.0	.0	.0	.0	.0
46 ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0	.0	.0	.0	.0
47 VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0	.0	.0	.0	.0
48 MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0	.0	.0	.0	.0
49 SULFUR DICHLORIDE	102.97	.0	.0	.0	.0	.0	.0	.0	.0
50 HYDROGEN SULFIDE	34.08	.0	.0	.0	.0	.0	.0	.0	.0
51 METHANE	27.67	.0	.0	.0	.0	.0	.0	.0	.0
52 PHOSPHINE	34.00	.0	.0	.0	.0	.0	.0	.0	.0
53 ARSINE	77.95	.0	.0	.0	.0	.0	.0	.0	.0
54 CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0	.0	.0	.0	.0
55 MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0	.0	.0	.0	.0
56 CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0	.0	.0	.0	.0
57 ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0	.0	.0	.0	.0
58 IRON HYDROXIDE	89.85	.0	.0	.0	.0	.0	.0	.0	.0
59 LEAD HYDROXIDE	241.20	.0	.0	.0	.0	.0	.0	.0	.0
60 NICKEL HYDROXIDE	92.72	.0	.0	.0	.0	.0	.0	.0	.0
61 COPPER HYDROXIDE	97.55	.0	.0	.0	.0	.0	.0	.0	.0
62 ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0	.0	.0	.0	.0
63 LIME (CAO)	56.08	.0	.0	.0	.0	.0	.0	.0	.0
64 SILICON DIOXIDE	60.08	.0	.0	.0	.0	.0	.0	.0	.0
65 SILOXANE	106.19	.0	.0	.0	.0	.0	.0	.0	.0
66 METHYL SILANE	46.14	.0	.0	.0	.0	.0	.0	.0	.0
67 DIMETHYL SILANE	60.17	.0	.0	.0	.0	.0	.0	.0	.0
68 METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0	.0	.0	.0	.0
69 METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0	.0	.0	.0	.0
70 DIMETHYL DICHLOROSILANE	129.06	.0	.0	.0	.0	.0	.0	.0	.0
ELEMENTAL COMPOSITION, LB-MO/HR									
71 CARBON (C)	12.01	.0	.0	.0	.0	.0	.0	.0	.0
72 HYDROGEN (H)	1.01	10.18	.0	.0	.0	.3287	.3741	.0	.0
73 NITROGEN (N)	14.01	.0	3.590	1.197	10.02	.0	9.209	.0	9.209
74 OXYGEN (O)	16.00	.0	.0	.0	.0	.0	.0	.0	.0
75 SILICON (SI)	28.09	.0	.0	.0	.0	.5912E-01	1.768	.0	.0
76 CHLORINE (CL)	35.45	.0	.0	.0	.0	.0	6.493	.0	.0
77 ARGON (AR)	39.95	.0	.0	.0	.0	3.110	.0	.0	.0
78 PHOSPHORUS (P)	30.97	.0	.0	.0	.0	.0	.0	.0	.0
79 BORON (B)	10.81	.0	.0	.0	.0	.0	.0	.0	.0
80 CHROMIUM (CR)	52.00	.0	.0	.0	.0	.0	.0	.0	.0
81 MANGANESE (MN)	54.94	.0	.0	.0	.0	.0	.0	.0	.0
82 CALCIUM (CA)	40.08	.0	.0	.0	.0	.0	.0	.0	.0
83 ALUMINUM (AL)	26.98	.0	.0	.0	.0	.0	.0	.0	.0
84 IRON (FE)	55.85	.0	.0	.0	.0	.0	.0	.0	.0
85 LEAD (PB)	207.19	.0	.0	.0	.0	.0	.0	.0	.0
86 TITANIUM (TI)	47.90	.0	.0	.0	.0	.0	.0	.0	.0
87 NICKEL (NI)	58.71	.0	.0	.0	.0	.0	.0	.0	.0
88 COPPER (CU)	63.54	.0	.0	.0	.0	.0	.0	.0	.0
89 VANADIUM (V)	50.94	.0	.0	.0	.0	.0	.0	.0	.0
90 ZIRCONIUM (ZR)	91.22	.0	.0	.0	.0	.0	.0	.0	.0
91 SULFUR (S)	32.06	.0	.0	.0	.0	.0	.0	.0	.0
92 ARSENIC (AS)	74.92	.0	.0	.0	.0	.0	.0	.0	.0
93 MAGNESIUM (MG)	24.31	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL		5.089	1.795	.5983	5.007	3.215	5.193	.0	4.604

TABLE E-III: (continued) 1000 MT/YR COMMERCIAL PLANT STREAM CATALOG (ISSUE 2)

STREAM NUMBER	2501	2502	1500	1501
PRESSURE, PSIA	90.00	510.70	100.00	100.00
TEMPERATURE, DEG F	-20.99	100.00	77.00	77.00
LIQUID FRACTION	0.0	0.0	0.0	0.0
ENTHALPY @ STREAM TEMP, BTU/HR	0.0	0.0	0.0	0.0
ENTHALPY @ 25C ,BTU/HR	0.0	0.0	0.0	0.0
HEAT OF FORMATION @25C, BTU/HR	0.0	0.0	0.0	0.0
HTOT = HST - H25 + HF ,BTU/HR	0.0	0.0	0.0	0.0
HTOT = HST - H25 + HF ,BTU/LB-MO	0.0	0.0	0.0	0.0
TOTAL SOLIDS ENTHALPY ,BTU/HR	0.0	0.0	0.0	0.0
AVERAGE MOLECULAR WEIGHT	6.2255	0.0	39.9440	39.9440

COMPOSITION, LB-MO/HR

1	HYDROGEN	2.02	4.553	.0	.0	.0
2	NITROGEN	28.01	.4418E-02	.0	.0	.0
3	ARGON	39.95	.0	.0	1.064	2.046
4	OXYGEN	32.00	.0	.0	.0	.0
5	CARBON MONOXIDE	28.01	.0	.0	.0	.0
6	CARBON DIOXIDE	44.01	.0	.0	.0	.0
7	METHANE	16.04	.0	.0	.0	.0
8	HYDROGEN CHLORIDE	36.46	.1099	.0	.0	.0
9	SILANE	32.12	.1179	.0	.0	.0
10	MONOCHLOROSILANE	66.56	.1418E-01	.0	.0	.0
11	DICHLOROSILANE	101.01	.9926E-01	.0	.0	.0
12	TRICHLOROSILANE	135.45	.1824E-01	.0	.0	.0
13	SILICON TETRACHLORIDE	169.90	.3202E-03	.0	.0	.0
14	CHLORINE	70.91	.0	.0	.0	.0
15	WATER/STEAM	18.02	.0	.0	.0	.0
16	SILICON	28.09	.0	.0	.0	.0
17	CHROMIUM DIOXIDE	83.99	.0	.0	.0	.0
18	MANGANESE DIOXIDE	86.94	.0	.0	.0	.0
19	CALCIUM	40.08	.0	.0	.0	.0
20	ALUMINUM OXIDE	101.96	.0	.0	.0	.0
21	IRON	55.85	.0	.0	.0	.0
22	LEAD	207.19	.0	.0	.0	.0
23	TITANIUM DIOXIDE	79.90	.0	.0	.0	.0
24	NICKEL	58.71	.0	.0	.0	.0
25	COPPER	63.54	.0	.0	.0	.0
26	PHOSPHORUS PENTOXIDE	141.94	.0	.0	.0	.0
27	VANADIUM PENTOXIDE	181.88	.0	.0	.0	.0
28	ZIRCONIUM DIOXIDE	123.22	.0	.0	.0	.0
29	CARBON	12.01	.0	.0	.0	.0
30	BORON OXIDE	69.62	.0	.0	.0	.0
31	ARSENIC PENTOXIDE	229.84	.0	.0	.0	.0
32	IRON SULFATE	151.91	.0	.0	.0	.0
33	CUPROUS OXIDE	95.54	.0	.0	.0	.0
34	MAGNESIUM OXIDE	40.31	.0	.0	.0	.0
35	PHOSPHORUS TRICHLORIDE	137.33	.0	.0	.0	.0
36	BORON TRICHLORIDE	117.17	.0	.0	.0	.0
37	CHROMIUM TRICHLORIDE	158.35	.0	.0	.0	.0
38	MANGANESE DICHLORIDE	125.84	.0	.0	.0	.0
39	CALCIUM CHLORIDE	110.99	.0	.0	.0	.0
40	ALUMINUM CHLORIDE	133.34	.0	.0	.0	.0
41	FERRIC CHLORIDE	162.21	.0	.0	.0	.0
42	LEAD DICHLORIDE	278.10	.0	.0	.0	.0
43	TITANIUM TETRACHLORIDE	189.71	.0	.0	.0	.0
44	NICKEL CHLORIDE	129.62	.0	.0	.0	.0
45	CUPRIC CHLORIDE	134.45	.0	.0	.0	.0
46	ZIRCONIUM TETRACHLORIDE	233.03	.0	.0	.0	.0
47	VANADIUM DICHLORIDE	121.85	.0	.0	.0	.0
48	MAGNESIUM CHLORIDE	95.22	.0	.0	.0	.0
49	SULFUR DICHLORIDE	102.97	.0	.0	.0	.0
50	HYDROGEN SULFIDE	34.08	.0	.0	.0	.0
51	DIBORANE	27.67	.0	.0	.0	.0
52	PHOSPHINE	34.00	.0	.0	.0	.0
53	ARSINE	77.95	.0	.0	.0	.0
54	CHROMIUM HYDROXIDE	86.01	.0	.0	.0	.0
55	MANGANESE HYDROXIDE	88.95	.0	.0	.0	.0
56	CALCIUM HYDROXIDE	74.09	.0	.0	.0	.0
57	ALUMINUM HYDROXIDE	78.00	.0	.0	.0	.0
58	IRON HYDROXIDE	89.86	.0	.0	.0	.0
59	LEAD HYDROXIDE	241.20	.0	.0	.0	.0
60	NICKEL HYDROXIDE	92.72	.0	.0	.0	.0
61	COPPER HYDROXIDE	97.55	.0	.0	.0	.0
62	ZIRCONIUM HYDROXIDE	159.25	.0	.0	.0	.0
63	LIME (CAO)	56.08	.0	.0	.0	.0
64	SILICON DIOXIDE	60.08	.0	.0	.0	.0
65	SILOXANE	106.19	.0	.0	.0	.0
66	METHYL SILANE	46.14	.0	.0	.0	.0
67	DIMETHYL SILANE	60.17	.0	.0	.0	.0
68	METHYLDICHLOROSILANE	115.04	.0	.0	.0	.0
69	METHYLTRICHLOROSILANE	150.49	.0	.0	.0	.0
70	DIMETHYLDICHLOROSILANE	129.06	.0	.0	.0	.0

ELEMENTAL COMPOSITION, LB-MO/HR

71	CARBON	(C)	12.01	.0	.0	.0	.0
72	HYDROGEN	(H)	1.01	9.946	.0	.0	.0
73	NITROGEN	(N)	14.01	.8835E-02	.0	.0	.0
74	OXYGEN	(O)	16.00	.0	.0	.0	.0
75	SILICON	(SI)	28.09	.2500	.0	.0	.0
76	CHLORINE	(CL)	35.45	.3787	.0	.0	.0
77	ARGON	(AR)	39.95	.0	.0	1.064	2.046
78	PHOSPHORUS	(P)	30.97	.0	.0	.0	.0
79	BORON	(B)	10.81	.0	.0	.0	.0
80	CHROMIUM	(CR)	52.00	.0	.0	.0	.0
81	MANGANESE	(MN)	54.94	.0	.0	.0	.0
82	CALCIUM	(CA)	40.08	.0	.0	.0	.0
83	ALUMINUM	(AL)	26.98	.0	.0	.0	.0
84	IRON	(FE)	55.85	.0	.0	.0	.0
85	LEAD	(PB)	207.19	.0	.0	.0	.0
86	TITANIUM	(TI)	47.90	.0	.0	.0	.0
87	NICKEL	(NI)	58.71	.0	.0	.0	.0
88	COPPER	(CU)	63.54	.0	.0	.0	.0
89	VANADIUM	(V)	50.94	.0	.0	.0	.0
90	ZIRCONIUM	(ZR)	91.22	.0	.0	.0	.0
91	SULFUR	(S)	32.06	.0	.0	.0	.0
92	ARSENIC	(AS)	74.92	.0	.0	.0	.0
93	MAGNESIUM	(MG)	24.31	.0	.0	.0	.0
	TOTAL FLOW			4.917	.0	1.064	2.046

TABLE E-IV: TRACE COMPONENT ANALYSIS

Compound LB-MOL/HR	W_1 PLANT FEEDS	W_2 119	W_3 112	W_4 2501	W_5 206	W_6 214	W_7 238	W_8 200	W_9 224	W_{10} 227	W_{11} 226	W_{12} 237	W_{13} 212	W_{14} 225
Aluminum (AL)	3,844E-2	1,339E-3	3,844E-2	6,717E-33	1,339E-3	1,308E-32	1,339E-3	1,339E-3	1,398E-28	2,402E-38	1,300E-28	2,402E-38	2,402E-38	1,300E-2
Antimony (Sb)	3,114E-5	5,148E-4	3,127E-5	1,062E-27	5,148E-4	1,374E-33	5,148E-4	5,148E-4	0	0	0	0	0	0
Argon (Ar)	7,612E-4	7,612E-4	0	7,612E-4	0	0	0	0	0	0	0	0	0	0
Arsenic (As)	4,929E-5	4,648E-5	2,821E-6	4,648E-5	5,670E-16	5,670E-16	2,402E-38	5,670E-16	5,671E-12	6,158E-31	5,670E-16	8,411E-26	8,411E-26	5,670E-1
Boron (B)	1,202E-3	1,197E-3	3,779E-6	1,197E-3	1,437E-11	1,437E-11	2,932E-30	1,437E-11	1,437E-7	6,485E-14	1,437E-11	2,042E-25	2,042E-22	1,437E-
Calcium (Ca)	5,542E-3	0	5,542E-3	0	0	0	0	0	0	0	0	0	0	0
Carbon (C)	1,537E-2	2,674E-4	1,537E-2	0	2,674E-4	0	2,674E-4	2,674E-4	0	0	0	0	0	0
Carbon Dioxide (CO_2)	2,861E-5	2,861E-5	0	2,861E-5	1,502E-13	1,502E-13	0	0	1,502E-13	1,502E-13	0	0	0	0
Chromium (Cr)	1,422E-3	2,475E-5	1,422E-3	0	2,475E-5	0	2,475E-5	2,475E-5	0	0	0	0	0	0
Copper (Cu)	1,135E-1	1,976E-3	1,135E-1	0	1,976E-3	0	1,976E-3	1,976E-3	0	0	0	0	0	0
Helium (He)	7,152E-4	7,152E-4	0	7,152E-4	0	0	0	0	0	0	0	0	0	0
Iron (Fe)	3,767E-2	7,285E-4	3,767E-2	7,285E-32	7,285E-4	0	7,285E-4	7,285E-4	0	0	0	0	0	0
Lead (Pb)	5,078E-5	8,836E-7	5,078E-5	0	8,836E-7	0	8,836E-7	8,836E-7	0	0	0	0	0	0
Magnesium (Mg)	2,560E-3	4,455E-5	2,560E-3	0	4,455E-5	0	4,455E-5	4,455E-5	0	0	0	0	0	0
Manganese (Mn)	1,349E-3	2,347E-5	1,349E-3	0	2,347E-5	0	2,347E-5	2,347E-5	0	0	0	0	0	0
Methane (CH_4)	2,292E-2	2,293E-2	0	2,292E-2	4,056E-20	4,056E-20	0	0	4,056E-20	4,056E-20	0	0	0	0
Nickel (Ni)	4,689E-4	8,337E-6	4,790E-4	0	8,337E-6	0	8,337E-6	8,337E-6	0	0	0	0	0	0
Nitrogen (N_2)	2,380E-1	2,380E-1	0	2,380E-1	9,915E-16	9,915E-16	0	0	9,915E-16	9,915E-16	0	0	0	0
Oxygen (O_2)	4,946E-2	0	0	0	0	0	0	0	0	0	0	0	0	0
Phosphorous (P)	2,387E-3	2,350E-3	3,704E-5	2,350E-3	1,314E-11	1,147E-16	1,314E-11	1,314E-11	1,148E-12	1,145E-20	1,147E-16	7,679E-32	7,679E-29	1,147E-1
Sulfur (S)	8,501E-4	8,158E-2	9,743E-4	4,095E-7	8,157E-2	1,871E-4	8,157E-2	8,173E-2	1,871	1,833E-20	1,871E-4	2,786E-17	1,786E-14	1,871
Titanium (Ti)	2,617E-3	2,431E-3	1,860E-4	2,431E-3	4,376E-32	2,402E-38	2,402E-38	2,402E-38	2,402E-38	2,402E-38	2,402E-38	2,402E-38	2,402E-38	2,402E-3
Vanadium (V)	1,418E-3	1,266E-2	1,448E-3	8,051E-18	1,266E-2	1,462E-20	1,266E-2	1,266E-2	2,402E-38	2,402E-38	2,402E-38	1,461E-23	1,461E-23	2,402E-3
Zinc (Zn)	5,689E-5	9,899E-7	5,689E-5	0	9,899E-7	0	9,899E-7	9,899E-7	0	0	0	0	0	0
Zirconium (Zr)	9,751E-4	2,021E-5	9,743E-4	2,021E-30	3,021E-5	2,021E-34	2,021E-5	2,021E-5	0	0	0	2,020E-37	2,020E-34	0
Hydrogen Chloride	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$SiH_3(CH_3)$	0	0	0	0	0	3,600E-8	0	1,048E-12	1,048E-8	7,218E-30	1,048E-12	1,023E-20	3,600E-8	1,048E-8
$SiCl_2H(CH_3)$	0	0	0	0	0	5,135E-7	4,093E-7	4,098E-7	1,754E-8	0	1,754E-12	5,305E-10	9,049E-7	1,754E-8
$SiCl_3H(CH_3)$	0	8,525E-2	1,583E-3	0	8,525E-2	8,664E-6	8,534E-2	8,534E-2	1,860E-8	0	1,860E-12	8,673E-9	8,264E-6	1,860E-8
$SiH_2(CH_3)_2$	0	0	0	0	0	1,071E-9	0	2,964E-14	2,961E-10	1,201E-38	2,961E-14	3,171E-17	1,021E-9	2,961E-1
$SiCl_2(CH_3)_2$	1,144E-2	1,101E-2	2,170E-4	0	1,102E-2	2,604E-7	1,101E-2	1,101E-2	1,021E-9	0	1,021E-13	2,612E-10	2,601E-7	1,021E-

TABLE E-V: 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	100	101	102	104	105	106	107
TEMPERATURE, DEG F.	0.75002E 02	0.75002E 02	0.75002E 02	0.30000E 03	0.15001E 03	0.75002E 02	0.94401E 03
PRESSURE, PSIA	0.15000E 02	0.15000E 02	0.20000E 02	0.51670E 03	0.51670E 03	0.14700E 02	0.51670E 03
LIQUID FRACTION	0.0	0.0	0.10000E 01	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.18305E-01	0.91282E-02	0.45648E 00	0.11581E-01	0.99447E-02	0.18385E-01	0.29096E-01
THER.COND., BTU/HR-FT-F	0.14779E-01	0.10538E 00	0.58240E-01	0.14218E 00	0.11906E 00	0.14779E-01	0.36460E-01
DENSITY, LB-MOLE/FT**3	0.26157E-02	0.26125E-02	0.49871E 00	0.62329E-01	0.37417E-01	0.25634E-02	0.34512E-01
SURFACE TENSION, DYNES/CM	0.0	0.0	0.18946E 02	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.71329E 00	0.72516E 00	0.36201E 01	0.68130E 00	0.70038E 00	0.71322E 00	0.37489E 00
DEW PT. / BUBBLE PT.,F	0.57397E 02	-0.45838E 03	0.15362E 03	-0.45846E 03	-0.45843E 03	0.56838E 02	0.36509E 03
ENTHALPY, BTU/LB-MOLE	0.37072E 04	0.36281E 04	-0.17929E 04	0.52145E 04	0.41684E 04	0.37072E 04	0.20543E 05
SPECIFIC HEAT, BTU/LB-MO-F	0.68255E 01	0.69763E 01	0.32439E 02	0.69705E 01	0.69878E 01	0.68245E 01	0.17101E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.28574E 00	0.28288E 02	0.0	0.20960E 03
2 NITROGEN	0.15536E 03	0.0	0.0	0.0	0.0	0.15535E 03	0.98389E-01
3 ARGON	0.18543E 01	0.0	0.0	0.0	0.0	0.18543E 01	0.0
4 OXYGEN	0.41679E 02	0.0	0.0	0.0	0.0	0.41679E 02	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.59606E-01	0.0	0.0	0.0	0.0	0.59606E-01	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.23740E 00
9 SILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.23283E-03
10 MONOCHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.75984E-02
11 DICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.27324E 00
12 TRICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.18868E 02
13 SILICON TETRACHLORIDE	0.0	0.0	0.17178E 01	0.0	0.0	0.0	0.20960E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.31595E 01	0.0	0.0	0.0	0.0	0.31595E 01	0.0
16 TOTAL MOLES	0.20211E 03	0.0	0.17178E 01	0.28574E 00	0.28288E 02	0.20210E 03	0.43868E 03

STREAM NUMBER	108	109	110	111	112	113	114
TEMPERATURE, DEG F.	0.93200E 03	0.12000E 03	0.37501E-03	0.35600E 03	0.35600E 03	0.35600E 03	0.10000E 03
PRESSURE, PSIA	0.51470E 03	0.20000E 02	0.51370E 03	0.57470E 03	0.51270E 03	0.51270E 03	0.51170E 03
LIQUID FRACTION	0.0	0.10000E 01	0.50000E 00	0.10000E 01	0.10000E 01	0.0	0.50000E 00
VISCOSITY, CENTIPOISE	0.28715E-01	0.36055E 00	0.47113E-01	0.11511E 00	0.11726E 00	0.20711E-01	0.30130E 00
THER.COND., BTU/HR-FT-F	0.33578E-01	0.52498E-01	0.25549E-01	0.38666E-01	0.38605E-01	0.15727E-01	0.56806E-01
DENSITY, LB-MOLE/FT**3	0.34804E-01	0.48897E 00	0.78374E-01	0.36944E 00	0.37059E 00	0.75960E-01	0.51494E 00
SURFACE TENSION, DYNES/CM	0.0	0.16716E 02	0.69470E-01	0.20667E 01	0.23803E 01	0.0	0.16683E 01
PRANDTL NUMBER	0.40079E 00	0.32013E 01	0.84248E 00	0.20156E 01	0.20407E 01	0.23450E 00	0.20419E 01
DEW PT. / BUBBLE PT.,F	0.36386E 03	0.15003E 03	0.37501E 03	-0.45606E 03	-0.45601E 03	0.39208E 03	0.10000E 03
ENTHALPY, BTU/LB-MOLE	0.20700E 05	-0.40638E 03	0.10950E 05	0.76852E 04	0.77229E 04	0.12341E 05	0.44354E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.17691E 02	0.32402E 02	0.31969E 02	0.44366E 02	0.44444E 02	0.22682E 02	0.25222E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.18560E 03	0.0	0.19630E 03	0.10700E 02	0.16467E-01	0.19100E 03	0.19150E 03
2 NITROGEN	0.98389E-01	0.0	0.10871E 00	0.10327E-01	0.15807E-04	0.10363E 00	0.10412E 00
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.34757E 00	0.0	0.54980E 00	0.20223E 00	0.22255E-03	0.47820E 00	0.49038E 00
9 SILANE	0.26658E-03	0.36572E-04	0.37453E-03	0.10795E-03	0.75979E-07	0.35045E-03	0.35823E-03
10 MONOCHLOROSILANE	0.20002E-01	0.18440E-02	0.44572E-01	0.24570E-01	0.83829E-04	0.36923E-01	0.38498E-01
11 DICHLOROSILANE	0.15490E 01	0.18807E-01	0.50520E 01	0.35031E 01	0.61416E-02	0.30763E 01	0.32190E 01
12 TRICHLOROSILANE	0.64178E 02	0.10306E 02	0.23538E 03	0.17120E 03	0.32863E 00	0.12975E 03	0.13587E 03
13 SILICON TETRACHLORIDE	0.17495E 03	0.19440E 03	0.80603E 03	0.63108E 03	0.13735E 01	0.36606E 03	0.38380E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.42674E 03	0.20473E 03	0.12435E 04	0.81672E 03	0.17250E 01	0.69050E 03	0.71502E 03

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TABLE E-V: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	115	116	117	118	119	120	121
TEMPERATURE, DEG F.	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03
PRESSURE, PSIA	0.51370E 03	0.51370E 03	0.57270E 03	0.51070E 03	0.51070E 03	0.51070E 03	0.52170E 03
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.10000E 01	0.0	0.10000E 01	0.0	0.0
VISCOSITY, CENTIPOISE	0.35294E 00	0.35294E 00	0.35294E 00	0.16082E-01	0.35294E 00	0.16082E-01	0.16187E-01
THER.COND., BTU/HR-FT-F	0.54397E-01	0.54397E-01	0.54397E-01	0.62400E-01	0.54397E-01	0.62400E-01	0.62650E-01
DENSITY, LB-MOLE/FT**3	0.51968E 00	0.51968E 00	0.51968E 00	0.84745E-01	0.51968E 00	0.84745E-01	0.86559E-01
SURFACE TENSION, DYNES/CM	0.80142E 01	0.80144E 01	0.73132E 01	0.0	0.80511E 01	0.0	0.0
PRANDTL NUMBER	0.31408E 01	0.31408E 01	0.31408E 01	0.25745E 00	0.21402E 01	0.25745E 00	0.25810E 00
DEW PT. / BUBBLE PT.,F	-0.45403E 03	-0.45403E 03	-0.45403E 03	0.21393E 03	-0.45403E 03	0.21393E 03	0.21555E 03
ENTHALPY, BTU/LB-MOLE	-0.12463E 04	-0.12463E 04	-0.12463E 04	0.45978E 04	-0.12463E 04	0.45978E 04	0.45981E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.31487E 02	0.31482E 02	0.31487E 02	0.96864E 01	0.31489E 02	0.96864E 01	0.96930E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.50435E 00	0.54179E 01	0.50435E 00	0.18103E 03	0.45525E 01	0.18103E 03	0.18103E 03
2 NITROGEN	0.48940E-03	0.52574E-02	0.48940E-03	0.93951E-01	0.44177E-02	0.93951E-01	0.93951E-01
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.12181E-01	0.13085E 00	0.12181E-01	0.23740E 00	0.10995E 00	0.23740E 00	0.23740E 00
9 SILANE	0.77807E-05	0.83586E-04	0.77807E-05	0.19663E-03	0.70234E-04	0.19663E-03	0.19663E-03
10 MONOCHLOROSILANE	0.15757E-02	0.16927E-01	0.15757E-02	0.57728E-02	0.14223E-01	0.57728E-02	0.57728E-02
11 DICHLOROSILANE	0.14273E 00	0.15333E 01	0.14273E 00	0.25462E 00	0.12884E 01	0.25462E 00	0.25462E 00
12 TRICHLOROSILANE	0.61250E 01	0.65798E 02	0.61250E 01	0.86644E 01	0.55288E 02	0.86644E 01	0.86644E 01
13 SILICON TETRACHLORIDE	0.17736E 02	0.19053E 03	0.17736E 02	0.15445E 02	0.16009E 03	0.15445E 02	0.15445E 02
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.24522E 02	0.26343E 03	0.24522E 02	0.20573E 03	0.22135E 03	0.20573E 03	0.20573E 03

STREAM NUMBER	122	123	124	125	126	127	128
TEMPERATURE, DEG F.	0.96100E 03	0.96901E 03	0.44299E 03	0.10000E 03	0.10000E 03	0.75002E 02	0.75002E 02
PRESSURE, PSIA	0.51670E 03	0.51670E 03	-0.52170E 03	0.95000E 02	0.10000E 03	0.20000E 02	0.52670E 03
LIQUID FRACTION	0.0	0.0	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01
VISCOSITY, CENTIPOISE	0.29062E-01	0.28189E-01	0.27952E-01	0.35294E 00	0.35294E 00	0.44965E 00	0.44965E 00
THER.COND., BTU/HR-FT-F	0.12573E 00	0.12591E-01	0.97127E-02	0.54397E-01	0.54397E-01	0.58110E-01	0.58110E-01
DENSITY, LB-MOLE/FT**3	0.33511E-01	0.36394E-01	0.12550E 00	0.51968E 00	0.51968E 00	0.50473E 00	0.50473E 00
SURFACE TENSION, DYNES/CM	0.0	0.0	0.0	0.14539E 02	0.14443E 02	0.18960E 02	0.87335E 01
PRANDTL NUMBER	0.25426E 00	0.84800E 00	-0.12221E 01	0.31404E 01	0.31402E 01	0.36022E 01	0.36022E 01
DEW PT. / BUBBLE PT.,F	0.21482E 03	0.44362E 03	0.44484E 03	-0.45403E 03	-0.45403E 03	0.15006E 03	0.44472E 03
ENTHALPY, BTU/LB-MOLE	0.12179E 05	0.31293E 05	0.16114E 05	-0.12463E 04	-0.12463E 04	-0.18605E 04	-0.18605E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.92839E 01	0.26332E 02	-0.16732E 02	0.31454E 02	0.31456E 02	0.32363E 02	0.32363E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.18103E 03	0.0	0.0	0.45525E 01	0.45525E 01	0.0	0.0
2 NITROGEN	0.93951E-01	0.0	0.0	0.44177E-02	0.44177E-02	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.23740E 00	0.0	0.0	0.10995E 00	0.10995E 00	0.0	0.0
9 SILANE	0.19663E-03	0.36206E-04	0.36206E-04	0.70234E-04	0.70234E-04	0.36572E-04	0.36572E-04
10 MONOCHLOROSILANE	0.57728E-02	0.18256E-02	0.18256E-02	0.14223E-01	0.14223E-01	0.18440E-02	0.18440E-02
11 DICHLOROSILANE	0.25462E 00	0.18619E-01	0.18619E-01	0.12884E 01	0.12884E 01	0.18807E-01	0.18807E-01
12 TRICHLOROSILANE	0.86644E 01	0.10203E 02	0.10203E 02	0.55288E 02	0.55288E 02	0.10306E 02	0.10306E 02
13 SILICON TETRACHLORIDE	0.15445E 02	0.19415E 03	0.19415E 03	0.16009E 03	0.16009E 03	0.19612E 03	0.19612E 03
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.20573E 03	0.20437E 03	0.20437E 03	0.22135E 03	0.22135E 03	0.20645E 03	0.20645E 03

TABLE E-V: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	129	131	132	200	201	202	203
TEMPERATURE, DEG F,	0.35600E 03	0.77000E 02	0.75002E 02	0.21700E 03	0.21481E 03	0.21900E 03	0.13021E 03
PRESSURE, PSIA	0.51270E 03	0.14900E 02	0.15000E 02	0.55000E 02	0.69600E 02	0.70000E 02	0.65400E 02
LIQUID FRACTION	0.10000E 01	0.0	0.0	0.10000E 01	0.10000E 01	0.0	0.0
VISCOSITY, CENTIPOISE	0.11511E 00	0.17845E-01	0.91282E-02	0.24725E 00	0.22803E 00	0.13769E-01	0.12398E-01
THER.COND., BTU/HR-FT-F	0.38666E-01	0.14968E-01	0.10538E 00	0.43561E-01	0.43923E-01	0.57433E-02	0.11402E-01
DENSITY, LB-MOLE/FT**3	0.36944E 00	0.25881E-02	0.26125E-02	0.44928E 00	0.47663E 00	0.10652E-01	0.10841E-01
SURFACE TENSION, DYNES/CM	0.22663E 01	0.0	0.0	0.11429E 02	0.10895E 02	0.0	0.0
PRANDTL NUMBER	0.20144E 01	0.70090E 00	0.72516E 00	0.27560E 01	0.27782E 01	0.73184E 00	0.43629E 00
DEW PT. / BUBBLE PT.,F	-0.45606E 03	-0.32022E 03	-0.45838E 03	0.21858E 03	0.21819E 03	0.22168E 03	0.13108E 03
ENTHALPY, BTU/LB-MOLE	0.76868E 04	0.37234E 04	0.36281E 04	0.27750E 04	0.33306E 04	0.12424E 05	0.64616E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.44220E 02	0.68084E 01	0.69763E 01	0.33754E 02	0.35106E 02	0.24210E 02	0.13677E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.10700E 02	0.0	0.10000E 01	0.0	0.0	0.0	0.45762E 01
2 NITROGEN	0.10327E-01	0.83565E-02	0.0	0.0	0.0	0.0	0.44664E-02
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.20223E 00	0.0	0.0	0.0	0.0	0.0	0.15419E 00
9 SILANE	0.10795E-03	0.0	0.0	0.36572E-04	0.85961E-02	0.82253E-02	0.17701E 00
10 MONOCHLOROSILANE	0.24570E-01	0.0	0.0	0.18440E-02	0.19140E-03	0.14563E-03	0.19813E 00
11 DICHLOROSILANE	0.35031E 01	0.0	0.0	0.18807E-01	0.28382E 01	0.16491E 01	0.73172E 01
12 TRICHLOROSILANE	0.17120E 03	0.0	0.0	0.10306E 02	0.98070E 02	0.42800E 02	0.39200E 01
13 SILICON TETRACHLORIDE	0.63108E 03	0.0	0.0	0.19440E 03	0.21779E 03	0.57699E 02	0.19786E 00
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.81672E 03	0.83565E-02	0.10000E 01	0.20473E 03	0.31871E 03	0.10216E 03	0.16545E 02

STREAM NUMBER	204	205	206	207	208	209	210
TEMPERATURE, DEG F,	-0.25600E 02	-0.25600E 02	0.21900E 03	0.21321E 03	0.21740E 03	0.15960E 03	0.15440E 03
PRESSURE, PSIA	0.64400E 02	0.70000E 02	0.70000E 02	0.54800E 02	0.55000E 02	0.50200E 02	0.49200E 02
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.0	0.0	0.10000E 01
VISCOSITY, CENTIPOISE	0.24378E 00	0.53410E 00	0.22897E 00	0.24720E 00	0.13625E-01	0.12565E-01	0.22707E 00
THER.COND., BTU/HR-FT-F	0.70085E-01	0.70117E-01	0.43613E-01	0.43864E-01	0.54722E-02	0.54578E-02	0.47786E-01
DENSITY, LB-MOLE/FT**3	0.71307E 00	0.80467E 00	0.46870E 00	0.45488E 00	0.82539E-02	0.81692E-02	0.59886E 00
SURFACE TENSION, DYNES/CM	0.39868E 01	0.18518E 02	0.10801E 02	0.11553E 02	0.0	0.0	0.11958E 02
PRANDTL NUMBER	0.20313E 01	0.39783E 01	0.27606E 01	0.27663E 01	0.69409E 00	0.65977E 00	0.27852E 01
DEW PT. / BUBBLE PT.,F	-0.45603E 03	-0.45253E 03	0.22254E 03	0.21537E 03	0.21832E 03	0.16025E 03	0.15320E 03
ENTHALPY, BTU/LB-MOLE	-0.34608E 04	-0.59562E 04	0.25549E 04	0.25942E 04	0.13475E 05	0.94423E 04	-0.76712E 03
SPECIFIC HEAT, BTU/LB-MO-F	0.19221E 02	0.24273E 02	0.34939E 02	0.33835E 02	0.24892E 02	0.18633E 02	0.30952E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.45762E 01	0.23682E-01	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.44664E-02	0.48757E-04	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.15419E 00	0.44245E-01	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.17701E 00	0.59063E-01	0.37081E-03	0.0	0.0	0.22081E 00	0.22081E 00
10 MONOCHLOROSILANE	0.19813E 00	0.18395E 00	0.45771E-04	0.0	0.0	0.31677E 01	0.31677E 01
11 DICHLOROSILANE	0.73172E 01	0.72179E 01	0.11891E 01	0.15242E 00	0.14032E 00	0.77930E 02	0.77930E 02
12 TRICHLOROSILANE	0.39200E 01	0.39018E 01	0.55270E 02	0.89263E 02	0.79303E 02	0.73036E 03	0.73036E 03
13 SILICON TETRACHLORIDE	0.19786E 00	0.19754E 00	0.16009E 03	0.88751E 03	0.69311E 03	0.13636E 02	0.13636E 02
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.16545E 02	0.1[illegible]E 02	0.21655E 03	0.97692E 03	0.77255E 03	0.82531E 03	0.82531E 03

TABLE E-V: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	211	212	213	214	215	216	217
TEMPERATURE, DEG F.	0.15440E 03	0.15800E 03	0.15440E 03	0.15440E 03	0.15800E 03	0.15800E 03	0.32689E 03
PRESSURE, PSIA	0.32000E 03	0.84000E 02	0.55000E 02	0.32000E 03	0.85000E 02	0.85000E 02	0.31990E 03
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01
VISCOSITY, CENTIPOISE	0.22707E 00	0.23110E 00	0.22707E 00	0.22707E 00	0.22906E 00	0.22906E 00	0.99677E-01
THER.COND., BTU/HR-FT-F	0.47786E-01	0.47654E-01	0.47786E-01	0.47786E-01	0.47564E-01	0.47564E-01	0.42546E-01
DENSITY, LB-MOLE/FT**3	0.59886E 00	0.58357E 00	0.59886E 00	0.59887E 00	0.58396E 00	0.58396E 00	0.45185E 00
SURFACE TENSION, DYNES/CM	0.89653E 01	0.11731E 02	0.11887E 02	0.89654E 01	0.11606E 02	0.11606E 02	0.31838E 01
PRANDTL NUMBER	0.27376E 01	0.27922E 01	0.27856E 01	0.27372E 01	0.27076E 01	0.27076E 01	0.17414E 01
DEW PT. / BUBBLE PT.,F	0.31857E 03	0.19592E 03	0.16091E 03	0.31857E 03	0.80173E 03	0.20173E 03	0.32716E 03
ENTHALPY, BTU/LB-MOLE	-0.78827E 03	-0.52388E 03	-0.76951E 03	-0.78828E 03	-0.53680E 03	-0.53680E 03	0.52865E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.31560E 02	0.32342E 02	0.32116E 02	0.31556E 02	0.31584E 02	0.31584E 02	0.41704E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.22081E 00	0.96983E-01	0.12345E 00	0.97359E-01	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.31677E 01	0.13967E 01	0.17710E 01	0.13967E 01	0.86611E-02	0.86692E-02	0.45255E-01
11 DICHLOROSILANE	0.77930E 02	0.33194E 02	0.43569E 02	0.34361E 02	0.23384E 01	0.23408E 01	0.11687E 02
12 TRICHLOROSILANE	0.73036E 03	0.27672E 03	0.40833E 03	0.32203E 03	0.34296E 03	0.34330E 03	0.12072E 04
13 SILICON TETRACHLORIDE	0.13636E 02	0.40313E 02	0.76234E 01	0.60122E 01	0.64000E 01	0.64064E 01	0.19851E 02
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.82531E 03	0.35171E 03	0.46142E 03	0.36390E 03	0.35171E 03	0.35206E 03	0.12388E 04

STREAM NUMBER	218	219	220	221	222	223	224
TEMPERATURE, DEG F.	0.32731E 03	0.25650E 03	0.24879E 03	0.24879E 03	0.24879E 03	0.12200E 03	0.12200E 03
PRESSURE, PSIA	0.32000E 03	0.31510E 03	0.32000E 03	0.31410E 03	0.55000E 03	0.54900E 03	0.54800E 03
LIQUID FRACTION	0.0	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01
VISCOSITY, CENTIPOISE	0.17560E-01	0.15488E-01	0.96507E-01	0.96508E-01	0.96508E-01	0.19617E 00	0.17347E 00
THER.COND., BTU/HR-FT-F	0.82604E-02	0.90088E-02	0.32589E-01	0.32589E-01	0.32589E-01	0.50254E-01	0.51042E-01
DENSITY, LB-MOLE/FT**3	0.54896E-01	0.57085E-01	0.61913E 00	0.61913E 00	0.61913E 00	0.76073E 00	0.72472E 00
SURFACE TENSION, DYNES/CM	0.0	0.0	0.32144E 01	0.32318E 01	0.25915E 01	0.59398E 01	0.58101E 01
PRANDTL NUMBER	0.99787E 00	0.33237E 00	0.13377E 02	0.13375E 02	0.13479E 02	0.28027E 01	0.22748E 01
DEW PT. / BUBBLE PT.,F	0.32800E 03	0.25792E 03	0.23801E 03	0.23612E 03	0.29772E 03	0.29750E 03	0.21410E 03
ENTHALPY, BTU/LB-MOLE	0.11777E 05	0.76792E 04	0.20197E 04	0.20228E 04	0.18638E 04	-0.28700E 04	-0.19146E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.38374E 02	0.10468E 02	0.94414E 02	0.76570E 02	0.18394E 03	0.29015E 02	0.27053E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.0	0.25337E 01	0.20706E 01	0.25337E 01	0.46304E 00	0.46304E 00	0.12191E 02
10 MONOCHLOROSILANE	0.36586E-01	0.10801E 03	0.88272E 02	0.10801E 03	0.19739E 02	0.19739E 02	0.18353E 02
11 DICHLOROSILANE	0.93461E 01	0.41413E 03	0.33845E 03	0.41413E 03	0.75684E 02	0.75684E 02	0.43668E 02
12 TRICHLOROSILANE	0.86392E 03	0.58100E 02	0.47482E 02	0.58100E 02	0.10618E 02	0.10618E 02	0.31898E 02
13 SILICON TETRACHLORIDE	0.13444E 02	0.19466E-01	0.15909E-01	0.19466E-01	0.35575E-02	0.35575E-02	0.39784E 00
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.88675E 03	0.58279E 03	0.47629E 03	0.58279E 03	0.10651E 03	0.10651E 03	0.10651E 03

TABLE E-V: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	225	226	227	230	231	232	233
TEMPERATURE, DEG F.	0.26701E 03	0.26701E 03	-0.25708E 02	-0.25708E 02	-0.25708E 02	-0.25708E 02	-0.25708E 02
PRESSURE, PSIA	0.36000E 03	0.36000E 03	0.35400E 03	0.35510E 03	0.35410E 03	0.36000E 03	0.37410E 03
LIQUID FRACTION	0.10000E 01	0.10000E 01	0.0	0.0	0.10000E 01	0.10000E 01	0.0
VISCOSITY, CENTIPOISE	0.93603E-0.	0.93602E-01	0.10388E-01	0.10396E-01	0.56724E-01	0.56724E-01	0.10560E-01
THER.COND., BTU/HR-FT-F	0.33181E-01	0.33181E-01	0.98706E-02	0.98824E-02	0.46522E-01	0.46522E-01	0.10101E-01
DENSITY, LB-MOLE/FT**3	0.57255E 00	0.57255E 00	0.11008E 00	0.11066E 00	0.90235E 00	0.90235E 00	0.12122E 00
SURFACE TENSION, DYNES/CM	0.32051E 01	0.32051E 01	0.0	0.0	0.30695E 01	0.30507E 01	0.0
PRANDTL NUMBER	0.21457E 01	0.21454E 01	-0.17099E 00	-0.17093E 00	0.20566E 01	0.20566E 01	-0.16986E 00
DEW PT. / BUBBLE PT.,F	0.25988E 03	0.25988E 03	-0.19856E 02	-0.19643E 02	-0.19836E 02	-0.18698E 02	-0.16028E 02
ENTHALPY, BTU/LB-MOLE	0.30813E 04	0.30813E 04	0.14093E 04	0.14093E 04	-0.22003E 04	-0.22003E 04	0.14093E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.30678E 02	0.30674E 02	0.22396E 02	0.22396E 02	0.22396E 02	0.22396E 02	0.22396E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.36568E 00	0.36572E-04	0.11825E 02	0.37840E 02	0.11707E 02	0.26015E 02	0.11824E 02
10 MONOCHLOROSILANE	0.18351E 02	0.18353E-02	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.43664E 02	0.43668E-02	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.31895E 02	0.31898E-02	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.39780E 00	0.39784E-04	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.94673E 02	0.94682E-02	0.11825E 02	0.37840E 02	0.11707E 02	0.26015E 02	0.11824E 02

STREAM NUMBER	234	235	236	237	238	239	240
TEMPERATURE, DEG F.	0.12600E 03	0.12600E 03	0.32751E 03	0.15800E 03	0.21740E 03	0.26701E 03	-0.25708E 02
PRESSURE, PSIA	0.37410E 03	0.25000E 02	0.32000E 03	0.85000E 02	0.55000E 02	0.36000E 03	0.35410E 03
LIQUID FRACTION	0.0	0.0	0.10000E 01	0.10000E 01	0.10000E 01	0.10000E 01	0.0
VISCOSITY, CENTIPOISE	0.12786E-01	0.12223E-01	0.99486E-01	0.22906E 00	0.24705E 00	0.93602E-01	0.10388E-01
THER.COND., BTU/HR-FT-F	0.13768E-01	-0.12582E-01	0.42594E-01	0.47564E-01	0.43532E-01	0.33181E-01	0.98717E-02
DENSITY, LB-MOLE/FT**3	0.66750E-01	0.40055E-02	0.45084E 00	0.58396E 00	0.44895E 00	0.57254E 00	0.11013E 00
SURFACE TENSION, DYNES/CM	0.0	0.0	0.31721E 01	0.11606E 02	0.31413E 02	0.32051E 01	0.0
PRANDTL NUMBER	0.69854E 00	0.63388E 00	0.18705E 01	0.27078E 01	0.21870E 03	0.21456E 01	-0.17099E 00
DEW PT. / BUBBLE PT.,F	-0.16028E 02	-0.14902E 03	0.32753E 03	0.20173E 03	0.27905E 04	0.25988E 03	-0.19836E 02
ENTHALPY, BTU/LB-MOLE	0.29548E 04	0.33291E 04	0.53191E 04	-0.53680E 03	0.33733E 02	0.30813E 04	0.14093E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.99875E 01	0.86635E 01	0.44987E 02	0.31586E 02	0.0	0.30678E 02	0.22396E 02
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0		0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.11824E 02	0.11824E 02	0.0	0.0	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.0	0.0	0.86692E-02	0.86693E-05	0.0	0.36572E 00	0.11824E 00
11 DICHLOROSILANE	0.0	0.0	0.23408E 01	0.23408E-02	0.32099E-01	0.18353E 02	0.0
12 TRICHLOROSILANE	0.0	0.0	0.34330E 03	0.34330E 00	0.99599E 01	0.43668E 02	0.0
13 SILICON TETRACHLORIDE	0.0	0.0	0.64064E 01	0.64064E-02	0.19439E 03	0.31898E 02	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.39784E 00	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.11824E 02	0.11824E 02	0.35206E 03	0.35206E 00	0.40436E 03	0.94682E 02	0.11824E 00

TABLE E-V: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	242	243	300	301	304	307	308
TEMPERATURE, DEG F.	0.26701E 03	0.26701E 03	0.77000E 02	0.15621E 04	0.11200E 04	0.26000E 04	0.11200E 04
PRESSURE, PSIA	0.36000E 03	0.36000E 03	0.25000E 02	0.20000E 02	0.20000E 02	0.20000E 02	0.20000E 02
LIQUID FRACTION	0.10000E 01	0.0	0.0	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.81062E-01	0.15900E-01	0.11295E-01	0.23056E-01	0.27579E-01	0.30414E-01	0.19253E-01
THER.COND., BTU/HR-FT-F	0.31891E-01	0.96848E-02	0.10989E-01	0.29363E 00	0.88681E-01	0.39094E 00	0.24771E 00
DENSITY, LB-MOLE/FT**3	0.57105E 00	0.63075E-01	0.43805E-02	0.92157E-03	0.11794E-02	0.60901E-03	0.11794E-02
SURFACE TENSION, DYNES/CM	0.25998E 01	0.0	0.0	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.19396E 01	0.46834E 00	0.65823E 00	0.66165E 00	0.18661E 00	0.74574E 00	0.66508E 00
DEW PT. / BUBBLE PT.,F	0.22887E 03	0.25985E 03	-0.14902E 03	-0.27861E 03	-0.17461E 03	-0.45834E 03	-0.45849E 03
ENTHALPY, BTU/LB-MOLE	0.34003E 04	0.74458E 04	0.29085E 04	0.14134E 05	0.10740E 05	0.22063E 05	0.10952E 05
SPECIFIC HEAT, BTU/LB-MO-F	0.19062E 02	0.10584E 02	0.85034E 01	0.72852E 01	0.46962E 01	0.79883E 01	0.71311E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.23531E 02	0.46089E-01	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.36660E 01	0.33003E 01	0.11824E 02	0.59122E-01	0.59122E-01	0.0	0.0
10 MONOCHLOROSILANE	0.47543E 02	0.29190E 02	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.73239E 02	0.29571E 02	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.43443E 02	0.11545E 02	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.47424E 00	0.76403E-01	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.16837E 03	0.73683E 02	0.11824E 02	0.23590E 02	0.10521E 00	0.0	0.0

STREAM NUMBER	311	312	313	314	2400	2401	2403
TEMPERATURE, DEG F.	0.15621E 04	0.10000E 03	0.30000E 03	0.77000E 02	0.10000E 03	0.10000E 03	0.10000E 03
PRESSURE, PSIA	0.20000E 02	0.15800E 02	0.55000E 03	0.50000E 02	0.20000E 02	0.20000E 02	0.20000E 02
LIQUID FRACTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.22833E-01	0.94191E-02	0.11580E-01	0.91464E-02	0.18380E-01	0.18380E-01	0.18380E-01
THER.COND., BTU/HR-FT-F	0.29541E 00	0.10954E 00	0.14226E 00	0.10581E 00	0.15507E-01	0.15507E-01	0.15507E-01
DENSITY, LB-MOLE/FT**3	0.92157E-03	0.26289E-02	0.66275E-01	0.86632E-02	0.33311E-02	0.33311E-02	0.33311E-02
SURFACE TENSION, DYNES/CM	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.67890E 00	0.71921E 00	0.68085E 00	0.72381E 00	0.69967E 00	0.69967E 00	0.69967E 00
DEW PT. / BUBBLE PT.,F	-0.45847E 03	-0.45839E 03	-0.45846E 03	-0.45838E 03	-0.31554E 03	-0.31554E 03	-0.31554E 03
ENTHALPY, BTU/LB-MOLE	0.14145E 05	0.38025E 04	0.52159E 04	0.36431E 04	0.38794E 04	0.38794E 04	0.38794E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.73199E 01	0.69704E 01	0.69705E 01	0.69785E 01	0.68363E 01	0.68363E 01	0.68363E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.23484E 02	0.23484E 02	0.28574E 02	0.50891E 01	0.0	0.0	0.0
2 NITROGEN	0.0	0.0	0.0	0.0	0.17950E 01	0.59833E 00	0.50090E 01
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.23484E 02	0.23484E 02	0.28574E 02	0.50891E 01	0.17950E 01	0.59833E 00	0.50090E 01

TABLE E-V: (continued) 1000 MT/YR COMMERCIAL PLANT PHYSICAL PROPERTIES FOR PROCESS STREAMS (ISSUE 2)

STREAM NUMBER	2404	2600	2601	2402	2501	2502	1500
TEMPERATURE, DEG F.	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45969E 03	0.75002E 02
PRESSURE, PSIA	0.0	0.0	0.0	0.0	0.0	0.0	0.15000E 02
LIQUID FRACTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VISCOSITY, CENTIPOISE	0.0	0.0	0.0	0.0	0.0	0.0	0.91282E-02
THER.COND., BTU/HR-FT-F	0.0	0.0	0.0	0.0	0.0	0.0	0.10538E 00
DENSITY, LB-MOLE/FT**3	0.0	0.0	0.0	0.0	0.0	0.0	0.26125E-02
SURFACE TENSION, DYNES/CM	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRANDTL NUMBER	0.0	0.0	0.0	0.0	0.0	0.0	0.72516E 00
DEW PT. / BUBBLE PT.,F	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45969E 03	-0.45838E 03
ENTHALPY, BTU/LB-MOLE	0.0	0.0	0.0	0.0	0.0	0.0	0.36281E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.0	0.0	0.0	0.0	0.0	0.0	0.69763E 01
FLOW * ENTHALPY, BTU/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPOSITION, LB-MOLES/HR							
1 HYDROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.10000E 01
2 NITROGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 ARGON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 OXYGEN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 CARBON MONOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 CARBON DIOXIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 METHANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 HYDROGEN CHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 SILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 MONOCHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 DICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 TRICHLOROSILANE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 SILICON TETRACHLORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 CHLORINE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 STEAM/WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 TOTAL MOLES	0.0	0.0	0.0	0.0	0.0	0.0	0.10000E 01

STREAM NUMBER	1501
TEMPERATURE, DEG F.	0.75002E 02
PRESSURE, PSIA	0.15000E 02
LIQUID FRACTION	0.0
VISCOSITY, CENTIPOISE	0.91282E-02
THER.COND., BTU/HR-FT-F	0.10538E 00
DENSITY, LB-MOLE/FT**3	0.26125E-02
SURFACE TENSION, DYNES/CM	0.0
PRANDTL NUMBER	0.72516E 00
DEW PT. / BUBBLE PT.,F	-0.45838E 03
ENTHALPY, BTU/LB-MOLE	0.36281E 04
SPECIFIC HEAT, BTU/LB-MO-F	0.69763E 01
FLOW * ENTHALPY, BTU/HR	0.0
COMPOSITION, LB-MOLES/HR	
1 HYDROGEN	0.10000E 01
2 NITROGEN	0.0
3 ARGON	0.0
4 OXYGEN	0.0
5 CARBON MONOXIDE	0.0
6 CARBON DIOXIDE	0.0
7 METHANE	0.0
8 HYDROGEN CHLORIDE	0.0
9 SILANE	0.0
10 MONOCHLOROSILANE	0.0
11 DICHLOROSILANE	0.0
12 TRICHLOROSILANE	0.0
13 SILICON TETRACHLORIDE	0.0
14 CHLORINE	0.0
15 STEAM/WATER	0.0
16 TOTAL MOLES	0.10000E 01