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FINAL REPORT
Covering the Period May 18, 1981 - July 30, 1982

SILICON PRODUCTION PROCESS EVALUATIONS

JPL Contract No. 956045
July 30, 1982

Prepared for

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California 91103

The JPL Flat-Plate Solar Array (FSA) Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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ABSTRACT

The Flat-Plate Solar Array (FSA) Project at Jet Propulsion Laboratory (JPL) in Pasadena, California, is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. In this program for silicon production process evaluations, the goals are to perform chemical engineering and cost analyses for the processes under consideration for the production of silicon at lower cost.

Chemical engineering analyses involving the preliminary process design of a plant (1,000 metric tons/year capacity) to produce silicon via the technology under consideration were accomplished for the following processes:

- . HSC Process for Silicon - Case A
- . HSC Process for Silicon - Case B

Major activities in the chemical engineering analyses included base case conditions, reaction chemistry, process flowsheet, material balance, energy balance, property data, equipment design, major equipment list, production labor and forward for economic analysis. The process design package provided detailed data for raw materials, utilities, major process equipment and production labor requirements necessary for polysilicon production in each process.

In Case A of the HSC process (Hemlock Semiconductor Corporation), the feed to the redistribution reactor is comprised of the bottom stream from the third distillation unit. In Case B, the redistribution reactor feed is composed of the distillate stream from the second distillation unit.

Using detailed data from the process design package, cost analyses for a 1,000 metric tons/year silicon plant were accomplished for the processes under consideration. Primary results issuing from the cost analyses included plant capital investment and product cost which are useful in identification of those processes showing promise for producing silicon at lower cost.

Cost and profitability results issuing from the chemical engineering and cost analyses are summarized below:

Process	Product Cost $/kg of silicon, 1980 dollars	Product Cost $/kg of silicon, 1982 dollars	Sales Price, $/kg of silicon, 1982 dollars
HSC Process for Silicon - Case A	22.65	26.46	32.47 @ 10% DCF
HSC Process for Silicon - Case B	22.62	26.43	32.33 @ 10% DCF

For the summary tabulation, the product cost represents all cost associated with producing silicon including direct manufacturing cost, indirect manufacturing cost, plant overhead and general expenses. The sales price includes a profit for the company measured in terms of DCF (discounted cash flow) rate of return after taxes on the capital investment that the company spent in going into the business.

These cost and profitability results for both Cases A and B of the HSC process indicate that this new technology shows promise for producing silicon at appreciable lower cost and comprises an alternate process capable of providing a less costly silicon material for solar cells.

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1. INTRODUCTION

The Flat-Plate Solar Array (FSA) Project at Jet Propulsion Laboratory (JPL) in Pasadena, California, is sponsored by the Department of Energy (DOE); and forms part of the Photovoltaic Energy Systems Program to initiate a major effort toward the development of low-cost solar arrays. An important overall objective of the project is to reduce the cost of electricity produced with solar cells.

Semiconductor grade silicon which is currently produced via the conventional Siemens process by major manufacturers in the United States is too expensive to meet the silicon material cost goals for low cost electricity from solar cells. Lower cost silicon is needed for solar cells. Alternate processes that depart from the conventional process need to be developed to produce a less costly silicon material.

Process evaluation - which is a very useful tool in research and development - is useful in investigation of such alternate processes for silicon. The planning and implementation of a research and development program involves decision making on what work can be left out with least jeopardy to short and long term consequences and what work should be pursued with the best chance for success in achieving short and long term goals. Early process evaluation investigation including preliminary economic evaluation aids the decision-making involved in whether to commit extra funds to carry out a project from research to large scale plant.

The early study particularly minimizes the risks involved in the process development from early research to large scale plant. The process evaluation investigation should be initiated with the very inception of the research project and continued throughout its life until the project is proved successful or abandoned because it cannot effectively meet the financial and product purity goals.

In research and development, a screening out is required for those projects and processes which are believed to be unsound or least attractive. Economics dictate that the money should not be wasted on projects which may turn out to be useless. The many alternate projects and processes which are available necessitate the effective use of a screening procedure, not to locate a fool-proof venture, but to try to select the best possible project.

Process evaluation investigation may effectively deal with a complete process or part of a process. Major cost areas of a process and profitability potential of a proposed process may be pinpointed. It is also equally valuable in comparing alternate processes and in the selection of processes with the best technical and economic features.

A typical sequence for process selection is presented in Figure 1-1. The process evaluation activities are shown in relation to their usefulness in the selection of a process for scale-up to pilot plant and large scale plant. These process evaluation activities (system properties, chemical engineering and economic analysis tasks) may be effectively utilized in the investigation of alternate processes for low cost, high volume production of silicon suitable for solar cells.

In this program for silicon production process evaluations, the goals are to perform chemical engineering studies and analyses for the processes under consideration for the production of silicon. The program also includes provisions for performing economic and cost analyses of the polysilicon production processes being evaluated by the Silicon Material Task.

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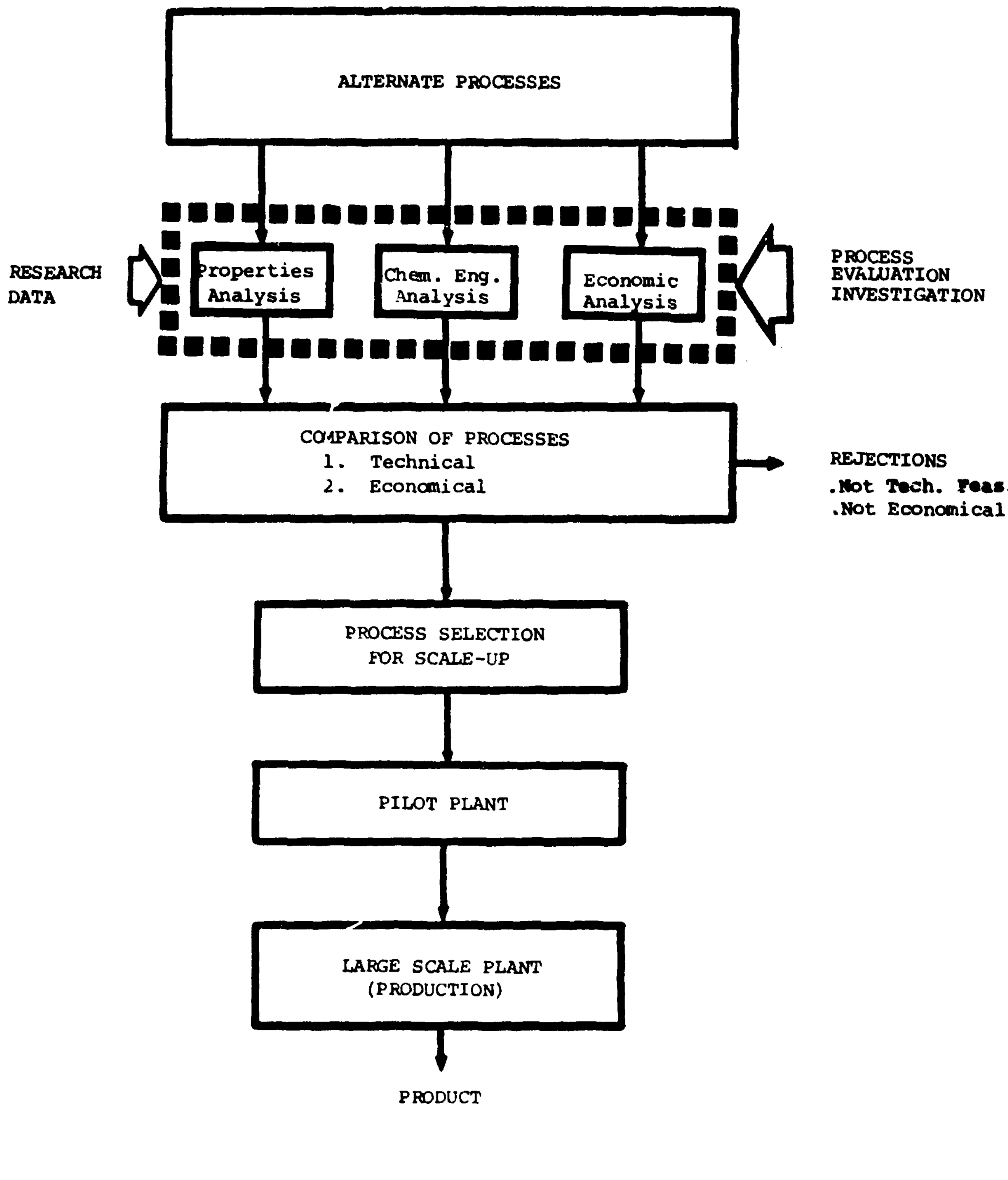

Figure 1-1 Typical Sequence for Process Selection

2. CHEMICAL ENGINEERING ANALYSIS

2.1 HSC Process for Silicon - Case A (Hemlock Semiconductor Corporation)

The chemical engineering analysis activity involves the preliminary process design of a plant to produce silicon via the technology under consideration.

The process flowsheet for Case A of HSC process (Hemlock Semiconductor Corporation) for silicon is shown in Figure 2.1-1. The process involves major processing operations of hydrochlorination, separation, several distillation units, redistribution, boron removal, silicon deposition, recovery unit and waste treatment.

Metallurgical grade silicon is hydrochlorinated in the presence of hydrogen and silicon tetrachloride in a fluidized bed reactor. In the process, the reaction product issuing from the hydrochlorination reactor (hydrochlorination-hydrogenation reaction) is cooled and undergoes a vapor-liquid flash separation. The vapor fraction containing the hydrogen from the flash is recycled back to the hydrochlorination reactor. The liquid fraction containing the chlorosilanes and dissolved gases is fed to the initial distillation column.

The function of the initial distillation column (D-01, stripper column) in the process is to remove volatile gases (such as hydrogen and nitrogen) which are dissolved in liquid chlorosilanes. For the engineering design, TCS (trichlorosilane) was selected as the heavy key component for the separation.

The second distillation column (D-02, TCS column) in the process separates TCS (trichlorosilane) and TET (silicon tetrachloride). The distillation column has three feeds (redistribution reactor effluent, chlorosilanes from the recovery unit and bottoms from the initial distillation). The TET from the distillation is recycled to the hydrochlorination reactor for additional conversion. The TCS from the distillation is sent to the boron removal unit and a subsequent additional distillation.

The third distillation column (D-03, DCS column) in the process separates DCS (dichlorosilane) and TCS (trichlorosilane). The TCS in the bottoms from the distillation is sent to the redistribution reactor. The DCS is sent to the silicon deposition reactors.

The design results for number of trays (equilibrium stages) required for each separation are shown in Figure 2.1-2, 2.1-3 and 2.1-4 for distillation D-01, D-02 and D-03. The design curve in each figure discloses the variation of number of trays with reflux ratio.

Intermediate in the several distillation units, the TCS is redistributed to DCS and TET by passing through a fixed bed of catalyst. After redistribution, the stream is fed to appropriate distillation unit for separation and purification. The reaction equation to produce DCS is shown as

$$2SiHCl_3 \rightleftarrows SiH_2Cl_2 + SiCl_4 \qquad (2.1\text{-}1)$$

The HSC process is based on the chemical vapor deposition of DCS (dichlorosilane) with hydrogen to produce polysilicon. This DCS deposition reaction rate is fast and has the following representative chemical reaction equation:

$$SiH_2Cl_2 + H_2 \rightarrow Si \downarrow + HCl + \text{By-products} \qquad (2.1\text{-}2)$$

The above reaction equation may include several reaction steps. Chemical equilibrium is involved and in reality, several chlorosilanes (such as SiH_2Cl_2, $SiHCl_3$ and $SiCl_4$) are also present in the gas phase by-products.

The process design of a plant to produce silicon by this new technology was performed to obtain data for a cost analysis. The design was based on a plant to produce 1,000 metric tons/yr of silicon via the HSC process - Case A. In Case A, the TCS (trichlorosilane) from distillation D-03 is sent to the redistribution reactor.

The detailed status sheet for the process design package is shown in Table 2.1-1 and is representative of the various sub-items that make up the activity. The summarized results for the preliminary process design are presented in a tabular format to make it easier to locate items of specific interest. The guide for these tables is given below:

- Process Flowsheet----------------Figure 2.1-5
- Base Case Conditions-------------Table 2.1-2
- Reaction Chemistry---------------Table 2.1-3
- Raw Material Requirements--------Table 2.1-4
- Utility Requirements-------------Table 2.1-5
- Major Process Equipment----------Table 2.1-6
- Production Labor Requirements----Table 2.1-7

The process design provides detailed data for raw materials, utilities, major process equipment and production labor requirements which are necessary for polysilicon production.

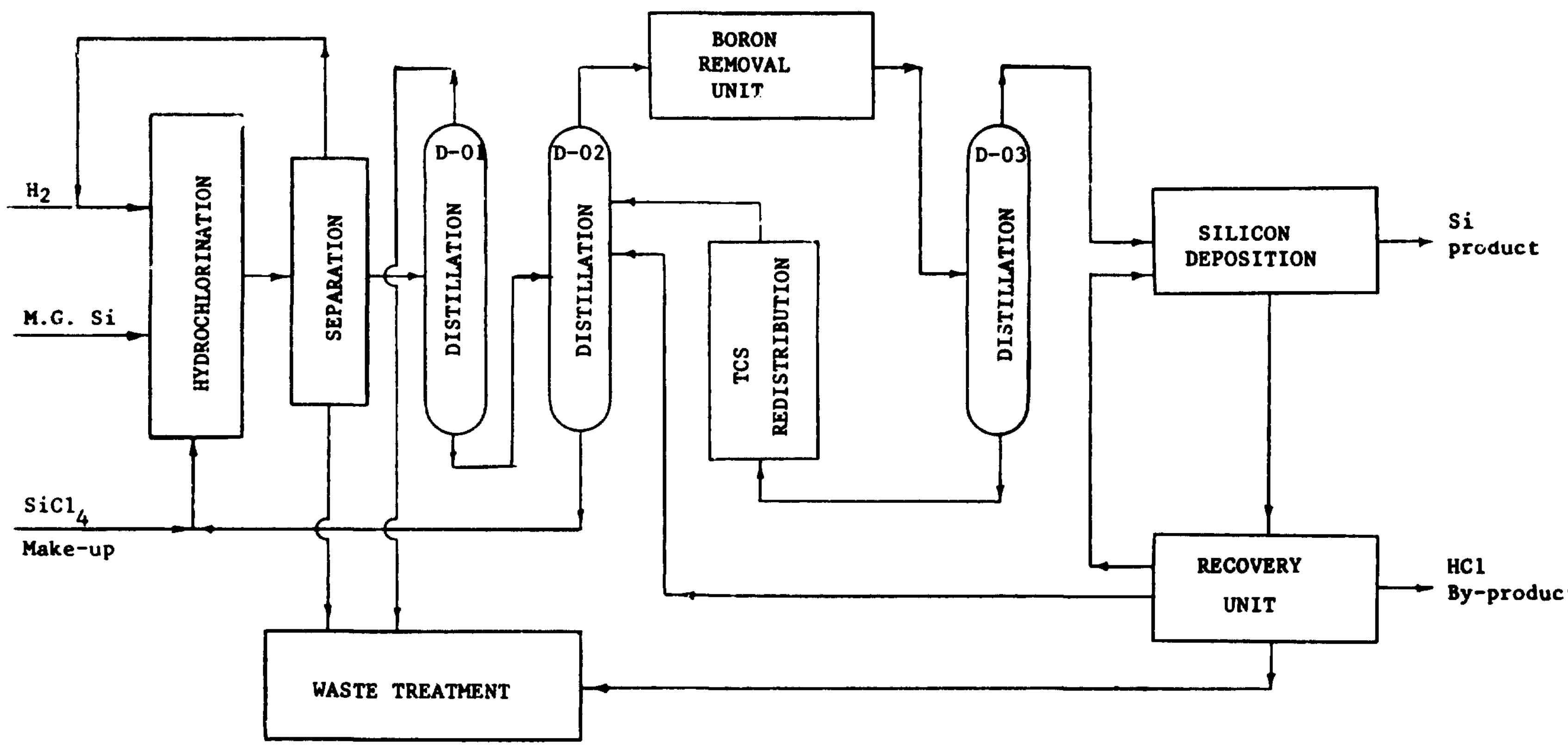

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Figure 2.1-1 Process Flowsheet for HSC Process - Case A

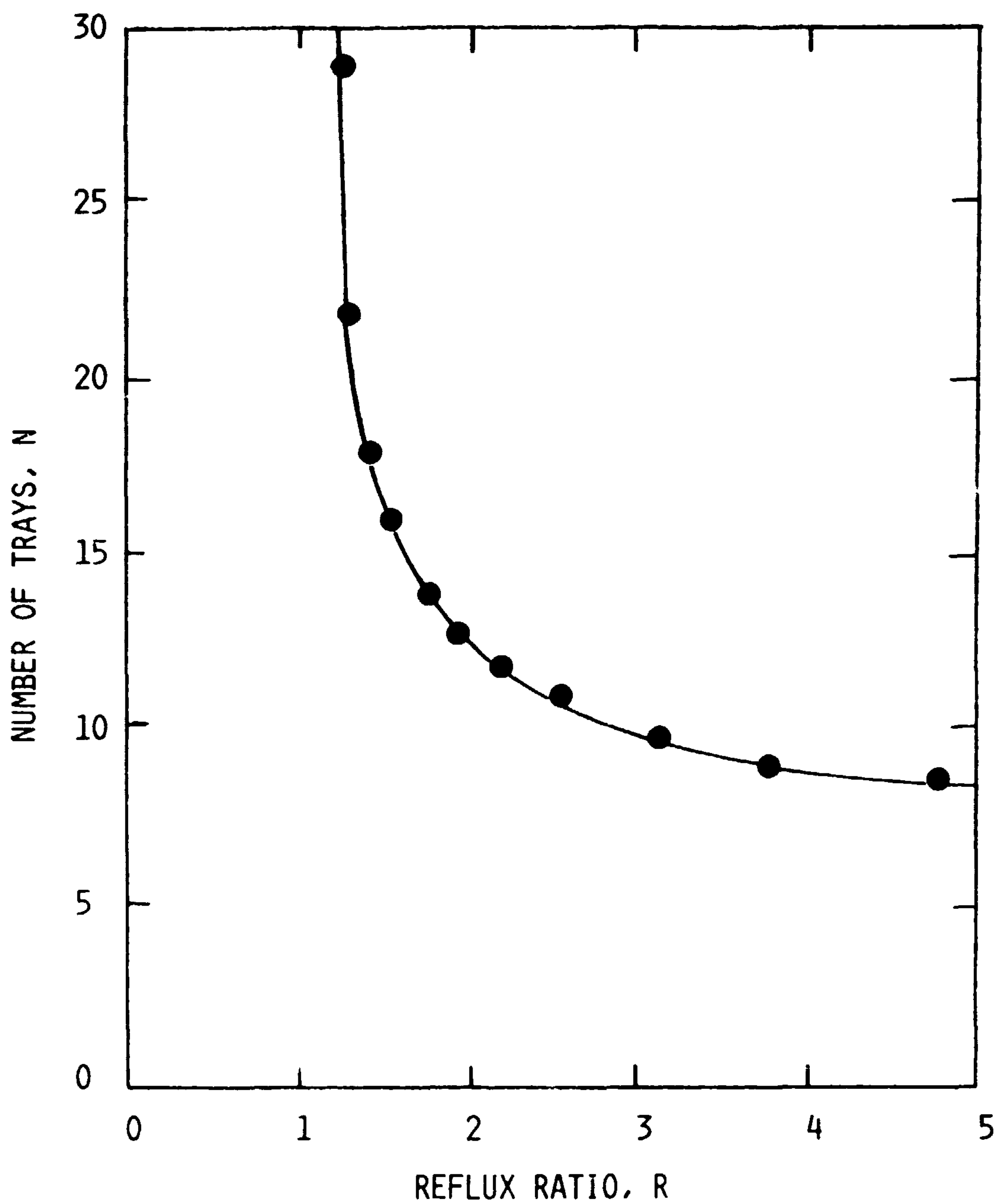

Figure 2.1-2 Design Curve for Distillation, D-01 - Case A

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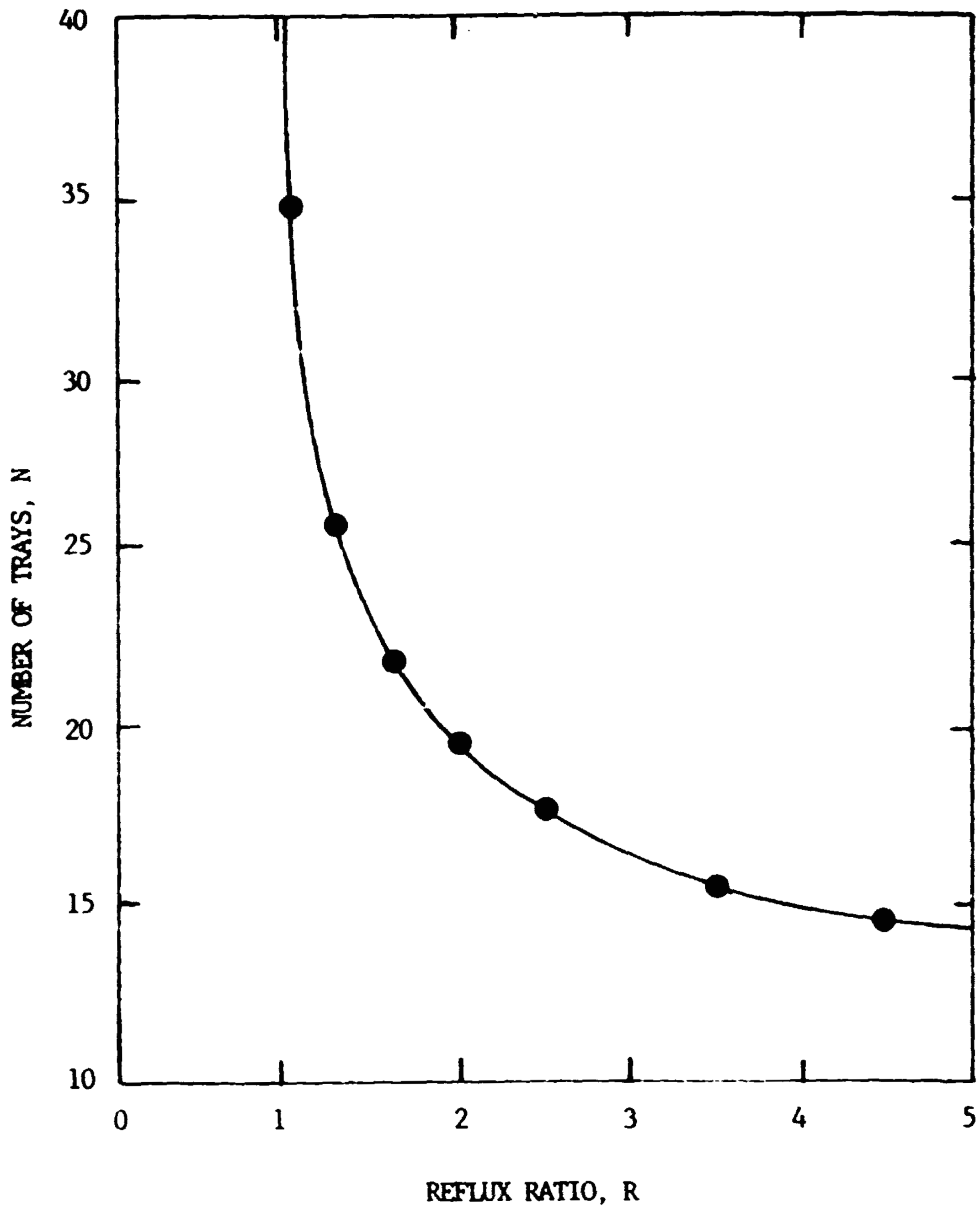

Figure 2.1-3 Design Curve for Distillation, D-02 - Case A

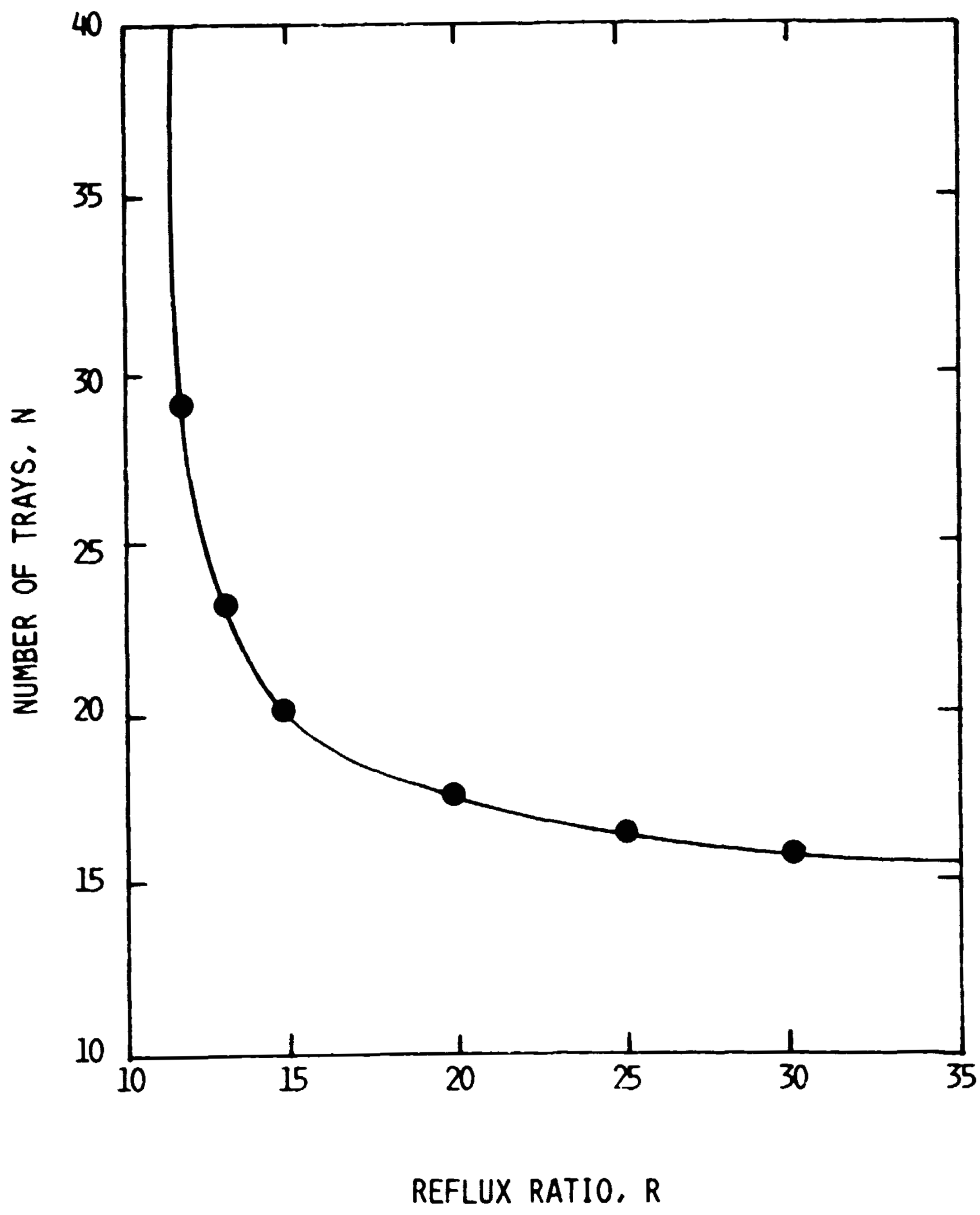

Figure 2.1-4 Design Curve for Distillation, D-03 - Case A

TABLE 2.1-1

CHEMICAL ENGINEERING ANALYSIS:

PRELIMINARY PROCESS DESIGN ACTIVITIES FOR HSC PROCESS - CASE A

Prel. Process Design Activity	Status
1. Specify Base Case Conditions	●
1. Plant Size	●
2. Product Specifics	●
3. Additional Conditions	●
2. Define Reaction Chemistry	●
1. Reactants, Products	●
2. Equilibrium	●
3. Process Flow Diagram	●
1. Flow Sequence, Unit Operations	●
2. Process Conditions (T, P, etc.)	●
3. Environmental	●
4. Company Interaction (Technology Exchange)	●
4. Material Balance Calculations	●
1. Raw Materials	●
2. Products	●
3. By-Products	●
5. Energy Balance Calculations	●
1. Heating	●
2. Cooling	●
3. Additional	●

Prel. Process Design Activity	Status
6. Property Data	●
1. Physical	●
2. Thermodynamic	●
3. Additional	●
7. Equipment Design Calculations	●
1. Storage Vessels	●
2. Unit Operations Equipment	●
3. Process Data (P, T. rate, etc.)	●
4. Additional	●
8. List of Major Process Equipment	●
1. Size	●
2. Type	●
3. Materials of Construction	●
9. Production Labor Requirements	●
1. Process Technology	●
2. Production Volume	●
10. Forward for Economic Analysis	●

O Plan
◐ In Progress
● Complete

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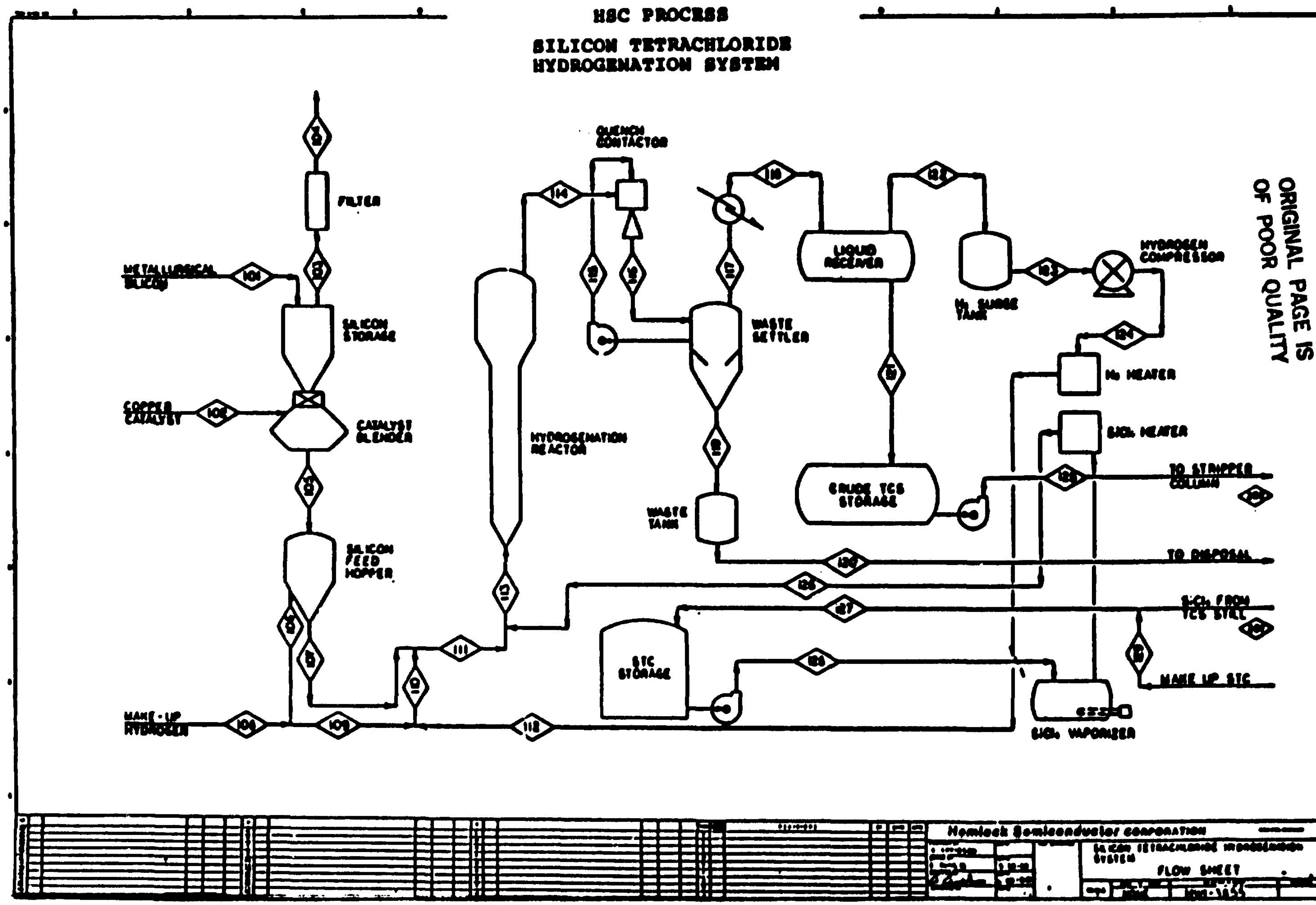

Figure 2.1-5 Process Flowsheet for HSC Process - Case A

HSC PROCESS
DICHLOROSILANE PRODUCTION
AND OURIFICATION

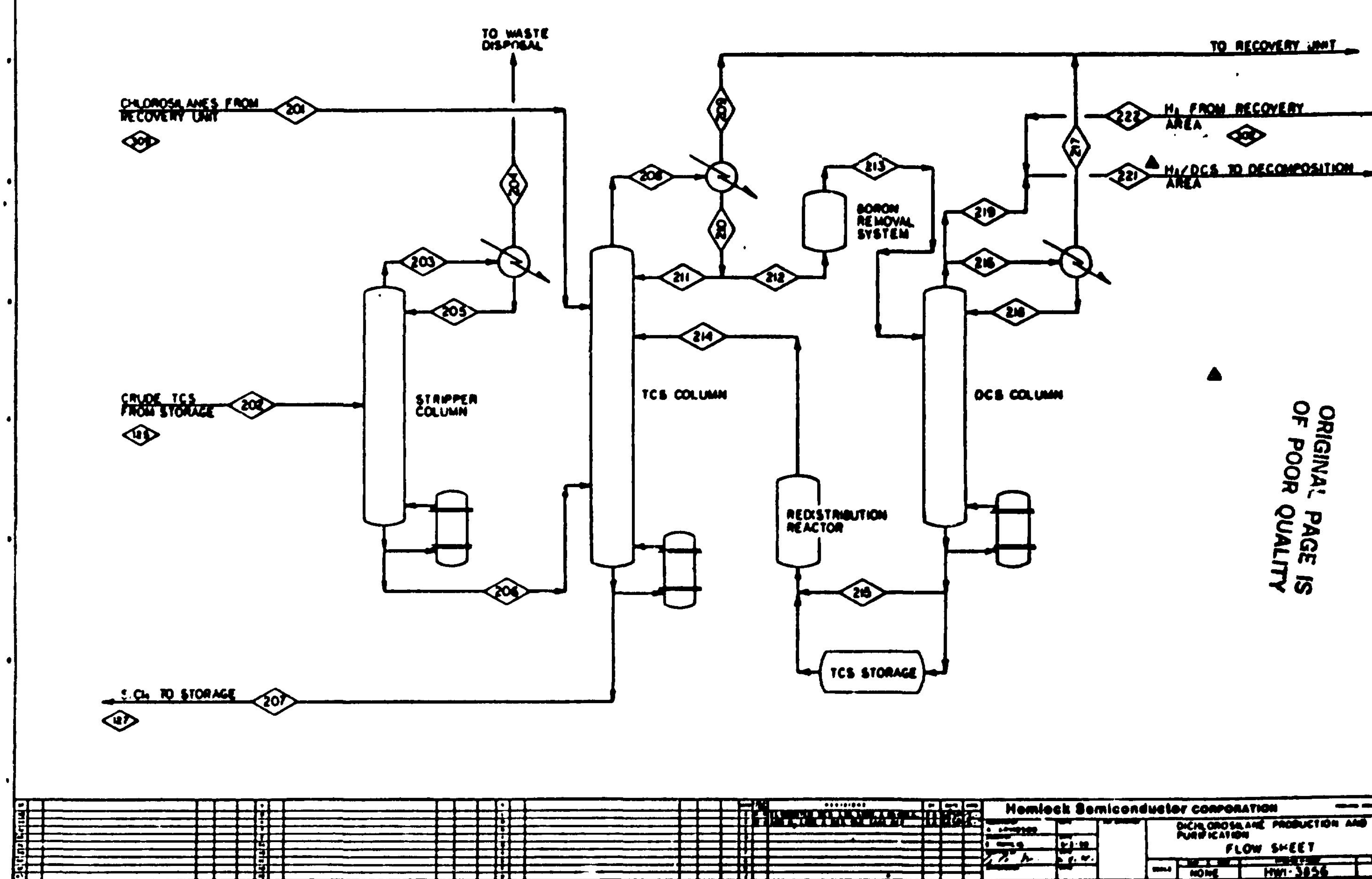

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Figure 2.1-5 (continued)

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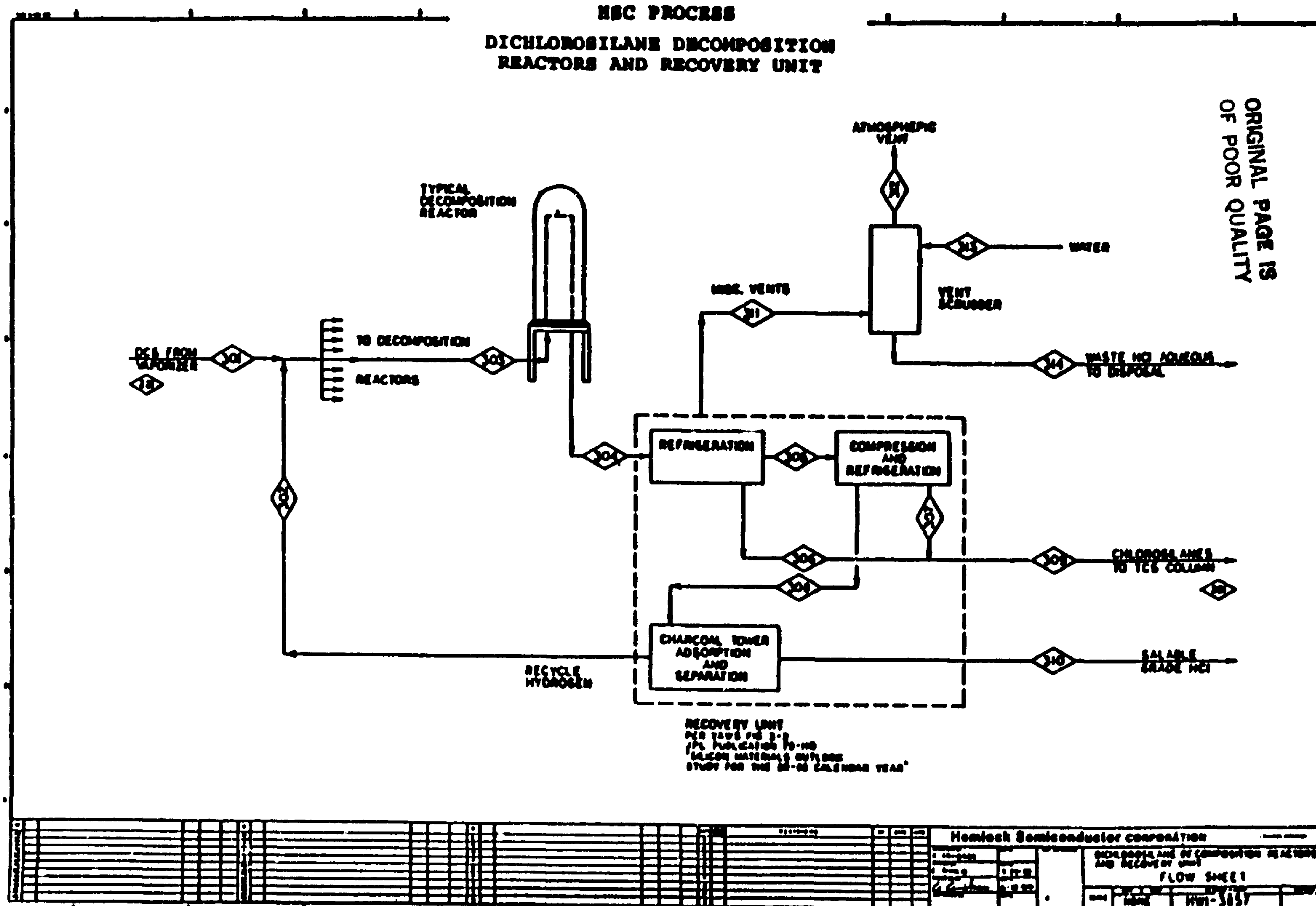

Figure 2.1-5 (continued)

TABLE 2.1-2

BASE CASE CONDITIONS FOR HSC PROCESS - CASE A

1. Plant Size
   - Silicon produced from dichlorosilane (DCS)
   - 1000 metric tons/yr of silicon
   - High purity silicon
   - Final product form (solid rods)

2. Hydrogenation Reaction
   - Metallurgical grade silicon, hydrogen, and recycle silicon tetrachloride (TET) used to produce trichlorosilane (TCS)
   - Copper catalyzed
   - Fluidized bed
   - 500°C, 514.7 psia
   - 29.5% conversion to TCS (example)

3. Recycle For Hydrogenation Unit
   - Unreacted hydrogen from hydrogenation reactor is separated from chlorosilanes by condensation and then recycled
   - Unreacted silicon tetrachloride (TET) is seperated by distillation and recycled

4. Distillation, D-01
   - Stripper column handles crude liquid chlorosilanes from hydrogenation
   - Removes volatile gases which are dissolved in the liquid chlorosilanes (such as H_2, N_2, HCl, etc.)

5. Distillation, D-02
   - Distillation column separates trichlorosilane (TCS) and silicon tetrachloride (TET)
   - Column has three feeds: stripper column bottoms, redistribution reactor chlorosilanes and chlorosilanes from the recovery unit (chlorosilanes from the silicon deposition reactors)

6. Distillation, D-03
   - Distillation column separates dichlorosilane (DCS) and trichlorosilane (TCS)
   - Column has one feed which is chlorosilanes from the boron removal unit
   - Overhead stream as the feed to CVD reactor
   - Bottom stream as the feed to redistribution reactor

7. Boron Removal
   - Removal of BCl_3 by complexation with nitrogen or oxygen base chemical which is supported on non-volatile substance
   - Fixed bed unit
   - No chlorosilane material loss

8. TCS Redistribution Reaction
   - TCS is redistributed to DCS and TET through catalytic reaction
   - Catalytic redistribution of TCS with amine function ion exchange resin (Dowex Ion Exchange Resin MWA-1)
   - Liquid phase 80 psia, 80C
   - Conversion from pure TCS feed is about 10.5% to DCS

TABLE 2.1-2 (continued)

9. Chemical Vapor Deposition Reaction
   - Silicon production
   - Siemens CVD reactor (modified)
   - Dichlorosilane and Hydrogen feed
   - Molar conversion to silicon of 40%
   - Deposition rate of 3000 g/hr
   - Reactor exhaust gas composition (per mole of DCS fed)

HCl	.14
DCS	.10
TCS	.34
STC	.16

10. Recycle From CVD Reactor
    - Chlorosilanes are recovered from a refrigeration process
    - Hydrogen is separated from HCl by adsorption process and recycled back to the CVD reactor
    - Hydrogen chloride (HCl) is recovered as a salable by-product.

11. Slim Rod Pullers
    - Prepare slim rods (small filaments)
    - Slim rods used in Siemen's CVD reactor for silicon deposition
    - Slim rod diameter of 6mm (approx. ¼ inch)

12. Operating Ratio
    - Approximately 85% utilization (on stream time)
    - Approximately 7445 hour/year production

13. Storage Consideration
    - Feed materials (several days supply)
    - Product (two shifts storage)
    - Process (several hours to 1 shift)

14. Wastes Treatment
    - Scrub and neutralize waste gas streams
    - Caustic solution used to neutralize

Note:

The following references were used in established the above tabulation: 1-20,26

TABLE 2.1-3

REACTION CHEMISTRY FOR HSC PROCESS - CASE A

1. Hydrochlorination Reaction

$$3SiCl_4 + Si + 2H_2 \rightleftarrows 4SiHCl_3$$

2. Redistribution Reaction

$$2SiHCl_3 \rightleftarrows SiH_2Cl_2 + SiCl_4$$

3. Waste Treatment (representative - overall)

$$SiH_2Cl_2 + Ca(OH)_2 \xrightarrow{aq.} SiO_2 + CaCl_2 + 2H_2O$$

$$SiHCl_3 + 1.5Ca(OH)_2 \xrightarrow{aq.} SiO_2 + 1.5CaCl_2 + 2H_2O$$

$$SiCl_4 + 2Ca(OH)_2 \xrightarrow{aq.} SiO_2 + 2CaCl_2 + 2H_2O$$

4. Decomposition Reaction

$$SiH_2Cl_2 + H_2 \rightarrow Si + \text{By-Products}$$

Note:

1. Reaction 1 product contains H_2, HCl, $SiCl_4$, $SiHCl_3$, SiH_2Cl_2 (trace), other trace chlorides
2. Reaction 2 product contains $SiHCl_3$, $SiCl_4$, SiH_2Cl_2, SiH_3Cl
3. By-products in reaction 4 include H_2, HCl, SiH_2Cl_2, $SiHCl_3$ and $SiCl_4$

TABLE 2.1-4

RAW MATERIAL REQUIREMENTS FOR HSC PROCESS - CASE A

RAW MATERIALS	REQUIREMENTS	
	lb/hr for 1000 MT/yr Silicon	lb/kg of Silicon
1. M. G. Silicon	270.11	2.014
2. Silicon Tetrachloride ($SiCl_4$, make-up)	535.73	3.67
3. Liquid Hydrogen (H_2, make-up)	45.82	0.342
4. Copper Catalyst	3.44	0.026
5. Hydrate Lime ($Ca(OH)_2$)	259.9	1.937
6. Hydrogen Chloride (HCl, by-product)	129.96	0.969

TABLE 2.1-5

UTILITY REQUIREMENTS FOR HSC PROCESS - CASE A

UTILITIES	TOTAL REQUIREMENTS FOR PLANT	REQUIREMENTS PER KG OF SILICON
1. Electricity		
1) For Deposition Reaction	12,000 kw	90.0 kw-hr
2) For Gas Compression	260 kw	1.94 kw-hr
3) For Pumping Liquid	55 kw	0.41 kw
	12,315 kw	92.35 kw
2. Steam		
1) Superheated, 100 psia	5 k lb/hr	37.3 lb
2) Saturated, 100 psia	17 k lb/hr	126.7 lb
	22 k lb/hr	164.0 lb
3. Cooling water		
1) Cooling and Condensing	96 k gal/hr	715.6 gal
4. Refrigerant	0.90 M BTU/hr	.007 M Btu
1) Refrigeration		
5. Process Water		
1) Waste Treatment	215 gal	3.39 gal
6. Fuel		
1) Direct-Fired Heater	4 M BTU/hr	.03 M BTU
2) Incineration	1.5 M BTU/hr	.011 M BTU
	5.5 M BTU/hr	.041 M BTU

NOTE:

$k = \text{kilo} = 10^3$

$M = \text{mega} = 10^6$

TABLE 2.1-6

LIST OF MAJOR PROCESS EQUIPMENT FOR HSC PROCESS - CASE A

Equipment	Function	Duty/Type	Size	Material of Construction
Distillation Columns				
1. D-01 Crude TCS Stripping Column	Remove inert gases	Distillation Column (Plate)	24 in.dia.x 49 ft.tall 26 sieve trays (actual)	CS
2. D-02 TCS/TET Distillation Column	Separate TCS and TET	Distillation Column (Plate)	5.5 ft. dia. x 74 ft. tall 32 sieve trays (actual)	CS
3. D-03 DCS/TCS Distillation Column	Separate DCS and TCS	Distillation Column (Plate)	4 ft.dia. x 58 ft.tall 32 sieve trays (actual)	CS
Heaters & Heat Exchangers				
4. H-01 Crude TCS Condenser	Condense Chlorosilanes	Shell-Tube H.E.	940 ft^2 515 psia	304SS
5. H-02 H_2 Gas Pre-Heater	Preheat H_2 for chlorination	Direct-Fired heater	1.5MM Btu/hr, 515 psia	CS/Firebrick
6. H-03 TET Vaporizer	Vaporize TET for chlorination	Kettle	530 ft^2 515 psia	304SS

TABLE 2.1-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
7. H-04 Stripper Condenser	Partial condenser for D-01 column	Shell-Tube H.E.	250 ft^2, 90 psia	Nickel Steel
8. H-05 Stripper Reboiler	Stripper reboiler of D-01 column	Kettle	20 ft^2, 90 psia	CS
9. H-06 TCS Condenser	Condenser for D-02 column	Shell-Tube H.E.	960 ft^2, 90 psia	Steel/Cupronickel
10. H-07 TCS Reboiler	Reboiler for D-02 column	Kettle	810 ft^2, 90 psia	CS
11. H-08 TET Heat Exchanger	TET Cooling	Shell-Tube H.E.	480 ft^2, 90 psia	CS
12. H-09 DCS Condenser	Condenser for D-03 column	Shell-Tube H.E.	1600 ft^2, 90 psia	Steel/Cupronickel
13. H-10 DCS Reboiler	Reboiler for D-03 column	Kettle	400 ft^2, 90 psia	CS
14. H-11 TCS Cooler	Cool TCS before redistribution reaction	Shell-Tube H.E.	30 ft^2, 90 psia	Steel/Cupronickel

TABLE 2.1-6 (continued)

	Equipment	Function	Duty/Type	Size	Material of Construction
15.	H-12 Waste Stream Cooler	Cool waste stream in waste treatment	Shell-Tube H.E.	125 ft^2, 60 psia	CS
16.	H-13 TET Superheater	Heat TET before hydrochlorination	Direct-fired heater	2.5M Btu/hr, 515 psia	CS/Firebrick
17.	H-14 H_2 Compressor Intercooler	Cool H_2 gas between compression stages	Shell-Tube H.E.	70 ft^2, 90 psia	CS
18.	H-15 CVD Reactor Gas Cooler (1st Stage)	Cool gas from CVD reactor (internal temp.)	Shell-Tube H.E.	45 ft^2, 20 psia	CS
19.	H-16 CVD Reactor Gas Cooler (2nd Stage)	Refrigerate gas from CVD reactor (low temp.)	Shell-Tube H.E.	450 ft^2, 20 psia	316 SS
20.	H-17 CVD Reactor Gas Cooler (3rd Stage)	Cool CVD reactor gas from compressor (internal temp.)	Shell-Tube H.E.	40 ft^2, 100 psia	316 SS

TABLE 2.1-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
21. H-18 CVD Reactor Gas Cooler (4th Stage)	Refrigerates CVD reactor gas from compressor (low temp.)	Shell-Tube H.E.	350 ft^2, 100 psia	316 SS
22. H-19 Gas Heater	Heats low temp. gases for adsorption	Shell-Tube H.E.	140 ft^2, 100 psia	316 SS
Reactors				
23. R-01 Hydrochlorination Reactor	Hydrochlorination of m.g. Si and TET	Fluid Bed Reactor	2.5 ft.dia. x 21 ft. height plus 6 ft. dia. x 9 ft. height (disengaging), 515 psia	Incoloy 800
24. R-02 TCS Redistribution Reactor	Conversion of TCS to DCS	Fixed Bed Reactor	3 ft. dia. x 18 ft. tall, 80 psia	CS
25. R-03 Waste Neutralizer	Waste Treatment	Agitated Vessel Reactor	3 ft.dia. x 20 ft., 14 psia	CS/Fiberglass
26. R-04 Waste Combuster	Incinerate waste vapors	Waste Combustion Reactor	3 ft. x 3 ft. x 9 ft., 14.7 psia	CS/Brick

TABLE 2.1-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
27. R-05 CVD Deposition Reactor (45)	Hydrogen reduction of chlorosilanes to produce Si	CVD Deposition Reactor (Siemens type, modified)	Large rods, several hairpin loading	Quartz/CS/SS
Tanks, Bins and Vessels				
28. B-01 Silicon Storage Bin with Feed Lock	Store and feed m.g. Si to reactor	Vertical Bin	7 ft.dia. x 22 ft. 60° cone	CS
29. T-01 Residue Settling Tank	Separate unreacted solid residues	Vertical Process Vessel	6 ft.dia. x 12 ft. 515 psia (2,500 gal)	304SS
30. T-02 Residue Withdraw Tank	Remove unreacted solid residues	Vertical Process Vessel	3 ft.dia. x 7.5 ft., 515 psia (400 gal)	CS
31. T-03 Hydrogen Separation Tank	Separate H_2 gas from chlorosilanes	Horizontal Process Vessel (mesh pad)	5 ft.dia. x 16 ft., 515 psia (2,400 gal)	CS
32. T-04 Crude TCS Storage Tank	Store crude TCS	Horizontal Process Vessel	12 ft.dia. x 34 ft., 100 psia (28,800 gal)	CS
33. T-05 TCS Stripper Reflux Drum	Reflux drum for D-01 column	Vertical Process Vessel	2 ft.dia. x 3.2 ft., 90 psia (80 gal)	304SS

TABLE 2.1-6 (continued)

	Equipment	Function	Duty/Type	Size	Material of Construction
34.	T-06 TCS/TET Distillation Reflux Drum	Reflux drum for D-02 column	Vertical Process Vessel	4.5 ft.dia. x 12 ft., 90 psia (1,400 gal)	CS
35.	T-07 TET Storage Tank	Store TET	Horizontal Process Vessel	10 ft.dia. x 30 ft., 25 psia (17,600 gal)	CS
36.	T-08 DCS/TCS Distillation Reflux Drum	Reflux drum for D-03 column	Vertical Process Vessel	5 ft.dia. x 10 ft., 90 psia (1,500 gal)	CS
37.	T-09 Vapor-Liquid Separator	Separate H_2 gas from chlorosilanes in recovery	Vertical Process Vessel	5 ft.dia. x 7 ft., 20 psia (1,000 gal)	304SS
38.	T-10 Vapor-Liquid Separator	Separate H_2 gas from chlorosilanes in recovery	Vertical Process Vessel	3.5 ft.dia. x 6 ft., 100 psia (430 gal)	304SS
39.	T-11 Flue Gas Separation Tank	Separate flue gas from lime solution	Vertical Process Vessel (mesh pad)	2 ft. dia. x 5 ft. (120 gal)	CS
40.	T-12 Lime Solution Preparation Tank	Prepare lime solution	Vertical Process Vessel	5 ft.dia. x 9.5 ft. (1,400 gal)	CS

TABLE 2.1-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
41. T-13 Waste Filtrate Storage Tank	Store waste filtrate	Vertical Process Vessel	5 ft.dia. x 8 ft. (1,200 gal)	CS
42. T-14 Hydrogen Surge Tank	Surge tank for Hydrogen	Vertical Process Vessel	3.5 ft.dia. x 8.5 ft. (600 gal)	CS
Compressors and Pumps				
43. C-01A Hydrogen Feed Compressor, First Stage	Compression of recycle and make-up H_2 gas	Reciprocating Compressor	38bhp.,discharge press. 87 psia	CS
44. C-01B Hydrogen Feed Compressor, Second Stage	Compression of recycle and make-up H_2 gas	Reciprocating Compressor	41bhp., discharge Press. 515 psia	CS
45. C-02 Hydrogen Circulation Compressor	Compression of recycle H_2 gas	Centrifugal Compressor	17bhp., ΔP=30 psi	CS
46. P-01 Feed Tank Blower	Load silicon to its storage bin	Centrifugal Blower	939ACFM, 32bhp	CS

TABLE 2.1-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
47. P-02 Settling Tank Circulation Pump	Circulation pump	Centrifugal Pump	37' Head, 1.75bhp	CS/304SS
48. P-03 Crude TCS Pump	Transport crude TCS to D-01 column	Centrifugal Pump	2bhp, discharge 90 psia	CS
49. P-04 TCS Reflux Pump	Reflux pump for D-02 column	Centrifugal Pump	9bhp, discharge press. 90 psia	CS
50. P-05 TET Feed Pump	Pumping TET to hydrochlorination reactor	Centrifugal Pump	16bhp, discharge press. 515 psia	CS
51. P-06 DCS Reflux Pump	Reflux pump for D-03 column	Centrifugal Pump	6bhp, discharge press. 90 psia	316SS
52. P-10 Waste Solution Pump	Feed slurry to filter	Centrifugal Pump	1.25 bhp	Cast Iron
53. P-11 Lime Solution Circulation Pump	Circulate lime solution to neutralizer	Centrifugal Pump	1.25 bhp	Cast Iron
54. P-12 Fresh Lime Solution Pump	Supply fresh lime solution	Centrifugal Pump	0.75 bhp	Cast Iron

TABLE 2.1-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
55. C-03 Cas Compressor	Compression of gases from CVD reactors	Centrifugal Compressor	250 hp, ΔP=80psia	304SS
Miscellaneous				
56. M-01 Silicon Dust Filter	Retain m.g. silicon dust	Gas-Solid/Bag Filter	20 ft^2 x 5μ	CS/cloth
57. M-02 Waste Slurry Filter	Remove waste sludge	Rotary Filter	2 ft^2	CS/cloth
58. M-03 Silicon Feed Cyclone	Feed m.g. silicon to storage bin	Cyclone	940ACFM	316SS
59. M-04 Quench Contact Ejector	Withdraw and cool effluent of hydro-chlorination	Contact Ejector	100 gpm 134 ACFM	316SS
60. M-05 Flue Gas Ejector	Withdraw flue gas from waste gas combustion	Gas Ejector	100 gpm 1 SCFM	CS
61. M-06 Adsorption Tower (3)	Adsorb HCl from H_2 gas in recovery	Vertical Process Vessel (packed)	4.6' diam. x 45'	CS
62. M-07 Boron Removal Unit (2)	Removal of boron from chlorosilanes	Vertical Process Vessei (packed)	2.3' diam x 22.5'	CS

TABLE 2.1-6 (continued)

	Equipment	Function	Duty/Type	Size	Material of Construction
63.	M-08 Vent Scrubber	Water scrubber for miscellaneous vents	Packed	4' diam x 15' packing	Fiberglass
64.	M-09 Slim Rod Pullers (5)	Produce slim rods (6 mm dia) for deposition	Average pull rate of 470 cm/hr	Filament Puller Size	CS/Other
65.	M-10 Catalyst Blender	Catalyst blender for hydrochlori-nation	Twin Shell	50 cu. ft.	CS
66.	M-11 Recovery System Pump	Pumps chloro-silanes back to distillation	Centrifugal Pump	1 bhp, 90 psia	CS
67.	M-12 Hydrogen Storage Tank	Store Hydrogen (liquid, make-up)	Horizontal Process Vessel	5.5 ft. dia. x 18.6 ft., 50 psia (13,200 gal)	304SS/ Insulation

TABLE 2.1-7

PRODUCTION LABOR REQUIREMENTS FOR HSC PROCESS - CASE A

Section	Labor man-hr/KG of Si	(oper/shift)
1. Hydrochlorination	0.018	(2)
2. Purification/Redistribution	0.026	(3)
3. Waste Treatment	0.009	(1)
4. Silicon Deposition	0.044	(5)
5. Recovery Unit	0.018	(2)
Total	0.114	(13)

Note

Manpower estimate for production labor requirements based on:

1. Dividing plant into sections
   - type of unit operation
   - mark off working area
2. Specify work duties required in each section
3. Estimate operators required to perform work duties in each section
   - type of unit operation
   - size of working area
   - degree of automation (batch, semi-continuous, etc.)

2.2 HSC Process for Silicon - Case B (Hemlock Semiconductor Corporation)

The chemical engineering analysis activity involves the preliminary process design of a plant to produce silicon via the technology under consideration.

The process flowsheet for Case B of HSC process (Hemlock Semiconductor Corporation) for silicon is shown in Figure 2.2-1. The process involves major processing operations of hydrochlorination, separation, several distillation units, redistribution, boron removal, silicon deposition, recovery unit and waste treatment.

Metallurgical grade silicon is hydrochlorinated in the presence of hydrogen and silicon tetrachloride in a fluidized bed reactor. In the process, the reaction product issuing from the hydrochlorination reactor (hydrochlorination-hydrogenation reaction) is cooled and undergoes a vapor-liquid flash separation. The vapor fraction containing the hydrogen from the flash is recycled back to the hydrochlorination reactor. The liquid fraction containing the chlorosilanes and dissolved gases is fed to the initial distillation column.

The function of the initial distillation column (D-01, stripper column) in the process is to remove volatile gases (such as hydrogen and nitrogen) which are dissolved in liquid chlorosilanes. For the engineering design, TCS (trichlorosilane) was selected as the heavy key component for the separation.

The second distillation column (D-02, TCS column) in the process separates TCS (trichlorosilane) and TET (silicon tetrachloride). The distillation column has three feeds (bottoms from the third distillation, chlorosilanes from the recovery unit and bottoms from the initial distillation). The TET from the distillation is recycled to the hydrochlorination reactor for additional conversion.

The TCS from the second distillation is sent to the redistribution reactor where TCS is redistributed to DCS and TET according to the representative chemical reaction equation:

$$2SiHCl_3 \rightleftarrows SiH_2Cl_2 + SiCl_4 \qquad (2.2\text{-}1)$$

After redistribution the stream is sent to the boron removal unit and the third distillation. The third distillation column (D-03, DCS column) in the process separates DCS (dichlorosilane) and TCS (trichlorosilane). DCS from the distillation is sent to the silicon deposition reactors.

The design results for number of trays (equilibrium stages) required for each separation are shown in Figure 2.2-2, 2.2-3 and 2.2-4 for distillation D-01, D-02 and D-03. The design curve in each figure discloses the variation of number of trays with reflux ratio.

The purified DCS is reacted with hydrogen (H_2) in a rod reactor to obtain polysilicon deposition via the following representative chemical reaction equation:

$$SiH_2Cl_2 + H_2 \rightarrow Si \downarrow + HCl + \text{By-products} \quad (2.2\text{-}2)$$

The above reaction equation may include several reaction steps. Chemical equilibrium is involved and in reality, several chlorosilanes (such as SiH_2Cl_2, $SiHCl_3$ and $SiCl_4$) are also present in the gas phase by-products.

The chemical vapor deposition reaction with DCS is very fast and occurs on the surface of a hot rod (1000-1200C) which is heated by passage of electrical current through the rod. Large electrical energy requirements are necessary because of the heat of reaction, radiation heat losses and incomplete conversion of the DCS. Unreacted chlorosilanes and hydrogen are separated and recycled.

The process design of a plant to produce silicon by this new technology was performed to obtain data for a cost analysis. The design was based on a plant to produce 1,000 metric tons/yr of silicon via the HSC process - Case B. In Case B, the TCS (trichlorosilane) from distillation D-02 is sent to the redistribution reactor.

The detailed status sheet for the process design package is shown in Table 2.2-1 and is representative of the various sub-items that make up the activity. The summarized results for the preliminary process design are presented in a tabular format to make it easier to locate items of specific interest. The guide for these tables is given below:

. Process Flowsheet----------------------Figure 2.2-5
. Base Case Conditions-------------------Table 2.2-2
. Reaction Chemistry---------------------Table 2.2-3
. Raw Material Requirements--------------Table 2.2-4
. Utility Requirements-------------------Table 2.2-5
. Major Process Equipment----------------Table 2.2-6
. Production Labor Requirements----------Table 2.2-7

The process design provides detailed data for raw materials, utilities, major process equipment and production labor requirements which are necessary for polysilicon production.

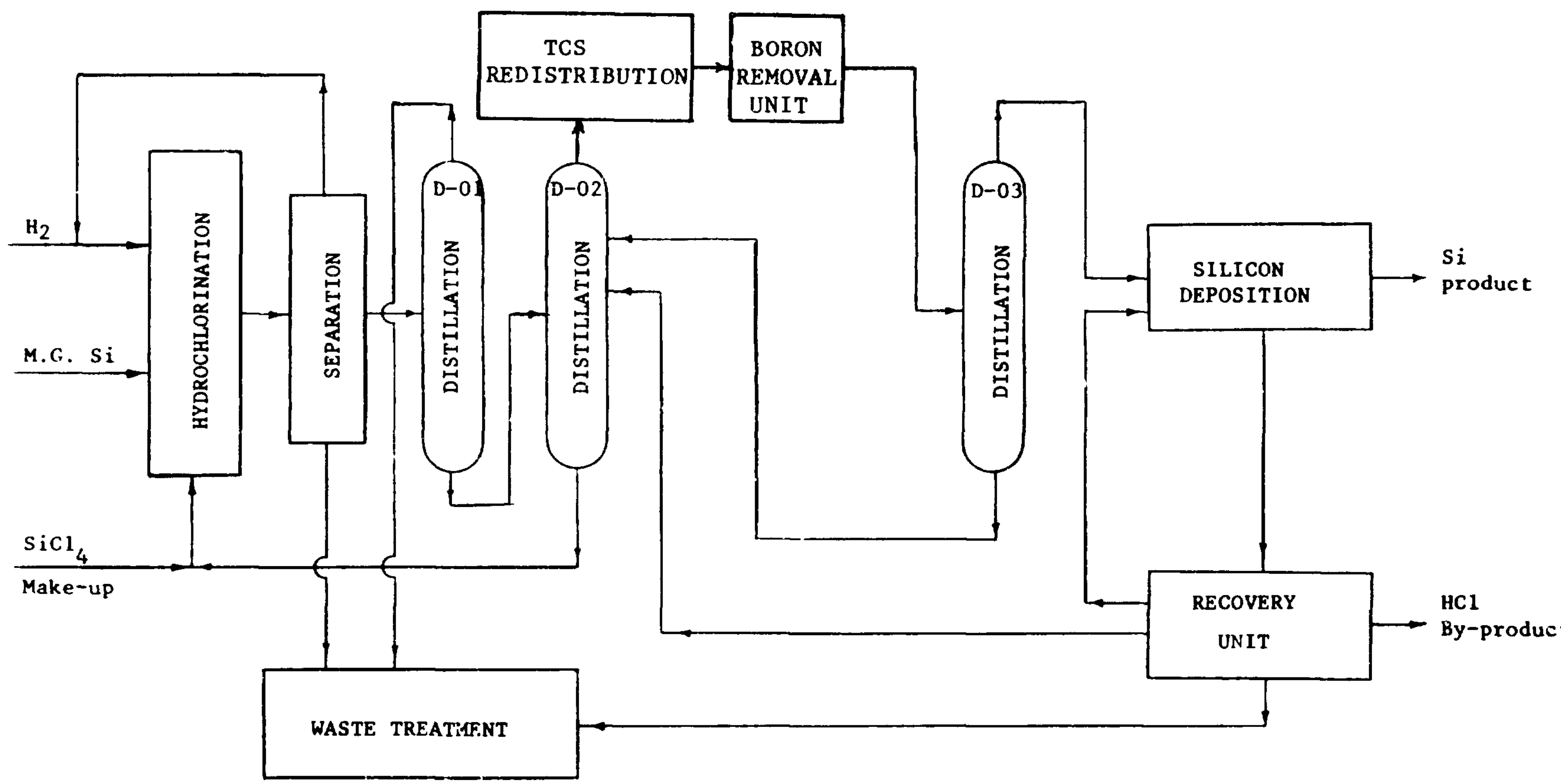

Figure 2.2-1 Process Flowsheet for HSC Process - Case B

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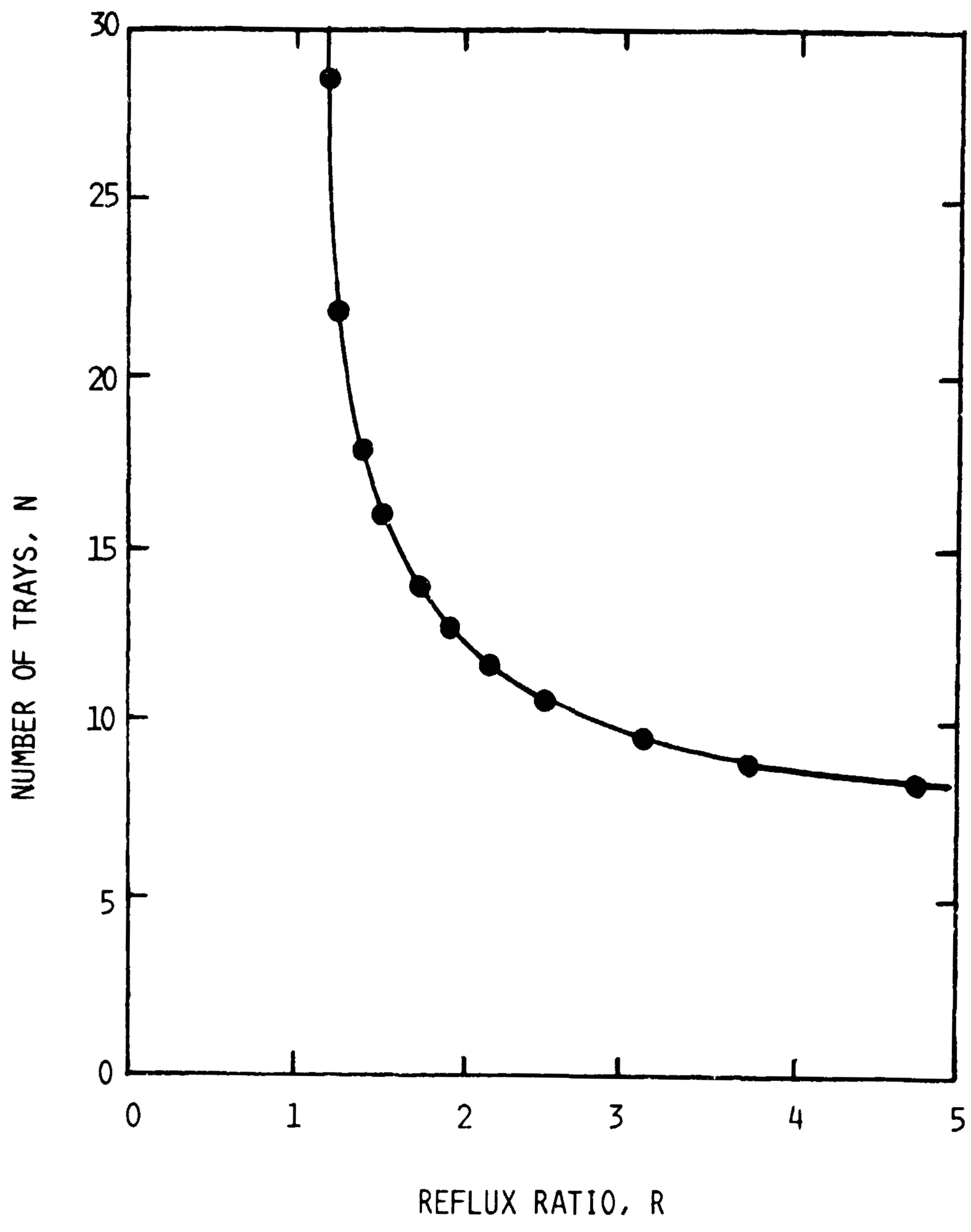

Figure 2.2-2 Design Curve for Distillation, D-01 - Case B

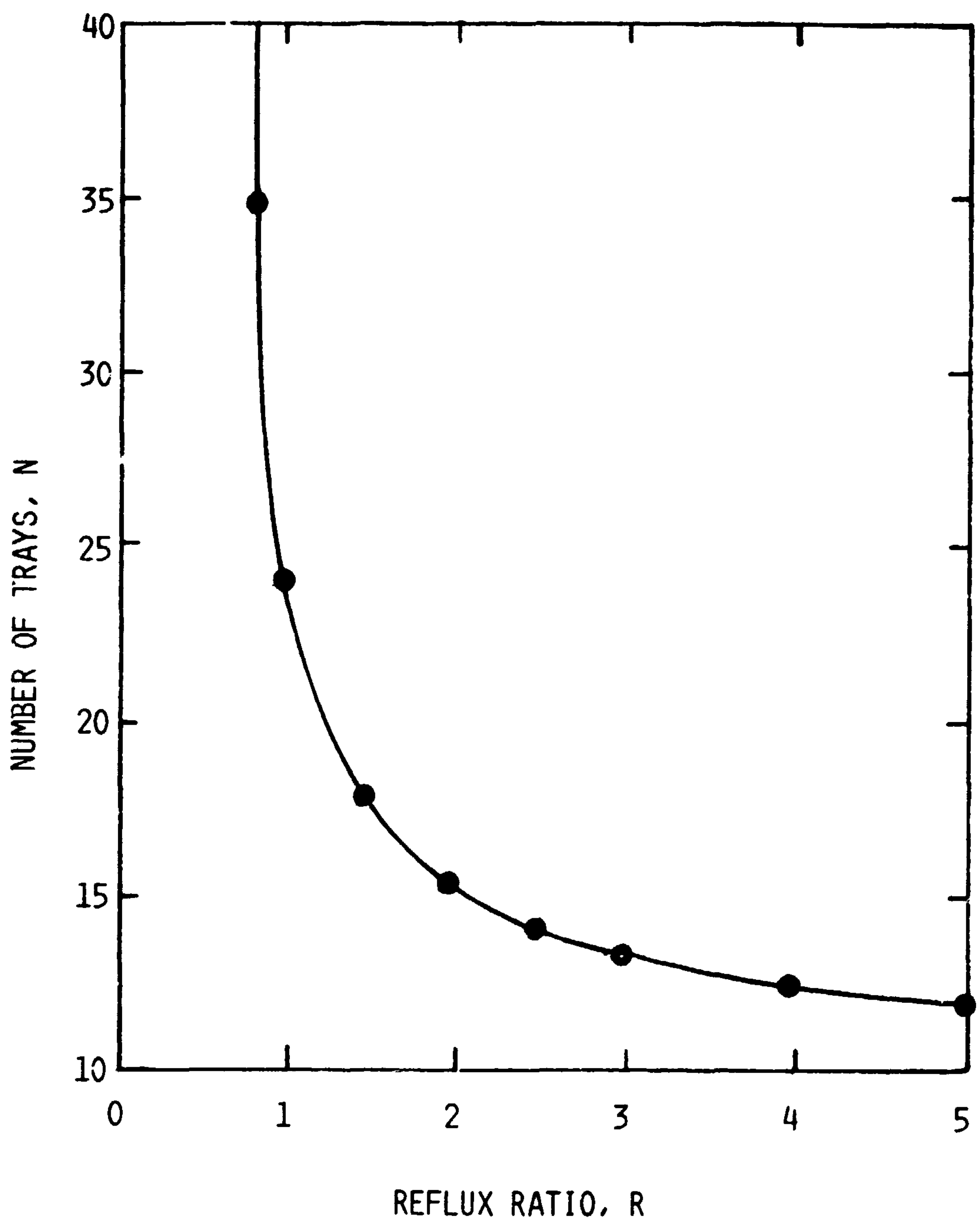

Figure 2.2-3 Design Curve for Distillation, D-02 - Case B

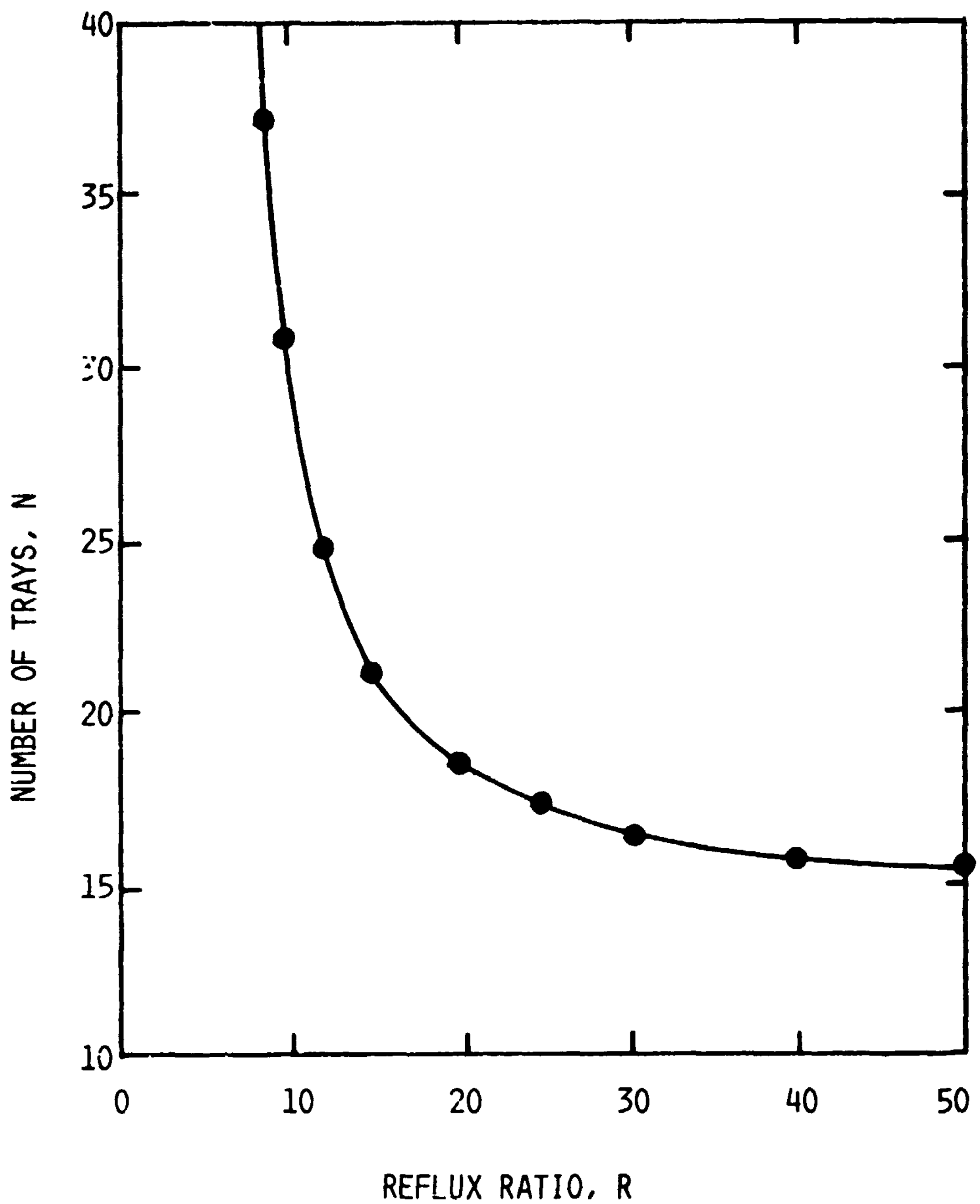

Figure 2.2-4 Design Curve for Distillation, D-03 - Case B

TALLE 2.2-1

CHEMICAL ENGINEERING ANALYSIS:

PRELIMINARY PROCESS DESIGN ACTIVITIES FOR HSC PROCESS - CASE B

Prel. Process Design Activity	Status
1. Specify Base Case Conditions	●
1. Plant Size	●
2. Product Specifics	●
3. Additional Conditions	●
2. Define Reaction Chemistry	●
1. Reactants, Products	●
2. Equilibrium	●
3. Process Flow Diagram	●
1. Flow Sequence, Unit Operations	●
2. Process Conditions (T, P, etc.)	●
3. Environmental	●
4. Company Interaction (Technology Exchange)	●
4. Material Balance Calculations	●
1. Raw Materials	●
2. Products	●
3. By-Products	●
5. Energy Balance Calculations	●
1. Heating	●
2. Cooling	●
3. Additional	●

Prel. Process Design Activity	Status
6. Property Data	●
1. Physical	●
2. Thermodynamic	●
3. Additional	●
7. Equipment Design Calculations	●
1. Storage Vessels	●
2. Unit Operations Equipment	●
3. Process Data (P, T. rate, etc.)	●
4. Additional	●
8. List of Major Process Equipment	●
1. Size	●
2. Type	●
3. Materials of Construction	●
9. Production Labor Requirements	●
1. Process Technology	●
2. Production Volume	●
10. Forward for Economic Analysis	●

O Plan
◐ In Progress
● Complete

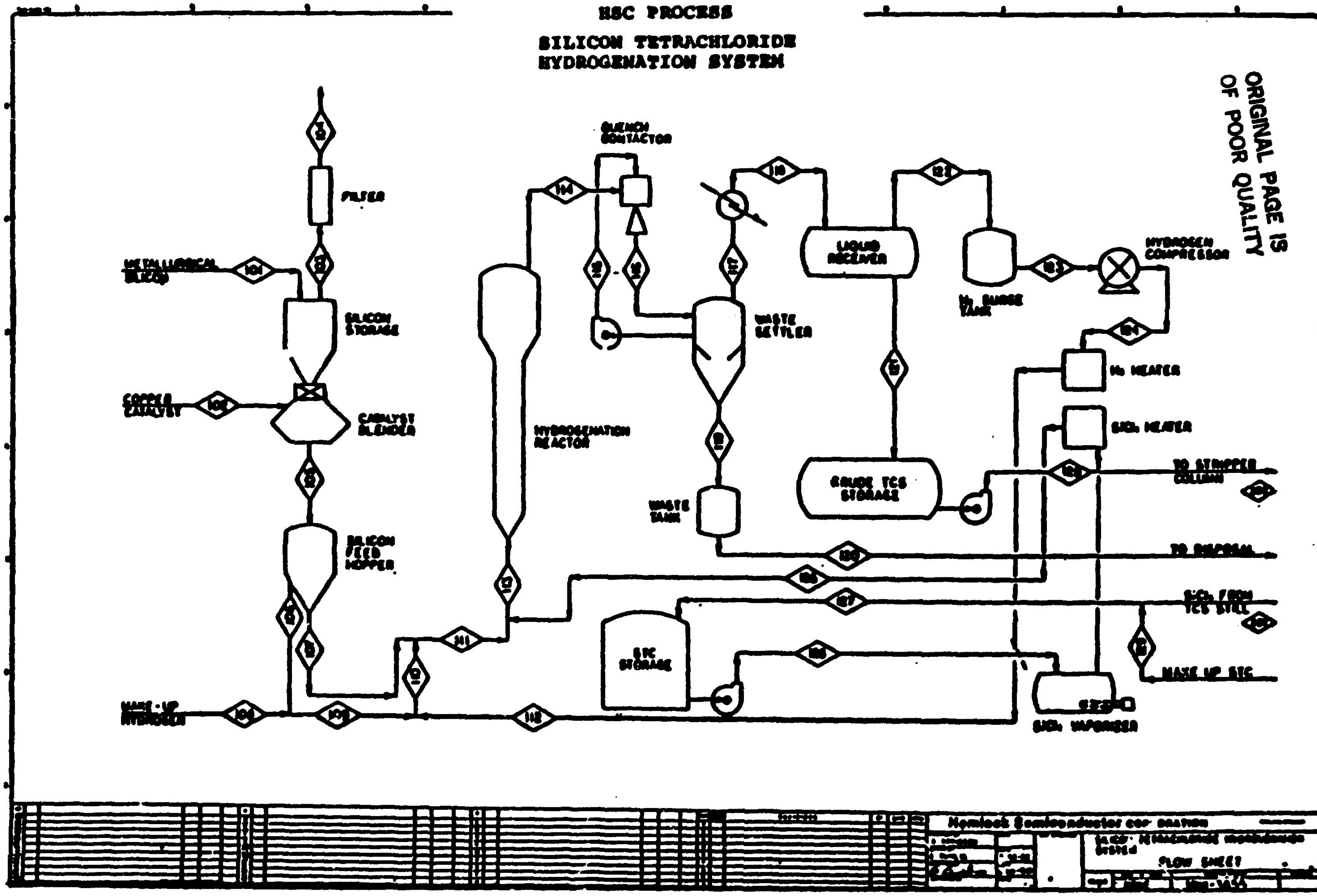

Figure 2.2-5 Process Flowsheet for HSC Process - Case B

HSC PROCESS
DICHLOROSILANE PRODUCTION
AND OURIFICATION

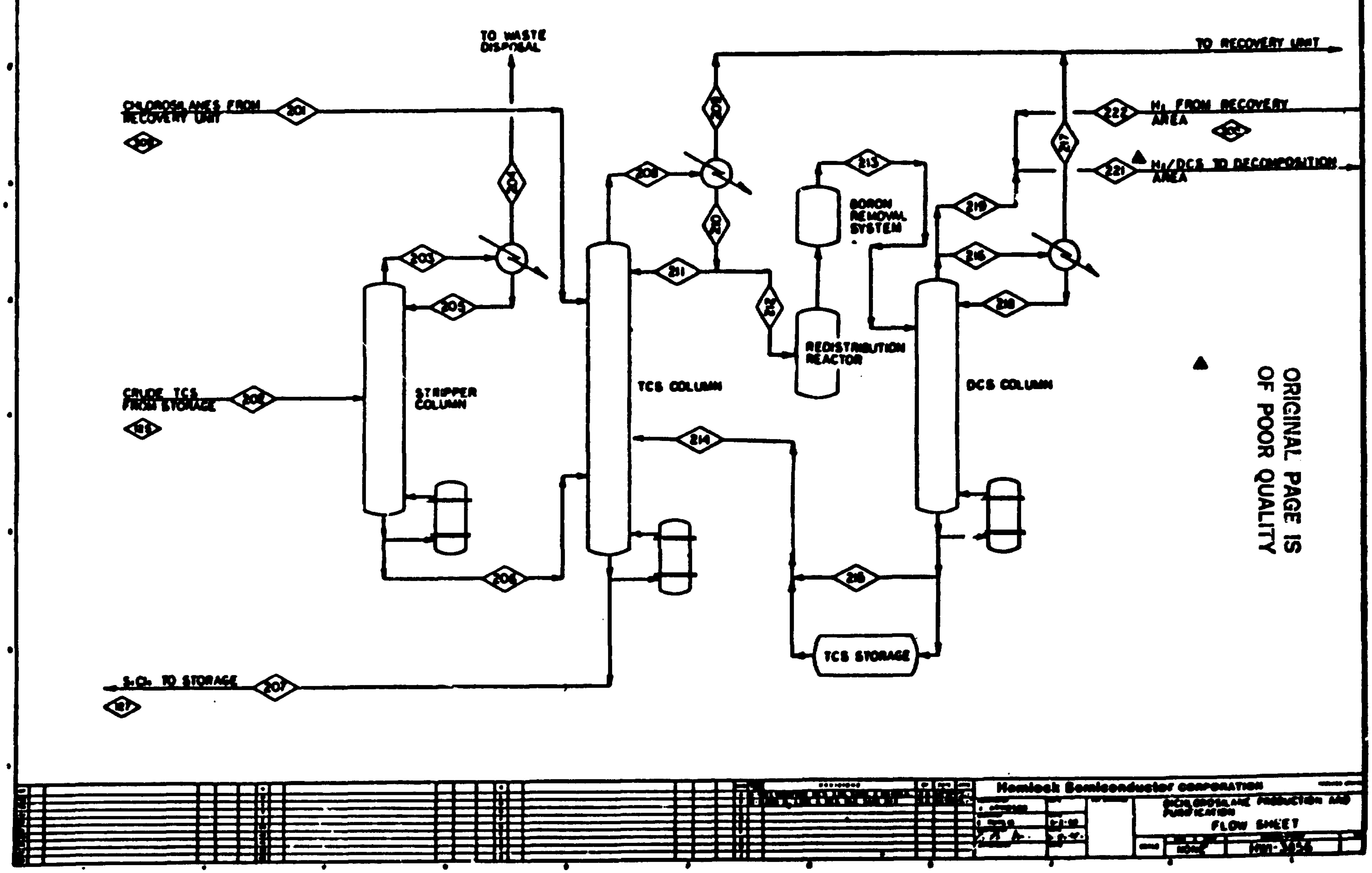

Figure 2.2-5 (continued)

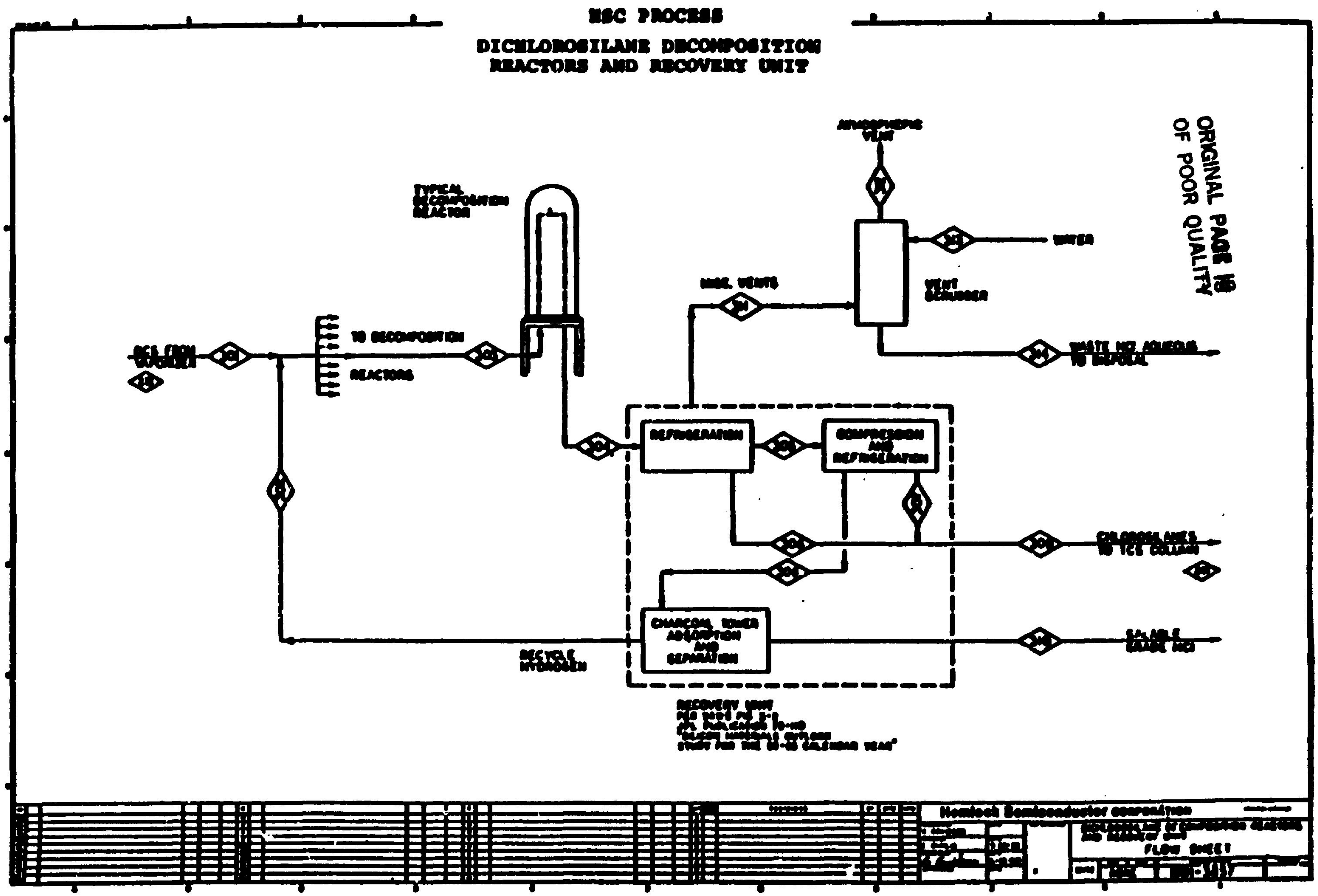

Figure 2.2-5 (continued)

TABLE 2.2-2

BASE CASE CONDITIONS FOR HSC PROCESS - CASE B

1. Plant Size
   - Silicon produced from dichlorosilane (DCS)
   - 1000 metric tons/yr of silicon
   - High purity silicon
   - Final product form (solid rods)

2. Hydrogenation Reaction
   - Metallurgical grade silicon, hydrogen, and recycle silicon tetrachloride (TET) used to produce trichlorosilane (TCS)
   - Copper catalyzed
   - Fluidized bed
   - 500°C, 514.7 psia
   - 29.5% conversion to TCS (example)

3. Recycle For Hydrogenation Unit
   - Unreacted hydrogen from hydrogenation reactor is separated from chlorosilanes by condensation and then recycled
   - Unreacted silicon tetrachloride (TET) is seperated by distillation and recycled

4. Distillation, D-01
   - Stripper column handles crude liquid chlorosilanes from hydrogenation
   - Removes volatile gases which are dissolved in the liquid chlorosilanes (such as H_2, N_2, HCl, etc.)

5. Distillation, D-02
   - Distillation column separates trichlorosilane (TCS) and silicon tetrachloride (TET)
   - Column has three feeds: stripper column bottoms, redistribution reactor chlorosilanes and chlorosilanes from the recovery unit (chlorosilanes from the silicon deposition reactors)

6. Distillation, D-03
   - Distillation column separates dichlorosilane (DCS) and trichlorosilane (TCS)
   - Column has one feed which is chlorosilanes from the boron removal unit
   - Overhead stream as the feed to CVD reactor
   - Bottom stream as the feed to redistribution reactor

7. Boron Removal
   - Removal of BCl_3 by complexation with nitrogen or oxygen base chemical which is supported on non-volatile substance
   - Fixed bed unit
   - No chlorosilane material loss

8. TCS Redistribution Reaction
   - TCS is redistributed to DCS and TET through catalytic reaction
   - Catalytic redistribution of TCS with amine function ion exchange resin (Dowex Ion Exchange Resin MWA-1)
   - Liquid phase 80 psia, 80C
   - Conversion from pure TCS feed is about 10.5% to DCS

TABLE 2.2-2 (continued)

9. Chemical Vapor Deposition Reaction
   - Silicon production
   - Siemens CVD reactor (modified)
   - Dichlorosilane and Hydrogen feed
   - Molar conversion to silicon of 40%
   - Deposition rate of 3000 g/hr
   - Reactor exhaust gas composition (per mole of DCS fed)

HCl	.14
DCS	.10
TCS	.34
STC	.16

10. Recycle From CVD Reactor
    - Chlorosilanes are recovered from a refrigeration process
    - Hydrogen is separated from HCl by adsorption process and recycled back to the CVD reactor
    - Hydrogen chloride (HCl) is recovered as a salable by-product.

11. Slim Rod Pullers
    - Prepare slim rods (small filaments)
    - Slim rods used in Siemen's CVD reactor for silicon deposition
    - Slim rod diameter of 6mm (approx. ¼ inch)

12. Operating Ratio
    - Approximately 85% utilization (on stream time)
    - Approximately 7445 hour/year production

13. Storage Consideration
    - Feed materials (several days supply)
    - Product (two shifts storage)
    - Process (several hours to 1 shift)

14. Wastes Treatment
    - Scrub and neutralize waste gas streams
    - Caustic solution used to neutralize

Note:

The following references were used in establishing the above tabulation: 1-20, 26

TABLE 2.2-3

REACTION CHEMISTRY FOR HSC PROCESS - CASE B

1. Hydrochlorination Reaction

$$3SiCl_4 + Si + 2H_2 \rightleftarrows 4SiHCl_3$$

2. Redistribution Reaction

$$2SiHCl_3 \rightleftarrows SiH_2Cl_2 + SiCl_4$$

3. Waste Treatment (representative - overall)

$$SiH_2Cl_2 + Ca(OH)_2 \xrightarrow{aq.} SiO_2 + CaCl_2 + 2H_2O$$

$$SiHCl_3 + 1.5Ca(OH)_2 \xrightarrow{aq.} SiO_2 + 1.5CaCl_2 + 2H_2O$$

$$SiCl_4 + 2Ca(OH)_2 \xrightarrow{aq.} SiO_2 + 2CaCl_2 + 2H_2O$$

4. Decomposition Reaction

$$SiH_2Cl_2 + H_2 \rightarrow Si + \text{By-Products}$$

Note:

1. Reaction 1 product contains H_2, HCl, $SiCl_4$, $SiHCl_3$, SiH_2Cl_2 (trace), other trace chlorides
2. Reaction 2 product contains $SiHCl_3$, $SiCl_4$, SiH_2Cl_2, SiH_3Cl
3. By-products in reaction 4 include H_2, HCl, SiH_2Cl_2, $SiHCl_3$ and $SiCl_4$

TABLE 2.2-4

RAW MATERIAL REQUIREMENTS FOR HSC PROCESS - CASE B

RAW MATERIALS	REQUIREMENTS	
	lb/hr for 1000 MT/yr Silicon	lb/kg of Silicon
1. M. G. Silicon	270.11	2.014
2. Silicon Tetrachloride ($SiCl_4$, make-up)	535.73	3.67
3. Liquid Hydrogen (H_2, make-up)	45.82	0.342
4. Copper Catalyst	3.44	0.026
5. Hydrate Lime ($Ca(OH)_2$)	259.9	1.937
6. Hydrogen Chloride (HCl, by-product)	129.96	0.969

TABLE 2.2-5

UTILITY REQUIREMENTS FOR HSC PROCESS - CASE B

UTILITIES	TOTAL REQUIREMENTS FOR PLANT	REQUIREMENTS PER KG OF SILICON
1. Electricity		
1) For Deposition Reaction	12,000 kw	90.0 kw-hr
2) For Gas Compression	260 kw	1.94 kw-hr
3) For Pumping Liquid	55 kw	0.41 kw
	12,315 kw	92.35 kw
2. Steam		
1) Superheated, 100 psia	5 k lb/hr	37.3 lb
2) Saturated, 100 psia	17 k lb/hr	126.7 lb
	22 k lb/hr	164.0 lb
3. Cooling water		
1) Cooling and Condensing	96 k gal/hr	715.6 gal
4. Refrigerant	0.90 M BTU/hr	.007 M Btu
1) Refrigeration		
5. Process Water		
1) Waste Treatment	215 gal	3.39 gal
6. Fuel		
1) Direct-Fired Heater	4 M BTU/hr	.03 M BTU
2) Incineration	1.5 M BTU/hr	.011 M BTU
	5.5 M BTU/hr	.041 M BTU

NOTE:

k = kilo = 10^3

M = mega = 10^6

TABLE 2.2-6

LIST OF MAJOR PROCESS EQUIPMENT FOR HSC PROCESS - CASE B

Equipment	Function	Duty/Type	Size	Material of Construction
Distillation Columns				
1. D-01 Crude TCS Stripping Column	Remove inert gases	Distillation Column (Plate)	24 in.dia.x 49 ft.tall 26 sieve trays (actual)	CS
2. D-02 TCS/TET Distillation Column	Separate TCS and TET	Distillation Column (Plate)	5.5 ft. dia. x 58 ft. tall 24 sieve trays (actual)	CS
3. D-03 DCS/TCS Distillation Column	Separate DCS and TCS	Distillation Column (Plate)	4 ft.dia. x 58 ft.tall 32 sieve trays (actual)	CS
Heaters & Heat Exchangers				
4. H-01 Crude TCS Condenser	Condense Chlorosilanes	Shell-Tube H.E.	940 ft^2 515 psia	304SS
5. H-02 H_2 Gas Pre-Heater	Preheat H_2 for chlorination	Direct-Fired heater	1.5MM Btu/hr, 515 psia	CS/Firebrick
6. H-03 TET Vaporizer	Vaporize TET for chlorination	Kettle	530 ft^2 515 psia	304SS

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
7. H-04 Stripper Condenser	Partial condenser for D-01 column	Shell-Tube H.E.	250 ft^2, 90 psia	Nickel Steel
8. H-05 Stripper Reboiler	Stripper reboiler of D-01 column	Kettle	20 ft^2, 90 psia	CS
9. H-06 TCS Condenser	Condenser for D-02 column	Shell-Tube H.E.	960 ft^2, 90 psia	Steel/Cupronickel
10. H-07 TCS Reboiler	Reboiler for D-02 column	Kettle	810 ft^2, 90 psia	CS
11. H-08 TET Heat Exchanger	TET Cooling	Shell-Tube H.E.	480 ft^2, 90 psia	CS
12. H-09 DCS Condenser	Condenser for D-03 column	Shell-Tube H.E.	1600 ft^2, 90 psia	Steel/Cupronickel
13. H-10 DCS Reboiler	Reboiler for D-03 column	Kettle	400 ft^2, 90 psia	CS
14. H-11 TCS Cooler	Cool TCS before redistribution reaction	Shell-Tube H.E.	30 ft^2, 90 psia	Steel/Cupronickel

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
15. H-12 Waste Stream Cooler	Cool waste stream in waste treatment	Shell-Tube H.E.	125 ft^2, 60 psia	CS
16. H-13 TET Superheater	Heat TET before hydrochlorination	Direct-fired heater	2.5MM Btu/hr, 515 psia	CS/Firebrick
17. H-14 H_2 Compressor Intercooler	Cool H_2 gas between compression stages	Shell-Tube H.E.	70 ft^2, 90 psia	CS
18. H-15 CVD Reactor Gas Cooler (1st Stage)	Cool gas from CVD reactor (internal temp.)	Shell-Tube H.E.	45 ft^2, 20 psia	CS
19. H-16 CVD Reactor Gas Cooler (2nd Stage)	Refrigerate gas from CVD reactor (low temp.)	Shell-Tube H.E.	450 ft^2, 20 psia	316 SS
20. H-17 CVD Reactor Gas Cooler (3rd Stage)	Cool CVD reactor gas from compressor (internal temp.)	Shell-Tube H.E.	40 ft^2, 100 psia	316 SS

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
21. H-18 CVD Reactor Gas Cooler (4th Stage)	Refrigerates CVD reactor gas from compressor (low temp.)	Shell-Tube H.E.	350 ft^2, 100 psia	316 SS
22. H-19 Gas Heater	Heats low temp. gases for adsorption	Shell-Tube H.E.	140 ft^2, 100 psia	316 SS
Reactors				
23. R-01 Hydrochlorination Reactor	Hydrochlorination of m.g. Si and TET	Fluid Bed Reactor	2.5 ft.dia. x 21 ft. height plus 6 ft. dia. x 9 ft. height (disengaging), 515 psia	Incoloy 800
24. R-02 TCS Redistribution Reactor	Conversion of TCS to DCS	Fixed Bed Reactor	3 ft. dia. x 18 ft. tall, 80 psia	CS
25. R-03 Waste Neutralizer	Waste Treatment	Agitated Vessel Reactor	3 ft.dia. x 20 ft., 14 psia	CS/Fiberglass
26. R-04 Waste Combuster	Incinerate waste vapors	Waste Combustion Reactor	3 ft. x 3 ft. x 9 ft., 14.7 psia	CS/Brick

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
27. R-05 CVD Deposition Reactor (45)	Hydrogen reduction of chlorosilanes to produce Si	CVD Deposition Reactor (Siemens type, modified)	Large rods, several hairpin loading	Quartz/CS/SS
Tanks, Bins and Vessels				
28. B-01 Silicon Storage Bin with Feed Lock	Store and feed m.g. Si to reactor	Vertical Bin	7 ft.dia. .. 22 ft. 60° cone	CS
29. T-01 Residue Settling Tank	Separate unreacted solid residues	Vertical Process Vessel	6 ft.dia. x 12 ft. 515 psia (2,500 gal)	304SS
30. T-02 Residue Withdraw Tank	Remove unreacted solid residues	Vertical Process Vessel	3 ft.dia. x 7.5 ft., 515 psia (400 gal)	CS
31. T-03 Hydrogen Separation Tank	Separate H_2 gas from chlorosilanes	Horizontal Process Vessel (mesh pad)	5 ft.dia. x 16 ft., 515 psia (2,400 gal)	CS
32. T-04 Crude TCS Storage Tank	Store crude TCS	Horizontal Process Vessel	12 ft.dia. x 34 ft., 100 psia (28,800 gal)	CS
33. T-05 TCS Stripper Reflux Drum	Reflux drum for D-01 column	Vertical Process Vessel	2 ft.dia. x 3.2 ft., 90 psia (80 gal)	304SS

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
34. T-06 TCS/TET Distillation Reflux Drum	Reflux drum for D-02 column	Vertical Process Vessel	4.5 ft.dia. x 12 ft., 90 psia (1,400 gal)	CS
35. T-07 TET Storage Tank	Store TET	Horizontal Process Vessel	10 ft.dia. x 30 ft., 25 psia (17,600 gal)	CS
36. T-08 DCS/TCS Distillation Reflux Drum	Reflux drum for D-03 column	Vertical Process Vessel	5 ft.dia. x 10 ft., 90 psia (1,500 gal)	CS
37. T-09 Vapor-Liquid Separator	Separate H_2 gas from chlorosilanes in recovery	Vertical Process Vessel	5 ft.dia. x 7 ft., 20 psia (1,000 gal)	304SS
38. T-10 Vapor-Liquid Separator	Separate H_2 gas from chlorosilanes in recovery	Vertical Process Vessel	3.5 ft.dia. x 6 ft., 100 psia (430 gal)	304SS
39. T-11 Flue Gas Separation Tank	Separate flue gas from lime solution	Vertical Process Vessel (mesh pad)	2 ft. dia. x 5 ft. (120 gal)	CS
40. T-12 Lime Solution Preparation Tank	Prepare lime solution	Vertical Process Vessel	5 ft.dia. x 9.5 ft. (1,400 gal)	CS

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
41. T-13 Waste Filtrate Storage Tank	Store waste filtrate	Vertical Process Vessel	5 ft.dia. x 8 ft. (1,200 gal)	CS
42. T-14 Hydrogen Surge Tank	Surge tank for Hydrogen	Vertical Process Vessel	3.5 ft.dia. x 8.5 ft. (600 gal)	CS
Compressors and Pumps				
43. C-01A Hydrogen Feed Compressor, First Stage	Compression of recycle and make-up H_2 gas	Reciprocating Compressor	38bhp.,discharge press. 87 psia	CS
44. C-01B Hydrogen Feed Compressor, Second Stage	Compression of recycle and make-up H_2 gas	Reciprocating Compressor	41bhp., discharge Press. 515 psia	CS
45. C-02 Hydrogen Circulation Compressor	Compression of recycle H_2 gas	Centrifugal Compressor	17bhp., ΔP=30 psi	CS
46. P-01 Feed Tank Blower	Load silicon to its storage bin	Centrifugal Blower	939ACFM, 32bhp	CS

TABLE 2.2-6 (continued)

	Equipment	Function	Duty/Type	Size	Material of Construction
47.	P-02 Settling Tank Circulation Pump	Circulation pump	Centrifugal Pump	37' Head, 1.75bhp	CS/304SS
48.	P-03 Crude TCS Pump	Transport crude TCS to D-01 column	Centrifugal Pump	2bhp, discharge 90 psia	CS
49.	P-04 TCS Reflux Pump	Reflux pump for D-02 column	Centrifugal Pump	9bhp, discharge press. 90 psia	CS
50.	P-05 TET Feed Pump	Pumping TET to hydrochlorination reactor	Centrifugal Pump	16bhp, discharge press. 515 psia	CS
51.	P-06 DCS Reflux Pump	Reflux pump for D-03 column	Centrifugal Pump	6bhp, discharge press. 90 psia	316SS
52.	P-10 Waste Solution Pump	Feed slurry to filter	Centrifugal Pump	1.25 bhp	Cast Iron
53.	P-11 Lime Solution Circulation Pump	Circulate lime solution to neutralizer	Centrifugal Pump	1.25 bhp	Cast Iron
54.	P-12 Fresh Lime Solution Pump	Supply fresh lime solution	Centrifugal Pump	0.75 bhp	Cast Iron

TABLE 2.2-6 (continued)

Equipment	Function	Duty/Type	Size	Material of Construction
55. C-03 Cas Compresscr	Compression of gases from CVD reactors	Centrifugal Compressor	250 hp, ΔP=80psia	304SS
Miscellaneous				
56. M-01 Silicon Dust Filter	Retain m.g. silicon dust	Gas-Solid/Bag Filter	20 ft^2 x 5μ	CS/cloth
57. M-02 Waste Slurry Filter	Remove waste sludge	Rotary Filter	2 ft^2	CS/cloth
58. M-03 Silicon Feed Cyclone	Feed m.g. silicon to storage bin	Cyclone	940ACFM	316SS
59. M-04 Quench Contact Ejector	Withdraw and cool effluent of hydro-chlorination	Contact Ejector	100 gpm 134 ACFM	316SS
60 M-05 Flue Gas Ejector	Withdraw flue gas from waste gas combustion	Gas Ejector	100 gpm 1 SCFM	CS
61. M-06 Adsorption Tower (3)	Adsorb HCl from H_2 gas in recovery	Vertical Process Vessel (packed)	4.6' diam. x 45'	CS
62. M-07 Boron Removal Unit (2)	Removal of boron from chlorosilanes	Vertical Process Vessel (packed)	2.3' diam x 22.5'	CS

TABLE 2.2-6 (continued)

	Equipment	Function	Duty/Type	Size	Material of Construction
63.	M-08 Vent Scrubber	Water scrubber for miscellaneous vents	Packed	4' diam x 15' packing	Fiberglass
64.	M-09 Slim Rod Pullers (5)	Produce slim rods (6 mm dia) for deposition	Average pull rate of 470 cm/hr	Filament Puller Size	CS/Other
65.	M-10 Catalyst Blender	Catalyst blender for hydrochlorination	Twin Shell	50 cu. ft.	CS
66.	M-11 Recovery System Pump	Pumps chlorosilanes back to distillation	Centrifugal Pump	1 bhp, 90 psia	CS
67.	M-12 Hydrogen Storage Tank	Store Hydrogen (liquid, make-up)	Horizontal Process Vessel	5.5 ft. dia. x 18.6 ft., 50 psia (13,200 gal)	304SS/ Insulation

TABLE 2.2-7

PRODUCTION LABOR REQUIREMENTS FOR HSC PROCESS - CASE B

Section	Labor man-hr/KG of Si	(oper/shift)
1. Hydrochlorination	0.018	(2)
2. Purification/Redistribution	0.026	(3)
3. Waste Treatment	0.009	(1)
4. Silicon Deposition	0.044	(5)
5. Recovery Unit	0.018	(2)
Total	0.114	(13)

Note

Manpower estimate for production labor requirements based on:

1. Dividing plant into sections
   -type of unit operation
   -mark off working area

2. Specify work duties required in each section

3. Estimate operators required to perform work duties in each section
   -type of unit operati
   -size of working area
   -degree of automation (batch, semi-continuous, etc.)

3. COST ANALYSIS

3 1 HSC Process for Silicon - Case A (Hemlock Semiconductor Corporation)

The cost analysis activity involves an economic analysis of the process under consideration for the production of silicon. The cost analysis for the particular technology is based on process design results, such as requirements for raw materials and major process equipment necessary to produce the product, from the chemical engineering analysis activity. Primary results issuing from the cost analysis include plant capital investment and product cost which are useful in identification of those processes showing promise for meeting project cost goals.

The cost analysis results for producing silicon by the HSC process-Case A (Hemlock Semiconductor Corporation) are presented in Table 3.1-1 including costs for raw materials, labor, utilities and other items composing the product cost (total cost of producing silicon). The tabulation summarizes all of these items to give a total product cost without profit of $22.65 (1980 dollars) and $26.46 (1982 dollars) per kg. This product cost without profit includes direct manufacturing cost, indirect manufacturing cost, plant overhead and general expenses.

A preliminary cost sensitivity analysis was performed to determine the influence of cost parameters on the economics of this new technology. The cost sensitivity results are given in Figure 3.1-1 in which product cost without profit ($/kg) is plotted vs variation (-100 to +100 per cent) of the primary cost parameters. The 0 per cent variation represents the base case, the -100 percent variation corresponds to the case of no costs for the parameter; and the +100 per cent represents the case for a doubling of cost for each parameter. The plot illustrates that product cost is influenced most by plant investment (fixed capital) and utilities (primarily electrical power). Raw materials and labor are intermediate and least in influence.

The product cost represents all cost associated with producing silicon. On top of these costs a producing company will include some profit. The sales price of the product silicon will actually be the sum of the product cost and a profit for the company. The profit is usually measured in terms of rate of return on the capital investment that the company spent in going into the business. Two profitability methods which are commonly used are the return on original investment (per cent ROI) and discounted cash flow rate of return (per cent DCF).

The cost and profitability analysis summary for the HSC process - Case A are presented in Table 3.1-2. The sales price of polysilicon at various rates of return for both profitability methods (per cent ROI and DCF) is shown in the lower half of the table. The results indicate a sales price of $35.86 per kg of silicon (1982 dollars) at 15 per cent DCF return on investment after taxes.

The detailed results for the cost analysis are presented in a tabular format to make it easire to locate cost items of specific interest. The guide for the tabular format is given below:

These cost and profitability results for the HSC process-Case A indicate that this new technology shows promise for producing silicon at appreciable lower cost.

TABLE 3.1-1

ESTIMATION OF PRODUCT COST FOR HSC PROCESS - CASE A

	PRODUCT COST, $/kg of silicon	
	1980 dollars	1982 dollars
1. Direct Manufacturing Cost (Direct Costs)......	13.19	15.49
Raw Materials		
Direct Operating Labor		
Utilities		
Supervision and Clerical		
Maintenance and Repairs		
Operating Supplies		
Laboratory Charge		
2. Indirect Manufacturing Cost (Fixed Cost).......	4.64	5.34
Depreciation		
Local Taxes		
Insurance		
3. Plant Overhead..............................	1.87	2.18
4. General Expenses............................	2.95	3.45
Administration		
Distribution and Sales		
Research and Development		
5. Product Cost Without Profit..................	22.65	26.46

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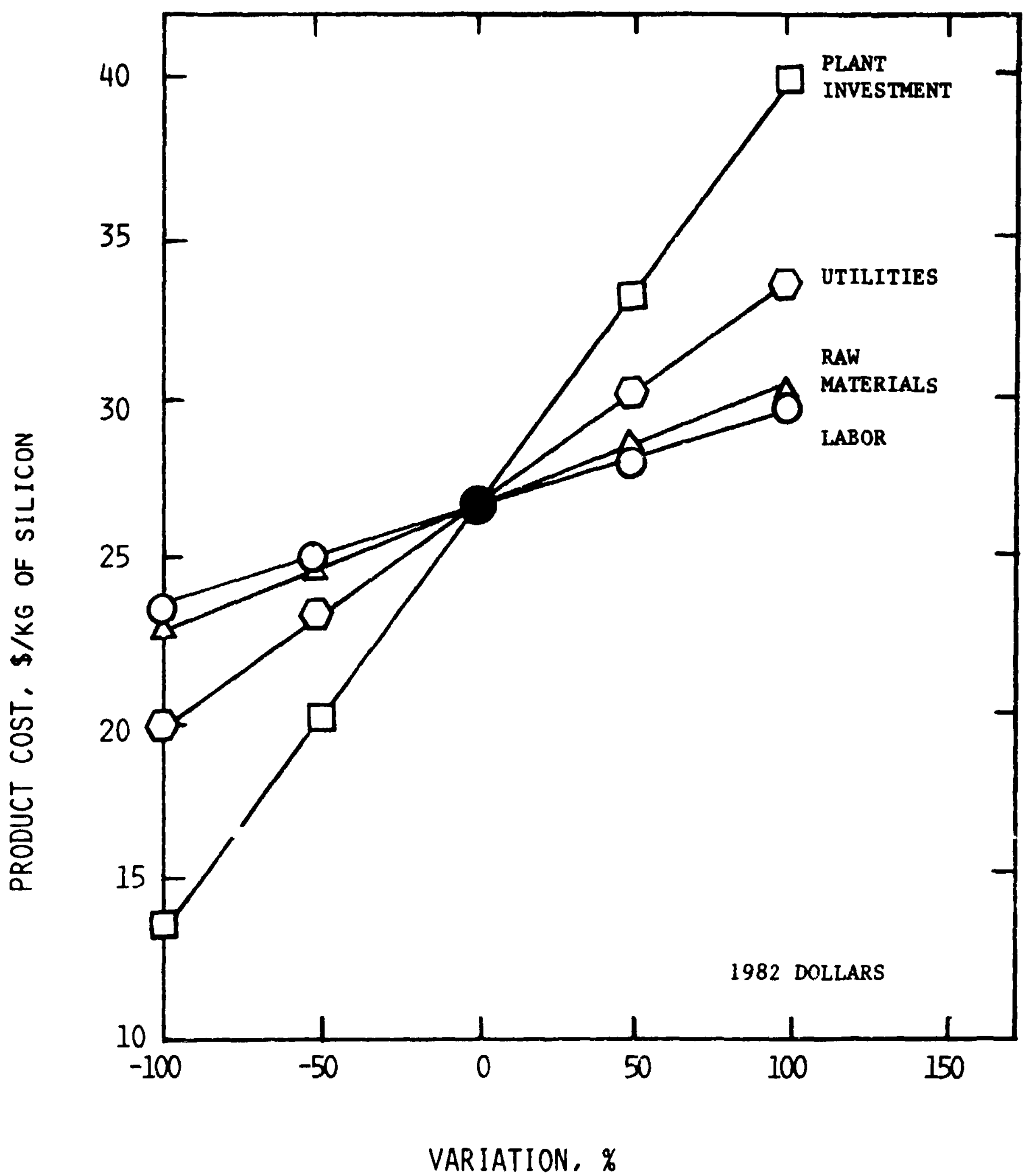

Figure 3.1-1 SENSITIVITY ANALYSIS OF PRODUCT COST WITHOUT PROFIT FOR HSC PROCESS - CASE A

TABLE 3.1-2

COST AND PROFITABILITY ANALYSIS SUMMARY FOR HSC PROCESS - CASE A

1. Process.................................... HSC Process - Case A
2. Plant Size.................................. 1,000 metric tons/year
3. Plant Product............................... Silicon
4. Product Form................................ Solid Rods
5. Plant Investment............................ $39,290,000 / $45,180,000 (1980 dollars) (1982 dollars)

		(1980 dollars)	(1982 dollars)
Fixed Capital		$35.72 Mega	$41.07 Mega
Working Capital		$ 3.57 Mega	$ 4.11 Mega
(15%)	Total	$39.29 Mega	$45.18 Mega

6. Return on Original Investment, after taxes (%ROI)

	Sales Price $/Kg of Silicon (1980 dollars)	Sales Price $/Kg of Silicon (1982 dollars)
0% ROI..............	$22.65	$26.46
5% ROI..............	$26.45	$30.90
10% ROI..............	$30.26	$35.34
15% ROI..............	$34.06	$39.78
20% ROI..............	$37.86	$44.22
25% ROI..............	$41.67	$48.66
30% ROI.............	$45.47	$53.11
40% ROI.............	$53.08	$61.99

7. Discounted Cash Flow Rate of Return, after taxes (% DCF)

	Sales Price $/Kg of Silicon (1980 dollars)	Sales Price $/Kg of Silicon (1982 dollars)
0% DCF..............	$22.65	$26.46
5% DCF..............	$25.10	$29.32
10% DCF..............	$27.79	$32.47
15% DCF..............	$30.70	$35.86
20% DCF..............	$33.80	$39.48
25% DCF..............	$37.04	$43.26
30% DCF..............	$40.41	$47.19
40% DCF..............	$47.41	$55.37

Based on 10 year project life and 10 year straight line depreciation.

8. Tax Rate........................... 46%

TABLE 3.1-3

COST ANALYSIS:
PRELIMINARY ECONOMIC ANALYSIS ACTIVITIES FOR HSC PROCESS - CASE A

Prel. Process Economic Activity	Status	Prel. Process Economic Activity	Status
1. Process Design Inputs	●	6. Production Labor Costs	●
1. Raw Material Requirements	●	1. Base Cost Per Man Hour	●
2. Utility Requirements	●	2. Cost/Kg Silicon Per Area	●
3. Equipment List	●	3. Total Cost/Kg Silicon	●
4. Labor Requirements	●		
		7. Estimation of Plant Investment	●
2. Specify Base Case Conditions	●	1. Battery Limits Direct Costs	●
1. Base Year for Costs	●	2. Other Direct Costs	●
2. Appropriate Indices for Costs	●	3. Indirect Costs	●
3. Additional	●	4. Contingency	●
		5. Total Plant Investment (Fixed Capital)	●
3. Raw Material Costs	●		
1. Base Cost/lb of Material	●		
2. Material Cost/Kg of Silicon	●	8. Estimation of Total Product Cost	●
3. Total Cost/Kg of Silicon	●	1. Direct Manufacturing Cost	●
		2. Indirect Manufacturing Cost	●
4. Utility Costs	●	3. Plant Overhead	●
1. Base Cost for Each Utility	●	4. By-Product Credit	●
2. Utility Cost/Kg of Silicon	●	5. General Expenses	●
3. Total Cost/Kg of Silicon	●	6. Total Cost of Product	●
5. Major Process Equipment Costs	●		
1. Individual Equipment Cost	●		
2. Cost Index Adjustment	●		

O Plan
◐ In Progress
● Complete

TABLE 3.1-4

PROCESS DESIGN INPUTS: PROCESS PLANT DESIGN CHECKLIST FOR HSC PROCESS - CASE A

1. Raw Material Requirements

   -raw material requirements for process
   -metallurgical grade silicon, silicon tetrachloride, hydrogen, copper catalyst, lime, etc.
   -see table for "Raw Material Cost"

2. Utility Requirements

   -utility requirements for process
   -electricity, steam, cooling water, regrigeration, etc.
   -see table for "Utility Cost"

3. Major Process Equipment Requirements

   -list of major process equipment required for process
   -distillation columns, heaters, heat exchangers, reactors, tanks, bins, vessels, compressors, pumps, etc.
   -see table for "Major Process Equipment Cost"

4. Production Labor Requirements

   -production labor requirements for process
   -labor for hydrochlorination, purification/redistribution, waste treatment, silicon deposition, etc.
   -see table for "Production Labor Cost"

TABLE 3.1-5

BASE CASE CONDITIONS: COST ANALYSIS CHECKLIST FOR HSC PROCESS - CASE A

1. Raw Material Cost (32-38)

   -cost of raw materials required in process
   -Chemical Marketing Reporter
   -industrial consultations
   -other personal communications

2. Utility Cost (21-27)

   -cost of utilities required in process
   -Chemical Week (Plant Sites), Peters and Timmenhaus (Rates for various industrial utilities)
   -industrial communications

3. Labor Cost (22-26, 31)

   -cost of labor required in process
   -labor rate representative of Petroleum, Coal, Chemical and Allied Industries
   -rate of $10/hr (1980 dollars)

4. Major Process Equipment Cost (9, 26-30)

   -cost of major process equipment required in process
   -vendor quotations
   -Richardson Process Plant Construction Estimating Standards
   -Guthrie, Popper, Peters and Timmerhaus
   -M & S Equipment Cost Index
   -Other personal sources

5. Capital Investment Cost (26-30)

   -major process equipment
   -installation, piping, instrumentation, electrical, process buildings
   -offsites, utilities, site development, general services, offices, receiving, shipping
   -engineering, contingency
   -fixed capital investment for plant
   -CE Plant Cost Index

TABLE 3.1-5 (Continued)

Note

1. The above tabulation provides documentation for sources of the cost data.

2. In this report, each respective table (Raw Material Cost, Utility Cost, etc.) gives detailed data such as cost per lb. of material, cost per kw-hr of electricity, major process equipment cost, cost of labor in $/hr and other costs.

3. The cost analysis results presented in this report are primarily applicable for

   -1980 dollars
   -1982 dollars

4. The numbers in parentheses are references for the above tabulation.

TABLE 3.1-6

RAW MATERIAL COST FOR HSC PROCESS - CASE A

Raw Material	Raw Material Requirement, lb/kg of Si	Raw Material Cost, \$/lb of Material		Cost, \$/kg of Si	
		1980 dollars	1982 dollars	1980 dollars	1982 dollars
1. M. G. Silicon	2.014	0.63	0.62	1.27	1.25
2. Silicon Tetrachloride ($SiCl_4$, make-up)	3.67	0.26	0.36	0.95	1.32
3. Liquid Hydrogen (H_2, make-up)	0.342	1.485	1.679	0.51	0.57
4. Copper Catalyst	0.026	0 [illegible] 5	0.75	0.02	0.02
5. Hydrate Lime ($Ca(OH)_2$)	1.937	0.017 (33.5 \$/ton)	0.017	0.03	0.03
6. Hydrogen Chloride (HCl, by-product)	0.969	0.12	0.12	(0.12)	(0.12)
				2.66	3.07

TABLE 3.1-7

UTILITY COST FOR HSC PROCESS - CASE A

	Utility	Utility Requirement Unit/kg of Si	Utility Cost, $/unit		Cost, $/kg of Si	
			1980 dollars	1982 dollars	1980 dollars	1982 dollars
1.	Electricity	92.35 kw-hr	.045 $/kw-hr	.054 $/kw-hr	4.16	4.99
2.	Steam	164 lb	1.89 $/k lb	2.268 $/k lb	0.310	0.372
3.	Cooling Water	715.6 gal	.126 $/k gal	0.151 $/k gal	0.090	0.108
4.	Refrigeration	.007 M BTU	14.7 $/M BTU	17.64 $/M BTU	0.103	0.124
5.	Process Water	3.39 gal	.567 $/k gal	0.680 $/k gal	0.002	0.002
6.	Fuel	.041 M BTU	1.96 $/M BTU	2.352 $/M BTU	0.080	0.096
					4.745	5.694

Note:

k = kilo = 10^3
M = mega = 10^6

TABLE 3.1-8

MAJOR PROCESS EQUIPMENT COST FOR HSC PROCESS - CASE A

Equipment	Equipment Cost, $1,000	
	1980 dollars	1982 dollars
1. D-01 Crude TCS Stripping Column	24.0	27.6
2. D-02 TCS/TET Distillation Column	71.9	82.7
3. D-03 DCS/TCS Distillation Column	60.9	70.0
4. H-01 Crude TCS Condenser	57.4	66.0
5. H-02 H_2 Gas Pre-Heater	19.1	22.0
6. H-03 TET Vaporizer	22.9	26.3
7. H-04 Stripper Condenser	11.6	13.3
8. H-05 Stripper Reboiler	2.9	3.3
9. H-06 TCS Condenser	30.0	34.5
10. H-07 TCS Reboiler	14.6	16.8
11. H-08 TET Heat Exchanger	10.8	12.4
12. H-09 DCS Condenser	35.7	41.1
13. H-10 DCS Reboiler	10.7	12.3

TABLE 3.1-3

(Continued)

	Equipment Cost, $1,000 1980 dollars	1982 dollars
14. H-11 TCS Cooler	5.2	6.0
15. H-12 Waste Stream Cooler	5.1	5.9
16. H-13 TET Super-heater	30.9	35.5
17. H-14 H_2 Compressor Intercooler	3.7	4.3
18. H-15 CVD Reactor Gas Cooler (1st Stage)	2.8	3.2
19. H-16 CVD Reactor Gas Cooler (2nd Stage)	21.7	25.0
20. H-17 CVD Reactor Gas Cooler (3rd Stage)	4.9	5.6
21. H-18 CVD Reactor Gas Cooler (4th Stage)	19.0	21.9
22. H-19 Gas Heater	10.6	12.2
23. R-01 Hydrochlorina-tion Reactor	179.0	205.9
24. R-02 TCS Redistribution Reactor	21.0	24.2
25. R-03 Waste Neutralizer	17.5	20.1
26. R-04 Waste Combuster	12.8	14.7
27. R-05 CVD Depostion Reactor (45)	122.0 ea.	140.3 ea.
28. B-01 Silicon Storage Bin with Feed Lock	29.8	34.3

TABLE 3.1-8

(Continued)

		Equipment Cost, $1,000	
		1980 dollars	1982 dollars
29.	T-01 Residue Settling Tank	88.2	101.4
30.	T-02 Residue Withdraw Tank	8.5	9.8
31.	T-03 Hydrogen Separation Tank	20.7	23.8
32.	T-04 Crude TCS Storage Tank	34.9	40.1
33.	T-05 TCS Stripper Reflux Drum	4.4	5.1
34.	T-06 TCS/TET Distillation Reflux Drum	8.4	9.7
35.	T-07 TET Storage Tank	19.9	22.9
36.	T-08 DCS/TCS Distillation Reflux Drum	9.6	11.0
37.	T-09 Vapor-Liquid Separator	15.8	18.2
38.	T-10 Vapor-Liquid Separator	17.8	20.5
39.	T-11 Flue Gas Separation Tank	1.7	2.0
40.	T-12 Lime Solution Preparation Tank	7.2	8.3
41.	T-13 Waste Filtrate Storage Tank	5.9	6.8
42.	T-14 Hydrogen Surge Tank	6.0	6.9
43.	C-01A Hydrogen Feed Compressor First Stage	43.0	49.5

TABLE 3.1-8

(Continued)

		Equipment Cost, $1,000	
		1980 dollars	1982 dollars
44.	C-01B Hydrogen Feed Compressor Second Stage	46.4	53.4
45.	C-02 Hydrogen Circulation Compressor	20.3	23.3
46.	P-01 Feed Tank Blower	16.0	18.4
47.	P-02 Settling Tank Circulation Pump	9.8	11.3
48.	P-03 Crude TCS Pump	2.5	2.9
49.	P-04 TCS Reflux Pump	4.3	4.9
50.	P-05 TET Feed Pump	5.8	6.7
51.	P-06 DCS Reflux Pump	3.8	4.4
52.	P-10 Waste Solution Pump	.9	1.0
53.	P-11 Lime Solution Circulation Pump	.9	1.0
54.	P-12 Fresh Lime Solution Pump	.9	1.0
55.	C-03 Gas Compressor	128.5	147.8
56.	M-01 Silicon Dust Filter	1.5	1.7
57.	M-02 Waste Slurry Filter	3.8	4.4
58.	M-03 Silicon Feed Cyclone	2.0	2.3
59.	M-04 Quench Contact Ejector	9.5	10.9
60.	M-05 Flue Gas Ejector	1.8	2.1
61.	M-06 Adsorption Tower (3)	45.5 ea.	52.3 ea.

TABLE 3.1-8

(Continued)

	Equipment Cost, $1,000 1980 dollars	1982 dollars
62. M-07 Boron Removal Unit (2)	9.5 ea.	10.9 ea.
63. M-08 Vent Scrubber	17.1	19.7
64. M-09 Slim Rod Pullers (5)	21. ea.	24.2 ea.
65. M-10 Catalyst Blender	21.8	25.1
66. M-11 Recovery System Pump	1.4	1.6
67. M-12 Hydrogen Storage Tank	53.0	61.0
Total	7,131.0	8,200.6

TABLE 3.1-9

PRODUCTION LABOR COST FOR HSC PROCESS - CASE A

Section	Labor Requirement, hr/kg of Si	Labor Rate, $/hr of labor		Cost, $/kg of Si	
		1980 dollars	1982 dollars	1980 dollars	1982 dollars
1. Hydrochlorination	0.018	10.00	12.00	0.18	0.22
2. Purification/Redistribution	0.026	10.00	12.00	0.26	0.31
3. Waste Treatment	0.009	10.00	12.00	0.09	0.11
4. Silicon Deposition	0.044	10.00	12.00	0.44	0.53
5. Recovery Unit	0.018	10.00	12.00	0.18	0.22
				1.15	1.38

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TABLE 3.1-10

ESTIMATION OF PLANT INVESTMENT FOR HSC PROCESS-CASE A

	Investment $1000 1980 Dollars	Investment $1000 1982 Dollars
1. DIRECT PLANT INVESTMENT COSTS		
1. Major Process Equipment Cost	7,131.0	8,200.6
2. Installation of Process Equipment	3,066.3	3,526.3
3. Process Piping, Installed	5,276.9	6,068.5
4. Instrumentation, Installed	1,354.9	1,558.1
5. Electrical, Installed	713.1	820.1
6. Process Building, Installed	713.1	820.1
1a. SUBTOTAL FOR DIRECT PLANT INVESTMENT (PRIMARILY BATTERY LIMIT FACILITIES)	18,255.4	20,993.7
2. OTHER DIRECT PLANT INVESTMENT COSTS		
1. Utilities, Installed	3,422.9	3,936.3
2. General Service, Site Development, Fire Protection, etc.	855.7	984.1
3. General Buildings, Offices, etc	998.3	1,148.1
4. Receiving, Shipping Facilities	1,497.5	1,722.1
2a. SUBTOTAL FOR OTHER DIRECT PLANT INVESTMENT COST (PRIMARILY OFFSET FACILITIES)	6,774.5	7,790.6
3. TOTAL DIRECT INVESTMENT COSTS, 1a+2a	25,029.8	28,784.3
4. INDIRECT PLANT INVESTMENT COSTS		
1. Engineering, Overhead, etc	3,922.1	4,510.4
2. Normal Cont. for Strikes, etc	5,063.0	5,822.5
4a. TOTAL INDIRECT INVESTMENT COST	8,985.1	10,332.8
5. TOTAL DIRECT AND INDIRECT INVESTMENT COST, 3+4a	34,014.9	39,117.1
6. OVERALL CONTINGENCY	1,700.7	1,955.9
7. FIXED CAPITAL INVESTMENT FOR PLANT 5+6	35,715.6	41,073.0

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TABLE 3.1-11

ESTIMATION OF TOTAL PRODUCT COST FOR HSC PROCESS-CASE A

		COST, $/kg of Silicon 1980 Dollars	1982 Dollars
1.	Direct Manufacturing Cost (Direct Charges)		
	1. Raw Materials	2.660	3.070
	2. Direct Operating Labor	1.150	1.380
	3. Utilities	4.745	5.694
	4. Supervision and Clerical	0.173	0.207
	5. Maintenance and Repairs	3.572	4.107
	6. Operating Supplies	0.714	0.821
	7. Laboratory Charge	0.173	0.207
2.	Indirect Manufacturing Cost (Fixed Charges)		
	1. Depreciation	3.572	4.107
	2. Local Taxes	0.714	0.821
	3. Insurance	0.357	0.411
3.	Plant Overhead	1.865	2.184
4.	By-Product Credit		
4a.	Total Manufacturing Cost, 1+2+3+4	19.695	23.011
5.	General Expenses		
	1. Administration	1.182	1.381
	2. Distribution and Sales	1.182	1.381
	3. Research and Develpoment	0.591	0.690
		-------	-------
6.	Total Cost of Product, 4a+5	22.649	26.462

3.2 HSC Process for Silicon - Case B (Hemlock Semiconductor Corporation)

The cost analysis activity involves an economic analysis of the process under consideration for the production of silicon. The cost analysis for the particular technology is based on process design results, such as requirements for raw materials and major process equipment necessary to produce the product, from the chemical engineering analysis activity. Primary results issuing from the cost analysis include plant capital investment and product cost which are useful in identification of those processes showing promise for meeting project cost goals.

The cost analysis results for producing silicon by the HSC process-Case B (Hemlock Semiconductor Corporation) are presented in Table 3.2-1 including costs for raw materials, labor utilities and other items composing the product cost (total cost of producing silicon). The tabulation summarizes all of these items to give a total product cost without profit of \$22.62 (1980 dollars) and \$26.43 (1982 dollars) per kg. This product cost without profit includes direct manufacturing cost, indirect manufacturing cost, plant overhead and general expenses.

A preliminary cost sensitivity analysis was performed to determine the influence of cost parameters on the economics of this new technology. The cost sensitivity results are given in Figure 3.2-1 in which product cost without profit (\$/kg) is plotted vs variation (-100 to +100 per cent) of the primary cost parameters. The 0 per cent variation represents the base case, the -100 per cent variation corresponds to the case of no costs for the parameter; and the +100 per cent represents the case for a doubling of cost for each parameter. The plot illustrates that product cost is influenced most by plant investment (fixed capital) and utilities (primarily electrical power). Raw materials and labor are intermediate and least in influence.

The product cost represents all cost associated with producing silicon. On top of these costs a producing company will include some profit. The sales price of the product silicon will actually be the sum of the product cost and a profit for the company. The profit is usually measured in terms of rate of return on the capital investment that the company spent in going into the business. Two profitability methods which are commonly used are the return on original investment (per cent ROI) and discounted cash flow rate of return (per cent DCF).

The cost and profitability analysis summary for the HSC process - Case B are presented in Table 3.2-2. The sales price of polysilicon at various rates of return for both profitability methods (per cent ROI and DCF) is shown in the lower half of the table. The results indicate a sales price of \$35.67 per kg of silicon (1982 dollars) at 15 per cent DCF return on investment after taxes.

The detailed results for the cost analysis are presented in a tabular format to make it easier to locate cost items of specific interest. The guide for the tabular format is given below:

- . Preliminary Economic Analysis Activities--------Table 3.2-3
- . Process Design Inputs---------------------------Table 3.2-4
- . Base Case Conditions----------------------------Table 3.2-5
- . Raw Material Cost-------------------------------Table 3.2-6
- . Utility Cost------------------------------------Table 3.2-7
- . Major Process Equipment Cost--------------------Table 3.2-8
- . Production Labor Cost---------------------------Table 3.2-9
- . Plant Investment--------------------------------Table 3.2-10
- . Total Product Cost------------------------------Table 3.2-11

These cost and profitability results for the HSC process-Case B indicate that this new technology shows promise for producing silicon at appreciable lower cost.

TABLE 3.2-1

ESTIMATION OF PRODUCT COST FOR HSC PROCESS - CASE B

	PRODUCT COST, $/kg of silicon	
	1980 dollars	1982 dollars
1. Direct Manufacturing Cost (Direct Costs)......	13.18	15.47
Raw Materials		
Direct Operating Labor		
Utilities		
Supervision and Clerical		
Maintenance and Repairs		
Operating Supplies		
Laboratory Charge		
2. Indirect Manufactuing Cost (Fixed Cost).......	4.63	5.33
Depreciation		
Local Taxes		
Insurance		
3. Plant Overhead...............................	1.86	2.18
4. General Expenses..............................	2.95	3.45
Administration		
Distribution and Sales		
Research and Development		
5. Product Cost Without Profit..................	22.62	26.43

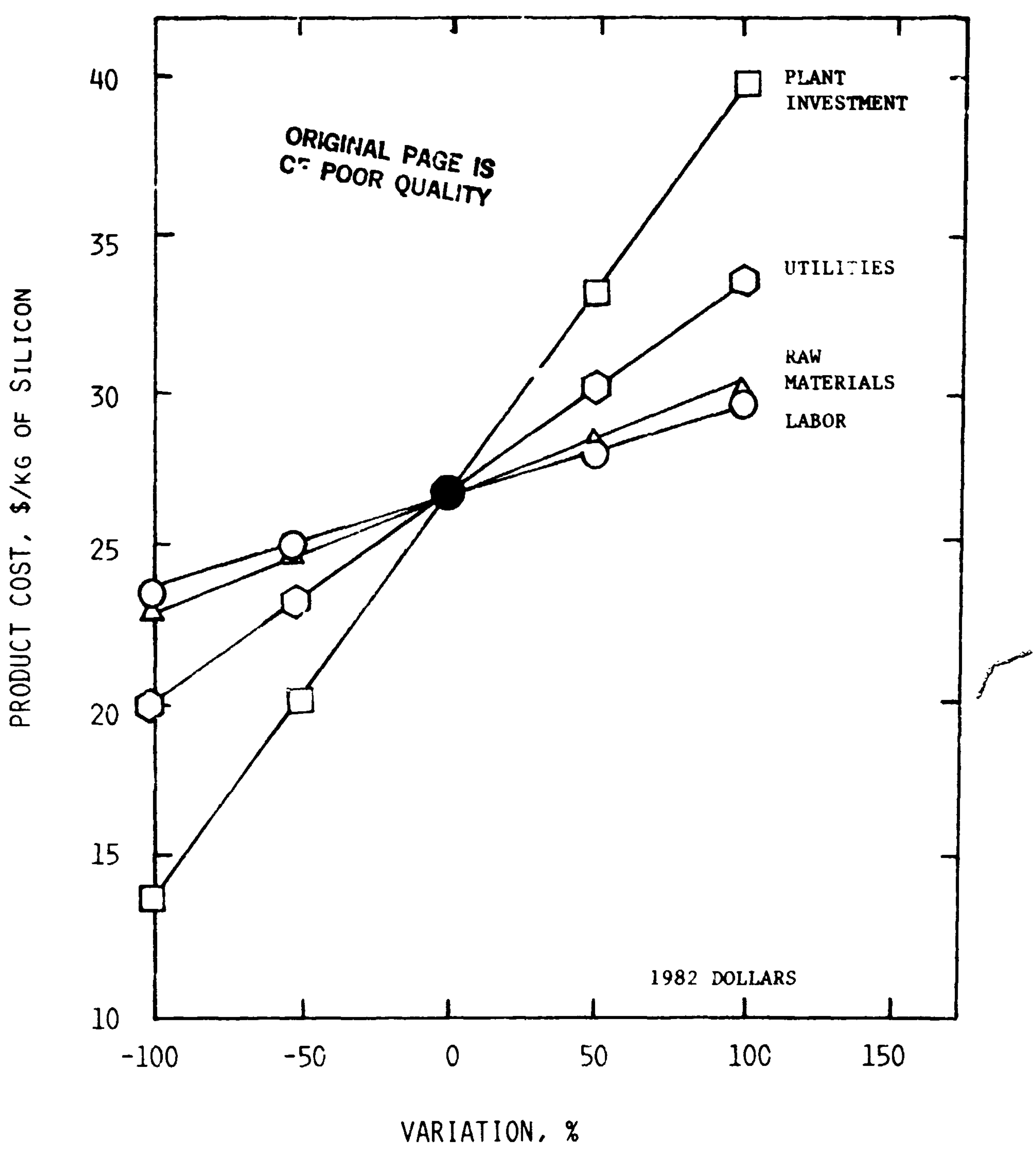

Figure 3.2-1 SENSITIVITY ANALYSIS OF PRODUCT COST WITHOUT PROFIT FOR HSC PROCESS - CASE B

TABLE 3.2-2

COST AND PROFITABILITY ANALYSIS SUMMARY FOR HSC PROCESS - CASE B

1. Process.................................... HSC Process - Case B
2. Plant Size.................................. 1,000 metric tons/year
3. Plant Product............................... Silicon
4. Product Form................................ Solid Rods
5. Plant Investment............................ $39,190,000 (1980 dollars) $45,070,000 (1982 dollars)

		(1980 dollars)	(1982 dollars)
Fixed Capital		$35.63 Mega	$40.97 Mega
Working Capital (15%)		$ 3.56 Mega	$ 4.10 Mega
	Total	$39.19 Mega	$45.07 Mega
		(1980 dollars)	(1982 dollars)

6. Return on Original Investment, after taxes (%ROI)

	Sales Price $/Kg of Silicon (1980 dollars)	Sales Price $/Kg of Silicon (1982 dollars)
0% ROI..............	$22.62	$26.43
5% ROI..............	$26.41	$30.79
10% ROI..............	$30.20	$35.15
15% ROI..............	$34.00	$39.52
20% ROI..............	$37.79	$43.88
25% ROI..............	$41.58	$48.24
30% ROI.............	$45.38	$52.60
40% ROI........	$52.96	$61.33

7. Discounted Cash Flow Rate of Return, after taxes (% DCF)

	Sales Price $/Kg of Silicon (1980 dollars)	Sales Price $/Kg of Silicon (1982 dollars)
0% DCF..............	$22.62	$26.43
5% DCF..............	$25.06	$29.24
10% DCF..............	$27.75	$32.33
15% DCF..............	$30.65	$35.67
20% DCF..............	$33.73	$39.21
25% DCF..............	$36.97	$42.94
30% DCF..............	$40.33	$46.80
40% DCF..............	$47.31	$54.83

Based on 10 year project life and 10 year straight line depreciation.

8. Tax Rate............................ 46%

TABLE 3.2-3

COST ANALYSIS:
PRELIMINARY [illegible]NOMIC ANALYSIS ACTIVITIES FOR HSC PROCESS - CASE B

Prel. Process Economic Activity	Status
1. Process Design Inputs	●
1. Raw Material Requirements	●
2. Utility Requirements	●
3. Equipment List	●
4. Labor Requirements	●
2. Specify Base Case Conditions	●
1. Base Year for Costs	●
2. Appropriate Indices for Costs	●
3. Additional	●
3. Raw Material Costs	●
1. Base Cost/Lb of Material	●
2. Material Cost/Kg of Silicon	●
3. Total Cost/Kg of Silicon	●
4. Utility Costs	●
1. Base Cost for Each Utility	●
2. Utility Cost/Kg of Silicon	●
3. Total Cost/Kg of Silicon	●
5. Major Process Equipment Costs	●
1. Individual Equipment Cost	●
2. Cost Index Adjustment	●

Prel. Process Economic Activity	Status
6. Production Labor Costs	●
1. Base Cost Per Man Hour	●
2. Cost/Kg Silicon Per Area	●
3. Total Cost/Kg Silicon	●
7. Estimation of Plant Investment	●
1. Battery Limits Direct Costs	●
2. Other Direct Costs	●
3. Indirect Costs	●
4. Contingency	●
5. Total Plant Investment (Fixed Capital)	●
8. Estimation of Total Product Cost	●
1. Direct Manufacturing Cost	●
2. Indirect Manufacturing Cost	●
3. Plant Overhead	●
4. By-Product Credit	●
5. General Expenses	●
6. Total Cost of Product	●

O Plan
◐ In Progress
● Complete

TABLE 3.2-4

PROCESS DESIGN INPUTS: PROCESS PLANT DESIGN CHECKLIST FOR HSC PROCESS - CASE B

1. Raw Material Requirements

   -raw material requirements for process
   -metallurgical grade silicon, silicon tetrachloride, hydrogen, copper catalyst, lime, etc.
   -see table for "Raw Material Cost"

2. Utility Requirements

   -utility requirements for process
   -electricity, steam, cooling water, regrigeration, etc.
   -see table for "Utility Cost"

3. Major Process Equipment Requirements

   -list of major process equipment required for process
   -distillation columns, heaters, heat exchangers, reactors, tanks, bins, vessels, compressors, pumps, etc.
   -see table for "Major Process Equipment Cost"

4. Production Labor Requirements

   -production labor requirements for process
   -labor for hydrochlorination, purification/redistribution, waste treatment, silicon deposition, etc.
   -see table for "Production Labor Cost"

TABLE 3.2-5

BASE CASE CONDITIONS: COST ANALYSIS CHECKLIST FOR HSC PROCESS - CASE B

1. Raw Material Cost (32-38)

   - cost of raw materials required in process
   - Chemical Marketing Reporter
   - industrial consultations
   - other personal communications

2. Utility Cost (21-27)

   - cost of utilities required in process
   - Chemical Week (Plant Sites), Peters and Timmenhaus (Rates for various industrial utilities)
   - industrial communications

3. Labor Cost (22-26, 31)

   - cost of labor required in process
   - labor rate representative of Petroleum, Coal, Chemical and Allied Industries
   - rate of $10/hr (1980 dollars)

4. Major Process Equipment Cost (9, 26-30)

   - cost of major process equipment required in process
   - vendor quotations
   - Richardson Process Plant Construction Estimating Standards
   - Guthrie, Popper, Peters and Timmerhaus
   - M & S Equipment Cost Index
   - Other personal sources

5. Capital Investment Cost (26-30)

   - major process equipment
   - installation, piping, instrumentation, electrical, process buildings
   - offsites, utilities, site development, general services, offices, receiving, shipping
   - engineering, contingency
   - fixed capital investment for plant
   - CE Plant Cost Index

TABLE 3.2-5 (Continued)

<u>Note</u>

1. The above tabulation provides documentation for sources of the cost data.

2. In this report, each respective table (Raw Material Cost, Utility Cost, etc.) gives detailed data such as cost per lb. of material, cost per kw-hr of electricity, major process equipment cost, cost of labor in $/hr and other costs.

3. The cost analysis results presented in this report are primarily applicable for

   -1980 dollars
   -1982 dollars

4. The numbers in parentheses re references for the above tabulation.

TABLE 3.2-6

RAW MATERIAL COST FOR HSC PROCESS - CASE B

	Raw Material	Raw Material Requirement, lb/kg of Si	Raw Material Cost, $/lb of Material		Cost, $/kg of Si	
			1980 dollars	1982 dollars	1980 dollars	1982 dollars
1.	M. G. Silicor	2.014	0.63	0.62	1.27	1.25
2.	Silicon Tetrachloride ($SiCl_4$, make-up)	3.67	0.26	0.36	0.95	1.32
3.	Liquid Hydrogen (H_2, make-up)	0.342	1.485	1.679	0.51	0.57
4.	Copper Catalyst	0.026	0.75	0.75	0.02	0.02
	Hydrate Lime ($Ca(OH)_2$)	1.937	0.017 (33.5 $/ton)	0.017	0.03	0.03
6.	Hydrogen Chloride (HCl, by-product)	0.969	0.12	0.12	(0.12)	(0.12)
					2.66	3.07

TABLE 3.2-7

UTILITY COST FOR HSC PROCESS - CASE B

	Utility	Utility Requirement Unit/kg of Si	Utility Cost, $/unit		Cost, $/kg of Si	
			1980 dollars	1982 dollars	1980 dollars	1982 dollars
1.	Electricity	92.35 kw-hr	.045 $/kw-hr	.054 $/kw-hr	4.16	4.99
2.	Steam	164 lb	1.89 $/k lb	2.268 $/k lb	0.310	0.372
3.	Cooling Water	715.6 gal	.126 $/k gal	0.151 $/k gal	0.090	0.108
4.	Refrigeration	.007 M BTU	14.7 $/M BTU	17.64 $/M BTU	0.103	0.124
5.	Process Water	3.39 gal	.567 $/k gal	0.680 $/k gal	0.002	0.002
6.	Fuel	.041 M BTU	1.96 $/M BTU	2.352 $/M BTU	0.080	0.096
					4.745	5.694

Note:

k = kilo = 10^3
M = mega = 10^6

TABLE 3.2-8

MAJOR PROCESS EQUIPMENT COST FOR HSC PROCESS - CASE B

Equipment	Equipment Cost, $1,000 1980 dollars	1982 dollars
1. D-01 Crude TCS Stripping Column	24.0	27.6
2. D-02 TCS/TET Distillation Column	53.9	62.0
3. D-03 DCS/TCS Distillation Column	60.9	70.0
4. H-01 Crude TCS Condenser	57.4	66.0
5. H-02 H_2 Gas Pre-Heater	19.1	22.0
6. H-03 TET Vaporizer	22.9	26.3
7. H-04 Stripper Condenser	11.6	13.3
8. H-05 Stripper Reboiler	2.9	3.3
9. H-06 TCS Condenser	30.0	34.5
10. H-07 TCS Reboiler	14.6	16.8
11. H-08 TET Heat Exchanger	10.8	12.4
12. H-09 DCS Condenser	35.7	41.1
13. H-10 DCS Reboiler	10.7	12.3

TABLE 3.2-8

(Continued)

		Equipment Cost, $1,000	
		1980 dollars	1982 dollars
14.	H-11 TCS Cooler	5.2	6.0
15.	H-12 Waste Stream Cooler	5.1	5.9
16.	H-13 TET Superheater	30.9	35.5
17.	H-14 H_2 Compressor Intercooler	3.7	4.3
18.	H-15 CVD Reactor Gas Cooler (1st Stage)	2.8	3.2
19.	H-16 CVD Reactor Gas Cooler (2nd Stage)	21.7	25.0
20.	H-17 CVD Reactor Gas Cooler (3rd Stage)	4.9	5.6
21.	H-18 CVD Reactor Gas Cooler (4th Stage)	19.0	21.9
22.	H-19 Gas Heater	10.6	12.2
23.	R-01 Hydrochlorination Reactor	179.0	205.9
24.	R-02 TCS Redistribution Reactor	21.0	24.2
25.	R-03 Waste Neutralizer	17.5	20.1
26.	R-04 Waste Combuster	12.8	14.7
27.	R-05 CVD Depostion Reactor (45)	122.0 ea.	140.3 ea.
28.	B-01 Silicon Storage Bin with Feed Lock	29.8	34.3

TABLE 3.2-8

(Continued)

	Equipment Cost, $1,000	
	1980 dollars	1982 dollars
29. T-01 Residue Settling Tank	88.2	101.4
30. T-02 Residue Withdraw Tank	8.5	9.8
31. T-03 Hydrogen Separation Tank	20.7	23.8
32. T-04 Crude TCS Storage Tank	34.9	40.1
33. T-05 TCS Stripper Reflux Drum	4.4	5.1
34. T-06 TCS/TET Distillation Reflux Drum	8.4	9.7
35. T-07 TET Storage Tank	19.9	22.9
36. T-08 DCS/TCS Distillation Reflux Drum	9.6	11.0
37. T-09 Vapor-Liquid Separator	15.8	18.2
38. T-10 Vapor-Liquid Separator	17.8	20.5
39. T-11 Flue Gas Separation Tank	1.7	2.0
40. T-12 Lime Solution Preparation Tank	7.2	8.3
41. T-13 Waste Filtrate Storage Tank	5.9	6.8
42. T-14 Hydrogen Surge Tank	6.0	6.9
43. C-01A Hydrogen Feed Compressor First Stage	43.0	49.5

TABLE 3.2-8

(Continued)

		Equipment Cost, $1,000	
		1980 dollars	1982 dollars
44.	C-01B Hydrogen Feed Compressor Second Stage	46.4	53.4
45.	C-02 Hydrogen Circulation Compressor	20.3	23.3
46.	P-01 Feed Tank Blower	16.0	18.4
47.	P-02 Settling Tank Circulation Pump	9.8	11.3
48.	P-03 Crude TCS Pump	2.5	2.9
49.	P-04 TCS Reflux Pump	4.3	4.9
50.	P-05 TET Feed Pump	5.8	6.7
51.	P-06 DCS Reflux Pump	3.8	4.4
52.	P-10 Waste Solution Pump	.9	1.0
53.	P-11 Lime Solution Circulation Pump	.9	1.0
54.	P-12 Fresh Lime Solution Pump	.9	1.0
55.	C-03 Gas Compressor	128.5	147.8
56.	M-01 Silicon Dust Filter	1.5	1.7
57.	M-02 Waste Slurry Filter	3.8	4.4
58.	M-03 Silicon Feed Cyclone	2.0	2.3
59.	M-04 Quench Contact Ejector	9.5	10.9
60.	M-05 Flue Gas Ejector	1.8	2.1
61.	M-06 Adsorption Tower (3)	45.5 ea.	52.3 ea.

TABLE 3.2-8

(Continued)

	Equipment Cost, $1,000	
	1980 dollars	1982 dollars
62. M-07 Boron Removal Unit (2)	9.5 ea.	10.9 ea.
63. M-08 Vent Scrubber	17.1	19.7
64. M-09 Slim Rod Pullers (5)	21. ea.	24.2 ea.
65. M-10 Catalyst Blender	21.8	25.1
66. M-11 Recovery System Pump	1.4	1.6
67. M-12 Hydrogen Storage Tank	53.0	61.0
Total	7,113.0	8,180.0

C-2

TABLE 3.2-9

PRODUCTION LABOR COST FOR HSC PROCESS - CASE B

Section	Labor Requirement, hr/kg of Si	Labor Rate, $/hr of labor 1980 dollars	1982 dollars	Cost, $/kg of Si 1980 dollars	1982 dollars
1. Hydrochlorination	0.018	10.00	12.00	0.18	0.22
2. Purification/Redistribution	0.026	10.00	12.00	0.26	0.31
3. Waste Treatment	0.009	10.00	12.00	0.09	0.11
4. Silicon Deposition	0.044	10.00	12.00	0.44	0.53
5. Recovery Unit	0.018	10.00	12.00	0.18	0.22
				1.15	1.38

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TABLE 3.2-10

ESTIMATION OF PLANT INVESTMENT FOR HSC PROCESS-CASE B

	Investment $1000	
	1980 Dollars	1982 Dollars
1. DIRECT PLANT INVESTMENT COSTS		
1. Major Process Equipment Cost	7,113.0	8,180.0
2. Installation of Process Equipment	3,058.6	3,517.4
3. Process Piping, Installed	5,263.6	6,053.2
4. Instrumentation, Installed	1,351.5	1,554.2
5. Electrical, Installed	711.3	818.0
6. Process Building, Installed	711.3	818.0
1a. SUBTOTAL FOR DIRECT PLANT INVESTMENT (PRIMARILY BATTERY LIMIT FACILITIES)	18,209.3	20,940.7
2. OTHER DIRECT PLANT INVESTMENT COSTS		
1. Utilities, Installed	3,414.2	3,926.4
2. General Service, Site Development, Fire Protection, etc.	853.6	981.6
3. General Buildings, Offices, etc	995.8	1,145.2
4. Receiving, Shipping Facilities	1,493.7	1,717.8
2a. SUBTOTAL FOR OTHER DIRECT PLANT INVESTMENT COST (PRIMARILY OFFSET FACILITIES)	6,757.4	7,771.0
3. TOTAL DIRECT INVESTMENT COSTS, 1a+2a	24,966.6	28,711.6
4. INDIRECT PLANT INVESTMENT COSTS		
1. Engineering, Overhead, etc	3,912.2	4,499.0
2. Normal Cont. for Strikes, etc	5,050.2	5,807.8
4a. TOTAL INDIRECT INVESTMENT COST	8,962.4	10,306.7
5. TOTAL DIRECT AND INDIRECT INVESTMENT COST, 3+4a	33,929.0	39,018.4
6. OVERALL CONTINGENCY	1,696.5	1,950.9
7. FIXED CAPITAL INVESTMENT FOR PLANT 5+6	35,625.5	40,969.3

TABLE 3.2-11

ESTIMATION OF TOTAL PRODUCT COST FOR HSC PROCESS-CASE B

		COST, $/kg of Silicon 1980 Dollars	1982 Dollars
1.	Direct Manufacturing Cost (Direct Charges)		
	1. Raw Materials	2.660	3.070
	2. Direct Operating Labor	1.150	1.380
	3. Utilities	4.745	5.694
	4. Supervision and Clerical	0.173	0.207
	5. Maintenance and Repairs	3.562	4.097
	6. Operating Supplies	0.712	0.819
	7. Laboratory Charge	0.173	0.207
2.	Indirect Manufacturing Cost (Fixed Charges)		
	1. Depreciation	3.562	4.097
	2. Local Taxes	0.712	0.819
	3. Insurance	0.356	0.410
3.	Plant Overhead	1.862	2.181
4.	By-Product Credit		
4a.	Total Manufacturing Cost, 1+2+3+4	19.667	22.982
5.	General Expenses		
	1. Administration	1.180	1.379
	2. Distribution and Sales	1.180	1.379
	3. Research and Develpoment	0.590	0.689
		-------	-------
6.	Total Cost of Product, 4a+5	22.617	26.429

4. CONCLUSIONS

The following conclusions are made as a result of analyses conducted for new technologies and processes being developed for the production of lower cost silicon for solar cells:

1. Chemical engineering analyses involving the preliminary process design of a plant (1,000 metric tons/year capacity) to produce silicon via the technology under consideration were accomplished for the following processes:

. HSC Process for Silicon - Case A
. HSC Process for Silicon - Case B

In Case A of the HSC process (Hemlock Semiconductor Corporation), the feed to the redistribution reactor is comprised of the bottom stream from the third distillation unit. In Case B, the redistribution reactor feed is composed of the distillate stream from the second distillation unit.

For each case, major activities in the chemical engineering analyses included base case conditions, reaction chemistry, process flowsheet, material balance, energy balance, property data, equipment design, major equipment list, production labor and forward for cost analysis. The process design package provided detailed data for raw materials, utilities, major process equipment and production labor requirements necessary for silicon production in each process.

2. Cost analyses were accomplished for the following processes under consideration for the production of silicon:

. HSC Process for Silicon - Case A
. HSC Process for Silicon - Case B

Primary activities in the cost analyses involved process design inputs, base case conditions, raw material costs, utility costs, major process equipment costs and production labor costs in the estimation of plant investment and total product cost.

3. The cost analysis results for producing silicon by the HSC process-Case A are presented including costs for raw materials, labor, utilities and other items composing the product cost (total cost of producing silicon). The results indicate a total product cost without profit of $22.65 (1980 dollars) and $26.46 (1982 dollars) per kg. The profitability analysis results disclose a sales price of $35.86 (1982 dollars) per kg of silicon at 15 per cent DCF (discounted cash flow) rate of return on investment after taxes.

These cost and profitability results for the HSC process - Case A indicate that this new technology shows promise for producing silicon at appreciable lower cost and comprises an alternate process capable of providing a less costly silicon material for solar cells.

4. The cost analysis results for producing silicon by the HSC process - Case B (Hemlock Semiconductor Corporation) are presented including costs for raw materials, labor, utilities and other items composing the product cost (total cost of producing silicon). The results give a total product cost without profit of $22.62 (1980 dollars) and $26.43 (1982 dollars) per kg. For profitability, the analysis indicates a sales pric e of $35.67 (1982 dollars) per kg of silicon at 15 per cent DCF (discounted case flow) rate of return on investment after taxes.

These cost and profitability results for the HSC process - Case B indicate that this new technology shows promise for producing silicon at appreciable lower cost and comprises an alternate process capable of providing a less costly silicon material for solar cells.

5. A comparison of Cases A and B of the HSC process is given below for product cost:

	$/KG OF SILICON	
	Case A	Case B
. Product Cost (1980 dollars)	22.65	22.62
. Product Cost (1982 dollars)	26.46	26.43

The comparison indicates that Case B exhibits slightly lower product cost ($26.43 vs $26.46 in 1982 dollars).

Although the cost for producing silicon in Case B is lower than Case A, it should be emphasized that the magnitude of the difference in product cost is relatively small ($0.03 out of $26.46 per kg in 1982 dollars). This small difference in product cost is probably in the noise level of the analysis.

6. The comparison of plant investment including fixed and working capital for Cases A and B is summarized below:

	$ MILLION	
	CASE A	CASE B
. Plant Investment (1980 dollars)	39.29	39.19
. Plant Investment (1982 dollars)	45.18	45.07

The comparison discloses that plant investment is slightly lower ($45.07 vs $45.18 million in 1982 dollars) for Case B.

For the lower plant investment for producing silicon in Case B, it should also be noted that the magnitude of the difference is relatively small ($110,000 out of $45,180,000 in 1982 dollars). This small difference in plant investment is probably in the noise level of the analysis.

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APPENDIX A1 SELECTED PROCESS ENGINEERING FOR HSC PROCESS - CASE A

APPENDIX A1.1-1

DESIGN SPECIFICATIONS FOR DISTILLATION, D-01

Issue No. Issue 1

1. Process Equipment Name Distillation, D-01 (Stripper Column)

2. Process Equipment Function Removes volatile gases from liquid chlorosilanes

3. Feed Specifications

    1. No. of Feeds 1
    2. No. of Feed Components 8
    3. Feed Components H_2, N_2, SiH_4, HCl, MCS, DCS, TCS, TET
    4. Feed Concentration See Plate-To-Plate*
    5. Feed Temperature 100F (37.8C)*
    6. Feed Pressure 90 psia
    7. Light Key - LK Hydrogen Chloride, HCl
    8. Heavy Key - HK Trichlorosilane, $SiHCl_3$ (TCS)

4. Distillate Specifications

    1. Recovery of Light Key (LK) in Distillate 98.6 %
    2. Concentration Spec. low chlorosilanes

5. Bottoms Specifications

    1. Recovery of Heavy Key (HK) in Bottoms 99.9 %
    2. Concentration Spec. low volatile gases

6. General Specifications

    1. Pressure for Distillation 90 psia
    2. Condenser Type partial

    Vapor from top tray is cooled and collected in accumulator. Liquid from accumulator is returned to column as reflux. Vapor from accumulator is overhead distillate for the column.

* Feed concentration is from Union Carbide Final Report (June,1979): pg. 212 (flowsheet, stream 125) and pg. E-9 (stream 125 composition, issue 2)

$$x_{Fi} = \frac{fi}{F} = \frac{\text{moles of i in feed}}{\text{total moles}}$$

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APPENDIX A1.1-2

DESIGN RESULTS FOR DISTILLATION, D-01

Issue No. Issue 1

1. Process Equipment Name Distillation, D-01 (Stripper Column)

2. Equipment Specifications

   1. No. of Equilibrium Trays N = 13
   2. No. of Equilibrium Feed Tray N_F = 9
   3. Tray Efficiency 50 %
   4. No. of Actual Trays N_{actual} = 26
   5. No. of Actual Feed Tray $N_{F,actual}$ = 18
   6. Tray Spacing 18 in.
   7. Type of Tray Sieve
   8. Column Diameter 1.5-2 (use) ft.
   9. Column Height 39 ft.+ends ft.
   10. Reflux Ratio R = 1.90
   11. Design Temp. Top = -29 C (-21F)
       Bottom = 117 C (242F)
   12. Design Pressure 90 psia
   13. Materials of Construction 3/2 nickel steel

3. Product Specifications

   1. Feed Specifications
      1. Feed Concentration See Item 7 of Design Spec.
      2. Light Key - LK Hydrogen Chloride, HCl
      3. Heavy Key - HK Trichlorosilane, $SiHCl_3$ (TCS)
   2. Distillate Specifications
      1. Recovery of Light Key (LK) in Distillate 98.6 %
      2. Concentration Spec. Low Chlorosilanes
   3. Bottoms Specifications
      1. Recovery of Heavy Key (HK) in Bottoms 99.9 %
      2. Concentration Spec. Low Volatile Gases

APPENDIX A1.1-2

(Continued)

4. Results for Number of Trays

Reflux Ratio, R	No. of Equil. Trays, N	No. of Actual Trays, N_{actual}
1.28	29	58
1.31	22	44
1.40	18	36
1.53	[illegible]	32
1.78	14	28
1.91	13	26
2.23	12	24
2.54	11	22
3.18	10	20
3.82	9	18
4.77	9	18

APPENDIX A1.1-3

PLATE-TO-PLATE RESULTS FOR DISTILLATION, D-01

TREI'S REPORT ON DISTILLATION DESIGN

DESIGN BASIS

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1. NAME OF TOWER	HSC D-01
2. NUMBER OF COMPONENTS	8
3. NUMBER OF FEEDS	1
4. LIGHT KEY	4
5. HEAVY KEY	7
6. TYPE OF CONDENSER	2

7. TOWER PRESSURE,mmHg	4653.060
8. REFLUX RATIO ,R	1.900
9. DISTILLATE IN lb-mole/hr	3.854
10. CONVERGENCE TOLERANCE	0.5000E-03

11.SYSTEM IDENTIFICATION AND ANTOINE COEFFICIENTS

H2	5.92100	71.62000	276.35000
N2	6.61130	264.65100	266.36200
SiH4	7.09738	703.98700	278.50200
HCl	7.16759	744.48900	258.55000
MCS	6.62743	753.84900	231.55900
DCS	6.98990	1034.46000	243.40600
TCS	6.78393	1014.10000	227.87200
TET	6.93126	1178.84000	233.79700

12.FEEDS

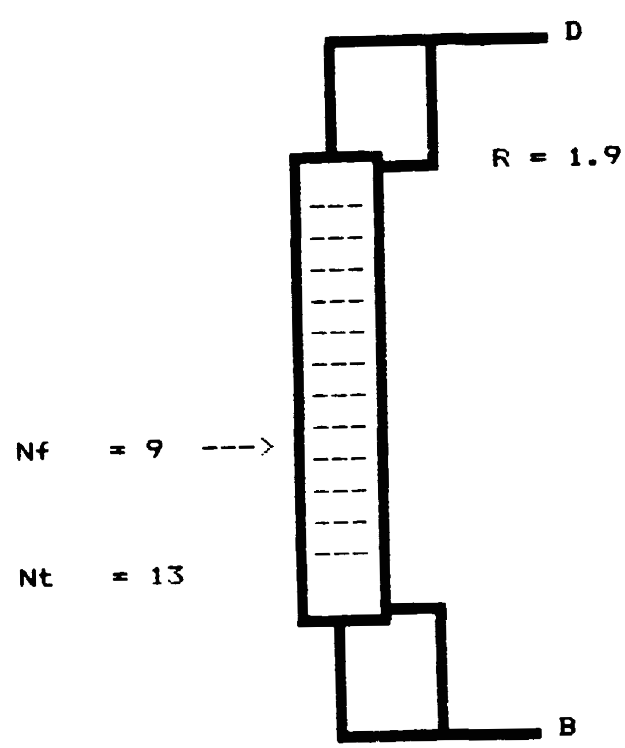
TRAY NUMBER	9
FLOWRATE,mole/hr	0.1782E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE,C	0.9856E+02
X(H2)	0.2057E-01
X(N2)	0.1900E-04
X(SiH4)	0.3000E-05
X(HCl)	0.4960E-03
X(MCS)	0.6400E-04
X(DCS)	0.5819E-02
X(TCS)	0.2498E+00
X(TET)	0.7233E+00

APPENDIX A1.1-3

(Continued)

DESIGN RESULTS

1. TOTAL NUMBER OF TRAYS 13
2. FEED TRAYS 9
3. REFLUX RATIO 1.9



APPENDIX A1.1-3

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4. FEEDS

TRAY NUMBER	9
FLOWRATE, mole/hr	0.1782E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE, C	0.9856E+02
X(H2)	0.2057E-01
X(N2)	0.1900E-04
X(SiH4)	0.3000E-05
X(HCl)	0.4960E-03
X(MCS)	0.6400E-04
X(DCS)	0.5819E-02
X(TCS)	0.2498E+00
X(TET)	0.7233E+00

5. DISTILLATE AND BOTTOM

PARTIAL CONDENSER

	Distillate	Bottom
FLOWRATE, mole/hr	0.3854E+01	0.1743E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04
TEMPERATURE, C	-.2514E+02	0.1175E+03
X(H2)	0.9550E+00	0.9820E-06
X(N2)	0.8824E-03	0.1254E-07
X(SiH4)	0.1387E-03	0.1692E-07
X(HCl)	0.2261E-01	0.1082E-04
X(MCS)	0.8397E-03	0.4867E-04
X(DCS)	0.1689E-01	0.5707E-02
X(TCS)	0.3607E-02	0.2551E+00
X(TET)	0.9756E-05	0.7391E+00

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APPENDIX A1.1-3

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TRAY PROFILE

TRAY NUMBER = 1

COMP	X(I)	Y(I)
H2	0.1043E-01	0.9550E+00
N2	0.1333E-04	0.8824E-03
SiH4	0.3569E-04	0.1387E-03
HCl	0.1321E-01	0.2261E-01
MCS	0.5204E-02	0.8397E-03
DCS	0.5853E+00	0.1689E-01
TCS	0.3824E+00	0.3607E-02
TET	0.3375E-02	0.9756E-05

TEMPERATURE = -30.635 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 2

COMP	X(I)	Y(I)
H2	0.3042E-02	0.3361E+00
N2	0.2245E-05	0.3130E-03
SiH4	0.2976E-05	0.7120E-04
HCl	0.1045E-02	0.1645E-01
MCS	0.1420E-02	0.3699E-02
DCS	0.4214E+00	0.3893E+00
TCS	0.5624E+00	0.2518E+00
TET	0.1071E-01	0.2214E-02

TEMPERATURE = 64.783 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 3

COMP	X(I)	Y(I)
H2	0.2974E-02	0.3313E+00
N2	0.2123E-05	0.3057E-03
SiH4	0.1919E-05	0.4977E-04
HCl	0.4892E-03	0.8481E-02
MCS	0.4171E-03	0.1220E-02
DCS	0.2636E+00	0.2819E+00
TCS	0.7041E+00	0.3697E+00
TET	0.2843E-01	0.7022E-02

TEMPERATURE = 70.743 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A1.1-3

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TRAY NUMBER = 4

COMP	X(I)	Y(I)
H2	0.2955E-02	0.3313E+00
N2	0.2070E-05	0.3057E-03
SiH4	0.1780E-05	0.4907E-04
HCl	0.4353E-03	0.8117E-02
MCS	0.1764E-03	0.5628E-03
DCS	0.1493E+00	0.1785E+00
TCS	0.7811E+00	0.4626E+00
TET	0.6594E-01	0.1863E-01

TEMPERATURE = 75.410 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 5

COMP	X(I)	Y(I)
H2	0.2939E-02	0.3313E+00
N2	0.2026E-05	0.3056E-03
SiH4	0.1685E-05	0.4898E-04
HCl	0.4072E-03	0.8082E-02
MCS	0.1178E-03	0.4051E-03
DCS	0.7885E-01	0.1037E+00
TCS	0.7814E+00	0.5130E+00
TET	0.1363E+00	0.4321E-01

TEMPERATURE = 79.530 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 6

COMP	X(I)	Y(I)
H2	0.2923E-02	0.3312E+00
N2	0.1984E-05	0.3056E-03
SiH4	0.1597E-05	0.4892E-04
HCl	0.3818E-03	0.8063E-02
MCS	0.9901E-04	0.3667E-03
DCS	0.3977E-01	0.5748E-01
TCS	0.7057E+00	0.5132E+00
TET	0.2511E+00	0.8928E-01

TEMPERATURE = 83.725 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

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APPENDIX A1.1-3

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TRAY NUMBER = 7

COMP	X(I)	Y(I)
H2	0.2905E-02	0.3312E+00
N2	0.1938E-05	0.3056E-03
SiH4	0.1505E-05	0.4886E-04
HCl	0.3556E-03	0.8047E-02
MCS	0.8812E-04	0.3544E-03
DCS	0.1986E-01	0.3188E-01
TCS	0.5692E+00	0.4636E+00
TET	0.4076E+00	0.1645E+00

TEMPERATURE = 88.509 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 8

COMP	X(I)	Y(I)
H2	0.2887E-02	0.3312E+00
N2	0.1890E-05	0.3055E-03
SiH4	0.1413E-05	0.4880E-04
HCl	0.3298E-03	0.8030E-02
MCS	0.7916E-04	0.3473E-03
DCS	0.1050E-01	0.1884E-01
TCS	0.4076E+00	0.3742E+00
TET	0.5786E+00	0.2670E+00

TEMPERATURE = 93.721 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 9

COMP	X(I)	Y(I)
H2	0.2870E-02	0.3312E+00
N2	0.1848E-05	0.3055E-03
SiH4	0.1334E-05	0.4874E-04
HCl	0.3081E-03	0.8013E-02
MCS	0.7197E-04	0.3414E-03
DCS	0.6411E-02	0.1271E-01
TCS	0.2624E+00	0.2683E+00
TET	0.7279E+00	0.3791E+00

TEMPERATURE = 98.564 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A1.1-3

(Continued)

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TRAY NUMBER = 10

COMP	X(I)	Y(I)
H2	0.4052E-03	0.4762E-01
N2	0.1729E-06	0.3067E-04
SiH4	0.5028E-06	0.2189E-04
HCl	0.1547E-03	0.4945E-02
MCS	0.7204E-04	0.4360E-03
DCS	0.6456E-02	0.1748E-01
TCS	0.2634E+00	0.3764E+00
TET	0.7295E+00	0.5531E+00

TEMPERATURE = 114.588 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 11

COMP	X(I)	Y(I)
H2	0.5698E-04	0.6711E-02
N2	0.1603E-07	0.2868E-05
SiH4	0.1817E-06	0.8082E-05
HCl	0.7316E-04	0.2399E-02
MCS	0.7000E-04	0.4366E-03
DCS	0.6446E-02	0.1814E-01
TCS	0.2635E+00	0.3925E+00
TET	0.7298E+00	0.5798E+00

TEMPERATURE = 116.687 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 12

COMP	X(I)	Y(I)
H2	0.7897E-05	0.9304E-03
N2	0.1474E-08	0.2641E-06
SiH4	0.6161E-07	0.2751E-05
HCl	0.3174E-04	0.1046E-02
MCS	0.6423E-04	0.4027E-03
DCS	0.6345E-02	0.1798E-01
TCS	0.2630E+00	0.3945E+00
TET	0.7306E+00	0.5851E+00

TEMPERATURE = 117.054 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A1.1-3

(Continued)

TRAY NUMBER = 13

COMP	X(I)	Y(I)
H2	0.9820E-06	0.1158E-03
N2	0.1254E-09	0.2251E-07
SiH4	0.1692E-07	0.7586E-06
HCl	0.1082E-04	0.3581E-03
MCS	0.4867E-04	0.3069E-03
DCS	0.5707E-02	0.1629E-01
TCS	0.2551E+00	0.3858E+00
TET	0.7391E+00	0.5972E+00

TEMPERATURE = 117.454 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A1.2-1

DESIGN SPECIFICATIONS FOR DISTILLATION, D-02

Issue No. 1

1. Process Equipment Name Distillation, D-02 (TCS Column)
2. Process Equipment Function Separation of TCS (Trichlorosilane) and TET (Tetrachlorosilane).
3. Feed Specifications
   1. No. of Feeds 3
   2. No. of Feed Components 4
   3. Feed Components MCS, DCS, TCS, TET
   4. Feed Concentration See Plate-To-Plate
   5. Feed Temperature See Plate-To-Plate
   6. Feed Pressure See Plate-To-Plate
   7. Light Key - LK Trichlorosilane (TCS)
   8. Heavy Key - HK Tetrachlorosilane (TET)
4. Distillate Specifications
   1. Recovery of Light Key (LK) in Distillate 96.6 %
   2. Concentration Spec. Low in TET
5. Bottoms Specifications
   1. Recovery of Heavy Key (HK) in Bottoms 98.1 %
   2. Concentration Spec. Low in MCS, DCS and TCS
6. General Specifications
   1. Pressure for Distillation 90 psia
   2. Condenser Type Total

APPENDIX A1.2-2

DESIGN RESULTS FOR DISTILLATION, D-02

Issue No. 1

1. Process Equipment Name Distillation, D-02 (TCS Column)
2. Equipment Specifications
   1. No. of Equilibrium Trays N = 20
   2. No. of Equilibrium Feed Tray N_F = 9, 12, 15
   3. Tray Efficiency 63 %
   4. No. of Actual Trays N_{actual} = 32
   5. No. of Actual Feed Tray $N_{F,actual}$ = 16, 19, 24
   6. Tray Spacing 24 in.
   7. Type of Tray Single Pass Flow Seive Tray
   8. Column Diameter 5.5 ft.
   9. Column Height 64 ft. + ends ft.
   10. Reflux Ratio R = 2.0
   11. Design Temp. Top = 91 C
       Bottom = 126 C
   12. Design Pressure 90 psia
   13. Materials of Construction Steel
3. Product Specifications
   1. Feed Specifications
      1. Feed Concentration See Item 7 of Design Spec.
      2. Light Key - LK Trichlorosilane (TCS)
      3. Heavy Key - HK Tetrachlorosilane (TET)
   2. Distillate Specifications
      1. Recovery of Light Key (LK) in Distillate 96.6 %
      2. Concentration Spec. See Plate-To-Plate
   3. Bottoms Specifications
      1. Recovery of Heavy Key (HK) in Bottoms 98.1 %
      2. Concentration Spec. See Plate-To-Plate

APPENDIX A1.2-2

(Continued)

4. Results for Number of Trays

Reflux Ratio, R	No. of Equil. Trays, N	No. of Actual Trays N_{actual}
1	35 (16, 26, 30)	56
1.2	26 (13, 18, 21)	42
1.6	22 (10, 13, 16)	35
2	20 (9, 12, 15)	32
2.5	18 (7, 10, 13)	29
3.5	16 (6, 9, 12)	26
4.5	15 (6, 8, 11)	24

NOTE:

Numbers in parentheses give feed plate location. For case of R = 2, $N_{F1} = 9$, $N_{F2} = 12$ and $N_{F3} = 15$.

APPENDIX A1.2-3

PLATE-TO-PLATE RESULTS FOR DISTILLATION, D-02

TREI'S REPORT ON DISTILLATION DESIGN

DESIGN BASIS

1. NAME OF TOWER HSC D-02
2. NUMBER OF COMPONENTS 4
3. NUMBER OF FEEDS 3
4. LIGHT KEY 3
5. HEAVY KEY 4
6. TYPE OF CONDENSER 1

7. TOWER PRESSURE,mmHg 4653.060
8. REFLUX RATIO ,R 2.000
9. DISTILLATE IN lb-mole/hr 256.030
10. CONVERGENCE TOLERANCE 0.1000E-01

11.SYSTEM IDENTIFICATION AND ANTOINE COEFFICIENTS

MCS	6.62743	753.84900	321.55900
DCS	6.98990	1034.46000	243.40600
TCS	6.78393	1014.10000	227.87200
TET	6.93126	1178.84000	233.79700

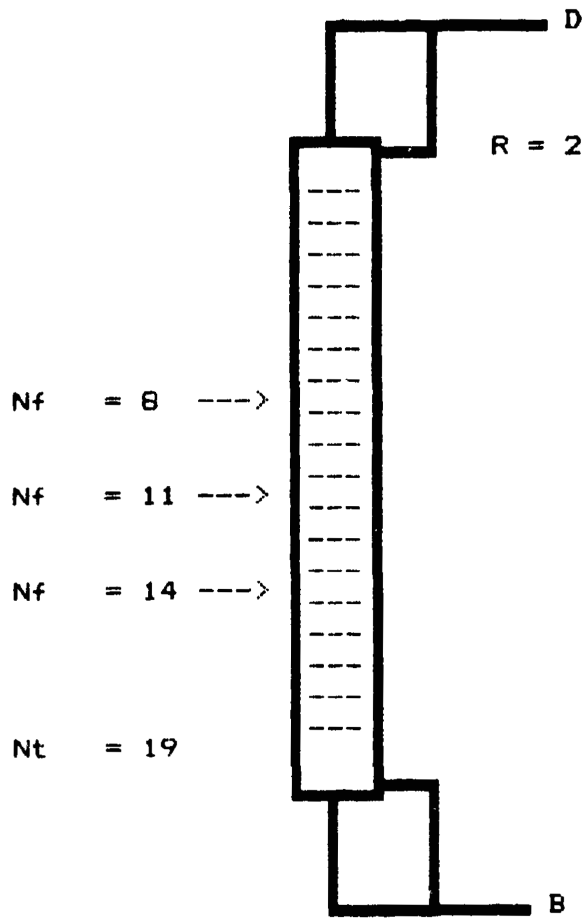
12.FEEDS

TRAY NUMBER	8	11	14
FLOWRATE,mole/hr	0.2302E+03	0.1525E+02	0.1743E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04	0.4653E+04
THERMAL COND.	0.1000E+01	0.1000E+01	0.1000E+01
TEMPERATURE,C	0.1000E+03	0.1073E+03	0.1174E+03
X(MCS)	0.5000E-02	0.0000E+00	0.0000E+00
X(DCS)	0.1000E+00	0.1670E+00	0.5500E-02
X(TCS)	0.7850E+00	0.5670E+00	0.2552E+00
X(TET)	0.1100E+00	0.2660E+00	0.7393E+00

APPENDIX A1.2-3
(Continued)

DESIGN RESULTS

1. TOTAL NUMBER OF TRAYS 19
2. FEED TRAYS 8 11 14
3. REFLUX RATIO 2



APPENDIX A1.2-3

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4. FEEDS

TRAY NUMBER	8	11	14
FLOWRATE, mole/hr	0.2302E+03	0.1525E+02	0.1743E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04	0.4653E+04
THERMAL COND.	0.1000E+01	0.1000E+01	0.1000E+01
TEMPERATURE, C	0.1000E+03	0.1073E+03	0.1174E+03
X (MCS)	0.5000E-02	0.0000E+00	0.0000E+00
X (DCS)	0.1000E+00	0.1670E+00	0.5500E-02
X (TCS)	0.7850E+00	0.5670E+00	0.2552E+00
X (TET)	0.1100E+00	0.2660E+00	0.7393E+00

5. DISTILLATE AND BOTTOM

TOTAL CONDENSER

	Distillate	Bottom
FLOWRATE, mole/hr	0.2560E+03	0.1638E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04
TEMPERATURE, C	0.9087E+02	0.1259E+03
X (MCS)	0.4499E-02	0.6225E-17
X (DCS)	0.1034E+00	0.6635E-05
X (TCS)	0.8853E+00	0.3918E-01
X (TET)	0.6766E-02	0.9608E+00

APPENDIX A1.2-3

(Continued)

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TRAY PROFILE

```
TRAY NUMBER =  1
COMP           X(I)            Y(I)
MCS        0.3174E-03      0.4499E-02
DCS        0.5574E-01      0.1034E+00
TCS        0.9299E+00      0.8853E+00
TET        0.1407E-01      0.6766E-02
TEMPERATURE         =      95.346   C
LIQUID FLOWRATE     =     512.060 lb-mole/hr
VAPOR  FLOWRATE     =     768.090 lb-mole/hr

TRAY NUMBER =  2
COMP           X(I)            Y(I)
MCS        0.1195E-03      0.1711E-02
DCS        0.3776E-01      0.7163E-01
TCS        0.9385E+00      0.9150E+00
TET        0.2357E-01      0.1164E-01
TEMPERATURE         =      96.410   C
LIQUID FLOWRATE     =     512.060 lb-mole/hr
VAPOR  FLOWRATE     =     768.090 lb-mole/hr

TRAY NUMBER =  3
COMP           X(I)            Y(I)
MCS        0.1096E-03      0.1579E-02
DCS        0.3109E-01      0.5965E-01
TCS        0.9329E+00      0.9208E+00
TET        0.3589E-01      0.1797E-01
TEMPERATURE         =      96.966   C
LIQUID FLOWRATE     =     512.060 lb-mole/hr
VAPOR  FLOWRATE     =     768.090 lb-mole/hr

TRAY NUMBER =  4
COMP           X(I)            Y(I)
MCS        0.1087E-03      0.1573E-02
DCS        0.2850E-01      0.5520E-01
TCS        0.9197E+00      0.9171E+00
TET        0.5170E-01      0.2618E-01
TEMPERATURE         =      97.427   C
LIQUID FLOWRATE     =     512.060 lb-mole/hr
VAPOR  FLOWRATE     =     768.090 lb-mole/hr

TRAY NUMBER =  5
COMP           X(I)            Y(I)
MCS        0.1081E-03      0.1572E-02
DCS        0.2733E-01      0.5347E-01
TCS        0.9009E+00      0.9082E+00
TET        0.7163E-01      0.3672E-01
TEMPERATURE         =      97.924   C
LIQUID FLOWRATE     =     512.060 lb-mole/hr
VAPOR  FLOWRATE     =     768.090 lb-mole/hr
```

TRAY NUMBER = 6

COMP	X(I)	Y(I)
MCS	0.1075E-03	0.1572E-02
DCS	0.2661E-01	0.5269E-01
TCS	0.8771E+00	0.8957E+00
TET	0.9615E-01	0.5001E-01

TEMPERATURE = 98.512 C
LIQUID FLOWRATE = 512.060 lb-mole/hr
VAPOR FLOWRATE = 768.090 lb-mole/hr

TRAY NUMBER = 7

COMP	X(I)	Y(I)
MCS	0.1067E-03	0.1571E-02
DCS	0.2599E-01	0.5221E-01
TCS	0.8485E+00	0.8799E+00
TET	0.1254E+00	0.6636E-01

TEMPERATURE = 99.212 C
LIQUID FLOWRATE = 512.060 lb-mole/hr
VAPOR FLOWRATE = 768.090 lb-mole/hr

TRAY NUMBER = 8

COMP	X(I)	Y(I)
MCS	0.1058E-03	0.1571E-02
DCS	0.2537E-01	0.5180E-01
TCS	0.8155E+00	0.8608E+00
TET	0.1591E+00	0.8586E-01

TEMPERATURE = 100.028 C
LIQUID FLOWRATE = 742.290 lb-mole/hr
VAPOR FLOWRATE = 768.090 lb-mole/hr

TRAY NUMBER = 9

COMP	X(I)	Y(I)
MCS	0.6817E-05	0.1032E-03
DCS	0.1365E-01	0.2901E-01
TCS	0.7693E+00	0.8479E+00
TET	0.2171E+00	0.1230E+00

TEMPERATURE = 102.032 C
LIQUID FLOWRATE = 742.290 lb-mole/hr
VAPOR FLOWRATE = 768.090 lb-mole/hr

TRAY NUMBER = 10

COMP	X(I)	Y(I)
MCS	0.4858E-06	0.7521E-05
DCS	0.7940E-02	0.1768E-01
TCS	0.6932E+00	0.8032E+00
TET	0.2988E+00	0.1791E+00

TEMPERATURE = 104.377 C
LIQUID FLOWRATE = 742.290 lb-mole/hr
VAPOR FLOWRATE = 768.090 lb-mole/hr

APPENDIX A1.2-3

(Continued)

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```
TRAY NUMBER =  11
COMP          X(I)            Y(I)
MCS         0.8811E-07      0.1402E-05
DCS         0.5163E-02      0.1217E-01
TCS         0.5926E+00      0.7298E+00
TET         0.4022E+00      0.2581E+00
TEMPERATURE        =     107.280   C
LIQUID FLOWRATE    =     757.540 lb-mole/hr
VAPOR  FLOWRATE    =     768.090 lb-mole/hr

TRAY NUMBER =  12
COMP          X(I)            Y(I)
MCS         0.6202E-07      0.1020E-05
DCS         0.2489E-02      0.6271E-02
TCS         0.4787E+00      0.6330E+00
TET         0.5188E+00      0.3607E+00
TEMPERATURE        =     110.749   C
LIQUID FLOWRATE    =     757.540 lb-mole/hr
VAPOR  FLOWRATE    =     768.090 lb-mole/hr

TRAY NUMBER =  13
COMP          X(I)            Y(I)
MCS         0.5853E-07      0.9940E-06
DCS         0.1350E-02      0.3634E-02
TCS         0.3667E+00      0.5206E+00
TET         0.6319E+00      0.4757E+00
TEMPERATURE        =     114.268   C
LIQUID FLOWRATE    =     757 540 lb-mole/hr
VAPOR  FLOWRATE    =     768.090 lb-mole/hr

TRAY NUMBER =  14
COMP          X(I)            Y(I)
MCS         0.5669E-07      0.9906E-06
DCS         0.8805E-03      0.2511E-02
TCS         0.2716E+00      0.4102E+00
TET         0.7275E+00      0.5873E+00
TEMPERATURE        =     117.408   C
LIQUID FLOWRATE    =     931.870 lb-mole/hr
VAPOR  FLOWRATE    =     768.090 lb-mole/hr

TRAY NUMBER =  15
COMP          X(I)            Y(I)
MCS         0.3432E-12      0.6123E-11
DCS         0.3595E-03      0.1070E-02
TCS         0.2051E+00      0.3242E+00
TET         0.7945E+00      0.6748E+00
TEMPERATURE        =     119.733  C
LIQUID FLOWRATE    =     931.870 lb-mole/hr
VAPOR  FLOWRATE    =     768.090 lb-mole/hr
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APPENDIX A1.2-3

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TRAY NUMBER =  16
COMP          X(I)           Y(I)
MCS        0.2290E-13     0.4164E-12
DCS        0.1407E-03     0.4348E-03
TCS        0.1461E+00     0.2405E+00
TET        0.8538E+00     0.7591E+00
TEMPERATURE        =    121.856 C
LIQUID FLOWRATE    =    931.870 lb-mole/hr
VAPOR  FLOWRATE    =    768.090 lb-mole/hr

TRAY NUMBER =  17
COMP          X(I)           Y(I)
MCS        0.1505E-14     0.2778E-13
DCS        0.5310E-04     0.1693E-03
TCS        0.9925E-01     0.1689E+00
TET        0.9007E+00     0.8310E+00
TEMPERATURE        =    123.588 C
LIQUID FLOWRATE    =    931.870 lb-mole/hr
VAPOR  FLOWRATE    =    768.090 lb-mole/hr

TRAY NUMBER =  18
COMP          X(I)           Y(I)
MCS        0.9772E-16     0.1825E-14
DCS        0.1931E-04     0.6301E-04
TCS        0.6424E-01     0.1121E+00
TET        0.9357E+00     0.8879E+00
TEMPERATURE        =    124.914 C
LIQUID FLOWRATE    =    931.870 lb-mole/hr
VAPOR  FLOWRATE    =    768.090 lb-mole/hr

TRAY NUMBER =  19
COMP          X(I)           Y(I)
MCS        0.6225E-17     0.1172E-15
DCS        0.6635E-05     0.2202E-04
TCS        0.3918E-01     0.6959E-01
TET        0.9608E+00     0.9304E+00
TEMPERATURE        =    125.880 C
LIQUID FLOWRATE    =    931.870 lb-mole/hr
VAPOR  FLOWRATE    =    768.090 lb-mole/hr
```

APPENDIX A1.3-1

DESIGN SPECIFICATIONS FOR DISTILLATION, D-03

Issue No. 1

1. Process Equipment Name Distillation, D-03 (DCS Column)
2. Process Equipment Function Separation of DCS (Dichlorosilane) and TCS (Trichlorosilane).
3. Feed Specifications
    1. No. of Feeds 1
    2. No. of Feed Components 4
    3. Feed Components MCS, DCS, TCS, TET
    4. Feed Concentration See Plate-To-Plate
    5. Feed Temperature See Plate-To-Plate
    6. Feed Pressure 90 Psia
    7. Light Key - LK Dichlorosilane (DCS)
    8. Heavy Key - HK Trichlorosilane (TCS)
4. Distillate Specifications
    1. Recovery of Light Key (LK) in Distillate 93.1 %
    2. Concentration Spec. Low TCS, TET
5. Bottoms Specifications
    1. Recovery of Heavy Key (HK) in Bottoms 99.7 %
    2. Concentration Spec. Low in MCS, DCS
6. General Specifications
    1. Pressure for Distillation 90 psia
    2. Condenser Type Partial

    Required amount for feed of CVD reactors is drawn from the top of this column in vapor phase. It is then mixtured with H_2 and fed to CVD reactors. Only reflux flow is condensed and fed back to column.

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APPENDIX A1.3-2

DESIGN RESULTS FOR DISTILLATION, D-03

Issue No. 1

1. Process Equipment Name Distillation, D-03 (DCS Column)

2. Equipment Specifications
   1. No. of Equilibrium Trays N = 20
   2. No. of Equilibrium Feed Tray N_F = 11
   3. Tray Efficiency 63 %
   4. No. of Actual Trays N_{actual} = 32
   5. No. of Actual Feed Tray $N_{F,actual}$ = 16
   6. Tray Spacing 18 in.
   7. Type of Tray Single Pass Crossflow Seive Tray
   8. Column Diameter 4 ft.
   9. Column Height 48 ft. + ends ft.
   10. Reflux Ratio R = 15
   11. Design Temp. Top = 52 C
       Bottom = 97 C
   12. Design Pressure 90 psia
   13. Materials of Construction Steel

3. Product Specifications
   1. Feed Specifications
      1. Feed Concentration See Item 7 of Design Spec.
      2. Light Key - LK Dichlorosilane (DCS)
      3. Heavy Key - HK Trichlorosilane (TCS)
   2. Distillate Specifications
      1. Recovery of Light Key (LK) in Distillate 93.1 %
      2. Concentration Spec. See Plate-To-Plate
   3. Bottoms Specifications
      1. Recovery of Heavy Key (HK) in Bottoms 99.7 %
      2. Concentration Spec. See Plate-To-Plate

APPENDIX A1.3-2

(Continued)

4. Results for Number of Trays

Reflux Ratio, R	No. of Equil. Trays, N	No. of Actual Trays N_{actual}
12	29 (13)	47
14	23 (12)	37
15	20 (11)	32
20	18 (11)	29
25	17 (10)	27
30	16 (10)	26

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APPENDIX A1.3-3

PLATE-TO-PLATE RESULTS FOR DISTILLATION, D-03

TREI'S REPORT ON DISTILLATION DESIGN

DESIGN BASIS

1. NAME OF TOWER	HSC D-03
2. NUMBER OF COMPONENTS	4
3. NUMBER OF FEEDS	1
4. LIGHT KEY	2
5. HEAVY KEY	3
6. TYPE OF CONDENSER	3

7. TOWER PRESSURE,mmHg	4653.060
8. REFLUX RATIO ,R	15.000
9. DISTILLATE IN lb-mole/hr	26.300
10.CONVERGENCE TOLERANCE	0.5000E-03

11.SYSTEM IDENTIFICATION AND ANTOINE COEFFICIENTS

MCS	6.62743	753.84900	231.55900
DCS	6.98990	1034.46000	243.40600
TCS	6.78393	1014.10000	227.87200
TET	6.93126	1178.84000	233.79700

12.FEEDS

TRAY NUMBER	11
FLOWRATE,mole/hr	0.2565E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE,C	0.9337E+02
X(MCS)	0.4487E-02
X(DCS)	0.1034E+00
X(TCS)	0.8856E+00
X(TET)	0.6476E-02

APPENDIX A1.3-3

(Continued)

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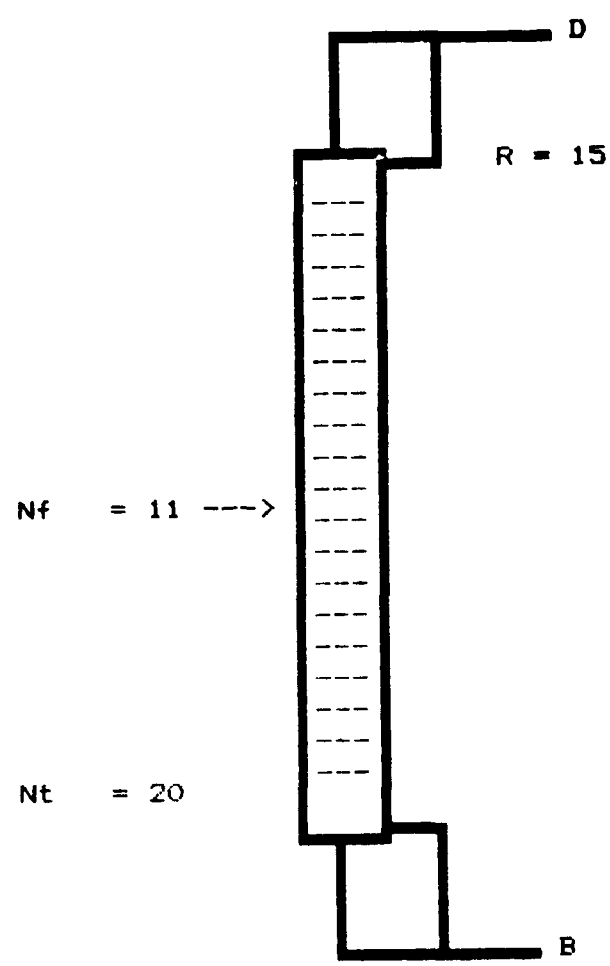
DESIGN RESULTS

1. TOTAL NUMBER OF TRAYS 20
2. FEED TRAYS 11
3. REFLUX RATIO 15



APPENDIX A1.3-3

(Continued)

4. FEEDS

TRAY NUMBER	11
FLOWRATE, mole/hr	0.2565E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE, C	0.9337E+02
X(MCS)	0.4487E-02
X(DCS)	0.1034E+00
X(TCS)	0.8856E+00
X(TET)	0.6476E-02

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5. DISTILLATE AND BOTTOM

PARTIAL CONDENSER

	Distillate	Bottom
FLOWRATE, mole/hr	0.2630E+02	0.2302E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04
TEMPERATURE, C	0.6525E+02	0.9742E+02
X(MCS)	0.4356E-01	0.4086E-07
X(DCS)	0.9390E+00	0.7623E-02
X(TCS)	0.1747E-01	0.9838E+00
X(TET)	0.3055E-07	0.8595E-02

APPENDIX A1.3-3

(Continued)

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TRAY PROFILE


TRAY NUMBER =   1
COMP            X(I)             Y(I)
MCS         0.1583E-01       0.4356E-01
DCS         0.9480E+00       0.9390E+00
TCS         0.3617E-01       0.1747E-01
TET         0.1358E-06       0.3055E-07
TEMPERATURE          =      67.587   C
LIQUID FLOWRATE      =     394.500 lb-mole/hr
VAPOR  FLOWRATE      =     420.800 lb-mole/hr

TRAY NUMBER =   2
COMP            X(I)             Y(I)
MCS         0.6209E-02       0.1756E-01
DCS         0.9240E+00       0.9474E+00
TCS         0.6980E-01       0.3500E-01
TET         0.5508E-06       0.1292E-06
TEMPERATURE          =      68.999   C
LIQUID FLOWRATE      =     394.500 lb-mole/hr
VAPOR  FLOWRATE      =     420.800 lb-mole/hr

TRAY NUMBER =   3
COMP            X(I)             Y(I)
MCS         0.2935E-02       0.8544E-02
DCS         0.8696E+00       0.9249E+00
TCS         0.1275E+00       0.6653E-01
TET         0.2113E-05       0.5183E-06
TEMPERATURE          =      70.509   C
LIQUID FLOWRATE      =     394.500 lb-mole/hr
VAPOR  FLOWRATE      =     420.800 lb-mole/hr

TRAY NUMBER =   4
COMP            X(I)             Y(I)
MCS         0.1805E-02       0.5474E-02
DCS         0.7798E+00       0.8739E+00
TCS         0.2184E+00       0.1206E+00
TET         0.7588E-05       0.1983E-05
TEMPERATURE          =      72.686   C
LIQUID FLOWRATE      =     394.500 lb-mole/hr
VAPOR  FLOWRATE      =     420.800 lb-mole/hr

TRAY NUMBER =   5
COMP            X(I)             Y(I)
MCS         0.1373E-02       0.4414E-02
DCS         0.6545E+00       0.7897E+00
TCS         0.3441E+00       0.2059E+00
TET         0.2490E-04       0.7116E-05
TEMPERATURE          =      75.814   C
LIQUID FLOWRATE      =     394.500 lb-mole/hr
VAPOR  FLOWRATE      =     42[illegible].800 lb-mole/hr
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APPENDIX A1.3-3

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```
TRAY NUMBER =  6
COMP           X(I)            Y(I)
MCS         0.1161E-02      0.4010E-02
DCS         0.5086E+00      0.6723E+00
TCS         0.4902E+00      0.3237E+00
TET         0.7315E-04      0.2335E-04
TEMPERATURE          =     79.765   C
LIQUID FLOWRATE      =    394.500 lb-mole/hr
VAPOR  FLOWRATE      =    420.800 lb-mole/hr

TRAY NUMBER =  7
COMP           X(I)            Y(I)
MCS         0.1025E-02      0.3811E-02
DCS         0.3687E+00      0.5355E+00
TCS         0.6301E+00      0.4607E+00
TET         0.1917E-03      0.6858E-04
TEMPERATURE          =     83.946   C
LIQUID FLOWRATE      =    394.500 lb-mole/hr
VAPOR  FLOWRATE      =    420.800 lb-mole/hr

TRAY NUMBER =  8
COMP           X(I)            Y(I)
MCS         0.9298E-03      0.3684E-02
DCS         0.2568E+00      0.4043E+00
TCS         0.7413E+00      0.5918E+00
TET         0.4558E-03      0.1798E-03
TEMPERATURE          =     87.623   C
LIQUID FLOWRATE      =    394.500 lb-mole/hr
VAPOR  FLOWRATE      =    420.800 lb-mole/hr

TRAY NUMBER =  9
COMP           X(I)            Y(I)
MCS         0.8660E-03      0.3594E-02
DCS         0.1792E+00      0.2994E+00
TCS         0.8189E+00      0.6966E+00
TET         0.1008E-02      0.4273E-03
TEMPERATURE          =     90.379   C
LIQUID FLOWRATE      =    394.500 lb-mole/hr
VAPOR  FLOWRATE      =    420.800 lb-mole/hr

TRAY NUMBER =  10
COMP           X(I)            Y(I)
MCS         0.8259E-03      0.3535E-02
DCS         0.1304E+00      0.2267E+00
TCS         0.8666E+00      0.7689E+00
TET         0.2128E-02      0.9454E-03
TEMPERATURE          =     92.218   C
LIQUID FLOWRATE      =    394.500 lb-mole/hr
VAPOR  FLOWRATE      =    420.800 lb-mole/hr
```

APPENDIX A1.3-3

(Continued)

```
TRAY NUMBER =  11
COMP          X(I)          Y(I)
MCS        0.8017E-03    0.3497E-02
DCS        0.1016E+00    0.1810E+00
TCS        0.8932E+00    0.8135E+00
TET        0.4361E-02    0.1995E-02
TEMPERATURE       =     93.375  C
LIQUID FLOWRATE   =    651.030 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  12
COMP          X(I)          Y(I)
MCS        0.2805E-03    0.1239E-02
DCS        0.8452E-01    0.1529E+00
TCS        0.9108E+00    0.8438E+00
TET        0.4394E-02    0.2049E-02
TEMPERATURE       =     94.130 C
LIQUID FLOWRATE   =    651.030 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  13
COMP          X(I)          Y(I)
MCS        0.9722E-04    0.4339E-03
DCS        0.6904E-01    0.1266E+00
TCS        0.9264E+00    0.8709E+00
TET        0.4422E-02    0.2096E-02
TEMPERATURE       =     94.777 C
LIQUID FLOWRATE   =    651.030 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  14
COMP          X(I)          Y(I)
MCS        0.3339E-04    0.1504E-03
DCS        0.5533E-01    0.1026E+00
TCS        0.9402E+00    0.8951E+00
TET        0.4448E-02    0.2139E-02
TEMPERATURE       =     95.342 C
LIQUID FLOWRATE   =    651.030 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  15
COMP          X(I)          Y(I)
MCS        0.1137E-04    0.5163E-04
DCS        0.4345E-01    0.8143E-01
TCS        0.9521E+00    0.9163E+00
TET        0.4478E-02    0.2180E-02
TEMPERATURE       =     95.832 C
LIQUID FLOWRATE   =    651.030 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr
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APPENDIX A1.3-3

(Continued)


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TRAY NUMBER =  16
COMP           X(I)              Y(I)
MCS         0.3844E-05     0.1757E-04
DCS         0.3335E-01     0.6305E-01
TCS         0.9621E+00     0.9347E+00
TET         0.4526E-02     0.2226E-02
TEMPERATURE          =    96.252 C
LIQUID FLOWRATE  =    651.030 lb-mole/hr
VAPOR  FLOWRATE  =    420.800 lb-mole/hr

TRAY NUMBER =  17
COMP           X(I)              Y(I)
MCS         0.1289E-05     0.5924E-05
DCS         0.2491E-01     0.4743E-01
TCS         0.9705E+00     0.9503E+00
TET         0.4637E-02     0.2301E-02
TEMPERATURE          =    96.607 C
LIQUID FLOWRATE  =    651.030 lb-mole/hr
VAPOR  FLOWRATE  =    420.800 lb-mole/hr

TRAY NUMBER =  18
COMP           X(I)              Y(I)
MCS         0.4267E-06     0.1971E 05
DCS         0.1793E-01     0.3436E-01
TCS         0.9771E+00     0.9632E+00
TET         0.4943E-02     0.2471E-02
TEMPERATURE          =    96.906 C
LIQUID FLOWRATE  =    651.030 lb-mole/hr
VAPOR  FLOWRATE  =    420.800 lb-mole/hr

TRAY NUMBER =  19
COMP           X(I)              Y(I)
MCS         0.1375E-06     0.6378E-06
DCS         0.1224E-01     0.2357E-01
TCS         0.9819E+00     0.9735E+00
TET         0.5852E-02     0.2945E-02
TEMPERATURE          =    97.167 C
LIQUID FLOWRATE  =    651.030 lb-mole/hr
VAPOR  FLOWRATE  =    420.800 lb-mole/nr

TRAY NUMBER =  20
COMP           X(I)              Y(I)
MCS         0.4086E-07     0.1903E-06
DCS         0.7623E-02     0.1476E-01
TCS         0.9838E+00     0.9809E+00
TET         0.8595E-02     0.4352E-02
TEMPERATURE          =    97.424 C
LIQUID FLOWRATE  =    651.030 lb-mole/hr
VAPOR  FLOWRATE  =    420.800 lb-mole/hr
```

APPENDIX A2 SELECTED PROCESS ENGINEERING FOR HSC PROCESS - CASE B

APPENDIX A2.1-1

DESIGN SPECIFICATIONS FOR DISTILLATION, D-01

Issue No. Issue 1

1. **Process Equipment Name** Distillation, D-01 (Stripper Column)
2. **Process Equipment Function** Removes volatile gases from liquid chlorosilanes
3. **Feed Specifications**
   1. **No. of Feeds** 1
   2. **No. of Feed Components** 8
   3. **Feed Components** H_2, N_2, SiH_4, HCl, MCS, DCS, TCS, TET
   4. **Feed Concentration** See Plate-To-Plate
   5. **Feed Temperature** 100F (37.8C)
   6. **Feed Pressure** 90 psia
   7. **Light Key - LK** Hydrogen Chloride, HCl
   8. **Heavy Key - HK** Trichlorosilane, $SiHCl_3$ (TCS)
4. **Distillate Specifications**
   1. **Recovery of Light Key (LK) in Distillate** 98.6 **%**
   2. **Concentration Spec.** low chlorosilanes
5. **Bottoms Specifications**
   1. **Recovery of Heavy Key (HK) in Bottoms** 99.9 **%**
   2. **Concentration Spec.** low volatile gases
6. **General Specifications**
   1. **Pressure for Distillation** 90 **psia**
   2. **Condenser Type** partial

APPENDIX A2.1-2

DESIGN RESULTS FOR DISTILLATION, D-01

Issue No. Issue 1

1. Process Equipment Name Distillation, D-01 (Stripper Column)

2. Equipment Specifications
   1. No. of Equilibrium Trays N = 13
   2. No. of Equilibrium Feed Tray N_F = 9
   3. Tray Efficiency 50 %
   4. No. of Actual Trays N_{actual} = 26
   5. No. of Actual Feed Tray $N_{F,actual}$ = 18
   6. Tray Spacing 18 in.
   7. Type of Tray Sieve
   8. Column Diameter 1.5-2 (use) ft.
   9. Column Height 39 ft.+ends ft.
   10. Reflux Ratio R = 1.90
   11. Design Temp. Top = -29 C (-21F)
       Bottom = 117 C (242F)
   12. Design Pressure 90 psia
   13. Materials of Construction 3/2 nickel steel

3. Product Specifications
   1. Feed Specifications
      1. Feed Concentration See Item 7 of Design Spec.
      2. Light Key - LK Hydrogen Chloride, HCl
      3. Heavy Key - HK Trichlorosilane, $SiHCl_3$ (TCS)
   2. Distillate Specifications
      1. Recovery of Light Key (LK) in Distillate 98.6 %
      2. Concentration Spec. Low Chlorosilanes
   3. Bottoms Specifications
      1. Recovery of Heavy Key (HK) in Bottoms 99.9 %
      2. Concentration Spec. Low Volatile Gases

APPENDIX A2.1-2

(Continued)

4. Results for Number of Trays

Reflux Ratio, R	No. of Equil. Trays, N	No. of Actual Trays, N_{actual}
1.28	29	58
1.31	22	44
1.40	18	36
1.53	16	32
1.78	14	28
1.91	13	26
2.23	12	24
2.54	11	22
3.18	10	20
3.82	9	18
4.77	9	18

APPENDIX A2.1-3
PLATE-TO-PLATE RESULTS FOR DISTILLATION, D-01

TREI'S REPORT ON DISTILLATION DESIGN

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DESIGN BASIS

1. NAME OF TOWER	HSC D-01
2. NUMBER OF COMPONENTS	8
3. NUMBER OF FEEDS	1
4. LIGHT KEY	4
5. HEAVY KEY	7
6. TYPE OF CONDENSER	2

7. TOWER PRESSURE,mmHg	4653.060
8. REFLUX RATIO ,R	1.900
9. DISTILLATE IN lb-mole/hr	3.854
10.CONVERGENCE TOLERANCE	0.5000E-03

11.SYSTEM IDENTIFICATION AND ANTOINE COEFFICIENTS

H2	5.92100	71.62000	276.35000
N2	6.61130	264.65100	266.36200
SiH4	7.09738	703.98700	278.50200
HCl	7.16759	744.48900	258.55000
MCS	6.62743	753.84900	231.55900
DCS	6.98990	1034.46000	243.40600
TCS	6.78393	1014.10000	227.87200
TET	6.93126	1178.84000	233.79700

12.FEEDS

TRAY NUMBER	9
FLOWRATE,mole/hr	0.1782E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE,C	0.9856E+02
X(H2)	0.2057E-01
X(N2)	0.1900E-04
X(SiH4)	0.3000E-05
X(HCl)	0.4960E-03
X(MCS)	0.6400E-04
X(DCS)	0.5819E-02
X(TCS)	0.2498E+00
X(TET)	0.7233E+00

APPENDIX A2.1-3

(Continued)

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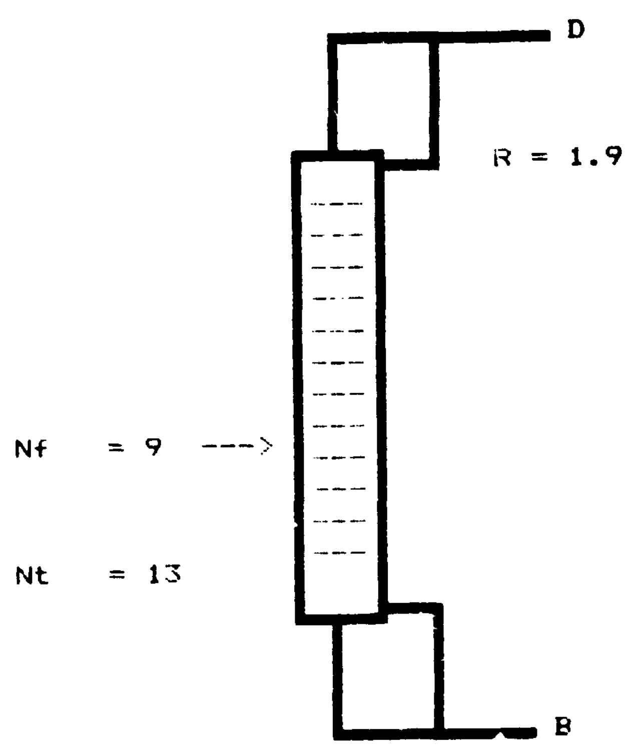
DESIGN RESULTS

1. TOTAL NUMBER OF TRAYS 13
2. FEED TRAYS 9
3. REFLUX RATIO 1.9



APPENDIX A2.1-3

(Continued)

4. FEEDS

TRAY NUMBER	9
FLOWRATE, mole/hr	0.1782E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE, C	0.9856E+02
X(H2)	0.2057E-01
X(N2)	0.1900E-04
X(SiH4)	0.3000E-05
X(HCl)	0.4960E-03
X(MCS)	0.6400E-04
X(DCS)	0.5819E-02
X(TCS)	0.2498E+00
X(TET)	0.7233E+00

5. DISTILLATE AND BOTTOM

PARTIAL CONDENSER

	Distillate	Bottom
FLOWRATE, mole/hr	0.3854E+01	0.1743E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04
TEMPERATURE, C	-.2514E+02	0.1175E+03
X(H2)	0.9550E+00	0.9820E-06
X(N2)	0.8824E-03	0.1254E-09
X(SiH4)	0.1387E-03	0.1692E-07
X(HCl)	0.2261E-01	0.1082E-04
X(MCS)	0.8397E-03	0.4867E-04
X(DCS)	0.1689E-01	0.5707E-02
X(TCS)	0.3607E-02	0.2551E+00
X(TET)	0.9756E-05	0.7391E+00

APPENDIX A2.1-3

(Continued)

TRAY PROFILE

TRAY NUMBER = 1

COMP	X(I)	Y(I)
H2	0.1043E-01	0.9550E+00
N2	0.1333E-04	0.8824E-03
SiH4	0.3569E-04	0.1387E-03
HCl	0.1321E-01	0.2261E-01
MCS	0.5204E-02	0.8397E-03
DCS	0.5853E+00	0.1689E-01
TCS	0.3824E+00	0.3607E-02
TET	0.3375E-02	0.9756E-05

TEMPERATURE = -30.635 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 2

COMP	X(I)	Y(I)
H2	0.3042E-02	0.3361E+00
N2	0.2245E-05	0.3130E-03
SiH4	0.2976E-05	0.7120E-04
HCl	0.1045E-02	0.1645E-01
MCS	0.1420E-02	0.3699E-02
DCS	0.4214E+00	0.3893E+00
TCS	0.5624E+00	0.2518E+00
TET	0.1071E-01	0.2214E-02

TEMPERATURE = 64.783 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 3

COMP	X(I)	Y(I)
H2	0.2974E-02	0.3313E+00
N2	0.2123E-05	0.3057E-03
SiH4	0.1919E-05	0.4977E-04
HCl	0.4892E-03	0.8481E-02
MCS	0.4171E-03	0.1220E-02
DCS	0.2636E+00	0.2819E+00
TCS	0.7041E+00	0.3697E+00
TET	0.2843E-01	0.7022E-02

TEMPERATURE = 70.743 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A2.1-3

(Continued)

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TRAY NUMBER = 4

COMP	X(I)	Y(I)
H2	0.2955E-02	0.3313E+00
N2	0.2070E-05	0.3057E-03
SiH4	0.1780E-05	0.4907E-04
HCl	0.4353E-03	0.8117E-02
MCS	0.1764E-03	0.5628E-03
DCS	0.1493E+00	0.1785E+00
TCS	0.7811E+00	0.4626E+00
TET	0.6594E-01	0.1863E-01

TEMPERATURE = 75.410 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 5

COMP	X(I)	Y(I)
H2	0.2939E-02	0.3313E+00
N2	0.2026E-05	0.3056E-03
SiH4	0.1685E-05	0.4898E-04
HCl	0.4072E-03	0.8082E-02
MCS	0.1178E-03	0.4051E-03
DCS	0.7885E-01	0.1037E+00
TCS	0.7814E+00	0.5130E+00
TET	0.1363E+00	0.4321E-01

TEMPERATURE = 79.530 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 6

COMP	X(I)	Y(I)
H2	0.2923E-02	0.3312E+00
N2	0.1984E-05	0.3056E-03
SiH4	0.1597E-05	0.4892E-04
HCl	0.3818E-03	0.8063E-02
MCS	0.9901E-04	0.3667E-03
DCS	0.3977E-01	0.5748E-01
TCS	0.7057E+00	0.5132E+00
TET	0.2511E+00	0.8928E-01

TEMPERATURE = 83.725 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A2.1-3

(Continued)

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TRAY NUMBER = 7

COMP	X(I)	Y(I)
H2	0.2905E-02	0.3312E+00
N2	0.1938E-05	0.3056E-03
SiH4	0.1505E-05	0.4886E-04
HCl	0.3556E-03	0.8047E-02
MCS	0.8812E-04	0.3544E-03
DCS	0.1986E-01	0.3188E-01
TCS	0.5692E+00	0.4636E+00
TET	0.4076E+00	0.1645E+00

TEMPERATURE = 88.509 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 8

COMP	X(I)	Y(I)
H2	0.2887E-02	0.3312E+00
N2	0.1890E-05	0.3055E-03
SiH4	0.1413E-05	0.4880E-04
HCl	0.3298E-03	0.8030E-02
MCS	0.7916E-04	0.3473E-03
DCS	0.1050E-01	0.1884E-01
TCS	0.4076E+00	0.3742E+00
TET	0.5786E+00	0.2670E+00

TEMPERATURE = 93.721 C
LIQUID FLOWRATE = 7.323 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 9

COMP	X(I)	Y(I)
H2	0.2870E-02	0.3312E+00
N2	0.1848E-05	0.3055E-03
SiH4	0.1334E-05	0.4874E-04
HCl	0.3081E-03	0.8013E-02
MCS	0.7197E-04	0.3414E-03
DCS	0.6411E-02	0.1271E-01
TCS	0.2624E+00	0.2683E+00
TET	0.7279E+00	0.3791E+00

TEMPERATURE = 98.564 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A2.1-3

(Continued)

TRAY NUMBER = 10

COMP	X(I)	Y(I)
H2	0.4052E-03	0.4762E-01
N2	0.1729E-06	0.3067E-04
SiH4	0.5028E-06	0.2189E-04
HCl	0.1547E-03	0.4945E-02
MCS	0.7204E-04	0.4360E-03
DCS	0.6456E-02	0.1748E-01
TCS	0.2634E+00	0.3764E+00
TET	0.7295E+00	0.5531E+00

TEMPERATURE = 114.588 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 11

COMP	X(I)	Y(I)
H2	0.5698E-04	0.6711E-02
N2	0.1603E-07	0.2868E-05
SiH4	0.1817E-06	0.8082E-05
HCl	0.7316E-04	0.2399E-02
MCS	0.7000E-04	0.4366E-03
DCS	0.6446E-02	0.1814E-01
TCS	0.2635E+00	0.3925E+00
TET	0.7298E+00	0.5798E+00

TEMPERATURE = 116.687 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

TRAY NUMBER = 12

COMP	X(I)	Y(I)
H2	0.7897E-05	0.9304E-03
N2	0.1474E-08	0.2641E-06
SiH4	0.6161E-07	0.2751E-05
HCl	0.3174E-04	0.1046E-02
MCS	0.6423E-04	0.4027E-03
DCS	0.6345E-02	0.1798E-01
TCS	0.2630E+00	0.3945E+00
TET	0.7306E+00	0.5851E+00

TEMPERATURE = 117.054 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

APPENDIX A2.1-3

(Continued)

TRAY NUMBER = 13

COMP	X(I)	Y(I)
H2	0.9820E-06	0.1158E-03
N2	0.1254E-09	0.2251E-07
SiH4	0.1692E-07	0.7586E-06
HCl	0.1082E-04	0.3581E-03
MCS	0.4867E-04	0.3069E-03
DCS	0.5707E-02	0.1629E-01
TCS	0.2551E+00	0.3858E+00
TET	0.7391E+00	0.5972E+00

TEMPERATURE = 117.454 C
LIQUID FLOWRATE = 185.503 lb-mole/hr
VAPOR FLOWRATE = 11.177 lb-mole/hr

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APPENDIX A2.2-1

DESIGN SPECIFICATIONS FOR DISTILLATION, D-02

Issue No. 1

1. Process Equipment Name Distillation, D-02 (TCS Column)
2. Process Equipment Function Separation of TCS (Trichlorosilane) and TET (Tetrachlorosilane).
3. Feed Specifications
    1. No. of Feeds 3
    2. No. of Feed Components 5
    3. Feed Components SiH_4, MCS, DCS, TCS, TET
    4. Feed Concentration See Plate-To-Plate
    5. Feed Temperature See Plate-To-Plate
    6. Feed Pressure See Plate-To-Plate
    7. Light Key - LK Trichlorosilane (TCS)
    8. Heavy Key - HK Tetrachlorosilane (TET)
4. Distillate Specifications
    1. Recovery of Light Key (LK) in Distillate 96.6 %
    2. Concentration Spec. Low in TET
5. Bottoms Specifications
    1. Recovery of Heavy Key (HK) in Bottoms 98.1 %
    2. Concentration Spec. Low in MCS, DCS and TCS
6. General Specifications
    1. Pressure for Distillation 90 psia
    2. Condenser Type Total

APPENDIX A2.2-2

DESIGN RESULTS FOR DISTILLATION, D-02

Issue No. 1

1. Process Equipment Name Distillation, D-02 (TCS Column)
2. Equipment Specifications
   1. No. of Equilibrium Trays N = 15
   2. No. of Equilibrium Feed Tray N_F = 4, 8, 11
   3. Tray Efficiency 63 %
   4. No. of Actual Trays N_{actual} = 24
   5. No. of Actual Feed Tray $N_{F,actual}$ = 7, 13, 18
   6. Tray Spacing 24 in.
   7. Type of Tray Single Pass Flow Seive Tray
   8. Column Diameter 5.5 ft.
   9. Column Height 48 ft. + ends ft.
   10. Reflux Ratio R = 2.0
   11. Design Temp. Top = 97.2 C
       Bottom = 125.4 C
   12. Design Pressure 90 psia
   13. Materials of Construction Steel
3. Product Specifications
   1. Feed Specifications
      1. Feed Concentration See Item 7 of Design Spec.
      2. Light Key - LK Trichlorosilane (TCS)
      3. Heavy Key - HK Tetrachlorosilane (TET)
   2. Distillate Specifications
      1. Recovery of Light Key (LK) in Distillate 96.6 %
      2. Concentration Spec. See Plate-To-Plate
   3. Bottoms Specifications
      1. Recovery of Heavy Key (HK) in Bottoms 98.1 %
      2. Concentration Spec. See Plate-To-Plate

APPENDIX A2.2-2

(Continued)

4. Results for Number of Trays

Reflux Ratio, R	No. of Equil, Trays, N	No. of Actual Trays N_{actual}
1	24 (9, 15, 20)	39
1.5	18 (6, 11, 14)	29
2	15 (5, 8, 11)	24
2.5	14 (5, 7, 11)	23
3	13 (5, 7, 10)	21
4	12 (4, 6, 9)	20
5	11 (4, 6, 9)	18

NOTE:

Numbers in parentheses give feed plate location. For case of R = 2, $N_{F1} = 5$, $N_{F2} = 8$ and $N_{F3} = 11$.

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APPENDIX A2.2-3

PLATE-TO-PLATE RESULTS FOR DISTILLATION, D-03

TREI'S REPORT ON DISTILLATION DESIGN

DESIGN BASIS

1. NAME OF TOWER	D-02 FOR CASE B OF HSC PROCESS
2. NUMBER OF COMPONENTS	5
3. NUMBER OF FEEDS	3
4. LIGHT KEY	4
5. HEAVY KEY	5
6. TYPE OF CONDENSER	1

7. TOWER PRESSURE,mmHg	4653.060
8. REFLUX RATIO ,R	2.000
9. DISTILLATE IN lb-mole/hr	256.900
10.CONVERGENCE TOLERANCE	0.5000E-03

11.SYSTEM IDENTIFICATION AND ANTOINE COEFFICIENTS

SiH4	7.09738	703.98700	278.50200
MCS	6.62743	753.84900	321.55900
DCS	6.98998	1034.46000	243.40600
TCS	6.78393	1014.10000	227.87200
TET	6.93126	1178.84000	233.79700

12.FEEDS

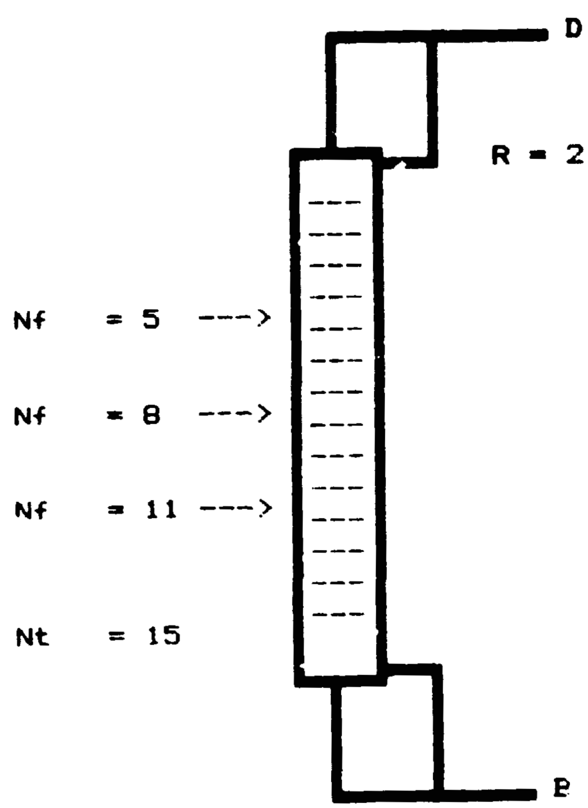
TRAY NUMBER	5	8	11
FLOWRATE,mole/hr	0.2306E+03	0.1525E+02	0.1743E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04	0.4653E+04
THERMAL COND.	0.1000E+01	0.1000E+01	0.1000E+01
TEMPERATURE,C	0.1011E+03	0.1078E+03	0.1179E+03
X(SiH4)	0.9071E-16	0.0000E+00	0.0000E+00
X(MCS)	0.1152E-06	0.0000E+00	0.0000E+00
X(DCS)	0.7756E-02	0.1670E+00	0.5500E-02
X(TCS)	0.8754E+00	0.5670E+00	0.2552E+00
X(TET)	0.1167E+00	0.2670E+00	0.7393E+00

APPENDIX A2.2-3

(Continued)

DESIGN RESULTS

1. TOTAL NUMBER OF TRAYS 15
2. FEED TRAYS 5 9 11
3. REFLUX RATIO 2



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APPENDIX A2.2-3

(Continued)

4. FEEDS

TRAY NUMBER	5	8	11
FLOWRATE, mole/hr	0.2306E+03	0.1525E+02	0.1743E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04	0.4653E+04
THERMAL COND.	0.1000E+01	0.1000E+01	0.1000E+01
TEMPERATURE, C	0.1011E+03	0.1078E+03	0.1179E+03
X(SiH4)	0.9071E-16	0.0000E+00	0.0000E+00
X(MCS)	0.1152E-06	0.0000E+00	0.0000E+00
X(DCS)	0.7756E-02	0.1670E+00	0.5500E-02
X(TCS)	0.8754E+00	0.5670E+00	0.2552E+00
X(TET)	0.1167E+00	0.2670E+00	0.7393E+00

5. DISTILLATE AND BOTTOM

TOTAL CONDENSER

	Distillate	Bottom
FLOWRATE, mole/hr	0.2569E+03	0.1633E+03
PRESSURE, mmHg	0.4653E+04	0.4653E+04
TEMPERATURE, C	0.9713E+02	0.1254E+03
X(SiH4)	0.8142E-16	0.5356E-34
X(MCS)	0.1361E-06	0.2731E-20
X(DCS)	0.2060E-01	0.1604E-04
X(TCS)	0.9593E+00	0.5233E-01
X(TET)	0.2010E-01	0.9477E+00

APPENDIX A2.2-3

(Continued)

TRAY PROFILE

TRAY NUMBER = 1

COMP	X(I)	Y(I)
SiH4	0.2244E-17	0.8142E-16
MCS	0.9354E-08	0.1361E-06
DCS	0.1051E-01	0.2060E-01
TCS	0.9503E+00	0.9593E+00
TET	0.3915E-01	0.2010E-01

TEMPERATURE = 97.984 C
LIQUID FLOWRATE = 513.800 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 2

COMP	X(I)	Y(I)
SiH4	0.7829E-18	0.2864E-16
MCS	0.3523E-08	0.5160E-07
DCS	0.6983E-02	0.1388E-01
TCS	0.9302E+00	0.9533E+00
TET	0.6281E-01	0.3280E-01

TEMPERATURE = 98.675 C
LIQUID FLOWRATE = 513.800 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 3

COMP	X(I)	Y(I)
SiH4	0.7502E-18	0.2766E-16
MCS	0.3234E-08	0.4772E-07
DCS	0.5715E-02	0.1152E-01
TCS	0.9029E+00	0.9399E+00
TET	0.9140E-01	0.4858E-01

TEMPERATURE = 99.390 C
LIQUID FLOWRATE = 513.800 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 4

COMP	X(I)	Y(I)
SiH4	0.7428E-18	0.2764E-16
MCS	0.3196E-08	0.4752E-07
DCS	0.5210E-02	0.1068E-01
TCS	0.8700E+00	0.9217E+00
TET	0.1248E+00	0.6764E-01

TEMPERATURE = 100.196 C
LIQUID FLOWRATE = 513.800 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 5

COMP	X(I)	Y(I)
SiH4	0.7351E-18	0.2764E-16
MCS	0.3166E-08	0.4750E-07
DCS	0.4954E-02	0.1034E-01
TCS	0.8328E+00	0.8998E+00
TET	0.1622E+00	0.8989E-01

TEMPERATURE = 101.104 C
LIQUID FLOWRATE = 744.400 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 6

COMP	X(I)	Y(I)
SiH4	0.1853E-19	0.7088E-18
MCS	0.9175E-09	0.1397E-07
DCS	0.4336E-02	0.9331E-02
TCS	0.7722E+00	0.8622E+00
TET	0.2235E+00	0.1285E+00

TEMPERATURE = 102.639 C
LIQUID FLOWRATE = 744.400 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 7

COMP	X(I)	Y(I)
SiH4	0.4257E-21	0.1669E-19
MCS	0.7585E-09	0.1180E-07
DCS	0.3894E-02	0.8734E-02
TCS	0.6865E+00	0.8037E+00
TET	0.3096E+00	0.1877E+00

TEMPERATURE = 104.862 C
LIQUID FLOWRATE = 744.400 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 8

COMP	X(I)	Y(I)
SiH4	0.0000E+00	0.0000E+00
MCS	0.7282E-09	0.1164E-07
DCS	0.3486E-02	0.8297E-02
TCS	0.5794E+00	0.7210E+00
TET	0.4171E+00	0.2708E+00

TEMPERATURE = 107.784 C
LIQUID FLOWRATE = 759.650 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

APPENDIX A2.2-3

(Continued)

TRAY NUMBER = 9

COMP	X(I)	Y(I)
SiH4	0.0000E+00	0.0000E+00
MCS	0.7037E-09	0.1163E-07
DCS	0.1837E-02	0.4677E-02
TCS	0.4618E+00	0.6177E+00
TET	0.5364E+00	0.3776E+00

TEMPERATURE = 111.308 C
LIQUID FLOWRATE = 759.650 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 10

COMP	X(I)	Y(I)
SiH4	0.0000E+00	0.0000E+00
MCS	0.6798E-09	0.1160E-07
DCS	0.1122E-02	0.3052E-02
TCS	0.3495E+00	0.5018E+00
TET	0.6494E+00	0.4952E+00

TEMPERATURE = 114.840 C
LIQUID FLOWRATE = 759.650 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 11

COMP	X(I)	Y(I)
SiH4	0.0000E+00	0.0000E+00
MCS	0.6597E-09	0.1158E-07
DCS	0.8151E-03	0.2347E-02
TCS	0.2563E+00	0.3911E+00
TET	0.7429E+00	0.6066E+00

TEMPERATURE = 117.932 C
LIQUID FLOWRATE = 933.980 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

TRAY NUMBER = 12

COMP	X(I)	Y(I)
SiH4	0.3326E-29	0.1537E-27
MCS	0.9868E-17	0.1770E-15
DCS	0.3273E-03	0.9847E-03
TCS	0.1876E+00	0.3000E+00
TET	0.8121E+00	0.6990E+00

TEMPERATURE = 120.353 C
LIQUID FLOWRATE = 933.980 lb-mole/hr
VAPOR FLOWRATE = 770.700 lb-mole/hr

APPENDIX A2.2-3

(Continued)


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TRAY NUMBER =   13
COMP          X(I)            Y(I)
SiH4       0.8541E-31     0.4031E-29
MCS        0.6543E-18     0.1196E-16
DCS        0.1259E-03     0.3932E-03
TCS        0.1299E+00     0.2162E+00
TET        0.8700E+00     0.7834E+00
TEMPERATURE        =     122.449 C
LIQUID FLOWRATE    =     933.980 lb-mole/hr
VAPOR  FLOWRATE    =     770.700 lb-mole/hr

TRAY NUMBER =   14
COMP          X(I)            Y(I)
SiH4       0.2157E-32     0.1035E-30
MCS        0.4273E-19     0.7923E-18
DCS        0.4634E-04     0.1491E-03
TCS        0.8512E-01     0.1463E+00
TET        0.9148E+00     0.8536E+00
TEMPERATURE        =     124.119 C
LIQUID FLOWRATE    =     933.980 lb-mole/hr
VAPOR  FLOWRATE    =     770.700 lb-mole/hr

TRAY NUMBER =   15
COMP          X(I)            Y(I)
SiH4       0.5356E-34     0.2602E-32
MCS        0.2731E-20     0.5120E-19
DCS        0.1604E-04     0.5276E-04
TCS        0.5233E-01     0.9206E-01
TET        0.9477E+00     0.9079E+00
TEMPERATURE        =     125.371 C
LIQUID FLOWRATE    =     933.980 lb-mole/hr
VAPOR  FLOWRATE    =     770.700 lb-mole/hr
```

APPENDIX A2.3-1

DESIGN SPECIFICATIONS FOR DISTILLATION, D-03

Issue No. 1

1. Process Equipment Name Distillation, D-03 (DCS Column)
2. Process Equipment Function Separation of DCS (Dichlorosilane) and TCS (Trichlorosilane).
3. Feed Specifications
   1. No. of Feeds 1
   2. No. of Feed Components 5
   3. Feed Components SiH_4, MCS, DCS, TCS, TET
   4. Feed Concentration See Plate-To-Plate
   5. Feed Temperature See Plate-To-Plate
   6. Feed Pressure 90 Psia
   7. Light Key - LK Dichlorosilane (DCS)
   8. Heavy Key - HK Trichlorosilane (TCS)
4. Distillate Specifications
   1. Recovery of Light Key (LK) in Distillate 93.1 %
   2. Concentration Spec. Low TCS, TET
5. Bottoms Specifications
   1. Recovery of Heavy Key (HK) in Bottoms 99.7 %
   2. Concentration Spec. Low in MCS, DCS
6. General Specifications
   1. Pressure for Distillation 90 psia
   2. Condenser Type Partial

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APPENDIX A2.3-2

DESIGN RESULTS FOR DISTILLATION, D-03

Issue No. 1

1. Process Equipment Name Distillation, D-03 (DCS Column)

2. Equipment Specifications
   1. No. of Equilibrium Trays N = 20
   2. No. of Equilibrium Feed Tray N_F = 11
   3. Tray Efficiency 63 %
   4. No. of Actual Trays N_{actual} = 32
   5. No. of Actual Feed Tray $N_{F,actual}$ = 16
   6. Tray Spacing 18 in.
   7. Type of Tray Single Pass Crossflow Seive Tray
   8. Column Diameter 4 ft.
   9. Column Height 48 ft. + ends ft.
   10. Reflux Ratio R = 15
   11. Design Temp. Top = 52 C
       Bottom = 97 C
   12. Design Pressure 90 psia
   13. Materials of Construction Steel

3. Product Specifications
   1. Feed Specifications
      1. Feed Concentration See Item 7 of Design Spec.
      2. Light Key - LK Dichlorosilane (DCS)
      3. Heavy Key - HK Trichlorosilane (TCS)
   2. Distillate Specifications
      1. Recovery of Light Key (LK) in Distillate 93.1 %
      2. Concentration Spec. See Plate-To-Plate
   3. Bottoms Specifications
      1. Recovery of Heavy Key (HK) in Bottoms 99.7 %
      2. Concentration Spec. See Plate-To-Plate

APPENDIX A2.3-2

(Continued)

4. Results for Number of Trays

Reflux Ratio, R	No. of Equil. Trays, N	No. of Actual Trays N_{actual}
10	30 (15)	48
12	25 (14)	40
15	20 (13)	32
20	18 (12)	29
25	17 (11)	27
40	16 (11)	26

APPENDIX A2.3-3

PLATE-TO-PLATE RESULTS FOR DISTILLATION, D-03

TREI'S REPORT ON DISTILLATION DESIGN

DESIGN BASIS

1. NAME OF TOWER	D-03 FOR CASE B OF HSC PROCESS
2. NUMBER OF COMPONENTS	5
3. NUMBER OF FEEDS	1
4. LIGHT KEY	3
5. HEAVY KEY	4
6. TYPE OF CONDENSER	3

7. TOWER PRESSURE,mmHg	4653.060
8. REFLUX RATIO ,R	15.000
9. DISTILLATE IN lb-mole/hr	26.300
10.CONVERGENCE TOLERANCE	0.5000E-03

11.SYSTEM IDENTIFICATION AND ANTOINE COEFFICIENTS

SiH4	7.09738	703.98700	278.50200
MCS	6.62743	753.84900	231.55900
DCS	6.98990	1034.46000	243.40600
TCS	6.78393	1014.10000	227.87200
TET	6.93126	1178.84000	233.79700

12.FEEDS

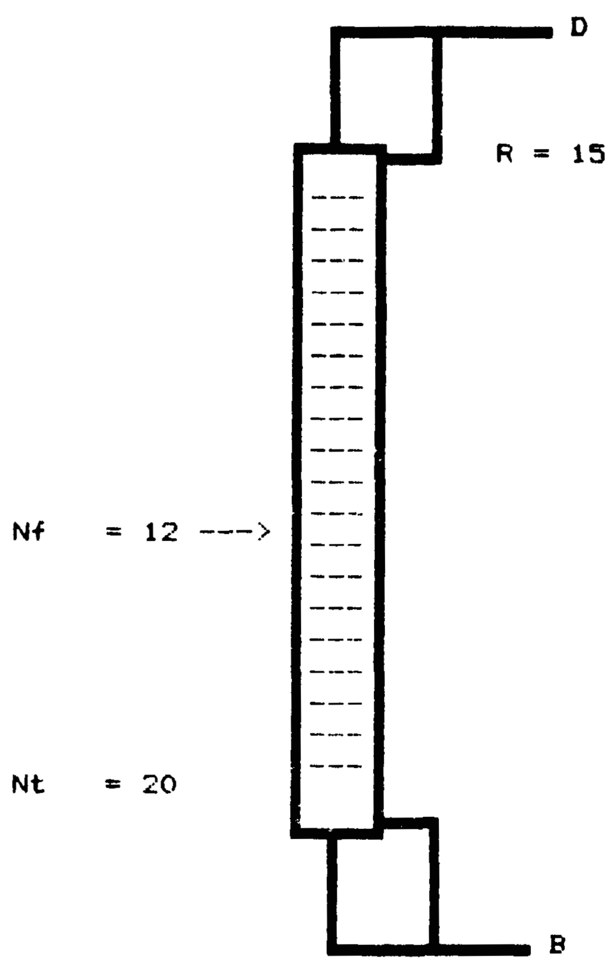
TRAY NUMBER	12
FLOWRATE,mole/hr	0.2569E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE,C	0.9454E+02
X(SiH4)	0.4430E-03
X(MCS)	0.6790E-02
X(DCS)	0.1000E+00
X(TCS)	0.7878E+00
X(TET)	0.1050E+00

APPENDIX A2.3-3

(Continued)

DESIGN RESULTS

1.	TOTAL NUMBER OF TRAYS	20
2.	FEED TRAYS	12
3.	REFLUX RATIO	15



APPENDIX A2.3-3

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4. FEEDS

TRAY NUMBER	12
FLOWRATE,mole/hr	0.2569E+03
PRESSURE, mmHg	0.4653E+04
THERMAL COND.	0.1000E+01
TEMPERATURE,C	0.9454E+02
X(SiH4)	0.4430E-03
X(MCS)	0.6790E-02
X(DCS)	0.1000E+00
X(TCS)	0.7878E+00
X(TET)	0.1050E+00

5. DISTILLATE AND BOTTOM

PARTIAL CONDENSER

	Distillate	Bottom
FLOWRATE,mole/hr	0.2630E+02	0.2306E+03
PRESSURE,mmHg	0.4653E+04	0.4653E+04
TEMPERATURE,C	0.5946E+02	0.9989E+02
X(SiH4)	0.4383E-02	0.9071E-16
X(MCS)	0.6719E-01	0.1516E-06
X(DCS)	0.9204E+00	0.7756E-02
X(TCS)	0.8002E-02	0.8754E+00
X(TET)	0.9476E-07	0.1169E+00

APPENDIX A2.3-3

(Continued)

TRAY PROFILE

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TRAY NUMBER = 1

COMP	X(I)	Y(I)
SiH4	0.1792E-03	0.4383E-02
MCS	0.2500E-01	0.6719E-01
DCS	0.9577E+00	0.9204E+00
TCS	0.1712E-01	0.8002E-02
TET	0.4369E-06	0.9476E-07

TEMPERATURE = 66.368 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 2

COMP	X(I)	Y(I)
SiH4	0.1769E-04	0.4419E-03
MCS	0.9971E-02	0.2763E-01
DCS	0.9561E+00	0.9554E+00
TCS	0.3394E-01	0.1655E-01
TET	0.1827E-05	0.4155E-06

TEMPERATURE = 67.946 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 3

COMP	X(I)	Y(I)
SiH4	0.1147E-04	0.2905E-03
MCS	0.4792E-02	0.1355E-01
DCS	0.9307E+00	0.9538E+00
TCS	0.6449E-01	0.3232E-01
TET	0.7332E-05	0.1719E-05

TEMPERATURE = 68.978 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 4

COMP	X(I)	Y(I)
SiH4	0.1105E-04	0.2847E-03
MCS	0.2999E-02	0.8691E-02
DCS	0.8794E+00	0.9301E+00
TCS	0.1175E+00	0.6096E-01
TET	0.2825E-04	0.6880E-05

TEMPERATURE = 70.272 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

APPENDIX A2.3-3

(Continued)

TRAY NUMBER = 5

COMP	X(I)	Y(I)
SiH4	0.1074E-04	0.2843E-03
MCS	0.2330E-02	0.7011E-02
DCS	0.7949E+00	0.8820E+00
TCS	0.2027E+00	0.1107E+00
TET	0.1026E-03	0.2649E-04

TEMPERATURE = 72.265 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 6

COMP	X(I)	Y(I)
SiH4	0.1032E-04	0.2840E-03
MCS	0.2007E-02	0.6383E-02
DCS	0.6745E+00	0.8028E+00
TCS	0.3232E+00	0.1905E+00
TET	0.3422E-03	0.9619E-04

TEMPERATURE = 75.228 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 7

COMP	X(I)	Y(I)
SiH4	0.9811E-05	0.2836E-03
MCS	0.1782E-02	0.6081E-02
DCS	0.5279E+00	0.6898E+00
TCS	0.46[illegible]3E+00	0.3035E+00
TET	0.1024E-02	0.3209E-03

TEMPERATURE = 79.094 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 8

COMP	X(I)	Y(I)
SiH4	0.9288E-05	0.2831E-03
MCS	0.1596E-02	0.5870E-02
DCS	0.3869E+00	0.5543E+00
TCS	0.6088E+00	0.4385E+00
TET	0.2729E-02	0.9601E-03

TEMPERATURE = 83.334 C
LIQUID FLOWRATE = 394.500 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

APPENDIX A2.3-3

(Continued)


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TRAY NUMBER =   9
COMP           X(I)            Y(I)
SiH4        0.8841E-05      0.2826E-03
MCS         0.1447E-02      0.5695E-02
DCS         0.2692E+00      0.4203E+00
TCS         0.7228E+00      0.5712E+00
TET         0.6556E-02      0.2558E-02
TEMPERATURE         =     87.223   C
LIQUID FLOWRATE     =    394.500 lb-mole/hr
VAPOR  FLOWRATE     =    420.800 lb-mole/hr

TRAY NUMBER =  10
COMP           X(I)            Y(I)
SiH4        0.8505E-05      0.2822E-03
MCS         0.1340E-02      0.5556E-02
DCS         0.1857E+00      0.3099E+00
TCS         0.7934E+00      0.6781E+00
TET         0.1453E-01      0.6146E-02
TEMPERATURE         =     90.315   C
LIQUID FLOWRATE     =    394.500 lb-mole/hr
VAPOR  FLOWRATE     =    420.800 lb-mole/hr

TRAY NUMBER =  11
COMP           X(I)            Y(I)
SiH4        0.8266E-05      0.2819E-03
MCS         0.1266E-02      0.5456E-02
DCS         0.1321E+00      0.2316E+00
TCS         0.8362E+00      0.7490E+00
TET         0.3034E-01      0.1362E-01
TEMPERATURE         =     92.635   C
LIQUID FLOWRATE     =    394.500 lb-mole/hr
VAPOR  FLOWRATE     =    420.800 lb-mole/hr

TRAY NUMBER =  12
COMP           X(I)            Y(I)
SiH4        0.8077E-05      0.2817E-03
MCS         0.1211E-02      0.5386E-02
DCS         0.9943E-01      0.1814E+00
TCS         0.8390E+00      0.7845E+00
TET         0.6036E-01      0.2844E-01
TEMPERATURE         =     94.539   C
LIQUID FLOWRATE     =    651.410 lb-mole/hr
VAPOR  FLOWRATE     =    420.800 lb-mole/hr
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APPENDIX A2.3-3

(Continued)


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TRAY NUMBER =  13
COMP          X(I)           Y(I)
SiH4       0.3554E-06     0.1252E-04
MCS        0.4164E-03     0.1879E-02
DCS        0.8065E-01     0.1499E+00
TCS        0.8581E+00     0.8189E+00
TET        0.6082E-01     0.2932E-01
TEMPERATURE        =    95.447 C
LIQUID FLOWRATE   =    651.410 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  14
COMP          X(I)           Y(I)
SiH4       0.1547E-07     0.5501E-06
MCS        0.1411E-03     0.6446E-03
DCS        0.6387E-01     0.1206E+00
TCS        0.8747E+00     0.8487E+00
TET        0.6130E-01     0.3011E-01
TEMPERATURE        =    96.193 C
LIQUID FLOWRATE   =    651.410 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  15
COMP          X(I)           Y(I)
SiH4       0.6690E-09     0.2396E-07
MCS        0.4734E-04     0.2184E-03
DCS        0.4947E-01     0.9462E-01
TCS        0.8886E+00     0.8743E+00
TET        0.6184E-01     0.3085E-01
TEMPERATURE        =    96.822 C
LIQUID FLOWRATE   =    651.410 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr

TRAY NUMBER =  16
COMP          X(I)           Y(I)
SiH4       0.2875E-10     0.1036E-08
MCS        0.1573E-04     0.7320E-04
DCS        0.3740E-01     0.7232E-01
TCS        0.8999E+00     0.8959E+00
TET        0.6268E-01     0.3168E-01
TEMPERATURE        =    97.356 C
LIQUID FLOWRATE   =    651.410 lb-mole/hr
VAPOR  FLOWRATE   =    420.800 lb-mole/hr
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APPENDIX A2.3-3

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TRAY NUMBER = 17

COMP	X(I)	Y(I)
SiH4	0.1229E-11	0.4450E-10
MCS	0.5176E-05	0.2427E-04
DCS	0.2747E-01	0.5364E-01
TCS	0.9080E+00	0.9134E+00
TET	0.6448E-01	0.3297E-01

TEMPERATURE = 97.823 C
LIQUID FLOWRATE = 651.410 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 18

COMP	X(I)	Y(I)
SiH4	0.5224E-13	0.1902E-11
MCS	0.1679E-05	0.7930E-05
DCS	0.1942E-01	0.3828E-01
TCS	0.9114E+00	0.9260E+00
TET	0.6916E-01	0.3576E-01

TEMPERATURE = 98.277 C
LIQUID FLOWRATE = 651.410 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 19

COMP	X(I)	Y(I)
SiH4	0.2205E-14	0.8082E-13
MCS	0.5280E-06	0.2516E-05
DCS	0.1295E-01	0.2582E-01
TCS	0.9051E+00	0.9312E+00
TET	0.8200E-01	0.4301E-01

TEMPERATURE = 98.853 C
LIQUID FLOWRATE = 651.410 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

TRAY NUMBER = 20

COMP	X(I)	Y(I)
SiH4	0.9071E-16	0.3364E-14
MCS	0.1516E-06	0.7343E-06
DCS	0.7756E-02	0.1579E-01
TCS	0.8754E+00	0.9213E+00
TET	0.1169E+00	0.6288E-01

TEMPERATURE = 99.895 C
LIQUID FLOWRATE = 651.410 lb-mole/hr
VAPOR FLOWRATE = 420.800 lb-mole/hr

APPENDIX A3 FACTORS USED IN ESTIMATION OF CAPITAL INVESTMENT FOR PLANT

Preliminary cost analysis should be performed early in a project before sizeable funds are expended on the venture. Early cost analysis can help prevent the waste of funds on losing causes. If the cost analysis results are unfavorable with product cost exceeding sales price of the product, then the project may be abandoned without the expenditure of additional funds. If the cost analysis results are favorable with the sales price greatly exceeding product cost, then the project may be continued or even expanded.

The capital investment required for the plant is important in the cost analysis of a project.

The plant investment cost is determined from the cost of the major process equipment required in the plant. This includes the purchase and installation of all major process equipment along with instrumentation, electrical, piping, buildings, utilities, fire protection, etc.; plus indirect costs such as engineering and overhead. For initial studies, overall contingency may be added. The total plant investment including fixed capital and working capital is determined next. Working capital investment is often estimated at 15% of fixed capital in initial investigations. It may also be determined from preliminary plant design.

The factors for estimation of plant investment are given in Table A3-1 for fluids processing. The plant investment cost is based on published plant cost data from a variety of sources and processes (Ref. 1,2,3,4,6,7, 8,9,10,11,12,13,14,15,16,17,18,19,20,22,25,26,30,32,37,38,39,40,43,44,46,47, 48,50,52,53,54,55,56,57,58 and 59).

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TABLE A3-1

FACTORS FOR ESTIMATION OF PLANT INVESTMENT

	Investment
1. DIRECT PLANT INVESTMENT COSTS	
1. Major process equipment cost	100.0
2. Installation of major process equipment	43.0
3. Processpiping, Installed	74.0
4. Instrumentation, Installed	19.0
5. Electrical, Installed	10.0
6. Process building, Installed	10.0
1a. SUBTOTAL FOR DIRECT PLANT INVESTMENT COSTS (PRIMARILY BATTERY LIMIT FACILITIES)	256.0
2. OTHER DIRECT PLANT INVESTMENT COSTS	
1. Utilities, Installed	48.0
2. General service, Site development, Fire protection, etc.	12.0
3. General buildings, Offices, Shops, etc	14.0
4. Receving, Shipping facilities	21.0
2a. SUBTOTAL FOR OTHER DIRECT PLANT INVESTMENT COST (PRIMARILY OFFSET FACILITIES)	95.0
3. TOTAL DIRECT INVESTMENT COSTS, 1a+2a	351.0
4. INDIRECT PLANT INVESTMENT COSTS	
1. Engineering, Overhead, etc	55.0
2. Normal Cont. for Floods, strikes, etc	71.0
4a. TOTAL INDIRECT INVESTMENT COST	126.0
5. TOTAL DIRECT AND INDIRECT INVESTMENT COST, 3+4a	477.0
6. OVERALL CONTINGENCY	
7. FIXED CAPITAL INVESTMENT FOR PLANT 5+6	

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APPENDIX A4 FACTORS USED IN ESTIMATION OF TOTAL PRODUCT COST

The estimation of total product cost is important in the cost analysis of a project.

The factors for estimation of total product are given in Table A4-1. The factors shown are intermediate values selected from published cost data on a variety of products. The typical values are useful in initial cost analysis (Ref. 2,3,4,5,6,7,8,10,12,13,20,21,26,27,28,29,31,32,33,34,38, 41,42,43,44,47,49,50,55,56 and 57 of Appendix A4).

In the table, direct manufacturing costs are covered in item 1. The first several subitems (1.1, 1.2, and 1.3)--raw materials, direct operating labor and utilities--depend on the process technology and evolve from the preliminary process design. For example, one process may only require one or two feed raw materials for production of the product. Another process may require three or more feed raw materials for the silicon production. The raw material requirements, both specific materials and quantities, will be different for each process. The preliminary process design provides the raw material requirements for the particular process. The operating labor and utility requirements also depend on the process. The preliminary process design provides the direct operating labor and utility requirements which are a function of the processing steps associated with the particular process under consideration.

The additional subitems (1.4 to 1.7) in direct manufacturing cost cover supervision (1.4) of personnel operating the production facilities; repair and maintenance (1.5) for the upkeep of the facilities; operating supplies (1.6); and laboratory work (1.7) for process and quality control. These subitems depend on the particular process and may be determined from the labor and capital investment requirements of the particular process.

Item 2 covers the indirect manufacturing costs which are a result of the production operation (but not a direct function of). The indirect manufacturing costs reflect fixed charges which, more or less, remain constant regardless of the production level. Indirect manufacturing costs includes provisions for depreciation (2.1) for the fixed capital investment, local taxes (2.2) on the production plant and insurance coverage (2.3) of the plant.

Plant overhead is included in item 3. This includes costs for holidays, vacations, disability pay, pensions, medical services, safety, maintenance on roads, sewer service, plant protection, general plant upkeep, etc. In general, plant overhead is related to direct labor; supervision and clerical and maintenance labor.

Item 4 covers credit for by-products. Some processes do not produce a by-product. Other processes may produce one or several by-products. If the by-product is saleable, a credit is obtained. If the by-product is not saleable and expenses are incurred in its disposal, then a debit will result for that by-product. The economics here depend on the nature of the by-product associated with the particular process under consideration.

Item 4a provides the total manufacturing cost. It is equal to the sum of direct manufacturing cost (1), indirect manufacturing costs (2), plant overhead (3) and by-product credit (4).

The general expenses associated with production of the product are covered in item 5. The general expenses includes provisions for administration expenses (5.1) for management salaries, legal fees, communications, etc.; distribution and sales expenses (5.2) and research and development costs (5.3).

Item 6 provides the total cost of the product for the particular process under consideration. The total product cost is the sum of the direct manufacturing cost (1), indirect manufacturing cost (2), plant overhead (3), by-product credit (4) and general expenses (5).

This method of estimation of total product cost is used widely in the chemical industry, particularly in evaluation of the process in the early research stage. Its early use aids in the decision making on whether to proceed with a process or to drop the process and investigate an alternate process. If the total product cost compares favorably with target cost goal (total product cost satisfies goal), then additional funding is merited for the process. However, if the total product cost does not compare favorably with target cost goal (total product cost exceeds goal), then additional funding and further investigation of the process is not merited.

TABLE A4-1

FACTORS FOR ESTIMATION OF PRODUCT COST

ITEMS	FACTORS
1. Direct Manfacturing Cost (Direct Charges)	
1. Raw Material	from prel. design
2. Direct Operating Labor	from prel. design
3. Utilities	from prel. design
4. Supervision and Clerical	15% of direct labor
5. Maintenance and repairs	10% of fixed capital
6. Operating Supplies	20% of maintenance
7. Laboratory Charges	15% of direct labor
2. Indirect Manfacturing Cost (Fixed Charges)	
1. Depreciation	10% of fixed capital
2. Lacal Taxes	2% of fixed capital
3. Insurances	1% of fixed capital
3. Plant Overhead	60% of labor in direct labor, Supervision and maintenance.
4. By-Product Credit	from prel. design
4a. Total Manfacturing Cost	1+2+3+4
5. General Expenses	
1. Administration	6% of manf. cost
2. Distribution and Sales	6% of manf. cost
3. Research and Development	3% of manf. cost
6. Total Product Cost	4a+5

APPENDIX A5 TYPICAL ELECTRICAL POWER COSTS

		Typical Electrical Power Costs: Average Cost, Statewide, Industrial Power (mills/kwh)				
		1977	1978	1979	1980	1981
1.	Arizona	27.8	29.9	32.2	--	--
2.	Louisiana	15.4	17.7	21.6	23-27*	33-38*
3.	Michigan	29.3	32.9	35.4	--	--
4.	Missouri	24.9	28.4	30.9	--	--
5.	Texas	21.5	23.6	27.3	33-37*	40-43*
6.	Source	Ref.24	Ref.23	Ref.22	Ref.20	Ref. 20

* Approximate values from bar charts

Note:

1. References are given on page 95
2. Ref. 27 gives a rate range for electrical power of 20-80 mils/kwh (Jan. 1979 dollars)