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FOSTER WHEELER DEVELOPMENT CORPORATION

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DRAFT

FINAL REPORT

FOR

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM RANGING IN TEMPERATURE FROM 300°F TO 550°F

(PHASE 1)

Period of Performance

September 30, 1978 to June 30, 1979

DOE Contract No. ET-78-C-03-2199

FWDC No. 9-41-4010

June 30, 1979

FOSTER WHEELER DEVELOPMENT CORPORATION

12 Peach Tree Hill Road, Livingston, New Jersey 07039

LEGAL NOTICE

FOREWORD

This is the Final Design Report of the work performed by Foster Wheeler Development Corporation under DOE Contract ET-78-C-03-2199 for Solar Production of Industrial Process Steam Ranging in Temperature From 300°F to 550°F. This report describes all aspects of systems analysis, performance, design, and economics of the solar energy steam system that will be integrated into the existing process steam system at Dow Chemical Company's Latex Manufacturing Plant in Dalton, Georgia.

Special acknowledgement must be made to the following personnel who contributed significantly to the successful completion of this work.

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DOE San Francisco Operations Office Oakland, California	William D. Nettleton, Jr. Janet M. Neville Robert H. Ragan
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Dow Chemical Company Resources Research, Texas Division	Roger Daniels
Dow Chemical Company Dalton, Georgia	Jim Geaman Joseph Szollosi
Lawrence Livermore Laboratories	Alan Casamajor William C. Dickinson
Sandia Laboratories	Duane Randall George W. Treadwell

Idaho Laboratories	James Mills
University of Maryland	Dave Anand
Solar Energy Research Institute	Ken Brown
Foster Wheeler Energy Corporation	Del Bress Joseph Conover Richard Nykin
Foster Wheeler Development Corporation	D. Allen G. Bhayana C. K. Cha A. C. Gangadharan M. D. Garber B. E. Manz R. Raghavan R. J. Zoschak
Suntec Systems, Inc.	Jon Davison George Kanappel

Foster Wheeler Development Corporation is honored to participate in the DOE Industrial Process Heat program. Our thanks to the many others at FWDC and FWEC who periodically provided their expertise.

Gopal D. Gupta
Program Manager
Foster Wheeler Development Corporation

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SECTION 1

EXECUTIVE SUMMARY

Section 1

EXECUTIVE SUMMARY

This section summarizes the Foster Wheeler Development Corporation/Dow Chemical Company Phase 1 solar industrial process steam system and includes a system schematic, a brief system description, general specifications of the major system components, expected system performance, and a cost estimate summary for Phases II and III. The objectives of Phase 1 are:

- Design a cost-effective solar steam generating system, using state-of-the-art components and technology, to supply steam for Dow Chemical Company's Dalton, Georgia, plant
- Predict the performance of the solar process steam plant
- Conduct a safety evaluation and an environmental impact assessment of the solar steam system
- Conduct an economic analysis to determine the potential economic benefits of a solar-augmented process steam production system compared with an existing fossil-fuel-fired steam generator
- Promote the project extensively to make it visible to industry and the general public.

1.1 INTRODUCTION

During the conceptual design of the system, five distributed collector concepts and three alternate system configurations were evaluated. As a result, the Suntec-Hexcel parabolic trough collector (see Subsection 2.1), and a system configuration which utilizes a heat-transfer fluid in the primary loop, were selected for this project. A brief description of the rationale for these selections is given in Section 2.

Section 3 describes the industrial application of the solar process steam system at Dow Chemical's latex plant. The plant's steam requirements and their effect on the interface between the existing system and the solar steam system are discussed, and the site and the criteria used in selecting it are outlined. Dow Chemical's Energy Conservation Plan and Environmental Impact Assessment are also included.

The solar collectors are described in Section 4 including collector specifications and the computer model utilized in calculating the solar collector output at Dalton, Georgia.

The systems analysis studies performed to determine the optimum system parameters are presented in Section 5. The computer model described in Section 4 was utilized extensively for this systems analysis. The amount of steam generated by the selected system is included in this section.

Section 6 details the economic analysis of the system. An economic model was developed which was used in the system studies presented in Section 5. This economic model is a simple, effective, and realistic assessment of the annualized cost of solar energy production. A detailed, industry-accepted type of life-cycle analysis and the conditions under which this solar process system would be economically attractive to the process industry are also presented.

The detail design of the solar process steam system is described in Section 7. Process and mechanical design descriptions and system drawings, equipment specifications, and instruments are included. The safety analysis of the final design is also presented in this section.

Section 8 concerns the performance testing and evaluation of the system. The performance calculation procedure and the instrumentation used in this performance evaluation are discussed. Three alternate data acquisition systems are evaluated and a final selection is made.

The plans and schedule for Phases II - Fabrication and Installation, are presented in Section 9. A list of references is provided in Section 10.

A number of appendices are included which contain the detail specifications, foundation calculations, and failure modes and effects analysis sheets.

1.2 SYSTEM SUMMARY

The following is a summary of the solar process steam system designed for Dow Chemical's Dalton plant. A schematic of the solar process steam system is given in Figure 1.1.

- System Description - The heat-transfer fluid circulates through the collectors and boils water in a kettle boiler to produce steam. An accumulator tank connected to the fluid loop serves both as expansion and dump tanks. No overnight freeze protection is required.
- Collector - Suntec-Hexcel collector, manufactured by Suntec Systems, Inc.; sun-hour tracking; north-south orientation with 10 deg tilt facing south; 15 rows; 9930 ft^2 collector area; smooth absorber tube with smooth inner plug.
- Storage - None required.
- Boiler - Kettle type; boiler surface area 250 ft^2; fitted with a pressure relief valve, low level alarm and a level transmitter to a feedwater flow control valve.
- Circulating Pump - Centrifugal pump, single speed, 3 hp motor.
- Accumulator Tank - 4 ft diameter x 8 ft long tank; fitted with pressure relief valve, level gage, and low level alarm; nitrogen purge.

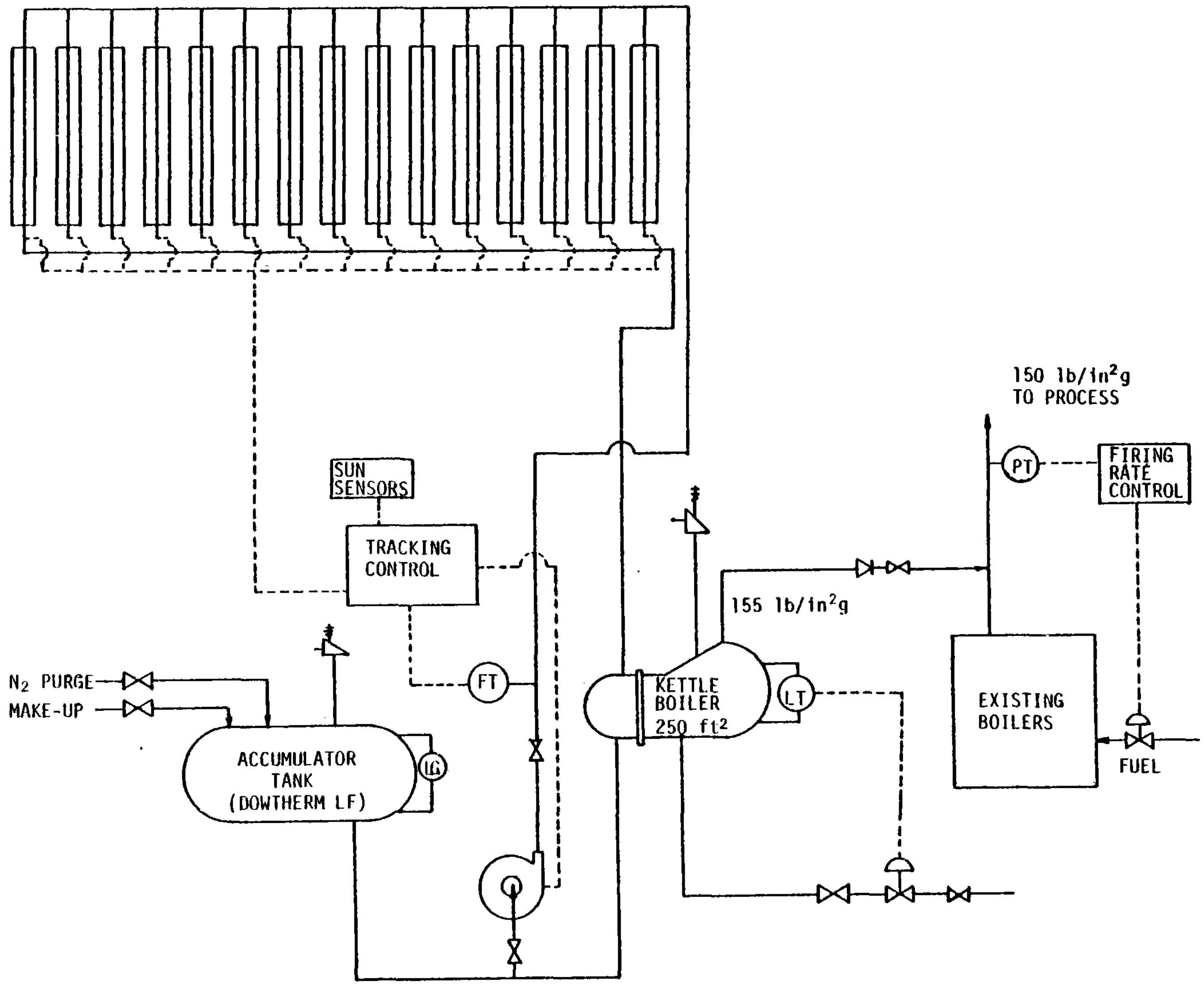

Figure 1.1 Schematic of the Selected Solar Steam System

FOSTER WHEELER DEVELOPMENT CORPORATION
JOHN BLIZARD RESEARCH CENTER
12 PEACH TREE HILL ROAD • LIVINGSTON, NEW JERSEY 07039 • PHONE 201-533-1100

May 24, 1979

U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

Attention: Mr. William D. Nettleton, Jr.
Engineering and Facilities Management Division

Gentlemen:

Subject: Solar Production of Industrial Process Steam
DOE Contract No. ET-78-C-03-2199
Draft Final Design Report

Enclosed is one copy of the subject report and an envelope containing four detail drawings. The report is approximately 80 percent complete; the missing items (figures and appendices) are designated with a page showing where they will appear in the Final Report.

Please note that this is a "working" report. Revisions are now being made, management is reviewing it, and a final editing cycle must be completed. Thus, the four detail drawings in the enclosed envelope were not reduced for inclusion in the body of the report. However, these and all other detail drawings, as well as the missing figures and appendices, will be included in the Final Report.

I am looking forward to meeting you on June 4 in McLean, Virginia. If you have any questions on this report before that time, please contact me.

Very truly yours,

Gopal Das Gupta

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Program Manager

GDG:clg
Enclosures

cc: Jerry Greyerbiehl
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Tom Lewis
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Roger Gaither

- Heat-Transfer Fluid - Dowtherm LF manufactured by Dow Chemical Company.

- Piping

- Collector inlet:*	2 in. Sch. 40 insulated
- Collector outlet:	2 in. Sch. 40 insulated
- No heat tracing	
- Feedwater piping:	1 in. Sch. 40 insulated
- Steam outlet piping:	3 in. Sch. 40 insulated.

- Design Conditions

- Dowtherm LF	
-- Boiler inlet temperature:	510°F
-- Boiler outlet temperature:	375°F
-- Fluid flow rate:	57 gal/min
-- Nitrogen pressure:	30 lb/in^{2}g.
- Steam/water	
-- Feedwater inlet temperature:	205°F
-- Steam outlet pressure:	155 lb/in^{2}g
-- Peak steam flow rate:	1500 lb/h.

- Thermal Performance

- Annual thermal collector output:	2842 x 10^6 Btu
- Annual piping thermal losses:	176 x 10^6 Btu
- Annual thermal losses from overnight cooling:	130 x 10^6 Btu
- Annual parasitic losses in pump, collector tracking motors, and automatic control system:	4.47 x 10^6 Btu electric (13.41 x 10^6 Btu equivalent thermal).

*Restriction orifices are installed in the absorber risers near the inlet manifold.

- Solar Steam Production
  - Annual thermal energy available for steam production: 2536×10^6 Btu
  - Estimated annual solar steam production: 2.5×10^6 Btu
  - Plant 2 steam requirement supplied by solar steam systems:
    - -- At peak solar conditions: 37.5 percent
    - -- Annual 7.1 percent.

1.3 COST-ESTIMATE SUMMARY

The following is a cost-estimate summary for Phases II and III of the project.

1.3.1 Phase II - Construction and Fabrication

Project Management	$ 60,268
Equipment Costs:	
Process (includes collectors, accumulator tank, boiler, pumps, and drum rack)	225,030
Other (includes piping, instrumentation, electrical, and testing)	69,670*
Subcontracted Items:	
Equipment Installation	177,665
Other Subcontracts (includes earthwork, roads and fencing, concrete foundations, gravel, building, insulation, painting, diking, and fire protection)	107,540
Engineering and Administrative (includes project engineering, drafting, procurement, field supervision)	91,278
Start-Up (includes operational testing and operation and maintenance manual)	18,308
TOTAL	$749,759

*The cost of Dowtherm LF is not included. Dow Chemical Company will provide the heat-transfer fluid at no cost to the project.

1.3.2 Phase III - Operation and Performance Evaluation Costs

Engineering and Administration		$ 53,000
Plant Operation and Maintenance		48,000
Travel		10,000
	TOTAL	$111,000

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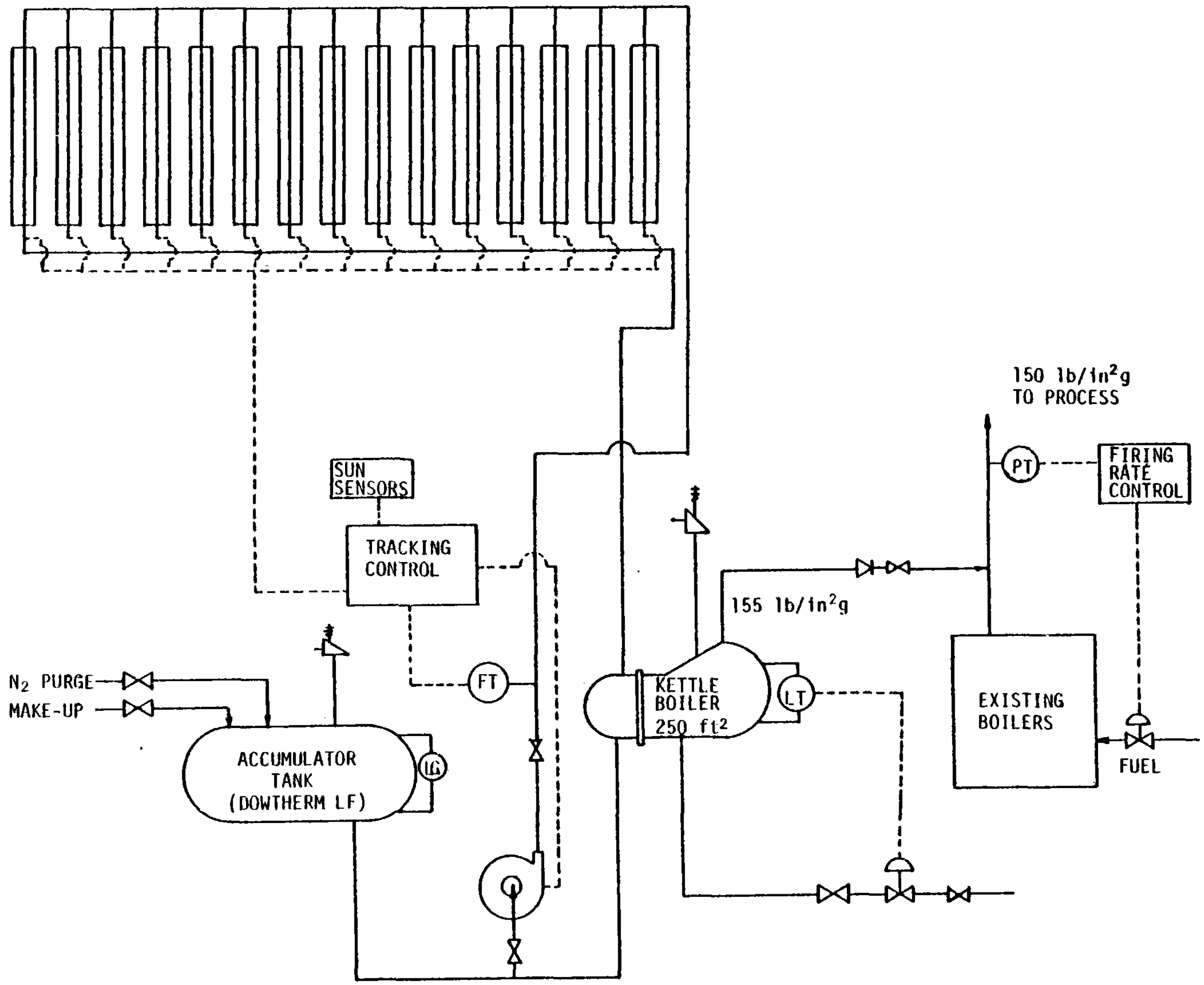

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SECTION 2

SELECTION OF THE SYSTEM CONCEPT AND SOLAR COLLECTORS

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SELECTION OF THE SYSTEM CONCEPT AND SOLAR COLLECTORS

This project began with the study and evaluation of various design configurations, from which a final candidate design configuration was selected and used for further detailed analysis and engineering. This selection process is briefly described in this section.

2.1 COLLECTOR SELECTION

During the conceptual design, several types of focusing collectors were compared to establish a suitable concept for solar steam production at the Dow Dalton plant. Comparison criteria included:

- Design features
- Development status
- Design complexity
- Thermal performance
- Land area utilization
- Drive/tracking complexity
- Relative cost
- Operating experience and maintainability.

Lens-type collector systems were excluded from these comparisons because of their limited concentration ratio and resultant low efficiency at elevated

temperatures. A preliminary investigation of four distributed collector system concepts included:

- Segmented reflector in planar array
- Parabolic trough with moving receiver
- Parabolic trough with stationary receiver
- Paraboloid; fully tracking.

The first three concepts were explored in detail. The paraboloid concept was not pursued further because it is still in development.

Five specific collector systems were evaluated. SLATS, manufactured by Suntec Systems, Inc., is a line-focusing collector. The remaining four (Jacobs-Del, Hexcel, Solar Kinetics, and Acurex) are parabolic trough collectors. Of these, three collectors (Hexcel, Solar Kinetics, and Acurex) are parabolic troughs with moving receivers. The Jacobs-Del collector is a parabolic trough with a stationary receiver. Early in 1979, Suntec Systems, Inc., purchased the solar collector business from Hexcel Corporation, Dublin, California. As a result, Suntec now manufactures the former Hexcel concentrating solar collector, now known as the Suntec-Hexcel Model SH-1655 parabolic trough solar collector.

The peak noon efficiencies of the five collectors are presented in Table 2.1. They are important because they were obtained from independent tests conducted by Sandia Laboratories in Albuquerque, New Mexico.[1*] They represent the most objective evaluation of the collector's thermal performance.

*Numbers designate references in Section 10.

Table 2.1 Peak Thermal Efficiencies of Various Collector Systems at Noon

Collector System	Thermal Performance at Noon*	
	Claimed Efficiency (%)	Demonstrated Efficiency (%)
SLATS	60	52.5
Suntec-Hexcel	60	59.5
Solar Kinetics	61	50.5
Acurex	50	Not Available
Jacobs-Del	52	Not Available

*At average fluid temperature through collector of 445°F.

The annual thermal energy collected by each collector is shown in Table 2.2. Both east-west and north-south collector orientations are considered. Only east-west orientation data are listed for SLATS because this collector cannot function in north-south orientation. All data were obtained from tests conducted by the manufacturers. The latitude of 34.8°N and average clear-day insolation values for Atlanta, Georgia, were used. Solar Kinetics calculations used the insolation values for Chattanooga, Tennessee, which are not significantly different from those for Atlanta, Georgia.

The installed costs for each of these collectors were reviewed and are also listed in Table 2.2. These costs are based on actual cost quotations from the collector manufacturers. Cost-effectiveness of each collector was evaluated in terms of the installed cost per million Btu collected annually by one square foot of collector area. Recognizing the potential for error in calculating

Table 2.2 Cost-Effectiveness of the Five Collector Systems

Collector Manufacturer	Installed Cost ($\$/ft^2$)	East-West Orientation		North-South Orientation	
		Annual Energy Collected* (10^3 Btu/ft^2)	Cost-Effectiveness ($\$/10^6$ Btu)	Annual Energy Collected* (10^3 Btu/ft^2)	Cost-Effectiveness ($\$/10^6$ Btu)
SLATS	30.0	210.0	142.9	---	---
Suntec-Hexcel	25.5	233.6	109.2	257.0	99.2
Solar Kinetics	25.0	211.2†	118.4	242.5†	103.1
Acurex	29.5	191.9	153.7	215.0	137.2
Jacobs-Del	27.5	138.4	198.7	156.6	175.6

*For average fluid temperature through collector of 445°F.
†Based on insolation data for Chatanooga, Tennessee. Other collector performance calculations use Atlanta, Georgia, insolation values.

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DATE: June 1979

annual energy and cost computations, these collectors can be ranked as follows in terms of cost effectiveness:

- Suntec-Hexcel/Solar Kinetics
- Acurex/SLATS
- Jacobs-Del.

The low ranking of the Jacobs-Del collector (which uses a glass mirror reflector) was surprising. A discussion with Jacobs-Del personnel revealed that this collector does not perform well at higher temperatures because an oversized receiver is used which renders low efficiencies at high temperatures. Based on the results presented in Table 2.2, the choice for the collector was narrowed to two candidates--Suntec-Hexcel and Solar Kinetics.

In order to make the final selection, information on operating experience and maintenance problems was gathered. This information is summarized in Table 2.3. Very little operational data are available for the Solar Kinetics collector. In contrast, the Suntec-Hexcel collector has been used quite extensively and today is a reasonably reliable system.

The major difference between these two collectors is in their receiver design. Solar Kinetics has a "sealed receiver" in which the receiver tube is encapsulated by a Pyrex glass tube in order to reduce the receiver convective losses. Each Pyrex glass tube contains a sealing ring every 10 ft. The sealing ring is designed to minimize the likelihood of any dust or moisture getting between the glass cover and the receiver tube. However, in the event that any

Table 2.3 Operating Experience and Maintainability of Suntec-Hexcel and Solar Kinetics Collectors

Criterion	Suntec-Hexcel	Solar Kinetics
Operating Experience		
Laboratory	Extensive	Adequate
Semi-Industrial	Extensive	Limited (less than 6 mo.)
Industrial	Adequate (2 yr)	None
Maintainability		
Receiver	Unsealed receiver	Sealed receiver
	Higher probability of dust and moisture entering glass cover	Lower probability of dust and moisture entering glass cover
	Easy maintenance	Extremely difficult maintenance
Tracking System	Mechanical	Hydraulic
	No significant problems	Limited experience
Reflector	Easy maintenance	Easy maintenance

dust or moisture is trapped therein, it is extremely difficult and expensive to clean the receiver.

The Suntec-Hexcel receiver has only a semicircular Pyrex glass cover facing the reflector on the receiver tube.[2] The remaining semicircle insulates the receiver tube. This design provides inherently less protection from dust or moisture getting between the glass cover and the receiver tube. However, the receiver is easily and inexpensively cleaned.

In order to evaluate the maintainability of the two systems quantitatively, records of their service experience at the Dow Dalton site would be required. After discussions with Foster Wheeler, Dow, and Sandia personnel, it was decided that selecting a system which is easy to maintain would be safer. Therefore, the Suntec-Hexcel collector was chosen.

2.2 SOLAR SYSTEM CONCEPT SELECTION

The three alternate design configurations evaluated are described below.

2.2.1 System Alternate 1

This system utilized a heat transport loop which delivers hot organic fluid from the collectors to the boiler and recirculates the fluid to the collectors via a circulating pump. A boiler is used in which the hot fluid from the collectors furnishes the heat required to convert the feedwater from the existing steam plant into saturated steam at 155 lb/in^2g. An accumulator tank is required for possible overnight draining, and draining if a leak forms in the circulation loop. This tank accommodates the thermal expansion of the

fluid after the temperature rises from the morning cold start to the normal operating conditions. A nitrogen blanket is provided over the organic fluid.

The advantages of this system are:

- Low pressure in the receiver and piping
- Proper fluid eliminates overnight draining or heat tracing.

The disadvantages of the system are:

- Organic fluid may be costly
- Leaks may be hazardous
- Boiler leaks may lead to contamination of heat-transfer fluid
- Requires an accumulator tank and inert gas blanketing, possibly increasing cost.

2.2.2 System Alternate 2

Pressurized water circulates through the collectors in this system and a flash boiler is used to generate steam. The feedwater flow rate is regulated by a level controller. The water pressure in this system is not large enough to affect receiver design.

The advantages of this system are:

- Organic fluid, accumulator tank, and inert gas blanketing are not required.
- Average temperature of the fluid in the collector is lower, thus significantly increasing collector efficiency.

temperatures. A preliminary investigation of four distributed collector system concepts included:

- Segmented reflector in planar array
- Parabolic trough with moving receiver
- Parabolic trough with stationary receiver
- Paraboloid; fully tracking.

The first three concepts were explored in detail. The paraboloid concept was not pursued further because it is still in development.

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The peak noon efficiencies of the five collectors are presented in Table 2.1. They are important because they were obtained from independent tests conducted by Sandia Laboratories in Albuquerque, New Mexico.[1*] They represent the most objective evaluation of the collector's thermal performance.

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Industrial	Adequate (2 yr)	None
Maintainability		
Receiver	Unsealed receiver	Sealed receiver
	Higher probability of dust and moisture entering glass cover	Lower probability of dust and moisture entering glass cover
	Easy maintenance	Extremely difficult maintenance
Tracking System	Mechanical	Hydraulic
	No significant problems	Limited experience
Reflector	Easy maintenance	Easy maintenance

dust or moisture is trapped therein, it is extremely difficult and expensive to clean the receiver.

The Suntec-Hexcel receiver has only a semicircular Pyrex glass cover facing the reflector on the receiver tube.[2] The remaining semicircle insulates the receiver tube. This design provides inherently less protection from dust or moisture getting between the glass cover and the receiver tube. However, the receiver is easily and inexpensively cleaned.

In order to evaluate the maintainability of the two systems quantitatively, records of their service experience at the Dow Dalton site would be required. After discussions with Foster Wheeler, Dow, and Sandia personnel, it was decided that selecting a system which is easy to maintain would be safer. Therefore, the Suntec-Hexcel collector was chosen.

2.2 SOLAR SYSTEM CONCEPT SELECTION

The three alternate design configurations evaluated are described below.

2.2.1 System Alternate 1

This system utilized a heat transport loop which delivers hot organic fluid from the collectors to the boiler and recirculates the fluid to the collectors via a circulating pump. A boiler is used in which the hot fluid from the collectors furnishes the heat required to convert the feedwater from the existing steam plant into saturated steam at 155 lb/in^2g. An accumulator tank is required for possible overnight draining, and draining if a leak forms in the circulation loop. This tank accommodates the thermal expansion of the

fluid after the temperature rises from the morning cold start to the normal operating conditions. A nitrogen blanket is provided over the organic fluid.

The advantages of this system are:

- Low pressure in the receiver and piping
- Proper fluid eliminates overnight draining or heat tracing.

The disadvantages of the system are:

- Organic fluid may be costly
- Leaks may be hazardous
- Boiler leaks may lead to contamination of heat-transfer fluid
- Requires an accumulator tank and inert gas blanketing, possibly increasing cost.

2.2.2 System Alternate 2

Pressurized water circulates through the collectors in this system and a flash boiler is used to generate steam. The feedwater flow rate is regulated by a level controller. The water pressure in this system is not large enough to affect receiver design.

The advantages of this system are:

- Organic fluid, accumulator tank, and inert gas blanketing are not required.
- Average temperature of the fluid in the collector is lower, thus significantly increasing collector efficiency.

temperatures. A preliminary investigation of four distributed collector system concepts included:

- Segmented reflector in planar array
- Parabolic trough with moving receiver
- Parabolic trough with stationary receiver
- Paraboloid; fully tracking.

The first three concepts were explored in detail. The paraboloid concept was not pursued further because it is still in development.

Five specific collector systems were evaluated. SLATS, manufactured by Suntec Systems, Inc., is a line-focusing collector. The remaining four (Jacobs-Del, Hexcel, Solar Kinetics, and Acurex) are parabolic trough collectors. Of these, three collectors (Hexcel, Solar Kinetics, and Acurex) are parabolic troughs with moving receivers. The Jacobs-Del collector is a parabolic trough with a stationary receiver. Early in 1979, Suntec Systems, Inc., purchased the solar collector business from Hexcel Corporation, Dublin, California. As a result, Suntec now manufactures the former Hexcel concentrating solar collector, now known as the Suntec-Hexcel Model SH-1655 parabolic trough solar collector.

The peak noon efficiencies of the five collectors are presented in Table 2.1. They are important because they were obtained from independent tests conducted by Sandia Laboratories in Albuquerque, New Mexico.[1*] They represent the most objective evaluation of the collector's thermal performance.

*Numbers designate references in Section 10.

Table 2.1 Peak Thermal Efficiencies of Various Collector Systems at Noon

Collector System	Thermal Performance at Noon*	
	Claimed Efficiency (%)	Demonstrated Efficiency (%)
SLATS	60	52.5
Suntec-Hexcel	60	59.5
Solar Kinetics	61	50.5
Acurex	50	Not Available
Jacobs-Del	52	Not Available

*At average fluid temperature through collector of 445°F.

The annual thermal energy collected by each collector is shown in Table 2.2. Both east-west and north-south collector orientations are considered. Only east-west orientation data are listed for SLATS because this collector cannot function in north-south orientation. All data were obtained from tests conducted by the manufacturers. The latitude of 34.8°N and average clear-day insolation values for Atlanta, Georgia, were used. Solar Kinetics calculations used the insolation values for Chattanooga, Tennessee, which are not significantly different from those for Atlanta, Georgia.

The installed costs for each of these collectors were reviewed and are also listed in Table 2.2. These costs are based on actual cost quotations from the collector manufacturers. Cost-effectiveness of each collector was evaluated in terms of the installed cost per million Btu collected annually by one square foot of collector area. Recognizing the potential for error in calculating

Table 2.2 Cost-Effectiveness of the Five Collector Systems

Collector Manufacturer	Installed Cost ($\$/ft^2$)	East-West Orientation: Annual Energy Collected* (10^3 Btu/ft^2)	East-West Orientation: Cost-Effectiveness ($\$/10^6$ Btu)	North-South Orientation: Annual Energy Collected* (10^3 Btu/ft^2)	North-South Orientation: Cost-Effectiveness ($\$/10^6$ Btu)
SLATS	30.0	210.0	142.9	---	---
Suntec-Hexcel	25.5	233.6	109.2	257.0	99.2
Solar Kinetics	25.0	211.2†	118.4	242.5†	103.1
Acurex	29.5	191.9	153.7	215.0	137.2
Jacobs-Del	27.5	138.4	198.7	156.6	175.6

*For average fluid temperature through collector of 445°F.
†Based on insolation data for Chatanooga, Tennessee. Other collector performance calculations use Atlanta, Georgia, insolation values.

annual energy and cost computations, these collectors can be ranked as follows in terms of cost effectiveness:

- Suntec-Hexcel/Solar Kinetics
- Acurex/SLATS
- Jacobs-Del.

The low ranking of the Jacobs-Del collector (which uses a glass mirror reflector) was surprising. A discussion with Jacobs-Del personnel revealed that this collector does not perform well at higher temperatures because an oversized receiver is used which renders low efficiencies at high temperatures. Based on the results presented in Table 2.2, the choice for the collector was narrowed to two candidates--Suntec-Hexcel and Solar Kinetics.

In order to make the final selection, information on operating experience and maintenance problems was gathered. This information is summarized in Table 2.3. Very little operational data are available for the Solar Kinetics collector. In contrast, the Suntec-Hexcel collector has been used quite extensively and today is a reasonably reliable system.

The major difference between these two collectors is in their receiver design. Solar Kinetics has a "sealed receiver" in which the receiver tube is encapsulated by a Pyrex glass tube in order to reduce the receiver convective losses. Each Pyrex glass tube contains a sealing ring every 10 ft. The sealing ring is designed to minimize the likelihood of any dust or moisture getting between the glass cover and the receiver tube. However, in the event that any

Table 2.3 Operating Experience and Maintainability of Suntec-Hexcel and Solar Kinetics Collectors

Criterion	Suntec-Hexcel	Solar Kinetics
Operating Experience		
Laboratory	Extensive	Adequate
Semi-Industrial	Extensive	Limited (less than 6 mo.)
Industrial	Adequate (2 yr)	None
Maintainability		
Receiver	Unsealed receiver	Sealed receiver
	Higher probability of dust and moisture entering glass cover	Lower probability of dust and moisture entering glass cover
	Easy maintenance	Extremely difficult maintenance
Tracking System	Mechanical	Hydraulic
	No significant problems	Limited experience
Reflector	Easy maintenance	Easy maintenance

dust or moisture is trapped therein, it is extremely difficult and expensive to clean the receiver.

The Suntec-Hexcel receiver has only a semicircular Pyrex glass cover facing the reflector on the receiver tube.[2] The remaining semicircle insulates the receiver tube. This design provides inherently less protection from dust or moisture getting between the glass cover and the receiver tube. However, the receiver is easily and inexpensively cleaned.

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2.2 SOLAR SYSTEM CONCEPT SELECTION

The three alternate design configurations evaluated are described below.

2.2.1 System Alternate 1

This system utilized a heat transport loop which delivers hot organic fluid from the collectors to the boiler and recirculates the fluid to the collectors via a circulating pump. A boiler is used in which the hot fluid from the collectors furnishes the heat required to convert the feedwater from the existing steam plant into saturated steam at 155 lb/in^2g. An accumulator tank is required for possible overnight draining, and draining if a leak forms in the circulation loop. This tank accommodates the thermal expansion of the

fluid after the temperature rises from the morning cold start to the normal operating conditions. A nitrogen blanket is provided over the organic fluid.

The advantages of this system are:

- Low pressure in the receiver and piping
- Proper fluid eliminates overnight draining or heat tracing.

The disadvantages of the system are:

- Organic fluid may be costly
- Leaks may be hazardous
- Boiler leaks may lead to contamination of heat-transfer fluid
- Requires an accumulator tank and inert gas blanketing, possibly increasing cost.

2.2.2 System Alternate 2

Pressurized water circulates through the collectors in this system and a flash boiler is used to generate steam. The feedwater flow rate is regulated by a level controller. The water pressure in this system is not large enough to affect receiver design.

The advantages of this system are:

- Organic fluid, accumulator tank, and inert gas blanketing are not required.
- Average temperature of the fluid in the collector is lower, thus significantly increasing collector efficiency.

temperatures. A preliminary investigation of four distributed collector system concepts included:

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The three alternate design configurations evaluated are described below.

2.2.1 System Alternate 1

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The advantages of this system are:

- Low pressure in the receiver and piping
- Proper fluid eliminates overnight draining or heat tracing.

The disadvantages of the system are:

- Organic fluid may be costly
- Leaks may be hazardous
- Boiler leaks may lead to contamination of heat-transfer fluid
- Requires an accumulator tank and inert gas blanketing, possibly increasing cost.

2.2.2 System Alternate 2

Pressurized water circulates through the collectors in this system and a flash boiler is used to generate steam. The feedwater flow rate is regulated by a level controller. The water pressure in this system is not large enough to affect receiver design.

The advantages of this system are:

- Organic fluid, accumulator tank, and inert gas blanketing are not required.
- Average temperature of the fluid in the collector is lower, thus significantly increasing collector efficiency.

The disadvantages of the system are:

- Freeze protection is required.
- Location at which flashing occurs is subjected to mechanical wear, requiring special design considerations.
- Bigger pump may be required, increasing parasitic power requirements.

2.2.3 System Alternate 3

In this system, water is partially boiled in the collector and circulated through a steam drum where steam is separated from water. Feedwater is added to the steam drum at a rate regulated by a level controller on the drum.

The advantages of this system are:

- Organic fluid, accumulator tank, and inert gas blanketing are not required.
- Average temperature of the fluid in the collector is the lowest of the three systems. Consequently, the highest collector efficiency would be expected.
- Pump size may be the same as in System Alternate 1. Lower parasitic power requirement than Alternate 2.

The disadvantages of this system are:

- Freeze protection is required
- Flow instability is possible
- Absorber tube may be more prone to corrosion.

A comparison of these systems indicated that System Alternate 3 was the most cost-effective,[3] followed by System Alternate 1. System Alternate 2 was the least cost-effective concept. However, System Alternate 3 is still under development and there are some problems which need to be investigated in detail. Therefore, System Alternate 3 was not selected, and was replaced by the next most cost-effective concept, System Alternate 1.

SECTION 3

INDUSTRIAL APPLICATION AT DOW CHEMICAL COMPANY

Section 3

INDUSTRIAL APPLICATION AT DOW CHEMICAL COMPANY

3.1 GENERAL

Dow Chemical Company, with headquarters in Midland, Michigan, is one of the four largest chemical manufacturing companies in the United States. Dow Chemical manufacturers more than 1100 chemical products including industrial, agricultural, pharmaceutical and aromatic chemicals, plastics (including latex), metals, and packaging materials.

The company has had one of the most rapid growth rates in the chemical industry, with 1978 sales of more than $6.9 billion. This growth record has resulted from a broad, fundamental base in research as well as experience and capability in product manufacture.

Dow Chemical operates large chemical complexes in Midland, Michigan; Freeport, Texas; Pittsburg, California; and Plaquemine, Louisiana; and smaller chemical production units in other areas. Total worldwide employment is more than 53,200.

Dow Chemical is the largest cogenerator of steam and electrical power in the United States and produces nearly two-thirds of its steam and electrical power needs for its manufacturing facilities through cogeneration.

Early solar energy activities at Dow Chemical concerned the development of insulated heat-trapping systems. More recent efforts have been directed toward development of improved heat-sink materials. The company's research into geothermal power has been in the utilization of geothermal steam and of hot geo-pressured resources.

3.2 DESCRIPTION OF THE SELECTED INDUSTRIAL PROCESS

The proposed solar energy plant will supply process steam at 150 lb/in^2g to the Dow Dalton plant. This plant is the world's largest producer of styrene-butadiene rubber latex (SBR) which is used as carpet backing, supplying about 20 percent of this latex market.

Latex is a generic term for families of vinyl-based polymers, copolymers, and terpolymers produced by emulsion polymerization. The important latex families include styrene-butadiene copolymers, vinyl-vinylidene copolymers, vinylacetate, and acrylates. Latex is used to produce adhesives, protective coatings, films, gums, elastomers, and synthetic fibers.

Latex production of all kinds in the United States is between 1.75 and 2×10^{12} lb/yr. Latex as an end product and/or polymers and copolymers resulting from latex are produced for their specific chemical and physical properties. These properties depend on the:

- Chemical composition of the monomers and, in the case of copolymers and terpolymers, the ratio of Monomer A to Monomers B and C
- Ratio of monomer(s) to water
- Polymerization recipe, i.e., catalyst (initiator) buffer, and emulsifier
- Polymerization schedule, i.e., time and temperature

- Polymerization terminating agent
- Methods employed for latex finishing
- Mixing or agitation rate (stirring) and kettle size.

Although the science of emulsion polymerization to produce latex is well established, the "art" of producing latex, i.e., production of a specific latex to perform a specific function, consists of closely guarded trade secrets. This art is concerned with polymerization recipes, e.g., catalysts, emulsifiers, polymerization schedules, agitation, and finishing. For those skilled in this art, it is readily apparent that the combination and permutation of latex recipes, composition and schedule, results in unlimited product possibilities. Figure 3.1 is a schematic of an SBR latex process.

Steam is used to heat the reaction kettle and for steam distillation of the unreacted monomer from the raw latex. Steam distillation is not unique to the production of latex. It is a standard unit operation in many chemical processes. Therefore, the demonstration of the technology of solar-produced process steam as applied to latex production has a broad application throughout the chemical-processing industry, e.g., the separation of high-boiling chemical mixtures where the components are sensitive to high temperatures (azeotropic distillation) and the conservation of energy. Steam is used in the petrochemical industry to provide process heat; to operate pumps, compressors, vacuum jets, and refrigeration units; and to generate power. Except for power generation and in instances where either high temperature or pressure is required for chemical

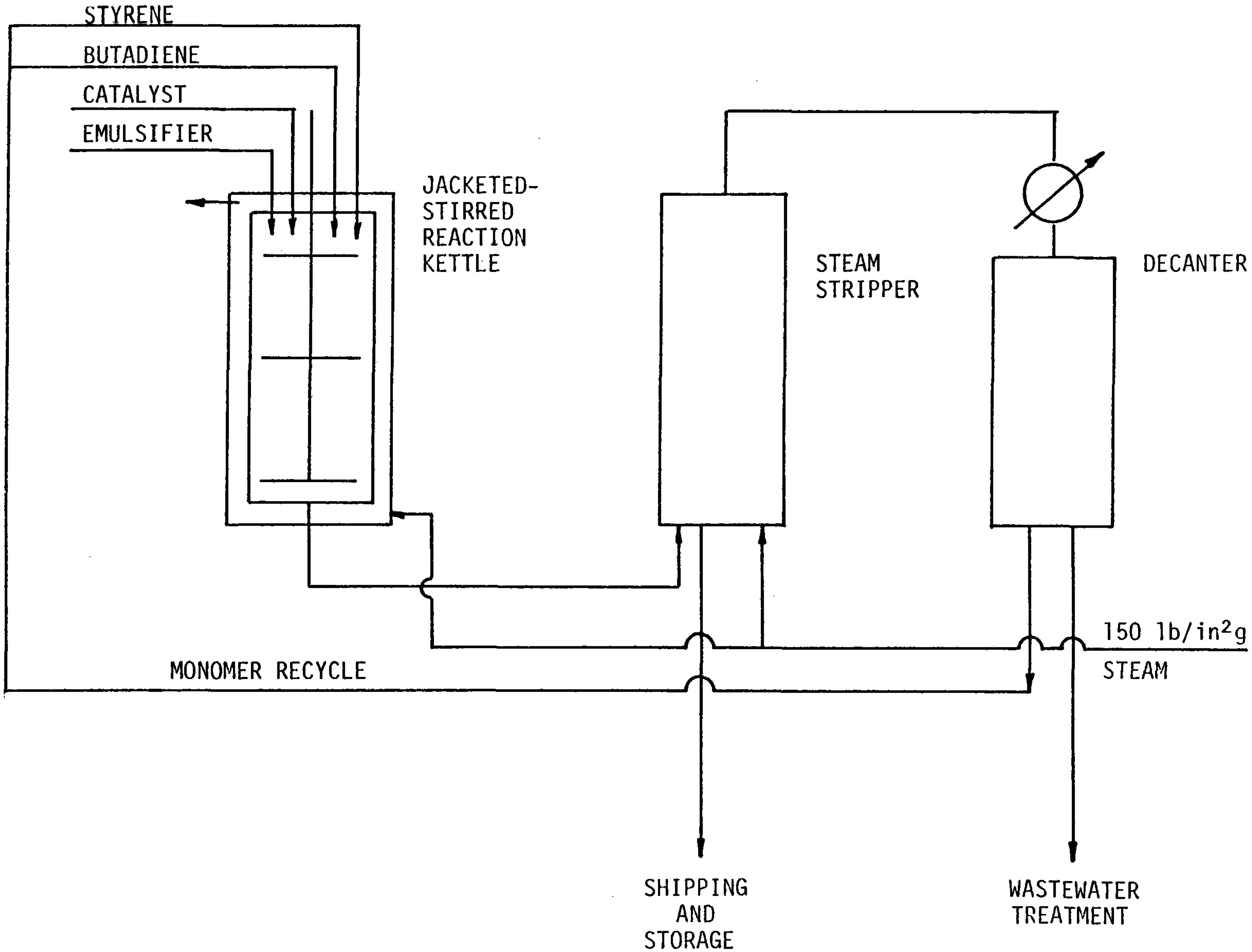

Figure 3.1 Schematic of SBR Latex Process

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processing, more than 50 percent of the heat requirement in a typical petrochemical complex is supplied through 150-lb/in^{2}g steam. Table 3.1 compares temperature, pressure, and average usage.

Table 3.1 Industrial Process Steam Usage vs. Steam Conditions

Pressure (lb/in^{2}g)	Temperature (°F)	Average Usage (%)
150	366	56
250	406	21
400	448	23

3.3 PLANT STEAM REQUIREMENTS

In 1978, steam production at Dow's Dalton plant consumed 103 x 10^9 Btu of energy from fuel oil and natural gas, with 75 percent obtained from natural gas and 25 percent from No. 2 fuel oil. Nearly two-thirds of the steam produced was used by the stripping process, which utilized steam at a pressure of 2 to 150 lb/in^{2}g. Approximately 1500 Btu is required to produce 1 lb of SBR latex.

The steam used by the Dalton plant is produced at 150 lb/in^{2}g by two package boilers of 20,000-lb/h nominal capacity each and is distributed to various processes within the plant. Average steam consumption is 11,000 lb/h. The maximum steam rate is 20,000 lb/h with intermittent peaks up to about 25,000 lb/h, and the minimum, practical steam rate is about 5000 lb/h. Stripping is done in batch units in Plant 1 and a continuous unit in Plant 2. Maximum batch stripper steam rate is 12,000 lb/h with peaks of 16,000 lb/h. The minimum practical load for batch units is 1500 to 2000 lb/h. For the continuous stripper the minimum rate is 3500 lb/h, and the maximum rate is 4000 lb/h. Typical steam-use profiles for each stripper type in the plant are shown in Figure 3.2. The solar steam-generating system is intended primarily as a supplementary steam supply system for the continuous stripper.

3.4 INTERFACE OF SOLAR STEAM SYSTEM WITH INDUSTRIAL PROCESS

The solar steam system will be easily integrated with the existing plant steam system, utilizing feedwater from the existing feedwater supply-and-deliver system to the existing steam main.

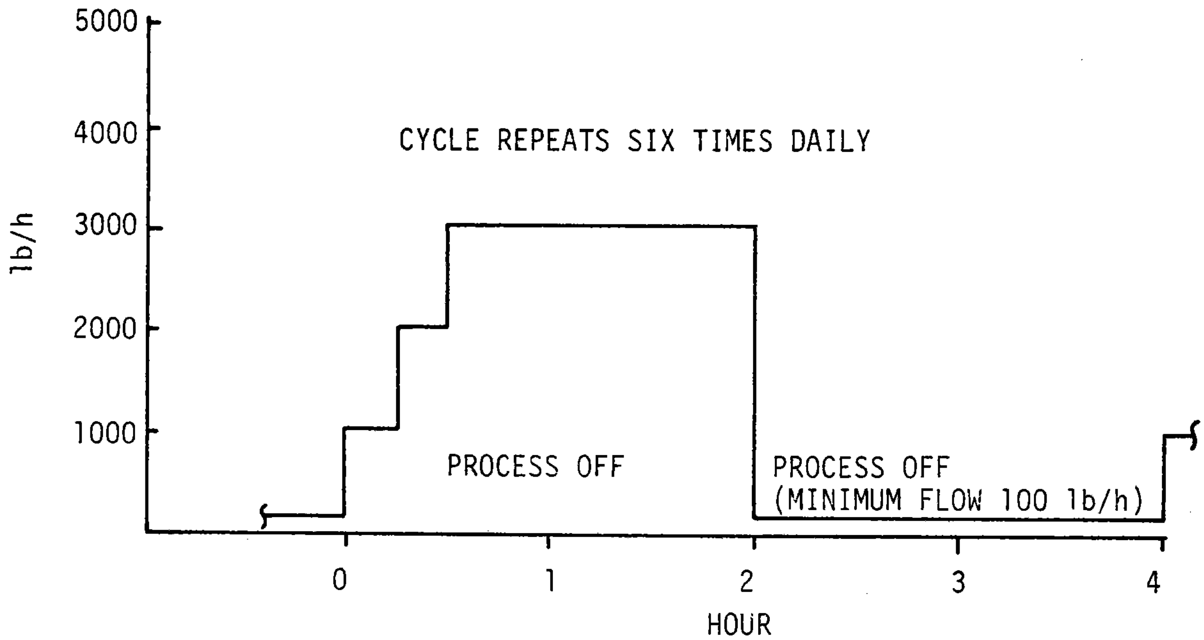
3.5 SITE SELECTION

The Dow Dalton plant is located about 28 miles south of Chattanooga, Tennessee, and 94 miles north of Atlanta, Georgia, just off Interstate 75. The site is easily accessible by road as well as by rail. The plant is located at 34°43' latitude.

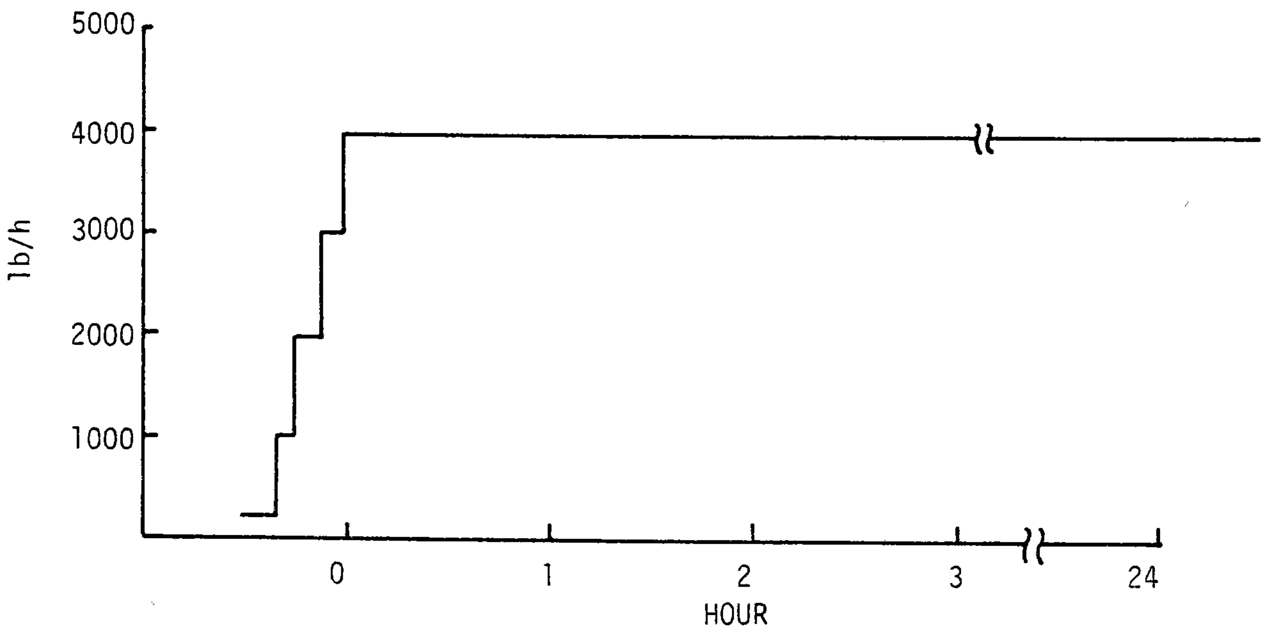
The aerial and plan views of the plant shown in Figures 3.3 and 3.4, show the relative location of the process plant units, boiler house, fuel-oil tanks, water tank, collector field warehouse, and administration building. Dow Chemical owns several hundred acres of land to the north and northeast of the existing facilities.

3.5.1 Shadow From Neighboring Structures

The only structure which may cast any shadows on the collectors is a water tank located 120 ft east of the collector site. The water tank is 25 ft



a. Batch Stripper



b. Continuous Stripper

Figure 3.2 Typical Steam-Use Profiles for Batch and Continuous Strippers at Dow's Dalton, Georgia, Plant

FIGURE 3.3 AERIAL VIEW OF DOW'S DALTON PLANT

(Being Prepared)

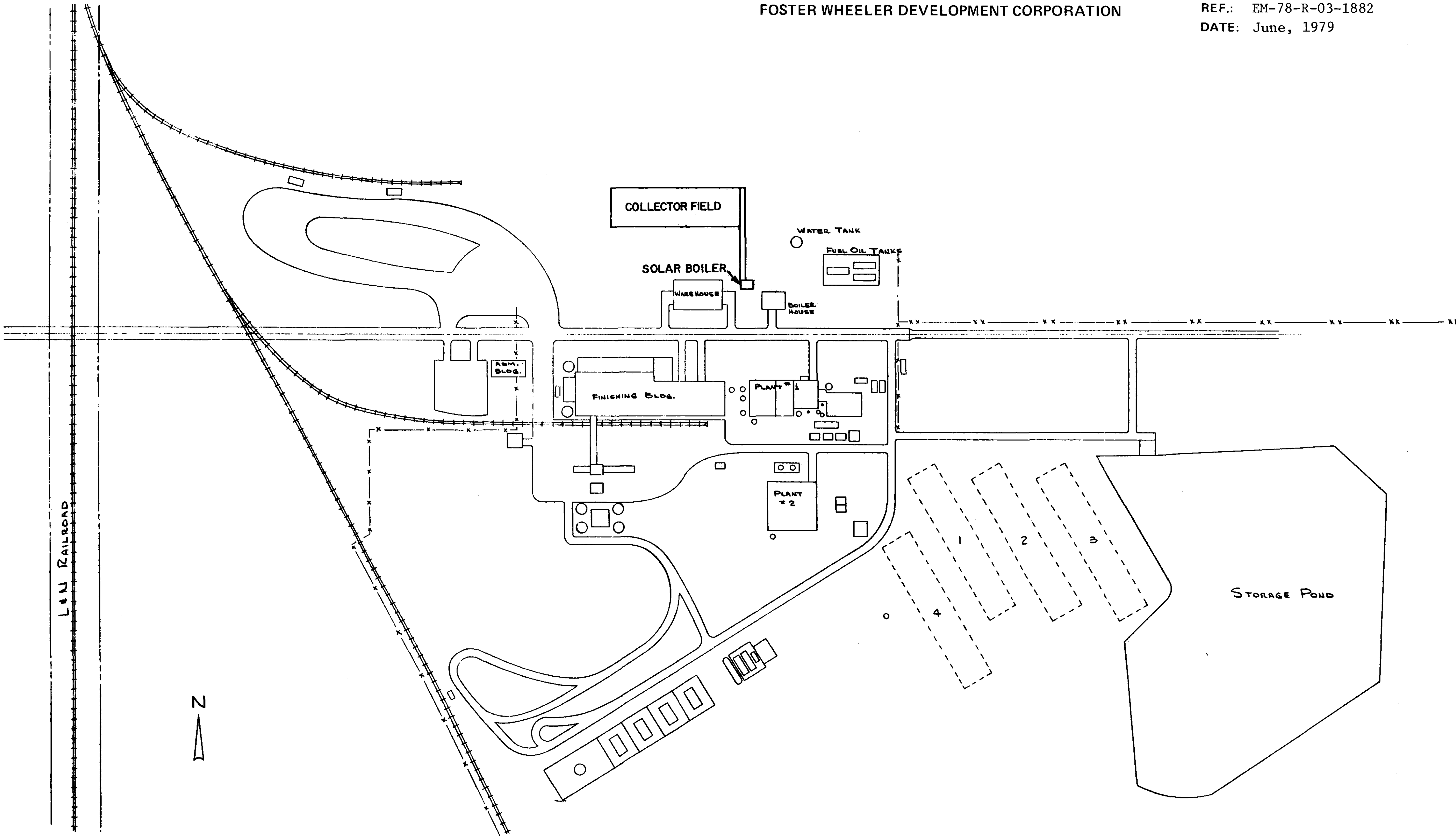


Figure 3.4 Plan View of Dow's Dalton Plant

in diameter, 33 ft high, and is located at an elevation of 117 ft. The plan and elevation of the relative locations of the water tank and the collector field are shown in Figure 3.5. This figure was utilized to develop the range of sun altitude and azimuth for which the water tank could cast a shadow on the collector field. This shadow zone is depicted on the sun chart[4] shown in Figure 3.6 for 35°N latitude. This figure shows that the months of June, July, and August are completely out of the shadow zone. For the remaining months, the shadows fall only before 7:45 a.m.

From the solar energy calculations presented in Subsection 4.6 of this report, it can be seen that the collector operation does not start in the morning until an adequate amount of insolation is available. An approximate locus of the collector start-up times is also shown in Figure 3.6. There is practically no interference between the collector start-up times and the shadow zone. This indicates that there will be no energy loss from the water tank shadowing the collector field.

3.5.2 Site Selection Considerations

The solar steam system will be built with the collector field located north of the warehouse. This location is ideal in many ways:

- Substantial land is available north of this location for future expansion.
- The existing boiler house, water tank, and warehouse are ideally located for use in the solar plant.
- The solar collectors are distinctly separated from the process plant units, allowing easy access to the solar plant for general maintenance and visits by the project team members, DOE, and the general public.

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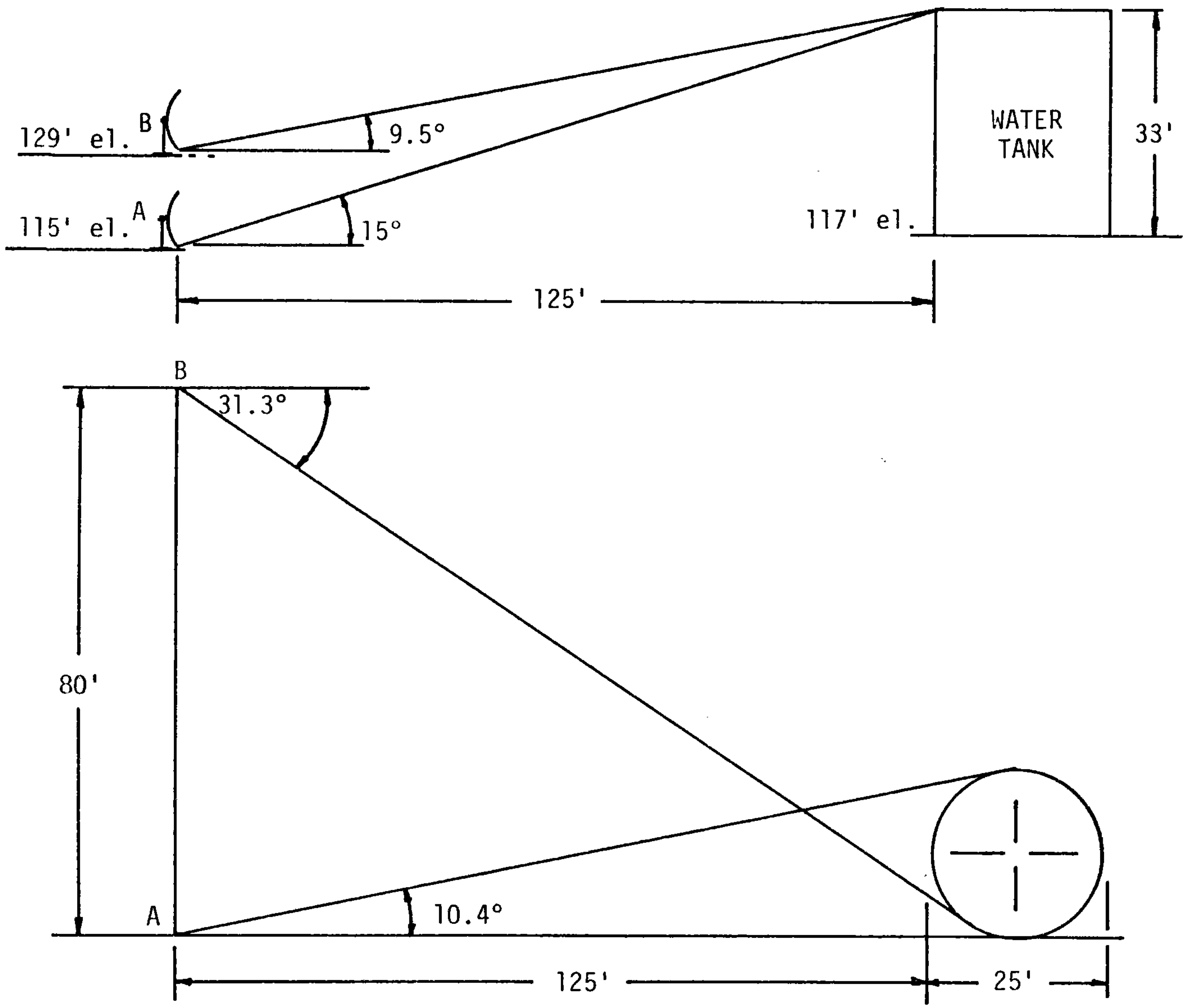


Figure 3.5 Shadow Angles of the Water Tank on the Collector Field

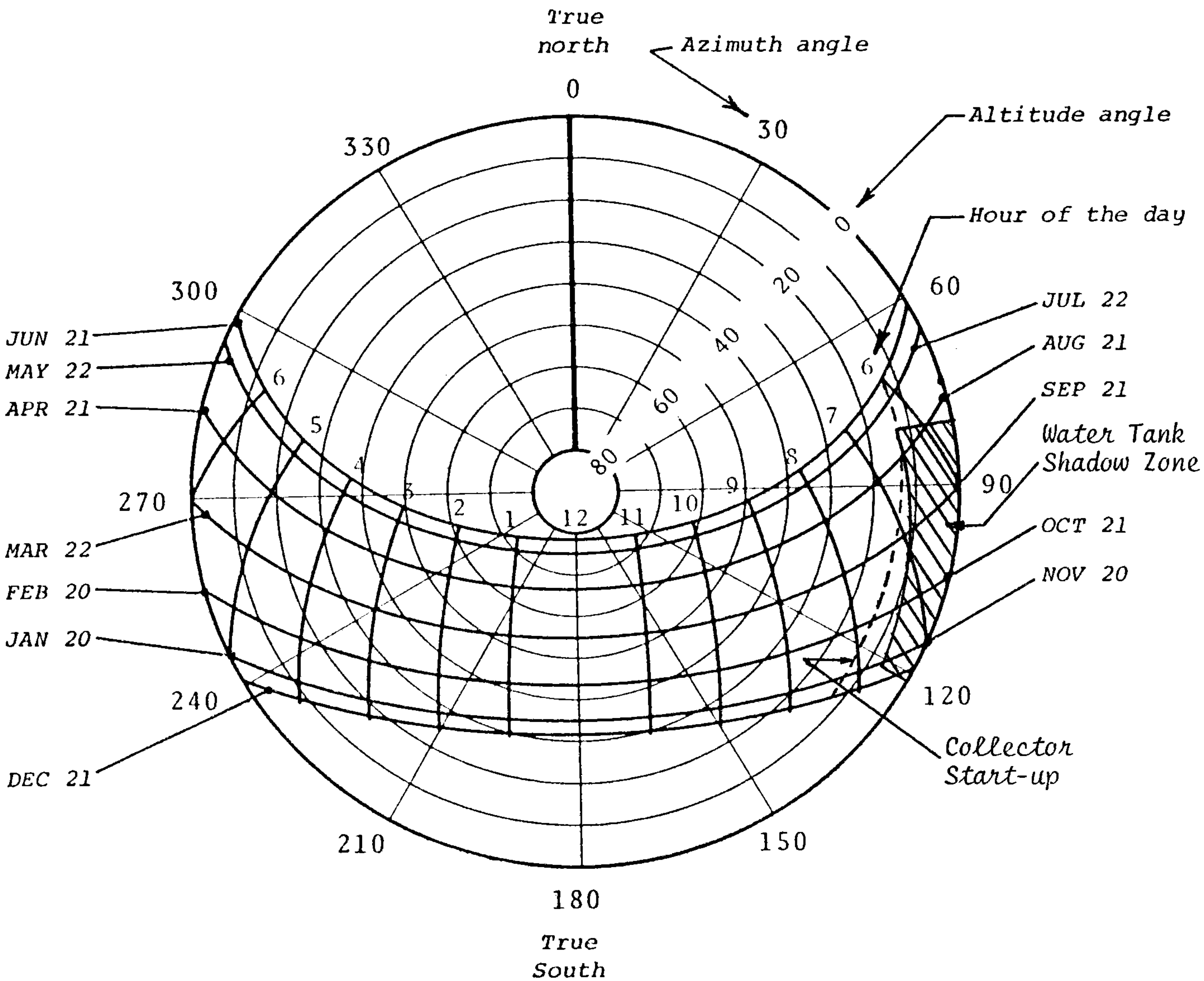


Figure 3.6 Water Tank Shadow Zone and Collector Start-Up Times

Site selection has been directed toward:

- Minimizing piping costs. The solar auxiliary boiler house has been located between the warehouse and existing boiler house rather than in the field.
- Minimizing the cost of site preparation. The collector field has a 10 deg tilt facing south to maximize the energy output of the collector field. Grade elevation of the lowest edge of the collector field will be 115 ft. For this configuration, the land excavated in the upper levels would be utilized in filling the lower levels, minimizing the cost of grading and compacting.
- Avoiding any shadow from the neighboring structures. The only structure which could shadow the mirrors in the early morning hours is a 33-ft-high water tank. As shown in Subsection 3.5.1, there will be no energy loss caused by the water tank shadowing the collector field.
- Ease of maintenance. A 10-ft-wide access road with a 5-ft-wide shoulder facilitates the general maintenance of the collectors.

3.6 DOW CHEMICAL'S ENERGY CONSERVATION PROGRAM

As a large energy consumer, Dow Chemical has engaged for the past 25 years in research on new and improved sources of energy. During the recent escalation of petroleum costs, extensive effort has been directed toward energy conservation processes. This effort in the past few years has resulted in a 20 percent reduction in the energy input required to produce an average pound of product.

Through proprietary in-house energy conservation programs, energy consumption has been reduced by one-third since start-up of the Dalton plant. Current projects strive for further energy reductions approaching one-half the energy required, on a per-pound basis, over the initial plant design. Implementation of this cost-effective solar demonstration program could reduce Dow Chemical's energy requirement an additional 20 to 30 percent.

The Dalton plant is ideally suited for demonstration of solar energy production capabilities because it is large enough to make a significant contribution to the U.S. energy conservation program and because Dow's contributions in the areas of cogeneration, use of alternative energy sources, and energy conservation will lend the industry credibility. Finally, the Dalton plant is small enough that capital investment, by industry standards, will be relatively small.

3.7 ENVIRONMENTAL IMPACT ASSESSMENT

The purpose of this assessment is to provide early identification of potential environmental impacts associated with the project so that necessary corrections may be incorporated into the project design.

3.7.1 Description of Existing Environment

The estimated 1978 population of Dalton, Georgia, is 25,000, making it the largest city in Whitfield County. Dalton is the "tufted carpet center of the world" with more than 80 percent of the world's carpet production concentrated within a 75-mile radius. The plant site covers more than 450 acres adjacent to the Conasauga River. The terrain around Dalton consists of rolling hills as part of the Smoky and Appalachian Mountains. The climate is generally semiarid with hot, dry summers and cool, wet winters. The average annual precipitation is 50 to 55 in. with very little snowfall.

Predominant winds in the area are from the south and east. Most of the precipitation is associated with winds from the southwest.

The major air pollution sources in the area are nearby argricultural operations and carpet mills. The pollutant of prime concern from these sources is particulate matter. There are no air quality monitoring stations in the Dalton area, so data on representative ambient levels of air pollutants are unavailable.

Wastewater produced within the plant runs through trenches to on-site primary and secondary treatment. Nearly all the treated water is recycled into the Dalton plant operation. It is only during the rainy season that any discharge from the secondary treatment needs to be made. This effluent is permitted under the NPDES system to discharge to the Conasauga River.

3.7.2 Potential Environmental Impact

The following general types of environmental impact were considered in the environmental impact assessment:

- Ambient air quality
- Ambient water quality and associated aquatic biota
- Surrounding landscape and associated biota
- Noise
- Energy.

These categories are either inapplicable or inconsequential in terms of their potential adverse impact of the proposed project. In some cases the expected impact is beneficial; in other cases, adverse impact can be easily mitigated with proper engineering controls. Each of these categories will be briefly discussed in the following subsections.

3.7.2.1 Ambient Air Quality. The direct impact on ambient air quality is expected to be beneficial to the extent that solar energy displaces the burning of fossil fuel for heat. The combustion of fossil fuels can create a variety of air pollutants, including NO_x, SO_x, and particulates. Because Dow Chemical uses gas-fired boilers to produce process steam, only a low level of air pollutants would be produced. Thus, the magnitude of the beneficial air quality impacts associated with displacing natural gas combustion with solar energy would be small. However, Dow's gas supply is interruptible and the replacement fuel, No. 2 fuel oil, does not burn as clean as natural gas. Under these circumstances, the air quality benefits associated with the project will be increased.

3.7.2.2 Ambient Water Quality and Associated Aquatic Biota. The collector heat-transfer loop uses aromatic hydrocarbons under a nitrogen blanket in a closed-loop system. Under normal operating conditions, no discharges will be made to the water environment. The only possible exceptions to this would be minor leaks that may occur at pump seals and other connections, and accidental spills resulting from a major break in the heat-transfer circuit. Any minor leaks that may be present are expected to be small. The system should be engineered to eliminate this type of loss as much as is practical. A major break in the heat-transfer circuit could result in a loss of about 250 gal of hot fluid. A diking system has been incorporated into the design of the project which will ensure collection of any fluid spills for proper disposal. The diking system will incorporate the use of Dow imbiber bead valves which release collected rainwater but swell shut when hydrocarbons are present. The rainwater will be released to the existing plant storm sewer system.

3.7.2.3 Surrounding Landscape and Associated Biota. Land resources have been allocated for the proposed project. The collector field will be placed on an existing hill, and other elements of the system will be situated adjacent to or in existing structures. There is substantial paving of the grounds in the general vicinity of the proposed installation site. The proposed site was partially graded for planned industrial development. Additional changes to the site will be minimal. No known archeological or historical sites will be involved in the proposed construction or operation of the project.

3.7.2.4 Noise. Human beings are the primary receptors of adverse noise impacts from the project. Existing noise levels on the plant site are low. The magnitude of any additional adverse noise impact caused by this project is minimal. There will be minor noise generated by the diesel engines of construction vehicles.

3.7.2.5 Energy. The energy impact of the proposed project is obviously beneficial. The project allows for the use of an energy resource that would otherwise be wasted, while conserving fossil fuels which are in short supply.

3.7.3 Coordination With Federal, State, Regional, and Local Governments

In light of the current nationwide energy situation, it is certain that the guidelines of federal, state, regional, or local Governments will not hinder development of the proposed project. The project would be in line with national goals to demonstrate the applicability of solar energy for useful purposes, while achieving conservation of fossil fuel energy resources.

During Phase II Dow officials will check with local and state environmental officials to determine whether the plant's wastewater discharge permits must be altered because of possible accidental discharges of the fluid inventory, and whether its "Permits to Operate" under the Air Quality Section need to be altered to include the project.

3.7.4 Community Services and Facilities

The existing Dow Dalton plant will provide on-site fire protection facilities, and plant personnel receive training in fire prevention and suppression. This minimizes the possible impact on local fire departments.

Minor injuries to personnel will be handled through first aid facilities on-site. First aid training is given to plant personnel. More serious injuries will require treatment at Hamilton Memorial Hospital located in Dalton.

Security will be provided by plant personnel. The plant is operated on an around-the-clock basis.

SECTION 4
SOLAR COLLECTORS

Section 4

SOLAR COLLECTORS

4.1 GENERAL FEATURES

The Suntec-Hexcel collector is of the single axis parabolic trough line focusing type. It may be oriented in any direction depending on the application. Usually, it will be installed along a north-south line to track the sun east-west or along an east-west line to track the sun north-south. The collector may also be tilted from horizontal to enhance energy output. The collector can effectively be used up to 600°F, the limiting factors being the heat-transfer fluids and the black chrome coating on the absorber tube surface.

The collector is supported by steel stanchions mounted on supporting piers. On top of the stanchions is installed the horizontal torque tube which is center driven along its length via a chain drive and electric motor/gearbox. The honeycomb reflector panels are mounted on the torque tubes and have a modified acrylic reflective film surface. The absorber tube/receiver housing is fixed to the torque tube assembly to rotate along with the trough and maintain the necessary optical alignment. Electronic controls are located at the motor drive. They provide tracking and safety control, and interface with supervisory controls.

The three basic modes of collector operation are start-up, energy collection, and shutdown.

The sun sensor, a field mounted photocell, signals the master controller that sufficient solar intensity is available to begin operation. With this signal, fluid-loop flow, and a demand for heat, the master controller sends a signal to the module controls and the collectors are driven upwards from the protect (inverted) position.

As the sun's image is centered on the tracking head (located at the receiver), feedback signals are sent to module controllers and tracking begins. The heat collected in the absorber tubing is extracted by the fluid flowing through it.

When the solar intensity or insolation falls below a preset limit (at nightfall or when a storm is approaching) the master controller signals the module controls to rotate the collectors to the protect position. When the sun is obstructed by a cloud, the collectors are locked in a fixed position for a preset time. If the sun reappears within this time, normal operation will continue; if it does not, the collectors will be rotated to the protect position.

Each module is driven by a battery powered, 24 vdc motor and chain-drive assembly. The motors are hard wired to the remotely located and environmentally protected battery pack. The batteries are maintained by an on-line 110 vac trickle charger.

4.2 DESIGN DESCRIPTION

4.2.1 Structure

Each collector module is supported from the ground by five painted-steel stanchions, each weighing 150 lb which are bolted to the foundation. Four painted-steel, 20-ft-long torque tubes, are mounted on the stanchions, supported at the drive stanchions by a thrust bearing, and at the other stanchions by pipe roller supports. Eight counterweights (two per torque tube), each weighing 110 lb, are mounted to the module assembly. Each counterweight is filled with 2/3 ft^3 of concrete.

4.2.2 Reflector Panel Assemblies

Four panel assemblies are attached to each of the four torque tubes that comprise the collector module. The 16 panels are shipped as complete assemblies ready for attachment to the torque tubes. Each panel is 9.67 ft long x 4.83 ft wide (as measured along the arc) x 1 in. thick.

19.34 ft x 9 ft x 4 x 15
= 10443.6

They are constructed of aluminum hexagonal honeycomb with front and back aluminum skins 0.02 in. thick. The reflective surface is aluminized acrylic, 3M FEK 244 or equivalent. Spectural reflectance is 82 percent (average), rim angle is 72 deg, and peak concentration ratio is 60 suns. Each panel weighs 35 lb.

4.2.3 Receiver

A receiver is installed at a focal length of 36 in. from the parabolic reflector surface, and runs the entire length of the 80-ft module. The receiver terminates at both ends of the module in fittings suitable for the attachment of flexible connections. The receiver riser weldments are bolted in the field to the torque tubes and support the receiver at the focal position.

The receiver housing encloses, insulates, and provides structural support for the absorber. Curved glass panels cover the receiver aperture. The housing is made of aluminum and is insulated with fiberglass. The receiver housing is shipped as a 20-ft-long assembly consisting of the housing, insulation and reflective surface. The glass panels are installed in the field.

The absorber tubing is supplied in 10-ft-long sections ready for field welding. The absorber has an annular flow passage created by centering a tube with closed ends inside an outer tube coated with a black chrome film to maximize solar radiation absorption and minimize radiated thermal losses. The outer tubing is made of 1.5-in. Sch. 40 carbon steel pipe (ASTM A178 or equivalent), rated at 40 atm at 520°F. The annular plugs are 1.187 in. O.D. x 10 ft long. The connections are welded at the site.

4.2.4 Controls

The controls are of the discrete logic type. The master controller operates on a 110 v, single phase, 60 Hz line source and draws 5 amp. Connections are provided for the sun sensor, demand, fluid loop, and module over-temperature controls. The unit is mounted in an enclosure (NEMA 12) with dimensions of 16 x 20 x 1 in.

The module drive controls consist of an electronic tracking control, feedback sensor, and travel limit switches, enclosed in a metal-gasketed box which is mounted on the module structure. Peak power required is 500 W. A connection is provided for the master controller. The motor drive is mounted on the drive stanchion and consists of a motor/gear reducer (TENV Type NEMA 56 frame) which connects to the torque tube with a corrosion resistant No. 50 roller chain.

4.2.5 Electrical Parasitic Power Losses

- Drive Motors (450 W)

	Hours
Start	0.025
Tracking 10 h x $\frac{3\ s}{90\ s}$	0.33
Finish	0.025
TOTAL	0.38/d/motor
	Wh/d
0.38 x 15 motors x 450 W	2565
• Drive Controls	
10 h/d x 15 controls x 10 W	1500
• Master Control	
10 h/d x 30 W	300
SUBTOTAL	4365
TOTAL (4365 Wh/d x 300 d/yr)	1310 kWh/yr

4.2.6 RECEIVER HEAT TRANSFER

4.2.6.1 Characteristics of Dowtherm LF at 445°F

Density (ρ) = 0.87 g/cm³ *H_2O = 1.0 gm/cm³*

Specific heat (Cp) = 0.53 Btu/lb·°F

Thermal conductivity (k) = 0.064 Btu/h·ft·°F

Dynamic viscosity (μ) = 0.3 centipoise

Converting these to convenient units,

$$\rho = 0.87\ \frac{g}{cc}\left(\frac{62.43\ lb/ft^3}{g/cm^3}\right) = 54.3\ lb/ft^3$$

$$\nu = \frac{\mu}{\rho} = 0.3cp\left(2.42\ \frac{lb/h \cdot ft}{cp}\right)\left(\frac{1}{54.3\ lb/ft^3}\right)$$

$$= 0.01337\ \frac{ft^2}{h} = 3.71 \times 10^{-6}\ \frac{ft^2}{s}$$

4.2.6.2 Flow Passage

$$\text{Outer pipe} = 1.38 \text{ in. I.D.}$$

$$\text{Inner plug} = 1.182 \text{ in. O.D.}$$

$$\text{Annular area (A)} = \frac{\pi}{4}(1.38^2 - 1.182^2) = 0.398 \text{ in}^2$$

$$\text{Hydraulic diameter } (D_H) = \frac{4(\text{area})}{\text{perimeter}}$$

$$= \frac{4(0.398)}{\pi(1.38 + 1.182)}$$

$$= 0.198 \text{ in.}$$

4.2.6.3 Head Loss and Heat Transfer Calculations

Total field flow rate = 57 gal/min (15 collectors in parallel)

$$\text{Flow of each collector (q)} = \frac{57}{15} = 3.8 \text{ gal/min}$$

$$\text{Fluid velocity (V)} = \frac{q}{A}$$

$$= 3.8 \text{ gal/min}\left(\frac{1}{0.398 \text{ in.}}\right)\left(\frac{144 \text{ in}^2}{\text{ft}^2}\right)\left(\frac{\text{ft}^3}{7.481 \text{ gal}}\right)\left(\frac{\text{min}}{60 \text{ s}}\right)$$

$$= 3.06 \text{ ft/s}$$

$$\text{Reynold's Number } (Re_H) = \frac{VD_H}{\nu}$$

$$= 3.06 \text{ ft/s}(0.198 \text{ in.})\left(\frac{\text{ft}}{12 \text{ in.}}\right)\left(\frac{1 \text{ s}}{3.71 \times 10^{-6} \text{ ft}^2}\right)$$

$$= 1.36 \times 10^4$$

From Moody Chart:

Friction factor (f) = 0.029

$$\text{Head loss } (h_L) = \frac{fLV^2}{2gD_H}$$

$$= \frac{(0.029)(80)(3.06)^2}{(2)(32.2)(0.198/12)}$$

$$= 20.4 \text{ ft}$$

$$\text{Temperature rise across collector } (\Delta T) = \frac{I\eta LW}{q\rho Cp}$$

where

I = 286 Btu/h•ft^2

η = Collector efficiency

L = Collector length

W = Aperture width

$$\Delta T = \frac{(286)(0.6)(80)(9)(7.481)}{(3.8)(54.3)(0.53)(60)}$$

$$= 141°F$$

$$\text{Prandtl Number (Pr)} = \frac{Cp\nu\rho}{k}$$

$$= \frac{(0.53)(3.71 \times 10^{-6})(54.3)(3600)}{0.064}$$

$$= 6.01$$

$$\text{Nusselt Number (Nu)} = 0.023(Pr)^{0.4}(Re)^{0.8}$$

$$= 0.023(6.01)^{0.4}(1.36 \times 10^4)^{0.8}$$

$$= 95.5$$

$$\text{Heat-transfer coefficient } (h) = \frac{Nuk}{D_H}$$

$$= \frac{(95.5)(0.064)}{(0.198/12)}$$

$$= \frac{370 \text{ Btu}}{h \cdot ft^2 \cdot {}^\circ F}$$

$$\text{Temperature rise in fluid film } (\Delta T_f) = \frac{(I)(CR)(n)}{h}$$

where

$$CR = \text{Collector concentration ratio}$$

$$\Delta T_f = \frac{(286)(45)(0.6)}{370}$$

$$= 21^\circ F$$

$$\text{Maximum fluid film temperature } (T_f) = T_{avg} + \frac{\Delta T}{2} = \Delta T_f$$

$$= 445 + \frac{141}{2} + 21$$

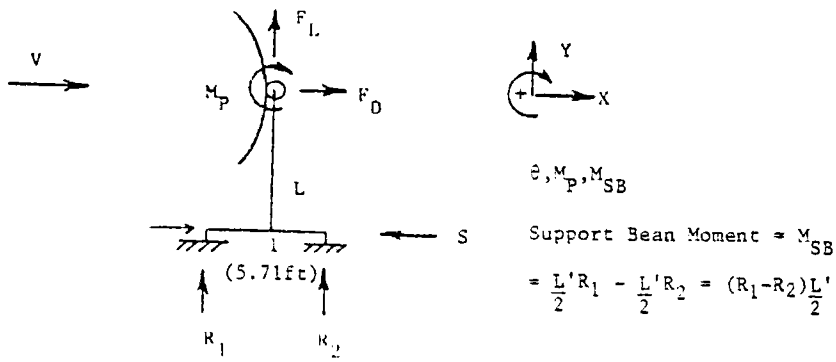
$$= 537^\circ F$$

4.2.7 Environmental Capability

The collector is designed to operate in winds up to 30 mph and survive winds up to 100 mph. Figure 4.1 shows the dead loads and structural loads resulting from a steady 80 mph wind. The local velocity is a function of the distance from the ground.

The relationship is:

$$V_{local} = \left(\frac{h}{30}\right)^{1/7} V_{ref}$$



(θ) (degrees)	R_1 (lbs)	R_2 (lbs)	S (lbs)	M_{SB} (ft lb)
0	-2950	2950	3120	-16847
15	-2382	3076	2947	-15583
30	-1507	2894	2427	-12566
45	-886	2793	2080	-10503
60	218	2902	1733	-7661
75	-358	1918	1040	-6500
90	-824	997	520	-5199
105	-1264	1438	693	-7713
120	-1650	1823	867	-9915
150	-1911	1738	1213	-10417
180	-2004	2004	2080	-11441
-15	-3294	2601	2947	-16830
-30	-3167	1781	2427	-14126
-45	-3121	1214	2080	-12376
-60	-3558	438	1733	-11406
-75	-1645	85	1040	-4940
-90	-164	4	520	-520
-105	-71	-102	693	87
-120	-20	-153	867	382
-150	-427	600	1213	-2930

Note: at end stanchions values are 1/2 of above values

Airspeed (Vref) (mph)	Airspeed (V_{local}) (mph)	qlocal (lb/ft^2)	Multiplier for R_1, R_2, S
40	31.39	2.52	.250
60	47.09	5.67	.562
80	62.78	10.08	1.000
100	78.48	15.75	1.562

DEAD LOAD

At end stanchion, each support pier load: $R_1=R_2=186$ lbs.

At other stanchions, each support pier load $R_1=R_2=372$ lbs.

Figure 4.1 Wind Loads for Steady Wind of 80 mph (Vref)

In this case,

$$V_{local} = \left(\frac{5.5}{30}\right)^{1/7} 80 = 62.78 \text{ mph}$$

The collector will withstand ice loads up to 1 in. radial thickness, snow accumulation of up to 12 in. on the collector, and temperatures ranging from -40 to 100°F.

4.3 SAFETY FEATURES

All of the collector safety functions are channeled through the electronic controls. The receiver is outfitted with an over-temperature sensor thermally connected to the absorber tube. In the event of insufficient fluid flow and resulting rise in tube temperature, the sensor, once its set point is reached, will direct the controls to drive the collector out of focus, stopping at the protect position. The master controls drive the collector to the stowed position if any of the following events occur:

- Loss of ac power
- Loss of fluid flow
- Loss of sufficient insolation
- Excessive wind
- Loss of energy demand (collector command) signal.

4.4 MAINTENANCE

Routine and scheduled maintenance will provide long life and maximum performance for the collector. Site conditions and environmental factors for

Dalton, Georgia, will determine the maintenance frequency. The basic maintenance actions are reflector surface cleaning in conformance with film coating manufacturer's (3Ms) instructions, visual inspection, periodic lubrication, and receiver glass cleaning. The cleaning of the receiver glass is periodically required because it is not truly "sealed" against the entry of dust. It is extremely difficult to seal the receiver and still be able to gain easy receiver access. The design does take a practical approach to the dust entry problem. Cleaning of the reflectors is expected to require 60 man-hours per year, using water and compressed-air spray; focusing is estimated to consume 40 man-hours per year. The controls and drive mechanisms are estimated to require 40 man-hours per year for lubrication of chains, seals, and drives; and to artificially create "out of limits" signals to check safety response. Receiver maintenance will require approximately 100 man-hours per year to remove and clean the glass covers. These estimates relate to the maintenance times required after the initial 1-year period of performance.

4.5 COMPUTER MODEL

In order to assess the impact of a solar energy system on an installation, the performance of the solar collectors under various conditions must be known. For a concentrating parabolic trough, the energy output will depend on such factors as latitude, time of year and day, ambient conditions, and physical layout of the system. To help optimize system designs, a computer model was developed which predicts the amount of solar energy collected by the Suntec-Hexcel parabolic trough for the specific collector location, orientation, and fluid temperatures.

The model starts by determining the solar energy available to the collector. This is a function of the sun's position in the sky and the amount of energy transmitted through the atmosphere to the earth's surface. The collector is then rotated about its axis, so that the maximum amount of solar energy is intercepted. Energy losses in reflection from the mirror surfaces, transmission through the glass covers, heat losses from the receiver tube, and shadowing losses are then calculated from laws of physics and geometry. The result is the amount of solar energy transferred to the system working fluid.

4.5.1 RADIATION MODEL

Solar radiation which reaches the earth can be characterized by its intensity and spectral distribution. Above the atmosphere the energy is in the form of a beam with a distribution which is a function of wavelengths. The intensity of solar radiation at the edge of the atmosphere normal to the beam is defined as the solar constant, I_{sc}. Its value changes inversely as the square of the distance from the sun. Because of the elliptical nature of the earth's orbit, I_{sc} equals 441 Btu/h/ft^2 in mid-winter and 413.1 Btu/h/ft^2 in mid-summer. The accepted average value throughout the year is 429.6 Btu/h/ft^2. The spectral distribution of energy depends on the chemical process in the sun. Outside the atmosphere, 9 percent is in the 0.29 to 0.4 μ band, 40 percent in the 0.4 to 0.7 μ band, and 40 percent in the 0.7 to 3.5 μ band.

As the rays pass through the earth's atmosphere, their intensity and distribution are altered by absorption and scattering. Absorption occurs in O_2, O_3, H_2O, and CO_2 molecules. The short wavelengths (ultraviolet rays) are absorbed high in the atmosphere by ozone molecules while the long wavelengths (infrared rays) are absorbed by H_2O and CO_2 molecules near the earth's surface. Scattering occurs from air molecules, water vapor, and dust suspended in the air. Generally, smaller wavelengths are more affected, according to the Ragleigh theory of scattering. The characteristics of the radiation reaching the earth's surface depend on local conditions such as humidity, aerosol content and barometric pressure, and length of travel through the atmosphere (more commonly called path length). The radiation at the earth's surface will have a beam component (attenuated) called direct normal and a diffuse component (scattered).

For concentrating solar collectors only the direct normal component is usable. The intensity at the earth's surface can be modeled by:

$$I_{DN} = A \exp (B/\sin \beta)$$

where

A = Solar irradiance at path length of zero
B = Extinction coefficient
β = Solar altitude angle

Variables A and B depend on local conditions. However, for representative clear days, these values are assumed to be constant. These values are given in Table 4.1 for each month of the year.

This model is called ASHRAE CLEAR DAY and is used in the computer program to predict average expected direct normal intensities. It should be noted that on exceptionally clear days, these predictions may be as much as 15 percent lower than values actually measured.

Table 4.1 Solar Radiation Intensity and Related Data (Btu/h/ft^2)

Month*	I_{sc}	Equation of Time (min:s)	Declination (deg)	A (Btu/h/ft^2)	B (Air Mass^{-1})
January	440.1	-11:18	-20	390	0.142
February	436.5	-13:28	-10.8	385	0.144
March	430.0	- 7:19	0	376	0.156
April	422.8	+ 0:08	+11.6	360	0.180
May	416.5	+ 3:32	+20.0	350	0.196
June	413.1	- 1:48	+23.45	345	0.205
July	413.5	- 6:25	+20.6	344	0.207
August	417.6	- 1:18	+12.3	351	0.201
September	424.0	+ 7:30	0	365	0.177
October	431.1	+15:06	-10.5	378	0.160
November	437.6	+13:55	-19.8	387	0.149
December	441.0	+ 1:32	-23.45	391	0.142

*Data obtained on 21st day of each month.

4.5.2 Solar Angles

To an observer on the earth, the sun travels across the sky. Each day, because of the earth's rotation about its axis, the sun rises in the east, climbs to its highest position in the sky at solar noon, and sets in the west. To the careful observer, the sun's position also changes with time of year as illustrated in Figure 4.2. In the northern hemisphere, the sun is highest in the sky on June 21, rising north of east and setting north of west, and lowest in the sky on December 21, rising south of east and setting south of west. This motion occurs because of the tilt of the earth's axis to the equitorial plane shown in Figure 4.3. Although the angle is fixed relative to the equatorial plane, the angle with respect to the sun changes depending on position of the earth in its orbit. The angle between the sun and the earth's axis is called declination (δ) and its value is given approximately by:

$$\delta = 23.45 \left[\sin \left(360 \times (284 + \text{day})/365\right)\right]$$

It has its maximum on solstice of 23.450 and minimum on equinox of 0. Declination also influences the number of daylight hours. The sunrise or sunset hour from solar noon is given by:

$$\sin H_s = \tan(\text{latitude}) \times \tan(\text{declination})$$

The position of the sun relative to a point on the earth can be described by the zenith angle Z, measured from local vertical, and the azimuth

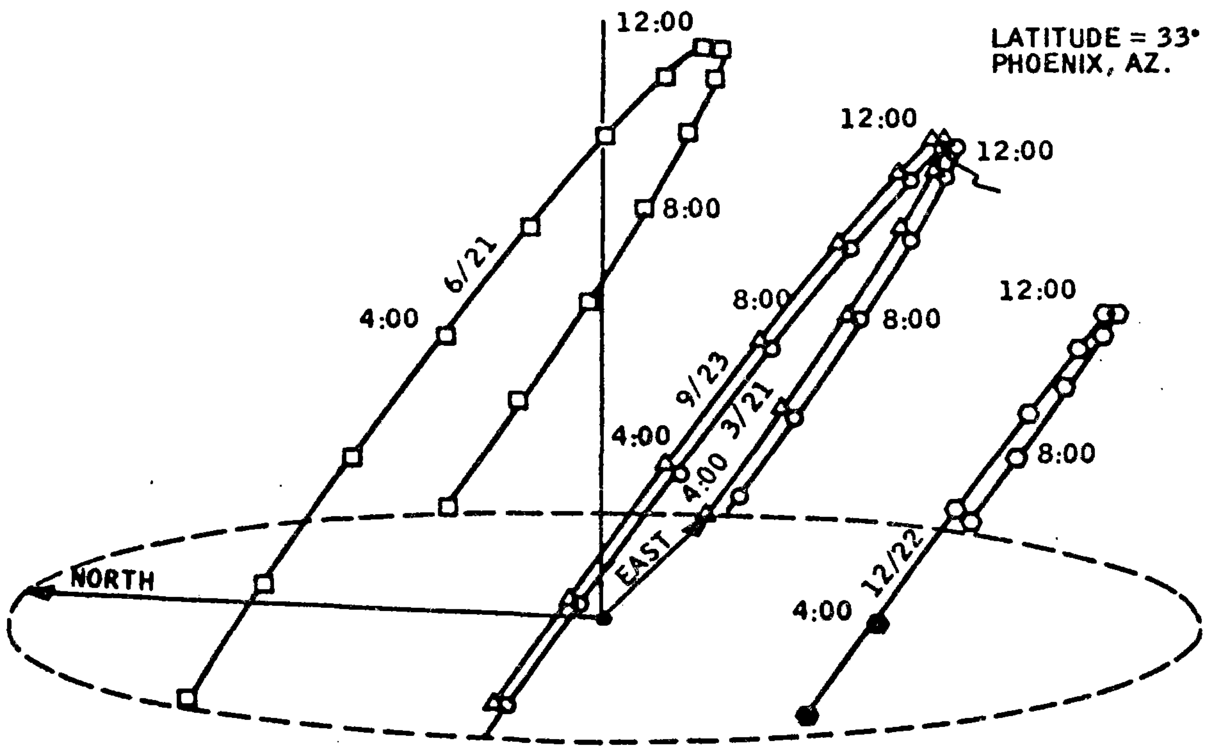


Figure 4.2 Tip Trace of Unit Vector Pointing at the Sun (perspective No. 2)

angle ϕ, measured west of south (Figure 4.4). These angles can be related to latitude, declination, and hour angle of sun using laws of trigonometry and are given by:

$$\cos(Z) = \cos L \cos \delta \cos H + \sin L \sin \delta$$

$$\sin(\phi) = \cos \delta \sin H/\cos \beta$$

where

l = Latitude
H = Hour angle

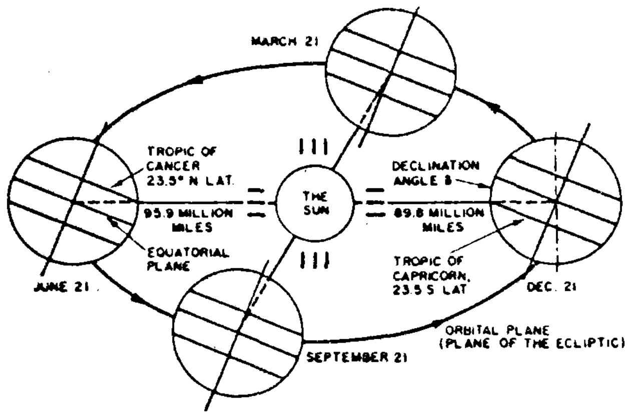
A vector can now be defined which connects the point O with the sun. Relative to a local coordinate system of i-east, j-south, and k-vertical, the components of the unit sun vector are given by:

$$\hat{i} = -\sin Z \sin \phi$$
$$\hat{j} = \sin Z \cos \phi$$
$$\hat{k} = \cos Z$$

For a specific day, the computer model calculates the declination and sunset hour, and then the hour and azimuth angles along with the corresponding direction cosines of the sun.

4.5.3 Tracking

Cylindrical parabolic troughs can partially follow the sun because of their rotation about one axis. The angular position of the collector is determined so that the optical plane of the parabola is colinear with the sun. This depends not only on the position of the sun but also on the orientation of rotational axis with respect to earth, i.e., aligned east-west, north-south, etc.



* *Time of orbit = 365.25 days.*

Figure 4.3 The Earth's Motion Around the Sun

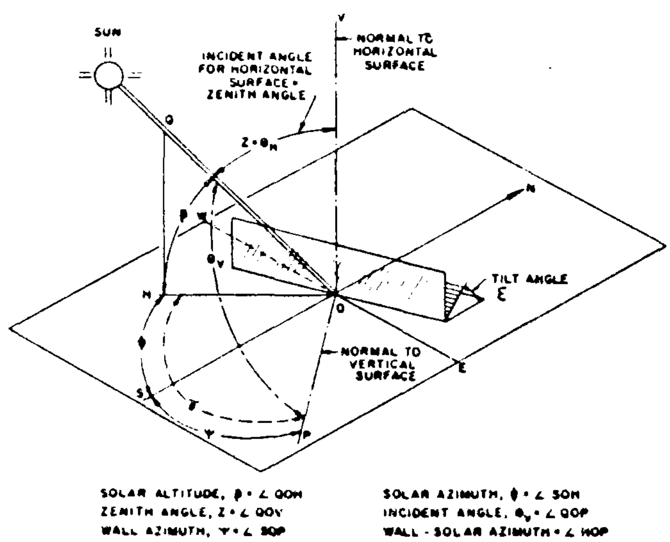


Figure 4.4 Solar Angles for Vertical and Horizontal Surfaces

Mathematically, the optimum rotation is determined by projecting the sun vector into the plane perpendicular to the rotational axis as shown in Figure 4.5. The collector is rotated to this position and the incidence angle between the collector and this plane are calculated. The usable direct normal is then determined from this angle. This calculation is performed for each hour of the day by the computer model.

4.5.4 Thermal Performance

A concentrating collector takes energy at its aperture and reflects it onto the receiver. For each unit of energy available to the collector, the amount after reflection is characterized by the solar reflectivity which for 3M FEK 244 is 0.84. The reflected energy then passes through the glass receiver cover losing some energy in reflection at each glass surface caused by the difference in refractive indices between air and glass and some due to absorption by reduced iron contained in the glass. The amount of energy absorbed will depend on both the path length through the glass and iron content. For our receiver cover an index of refraction of 1.525 and an extinction coefficient of 0.25/in. are used. The energy then strikes the receiver tube and is absorbed by the black chrome surface. For black chrome a solar absorptance of 0.92 is used. Thus, for a unit of energy incident on the collector, the amount absorbed by the receiver is now known.

However, not all the aperture area of the collector contributes energy to the receiver. Shadowing from one collector row to another, end losses resulting from the angle between the sun and optical axis, and spaces between reflector

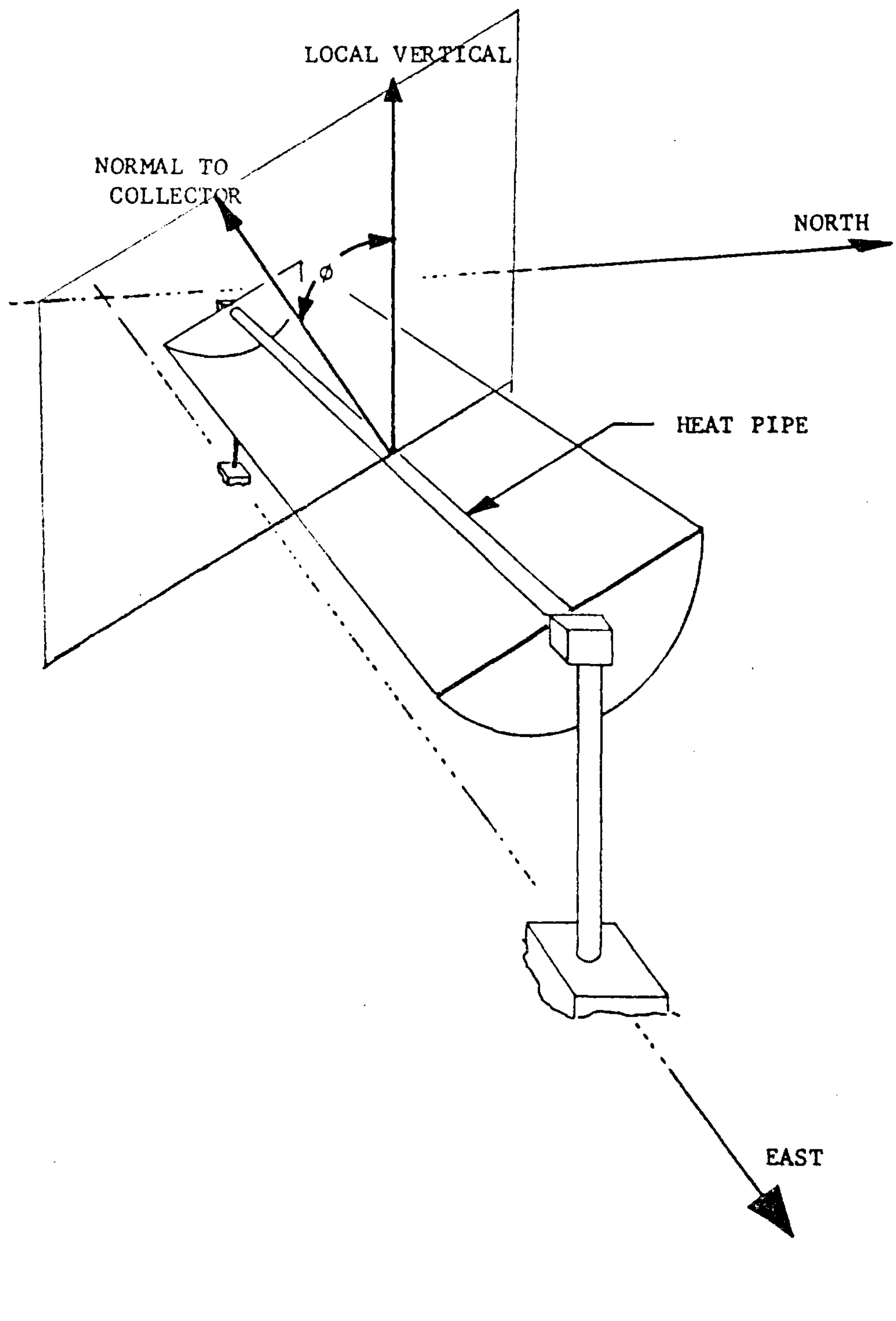


Figure 4.5 Normal to Collector Aperture Plane

panels will cause less energy to reach the receiver. The percentage of the aperture area not contributing to energy collection is subtracted from the total and the energy absorbed by each collector unit calculated.

Some of the energy absorbed by the receiver will be lost as heat to the environment by convection and radiation. The heat loss at any position along the pipes is determined by calculating the temperature differences between the fluid and ambient and using the heat loss curve generated by Sandia Laboratories[1] for the Hexcel receiver (Figure 4.6). These values are then integrated from the inlet to outlet of the receiver to obtain the total heat loss. This number is subtracted from energy absorbed by the receiver to obtain net energy transferred to the working fluid.

This calculation procedure is performed for every hour from sunrise to sunset, with the half hour values assumed to be representative of each hour's performance. These values are then summed to obtain daily and yearly totals.

4.6 SOLAR ENERGY CALCULATION RESULTS

The computer model was used to predict the thermal performance of the Suntec-Hexcel parabolic trough at Atlanta, Georgia. A system consisting of fifteen 80-ft rows was used in conjunction with data given in Table 4.2. The ambient temperatures were taken from Reference 5 and the sunshine factors from Reference 6.

Three studies were performed to determine the effect of spacing and tilt from horizontal in north-south orientation on annual collected energy. The

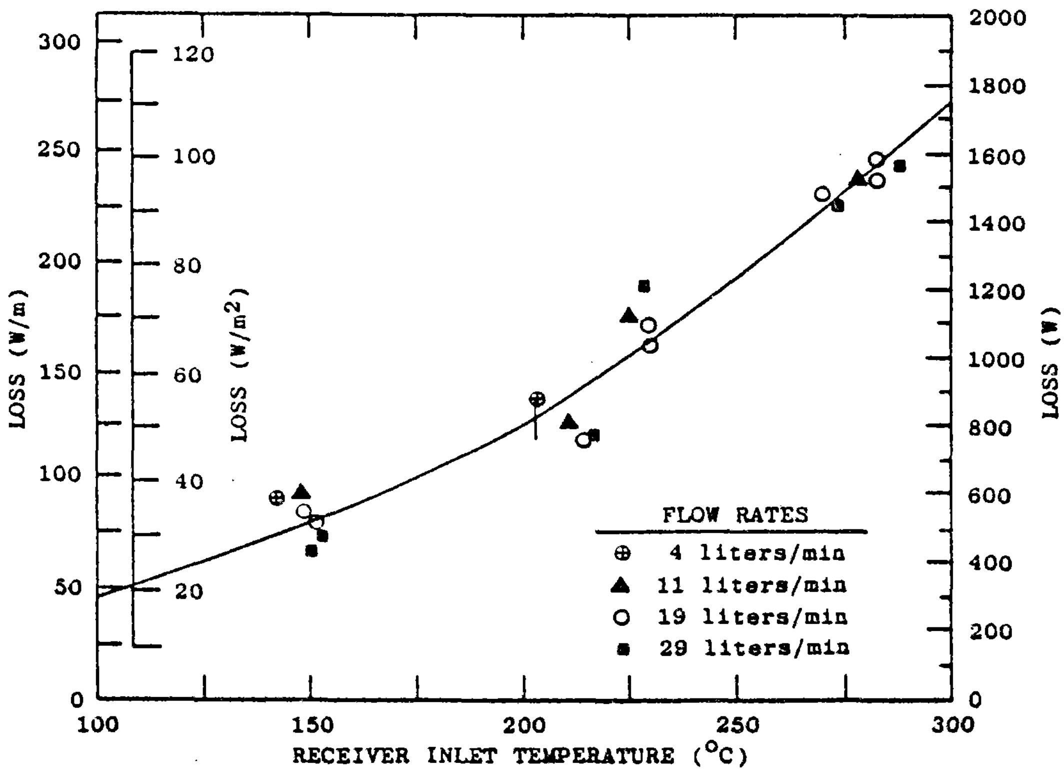


Figure 4.6 Hexcel Receiver Thermal Loss

Table 4.2 Ambient Temperatures and Sunshine Factors for Atlanta, Georgia

Month	Ambient Temperature (°F)	Sunshine Factor (%)
January	47.2	48
February	49.6	53
March	55.9	57
April	65.0	65
May	73.2	68
June	80.9	68
July	82.4	62
August	81.6	63
September	77.4	65
October	66.5	67
November	54.8	60
December	47.7	47

results are shown in Figures 4.7 and 4.8. The energy output was normalized to a collector configuration of 18-ft spacing, 0 deg tilt, and north-south orientation.

Hourly clear day performances were run for each month of the year for the following cases:

- North-south orientation, 18-ft spacing, 0 deg tilt (Table 4.3)
- North-south orientation, 18-ft spacing, 10 deg tilt (Table 4.4)
- East-west orientation, 18-ft spacing (Table 4.5).

A legend for the computer program is given in Table 4.6.

The results shown in Figures 4.7 and 4.8, and Tables 4.4 through 4.5 are used in the system optimization studies presented in Section 5 of this report.

4.7 CONTROLS

The control system for the Suntec-Hexcel parabolic trough must position the collector during the day with respect to the sun and defocus the mirrors in emergencies. This is accomplished by having one master control unit for the system and a drive controller for each of the 15 modules. The master controller provides a "go" signal to the drive control units while the drive controllers actively control the mirrors to reflect the light on the absorber tube.

4.7.1 Basic Control Requirements

The controls must perform the following functions:

- Aim reflected light (tracking) within ±0.25 deg.

Table 4.3 Collector Output for 0 deg Tilt, North-South Orientation

	21.000000	1.313068	-0.351530	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.000000
1	-67.5000.	92.3768	2.9290	0.0317	0.30035E 05
2	-52.5000	231.7699	64.6347	0.2789	0.66280E 06
3	-37.5000	277.0243	92.8255	0.3351	0.95189E 06
4	-22.5000	296.1384	83.9294	0.2834	0.86066E 06
5	-7.5000	303.7111	76.0701	0.2505	0.78007E 06
6	7.5000	303.7111	76.0701	0.2505	0.78007E 06
7	22.5000	296.1384	83.9294	0.2834	0.86066E 06
8	37.5000	277.0243	92.8255	0.3351	0.95189E 06
9	52.5000	231.7699	64.6348	0.2789	0.66280E 06
10	67.5000	92.3768	2.9289	0.0317	0.30034E 05
	640.77734		2402.04150		
	0.65709E 07		0.26676		
	0.20370E 09		0.15946E 07		
	52.000000	1.432317	-0.196074	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.000000
1	-67.5000	185.4349	38.8119	0.2093	0.39800E 06
2	-52.5000	263.3479	104.3499	0.3962	0.10701E 07
3	-37.5000	293.0748	117.6930	0.4016	0.12069E 07
4	-22.5000	306.6579	110.8351	0.3614	0.11366E 07
5	-7.5000	312.2303	105.0913	0.3366	0.10777E 07
6	7.5000	312.2303	105.0913	0.3366	0.10777E 07
7	22.5000	306.6578	110.8352	0.3614	0.11366E 07
8	37.5000	293.0748	117.6931	0.4016	0.12069E 07
9	52.5000	263.3479	104.3498	0.3962	0.10701E 07
10	67.5000	185.4349	38.8119	0.2093	0.39800E 06
	953.56250		2721.49170		
	0.97784E 07		0.35038		
	0.27380E 09		0.15759E 07		
	80.000000	1.565768	-0.007233	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.000000
1	-82.5000	82.8570	2.3287	0.0281	0.23880E 05
2	-67.5000	227.3868	75.1521	0.3305	0.77066E 06
3	-52.5000	274.4971	135.9587	0.4953	0.13942E 07
4	-37.5000	295.4802	137.8445	0.4665	0.14135E 07
5	-22.5000	305.7684	134.1893	0.4389	0.13761E 07
6	-7.5000	310.1289	130.8535	0.4219	0.13419E 07
7	7.5000	310.1289	130.8535	0.4219	0.13419E 07
8	22.5000	305.7684	134.1893	0.4389	0.13761E 07
9	37.5000	295.4802	137.8445	0.4665	0.14135E 07
10	52.5000	274.4971	135.9587	0.4953	0.13942E 07
11	67.5000	227.3868	75.1521	0.3305	0.77066E 06
12	82.5000	82.8570	2.3287	0.0281	0.23880E 05
	1232.65356		2992.23633		
	0.12640E 08		0.41195		
	0.39185E 09		0.18337E 07		
	111.000000	1.713527	0.201900	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.000000
1	-97.5000	0.0000	0.0000	0.0000	0.00000E 00
2	-82.5000	158.5667	34.2098	0.2157	0.35081E 06
3	-67.5000	235.0810	107.3360	0.4566	0.11007E 07
4	-52.5000	267.2522	142.0497	0.5315	0.14567E 07
5	-37.5000	283.4279	146.4249	0.5166	0.15015E 07
6	-22.5000	291.8477	146.1703	0.5008	0.14989E 07
7	-7.5000	295.5206	145.0751	0.4909	0.14877E 07
8	7.5000	295.5206	145.0751	0.4909	0.14877E 07
9	22.5000	291.8477	146.1703	0.5008	0.14989E 07
10	37.5000	283.4279	146.4249	0.5166	0.15015E 07
11	52.5000	267.2522	142.0497	0.5315	0.14567E 07
12	67.5000	235.0810	107.3360	0.4566	0.11007E 07
13	82.5000	158.5667	34.2097	0.2157	0.35081E 06
14	97.4999	0.0000	0.0000	0.0000	0.00000E 00

Table 4.3 Collector Output for 0 deg Tilt, North-South Orientation (Cont)

	1442.53174		3063.39307			
	0.14793E 08		0.47089			
	0.44378E 09		0.20469E 07			
	141.000000	1.828361	0.351336		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.000000
1	-97.5000	45.2991	0.7840	0.0173	0.80395E 04	
2	-82.5000	180.9570	55.5309	0.3069	0.56945E 06	
3	-67.5000	234.8993	125.5734	0.5346	0.12877E 07	
4	-52.5000	260.7444	142.0794	0.5449	0.14570E 07	
5	-37.5000	274.6178	148.0177	0.5390	0.15179E 07	
6	-22.5000	282.0936	149.6575	0.5305	0.15347E 07	
7	-7.5000	285.4098	149.7605	0.5247	0.15357E 07	
8	7.5000	285.4098	149.7605	0.5247	0.15357E 07	
9	22.5000	282.0936	149.6575	0.5305	0.15347E 07	
10	37.5000	274.6178	148.0177	0.5390	0.15179E 07	
11	52.5000	260.7444	142.0795	0.5449	0.14570E 07	
12	67.5000	234.8993	125.5734	0.5346	0.12877E 07	
13	82.5000	180.9570	55.5310	0.3069	0.56945E 06	
14	97.4999	45.2991	0.7840	0.0173	0.80395E 04	
	1542.80737		3128.04248			
	0.15821E 08		0.49322			
	0.49045E 09		0.19681E 07			
	172.000000	1.876977	0.409245		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.000000
1	-97.5000	70.2782	2.7643	0.0393	0.28347E 05	
2	-82.5000	183.7781	62.5835	0.3405	0.64177E 06	
3	-67.5000	231.7867	123.7813	0.5340	0.12693E 07	
4	-52.5000	255.8485	140.0258	0.5473	0.14359E 07	
5	-37.5000	269.0734	146.6704	0.5451	0.15040E 07	
6	-22.5000	276.2924	148.9804	0.5392	0.15277E 07	
7	-7.5000	279.5086	149.4789	0.5348	0.15328E 07	
8	7.5000	279.5086	149.4789	0.5348	0.15328E 07	
9	22.5000	276.2924	148.9804	0.5392	0.15277E 07	
10	37.5000	269.0734	146.6704	0.5451	0.15040E 07	
11	52.5000	255.8485	140.0272	0.5473	0.14359E 07	
12	67.5000	231.7867	123.7816	0.5340	0.12693E 07	
13	82.5000	183.7781	62.5837	0.3405	0.64177E 06	
14	97.4999	70.2782	2.7643	0.0393	0.28347E 05	
	1548.57129		3133.13184			
	0.15880E 08		0.49426			
	0.47640E 09		0.18980E 07			
	202.000000	1.832884	0.356869		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.000000
1	-97.5000	42.5341	0.7168	0.0169	0.73510E 04	
2	-82.5000	172.4916	53.3868	0.3095	0.54746E 06	
3	-67.5000	226.2175	121.5139	0.5372	0.12461E 07	
4	-52.5000	252.3102	137.6805	0.5457	0.14119E 07	
5	-37.5000	266.4050	143.9105	0.5402	0.14757E 07	
6	-22.5000	274.0249	145.7885	0.5320	0.14950E 07	
7	-7.5000	277.4103	146.0231	0.5264	0.14974E 07	
8	7.5000	277.4103	146.0231	0.5264	0.14974E 07	
9	22.5000	274.0249	145.7885	0.5320	0.14950E 07	
10	37.5000	266.4050	143.9105	0.5402	0.14757E 07	
11	52.5000	252.3102	137.6805	0.5457	0.14119E 07	
12	67.5000	226.2175	121.5139	0.5372	0.12461E 07	
13	82.5000	172.4916	53.3868	0.3095	0.54746E 06	
14	97.4999	42.5341	0.7168	0.0169	0.73510E 04	

Table 4.3 Collector Output for 0 deg Tilt, North-South Orientation (Cont)

	1498.04028		3022.78711			
	0.15362E 08		0.49558			
	0.47622E 09		0.18847E 07			
	232.000000	1.720513	0.211427		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.000000
1	-97.5000	0.0006	0.0000	0.0000	0.00000E 00	
2	-82.5000	143.4563	31.5765	0.2201	0.32380E 06	
3	-67.5000	219.2333	101.3762	0.4624	0.10396E 07	
4	-52.5000	252.2682	134.6368	0.5337	0.13806E 07	
5	-37.5000	269.1227	139.8490	0.5196	0.14341E 07	
6	-22.5000	277.9588	140.2231	0.5045	0.14379E 07	
7	-7.5000	281.8267	139.4674	0.4949	0.14302E 07	
8	7.5000	281.8267	139.4674	0.4949	0.14302E 07	
9	22.5000	277.9588	140.2230	0.5045	0.14379E 07	
10	37.5000	269.1227	139.8490	0.5196	0.14341E 07	
11	52.5000	252.2682	134.6368	0.5337	0.13806E 07	
12	67.5000	219.2333	101.3762	0.4624	0.10396E 07	
13	82.5000	143.4563	31.5765	0.2201	0.32380E 06	
14	97.4999	0.0006	0.0000	0.0000	0.00000E 00	
	1374.25806		2887.73340			
	0.14092E 08		0.47590			
	0.43687E 09		0.18918E 07			
	264.000000	1.568544	-0.003239		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.000000
1	-82.5000	68.0991	1.8395	0.0270	0.18864E 05	
2	-67.5000	207.1478	69.0855	0.3335	0.70845E 06	
3	-52.5000	255.8351	127.3615	0.4978	0.13060E 07	
4	-37.5000	277.9481	130.5367	0.4696	0.13386E 07	
5	-22.5000	288.8809	127.7924	0.4424	0.13105E 07	
6	-7.5000	293.5322	124.9398	0.4256	0.12812E 07	
7	7.5000	293.5322	124.9398	0.4256	0.12812E 07	
8	22.5000	288.8809	127.7924	0.4424	0.13105E 07	
9	37.5000	277.9481	130.5368	0.4696	0.13386E 07	
10	52.5000	255.8351	127.3615	0.4978	0.13060E 07	
11	67.5000	207.1478	69.0856	0.3335	0.70845E 06	
12	82.5000	68.0991	1.8395	0.0270	0.18864E 05	
	1163.11133		2782.88672			
	0.11927E 08		0.41795			
	0.35782E 09		0.16538E 07			
	294.000000	1.425885	-0.204874		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.000000
1	-67.5000	164.0231	32.8897	0.2005	0.33727E 06	
2	-52.5000	246.2579	96.2705	0.3909	0.98722E 06	
3	-37.5000	278.1731	111.1949	0.3997	0.11403E 07	
4	-22.5000	292.8272	105.1613	0.3591	0.10784E 07	
5	-7.5000	298.8509	99.7937	0.3339	0.10233E 07	
6	7.5000	298.8508	99.7937	0.3339	0.10233E 07	
7	22.5000	292.8272	105.1613	0.3591	0.10784E 07	
8	37.5000	278.1731	111.1950	0.3997	0.11403E 07	
9	52.5000	246.2579	96.2705	0.3909	0.98722E 06	
10	67.5000	164.0231	32.8897	0.2005	0.33727E 06	
	890.62000		2560.26416			
	0.91330E 07		0.34786			
	0.28312E 09		0.14516E 07			

Table 4.3 Collector Output for 0 deg Tilt, North-South Orientation (Cont)

	325.000000	1.308933	-0.356591	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.000000
1	-67.5000	81.0817	1.7664	0.0218	0.18113E 05
2	-52.5000	222.5375	61.2219	0.2751	0.62781E 06
3	-37.5000	269.3898	89.8096	0.3334	0.92096E 06
4	-22.5000	289.2386	81.4060	0.2814	0.83479E 06
5	-7.5000	297.1097	73.7590	0.2483	0.75637E 06
6	7.5000	297.1097	73.7590	0.2483	0.75637E 06
7	22.5000	289.2386	81.4060	0.2814	0.83479E 06
8	37.5000	269.3898	89.8096	0.3334	0.92096E 06
9	52.5000	222.5375	61.2219	0.2751	0.62781E 06
10	67.5000	81.0817	1.7664	0.0218	0.18113E 05
	615.92554		2318.71484		
	0.63161E 07		0.26563		
	0.18948E 09		0.15363E 07		
	354.000000	1.264642	-0.409211	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.000000
1	-67.5000	38.5633	0.2716	0.0070	0.27851E 04
2	-52.5000	211.7881	49.3108	0.2328	0.50566E 06
3	-37.5000	266.5581	82.0132	0.3077	0.84101E 06
4	-22.5000	288.8509	72.6803	0.2516	0.74531E 06
5	-7.5000	297.5413	64.0527	0.2153	0.65684E 06
6	7.5000	297.5413	64.0527	0.2153	0.65684E 06
7	22.5000	288.8509	72.6803	0.2516	0.74531E 06
8	37.5000	266.5581	82.0132	0.3077	0.84101E 06
9	52.5000	211.7881	49.3108	0.2328	0.50566E 06
10	67.5000	38.5633	0.2716	0.0070	0.27851E 04
	536.65735		2206.60352		
	0.55032E 07		0.24321		
	0.17060E 09		0.15906E 07		

Table 4.4 Collector Output for 10 deg Tilt, North-South Orientation

	0.41941E 10					
	21.000000	1.313068	-0.351530		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.174520
1	-67.5000	92.3768	10.5239	0.1139	0.10792E 06	
2	-52.5000	231.7699	87.5040	0.3775	0.89732E 06	
3	-37.5000	277.0243	107.1545	0.3868	0.10988E 07	
4	-22.5000	296.1384	106.4994	0.3596	0.10921E 07	
5	-7.5000	303.7111	104.2160	0.3431	0.10687E 07	
6	7.5000	303.7111	104.2160	0.3431	0.10687E 07	
7	22.5000	296.1384	106.4994	0.3596	0.10921E 07	
8	37.5000	277.0243	107.1545	0.3868	0.10988E 07	
9	52.5000	231.7699	87.5040	0.3775	0.89732E 06	
10	67.5000	92.3768	10.5238	0.1139	0.10792E 06	
	831.79553		2402.04150			
	0.85297E 07		0.34629			
	0.26442E 09		0.15946E 07			
	52.000000	1.432317	-0.196074		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.174520
1	-67.5000	185.4349	48.5600	0.2619	0.49796E 06	
2	-52.5000	263.3479	123.6866	0.4697	0.12684E 07	
3	-37.5000	293.0748	131.2409	0.4478	0.13458E 07	
4	-22.5000	306.6578	130.9237	0.4269	0.13426E 07	
5	-7.5000	312.2303	129.4143	0.4145	0.13271E 07	
6	7.5000	312.2303	129.4143	0.4145	0.13271E 07	
7	22.5000	306.6578	130.9237	0.4269	0.13426E 07	
8	37.5000	293.0748	131.2409	0.4478	0.13458E 07	
9	52.5000	263.3479	123.6866	0.4697	0.12684E 07	
10	67.5000	185.4349	48.5600	0.2619	0.49796E 06	
	1127.65112		2721.49170			
	0.11564E 08		0.41435			
	0.32378E 09		0.15759E 07			
	80.000000	1.565768	-0.007233		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.174520
1	-82.5000	82.8570	2.3362	0.0282	0.23957E 05	
2	-67.5000	227.3868	83.3671	0.3666	0.85490E 06	
3	-52.5000	274.4971	141.7157	0.5163	0.14532E 07	
4	-37.5000	295.4802	148.5051	0.5026	0.15229E 07	
5	-22.5000	305.7684	149.5687	0.4892	0.15338E 07	
6	-7.5000	310.1289	149.1839	0.4810	0.15298E 07	
7	7.5000	310.1289	149.1839	0.4810	0.15298E 07	
8	22.5000	305.7684	149.5687	0.4892	0.15338E 07	
9	37.5000	295.4802	148.5051	0.5026	0.15229E 07	
10	52.5000	274.4971	141.7158	0.5163	0.14532E 07	
11	67.5000	227.3868	83.3671	0.3666	0.85490E 06	
12	82.5000	82.8570	2.3362	0.0282	0.23957E 05	

Table 4.4 Collector Output for 10 deg Tilt, North-South Orientation (Cont)

	1349.35352		2992.23633		
	0.13837E 08		0.45095		
	0.42895E 09		0.18337E 07		
	111.000000	1.713527	0.201900	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.174520
1	-97.5000	0.0000	0.0000	0.0000	0.00000E 00
2	-82.5000	158.5667	31.0620	0.1959	0.31853E 06
3	-67.5000	235.0810	107.9465	0.4592	0.11069E 07
4	-52.5000	267.2522	145.0231	0.5426	0.14872E 07
5	-37.5000	283.4279	152.6141	0.5385	0.15650E 07
6	-22.5000	291.8477	155.4411	0.5326	0.15940E 07
7	-7.5000	295.5206	156.2416	0.5287	0.16022E 07
8	7.5000	295.5206	156.2417	0.5287	0.16022E 07
9	22.5000	291.8477	155.4411	0.5326	0.15940E 07
10	37.5000	283.4279	152.6141	0.5385	0.15650E 07
11	52.5000	267.2522	145.0231	0.5426	0.14872E 07
12	67.5000	235.0810	107.9465	0.4592	0.11069E 07
13	82.5000	158.5667	31.0622	0.1959	0.31853E 06
14	97.4999	0.0000	0.0000	0.0000	0.00000E 00
	1496.65723		3063.39307		
	0.15348E 08		0.48856		
	0.46043E 09		0.20469E 07		
	141.000000	1.829361	0.351336	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.174520
1	-97.5000	45.2991	0.7749	0.0171	0.79459E 04
2	-82.5000	180.9570	47.7995	0.2641	0.49016E 06
3	-67.5000	234.8993	119.5599	0.5090	0.12260E 07
4	-52.5000	260.7444	141.5991	0.5431	0.14520E 07
5	-37.5000	274.6178	150.8984	0.5495	0.15474E 07
6	-22.5000	282.0936	154.6532	0.5482	0.15859E 07
7	-7.5000	285.4098	156.1082	0.5470	0.16008E 07
8	7.5000	285.4098	156.1082	0.5470	0.16008E 07
9	22.5000	282.0936	154.6532	0.5482	0.15859E 07
10	37.5000	274.6178	150.8984	0.5495	0.15474E 07
11	52.5000	260.7444	141.5991	0.5431	0.14520E 07
12	67.5000	234.8993	119.5599	0.5090	0.12260E 07
13	82.5000	180.9570	47.7999	0.2642	0.49017E 06
14	97.4999	45.2991	0.7749	0.0171	0.79459E 04
	1542.78687		3128.04248		
	0.15821E 08		0.49321		
	0.49044E 09		0.19631E 07		
	172.000000	1.876977	0.409245	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.174520
1	-97.5000	70.2782	1.6467	0.0234	0.16887E 05
2	-82.5000	183.7781	53.1239	0.2891	0.54476E 06
3	-67.5000	231.7867	121.0546	0.5223	0.12414E 07
4	-52.5000	255.8485	137.9187	0.5391	0.14143E 07
5	-37.5000	269.0734	147.3057	0.5475	0.15106E 07
6	-22.5000	276.2924	152.2398	0.5510	0.15612E 07
7	-7.5000	279.5086	154.0068	0.5510	0.15793E 07
8	7.5000	279.5086	154.0068	0.5510	0.15793E 07
9	22.5000	276.2924	152.2398	0.5510	0.15612E 07
10	37.5000	269.0734	147.3057	0.5475	0.15106E 07
11	52.5000	255.8485	137.9188	0.5391	0.14143E 07
12	67.5000	231.7867	121.0550	0.5223	0.12414E 07
13	82.5000	183.7781	53.1243	0.2891	0.54477E 06
14	97.4999	70.2782	1.6467	0.0234	0.16887E 05
	1534.59326		3133.13184		
	0.15737E 08		0.48980		
	0.47210E 09		0.18980E 07		

Table 4.4 Collector Output for 10 deg Tilt, North-South Orientation (Cont)

	202.000000	1.832884	0.356869	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.174520
1	-97.5000	42.5341	0.7078	0.0166	0.72581E 04
2	-82.5000	172.4916	45.8713	0.2659	0.47039E 06
3	-67.5000	226.2175	115.5374	0.5107	0.11848E 07
4	-52.5000	252.3102	137.0529	0.5432	0.14054E 07
5	-37.5000	266.4050	146.4326	0.5497	0.15016E 07
6	-22.5000	274.0249	150.4954	0.5492	0.15433E 07
7	-7.5000	277.4103	152.0331	0.5480	0.15590E 07
8	7.5000	277.4103	152.0331	0.5480	0.15590E 07
9	22.5000	274.0249	150.4954	0.5492	0.15433E 07
10	37.5000	266.4050	146.4326	0.5497	0.15016E 07
11	52.5000	252.3102	137.0529	0.5432	0.14054E 07
12	67.5000	226.2175	115.5374	0.5107	0.11848E 07
13	82.5000	172.4916	45.8713	0.2659	0.47039E 06
14	97.4999	42.5341	0.7078	0.0166	0.72581E 04
	1496.26099		3022.78711		
	0.15344E 08		0.49499		
	0.47565E 09		0.18847E 07		
	232.000000	1.720513	0.211427	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.174520
1	-97.5000	0.0006	0.0000	0.0000	0.00000E 00
2	-82.5000	143.4563	28.4985	0.1987	0.29224E 06
3	-67.5000	219.2333	101.5563	0.4632	0.10414E 07
4	-52.5000	252.2682	137.3106	0.5443	0.14081E 07
5	-37.5000	269.1227	145.5350	0.5408	0.14924E 07
6	-22.5000	277.9588	148.8085	0.5354	0.15260E 07
7	-7.5000	281.8267	149.8393	0.5317	0.15365E 07
8	7.5000	281.8267	149.8393	0.5317	0.15365E 07
9	22.5000	277.9588	148.8085	0.5354	0.15260E 07
10	37.5000	269.1227	145.5350	0.5408	0.14924E 07
11	52.5000	252.2682	137.3106	0.5443	0.14081E 07
12	67.5000	219.2333	101.5563	0.4632	0.10414E 07
13	82.5000	143.4563	28.4985	0.1987	0.29224E 06
14	97.4999	0.0006	0.0000	0.0000	0.00000E 00
	1423.09644		2887.73340		
	0.14593E 08		0.49281		
	0.45239E 09		0.18918E 07		
	264.000000	1.568544	-0.003239	0.607330	445.000000
	445.000000	15.000000	18.000000	0.000000	0.174520
1	-82.5000	68.0991	1.8457	0.0271	0.18926E 05
2	-67.5000	207.1478	76.4460	0.3690	0.78392E 06
3	-52.5000	255.8351	132.6877	0.5186	0.13607E 07
4	-37.5000	277.9481	140.4963	0.5055	0.14407E 07
5	-22.5000	288.8809	142.2243	0.4923	0.14585E 07
6	-7.5000	293.5322	142.1712	0.4843	0.14579E 07
7	7.5000	293.5322	142.1712	0.4843	0.14579E 07
8	22.5000	288.8809	142.2242	0.4923	0.14585E 07
9	37.5000	277.9481	140.4963	0.5055	0.14407E 07
10	52.5000	255.8351	132.6877	0.5186	0.13607E 07
11	67.5000	207.1478	76.4459	0.3690	0.78392E 06
12	82.5000	68.0991	1.8457	0.0271	0.18926E 05

Table 4.4 Collector Output for 10 deg Tilt, North-South Orientation (Cont)

	1271.74219		2782.88672			
	0.13041E 08		0.45699			
	0.39124E 09		0.16538E 07			
	294.000000	1.425885	-0.204674		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.174520
1	-67.5000	164.0231	41.7225	0.2544	0.42785E 06	
2	-52.5000	246.2579	115.2654	0.4681	0.11820E 07	
3	-37.5000	278.1731	124.1633	0.4464	0.12732E 07	
4	-22.5000	292.8272	124.5375	0.4253	0.12771E 07	
5	-7.5000	298.8508	123.3317	0.4127	0.12647E 07	
6	7.5000	298.8508	123.3317	0.4127	0.12647E 07	
7	22.5000	292.8272	124.5376	0.4253	0.12771E 07	
8	37.5000	278.1731	124.1633	0.4464	0.12732E 07	
9	52.5000	246.2579	115.2654	0.4681	0.11820E 07	
10	67.5000	164.0231	41.7225	0.2544	0.42785E 06	
	1058.04102		2560.26416			
	0.10850E 08		0.41325			
	0.33634E 09		0.14516E 07			
	325.000000	1.308933	-0.356591		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.174520
1	-67.5000	81.0817	7.7623	0.0957	0.79600E 05	
2	-52.5000	222.5375	83.2499	0.3741	0.85370E 06	
3	-37.5000	269.3898	103.7758	0.3852	0.10642E 07	
4	-22.5000	289.2386	103.5380	0.3580	0.10617E 07	
5	-7.5000	297.1097	101.4285	0.3414	0.10401E 07	
6	7.5000	297.1097	101.4285	0.3414	0.10401E 07	
7	22.5000	289.2386	103.5380	0.3580	0.10617E 07	
8	37.5000	269.3898	103.7758	0.3852	0.10642E 07	
9	52.5000	222.5375	83.2500	0.3741	0.85370E 06	
10	67.5000	81.0817	7.7623	0.0957	0.79600E 05	
	799.50940		2318.71484			
	0.81987E 07		0.34481			
	0.24596E 09		0.15363E 07			
	354.000000	1.264642	-0.409211		0.607330	445.000000
	445.000000	15.000000	18.000000		0.000000	0.174520
1	-67.5000	38.5633	0.2915	0.0076	0.29894E 04	
2	-52.5000	211.7881	70.8684	0.3346	0.72673E 06	
3	-37.5000	266.5581	96.0905	0.3605	0.98537E 06	
4	-22.5000	288.8509	95.6278	0.3311	0.98063E 06	
5	-7.5000	297.5413	93.1209	0.3130	0.95492E 06	
6	7.5000	297.5413	93.1209	0.3130	0.95492E 06	
7	22.5000	288.8509	95.6278	0.3311	0.98063E 06	
8	37.5000	266.5581	96.0905	0.3605	0.98537E 06	
9	52.5000	211.7881	70.8684	0.3346	0.72673E 06	
10	67.5000	38.5633	0.2915	0.0076	0.29894E 04	
	711.99829		2206.60352			
	0.73013E 07		0.32267			
	0.22634E 09		0.15906E 07			

Table 4.5 Collector Output for 0 deg Tilt, East-West Orientation

	0.45680E 10					
	21.000000	1.313069	-0.351530		0.607330	445.000000
	445.000000	15.000000	18.000000		1.570681	0.000000
1	-67.5000	92.3768	0.4864	0.0053	0.49878E 04	
2	-52.5000	231.7699	58.6052	0.2529	0.60097E 06	
3	-37.5000	277.0243	114.7902	0.4144	0.11771E 07	
4	-22.5000	296.1384	146.7080	0.4954	0.15044E 07	
5	-7.5000	303.7111	163.9945	0.5400	0.16817E 07	
6	7.5000	303.7111	164.0004	0.5400	0.16818E 07	
7	22.5000	296.1384	146.7185	0.4954	0.15045E 07	
8	37.5000	277.0243	114.7977	0.4144	0.11772E 07	
9	52.5000	231.7699	58.6143	0.2529	0.60107E 06	
10	67.5000	92.3768	0.4859	0.0053	0.49831E 04	
	969.20129		2402.04150			
	0.99388E 07		0.40349			
	0.30810E 09		0.15946E 07			
	52.000000	1.432317	-0.196074		0.607330	445.000000
	445.000000	15.000000	18.000000		1.570681	0.000000
1	-67.5000	185.4349	18.6921	0.1008	0.19168E 06	
2	-52.5000	263.3479	73.0963	0.2776	0.74957E 06	
3	-37.5000	293.0748	118.7545	0.4052	0.12178E 07	
4	-22.5000	306.6578	151.2621	0.4933	0.15511E 07	
5	-7.5000	312.2303	169.0017	0.5413	0.17330E 07	
6	7.5000	312.2303	169.0072	0.5413	0.17331E 07	
7	[illegible].5000	306.6578	151.2719	0.4933	0.15512E 07	
8	37.5000	293.0748	118.7605	0.4052	0.12178E 07	
9	52.5000	263.3479	73.0906	0.2775	0.74952E 06	
10	67.5000	185.4349	18.6840	0.1008	0.19160E 06	
	1061.62109		2721.49170			
	0.10887E 08		0.39009			
	0.30482E 09		0.15759E 07			
	80.000000	1.565763	-0.007233		0.607330	445.000000
	445.000000	15.000000	18.000000		1.570681	0.000000
1	-82.5000	82.8570	0.0000	0.0000	0.00000E 00	
2	-67.5000	227.3868	21.4168	0.0942	0.21962E 06	
3	-52.5000	274.4971	73.4615	0.2676	0.75332E 06	
4	-37.5000	295.4802	118.4977	0.4010	0.12151E 07	
5	-22.5000	305.7684	150.5862	0.4925	0.15442E 07	
6	-7.5000	310.1289	168.1260	0.5421	0.17241E 07	
7	7.5000	310.1289	168.1302	0.5421	0.17241E 07	
8	22.5000	305.7684	150.5939	0.4925	0.15443E 07	
9	37.5000	295.4802	118.5020	0.4010	0.12152E 07	
10	52.5000	274.4971	73.4561	0.2676	0.75326E 06	
11	67.5000	227.3868	21.4027	0.0941	0.21948E 06	
12	82.5000	82.8570	0.0000	0.0000	0.00000E 00	

Table 4.5 Collector Output for 0 deg Tilt, East-West Orientation (Cont)

	1064.17310		2992.23633		
	0.10913E 08		0.35564		
	0.33829E 09		0.18337E 07		
	111.000000	1.713527	0.201900	0.607330	445.000000
	445.000000	15.000000	18.000000	1.570681	0.000000
1	-97.5000	0.0000	0.0000	0.0000	0.00000E 00
2	-82.5000	158.5667	0.0000	0.0000	0.00000E 00
3	-67.5000	235.0810	30.2985	0.1289	0.31070E 06
4	-52.5000	267.2522	75.6617	0.2831	0.77588E 06
5	-37.5000	283.4279	115.5189	0.4076	0.11846E 07
6	-22.5000	291.8477	144.3408	0.4946	0.14802E 07
7	-7.5000	295.5206	160.2354	0.5422	0.16432E 07
8	7.5000	295.5206	160.2379	0.5422	0.16432E 07
9	22.5000	291.8477	144.3455	0.4946	0.14802E 07
10	37.5000	283.4279	115.5217	0.4076	0.11846E 07
11	52.5000	267.2522	75.6597	0.2831	0.77586E 06
12	67.5000	235.0810	30.2959	0.1289	0.31067E 06
13	82.5000	158.5667	0.0000	0.0000	0.00000E 00
14	97.4999	0.0000	0.0000	0.0000	0.00000E 00
	1052.11621		3063.39307		
	0.10789E 08		0.34345		
	0.32367E 09		0.20469E 07		
	141.000000	1.828361	0.351336	0.607330	445.000000
	445.000000	15.000000	18.000000	1.570681	0.000000
1	-97.5000	45.2991	0.0000	0.0000	0.00000E 00
2	-82.5000	180.9570	13.0839	0.0723	0.13417E 06
3	-67.5000	234.8993	43.0626	0.1833	0.44159E 06
4	-52.5000	260.7444	81.0506	0.3108	0.83114E 06
5	-37.5000	274.6178	115.4044	0.4202	0.11834E 07
6	-22.5000	282.0936	140.7948	0.4991	0.14438E 07
7	-7.5000	285.4098	154.9696	0.5430	0.15892E 07
8	7.5000	285.4098	154.9711	0.5430	0.15892E 07
9	22.5000	282.0936	140.7975	0.4991	0.14438E 07
10	37.5000	274.6178	115.4059	0.4202	0.11834E 07
11	52.5000	260.7444	81.0504	0.3108	0.83114E 06
12	67.5000	234.8993	43.0626	0.1833	0.44159E 06
13	82.5000	180.9570	13.0832	0.0723	0.13416E 06
14	97.4999	45.2991	0.0000	0.0000	0.00000E 00
	1096.73657		3128.04248		
	0.11247E 08		0.35061		
	0.34864E 09		0.19681E 07		
	172.000000	1.876977	0.409245	0.607330	445.000000
	445.000000	15.000000	18.000000	1.570681	0.000000
1	-97.5000	70.2782	0.0041	0.0001	0.42533E 02
2	-82.5000	183.7781	20.4511	0.1113	0.20972E 06
3	-67.5000	231.7867	48.3542	0.2086	0.49585E 06
4	-52.5000	255.8485	83.1025	0.3248	0.85218E 06
5	-37.5000	269.0734	114.9340	0.4271	0.11786E 07
6	-22.5000	276.2924	138.6984	0.5020	0.14223E 07
7	-7.5000	279.5086	152.0325	0.5439	0.15590E 07
8	7.5000	279.5086	152.0337	0.5439	0.15590E 07
9	22.5000	276.2924	138.7004	0.5020	0.14223E 07
10	37.5000	269.0734	114.9350	0.4272	0.11786E 07
11	52.5000	255.8485	83.1024	0.3248	0.85218E 06
12	67.5000	231.7867	48.3540	0.2086	0.49585E 06
13	82.5000	183.7781	20.4504	0.1113	0.20971E 06
14	97.4999	70.2782	0.0041	0.0001	0.42533E 02

Table 4.5 Collector Output for 0 deg Tilt, East-West Orientation (Cont)

	1115.15698		3133.13184		
	0.11436E 08		0.35592		
	0.34307E 09		0.18980E 07		
	202.000000	1.832884	0.356869	0.607330	445.000000
	445.000000	15.000000	18.000000	1.570681	0.000000
1	-97.5000	42.5341	0.0000	0.0000	0.00000E 00
2	-82.5000	172.4916	12.9890	0.0753	0.13320E 06
3	-67.5000	226.2175	42.0469	0.1859	0.43117E 06
4	-52.5000	252.3102	78.8621	0.3126	0.80870E 06
5	-37.5000	266.4050	112.2647	0.4214	0.11512E 07
6	-22.5000	274.0249	137.0010	0.5000	0.14049E 07
7	-7.5000	277.4103	150.8203	0.5437	0.15466E 07
8	7.5000	277.4103	150.8217	0.5437	0.15466E 07
9	22.5000	274.0249	137.0036	0.5000	0.14049E 07
10	37.5000	266.4050	112.2661	0.4214	0.11512E 07
11	52.5000	252.3102	78.8619	0.3126	0.80870E 06
12	67.5000	226.2175	42.0469	0.1859	0.43117E 06
13	82.5000	172.4916	12.9890	0.0753	0.13320E 06
14	97.4999	42.5341	0.0000	0.0000	0.00000E 00
	1067.97314		3022.78711		
	0.10952E 08		0.35331		
	0.33950E 09		0.18847E 07		
	232.000000	1.720513	0.211427	0.607330	445.000000
	445.000000	15.000000	18.000000	1.570681	0.000000
1	-97.5000	0.0006	0.0000	0.0000	0.00000E 00
2	-82.5000	143.4563	0.0000	0.0000	0.00000E 00
3	-67.5000	219.2333	29.9703	0.1321	0.29708E 06
4	-52.5000	252.2682	72.0307	0.2855	0.73865E 06
5	-37.5000	269.1227	110.1951	0.4095	0.11300E 07
6	-22.5000	277.9588	137.9125	0.4962	0.14142E 07
7	-7.5000	281.8267	153.2171	0.5437	0.15712E 07
8	7.5000	281.8267	153.2198	0.5437	0.15712E 07
9	22.5000	277.9588	137.9170	0.4962	0.14143E 07
10	37.5000	269.1227	110.1976	0.4095	0.11300E 07
11	52.5000	252.2682	72.0290	0.2855	0.73863E 06
12	67.5000	219.2333	28.9683	0.1321	0.29706E 06
13	82.5000	143.4563	0.0000	0.0000	0.00000E 00
14	97.4999	0.0006	0.0000	0.0000	0.00000E 00
	1004.65735		2887.73340		
	0.10302E 08		0.34791		
	0.31937E 09		0.18918E 07		
	264.000000	1.568544	-0.003239	0.607330	445.000000
	445.000000	15.000000	18.000000	1.570681	0.000000
1	-82.5000	68.0991	0.0000	0.0000	0.00000E 00
2	-67.5000	207.1478	19.6315	0.0948	0.20131E 06
3	-52.5000	255.8351	68.8902	0.2693	0.70644E 06
4	-37.5000	277.9481	112.0124	0.4030	0.11486E 07
5	-22.5000	288.8809	142.8757	0.4946	0.14651E 07
6	-7.5000	293.5322	159.7596	0.5443	0.16383E 07
7	7.5000	293.5322	159.7636	0.5443	0.16383E 07
8	22.5000	288.8809	142.8828	0.4946	0.14652E 07
9	37.5000	277.9481	112.0165	0.4030	0.11487E 07
10	52.5000	255.8351	68.8853	0.2693	0.70639E 06
11	67.5000	207.1478	19.6189	0.0947	0.20118E 06
12	82.5000	68.0991	0.0000	0.0000	0.00000E 00

Table 4.5 Collector Output for 0 deg Tilt, East-West Orientation (Cont)

	1006.33655		2782.88672			
	0.10320E 08		0.36162			
	0.30959E 09		0.16538E 07			
	294.000000	1.425885	-0.204874		0.607330	445.000000
	445.000000	15.000000	18.000000		1.570681	0.000000
1	-67.5000	164.0231	15.8756	0.0968	0.16280E 06	
2	-52.5000	246.2579	68.8585	0.2796	0.70612E 06	
3	-37.5000	278.1731	113.2780	0.4072	0.11616E 07	
4	-22.5000	292.8272	144.9883	0.4951	0.14868E 07	
5	-7.5000	298.8508	162.2931	0.5431	0.16643E 07	
6	7.5000	298.8508	162.2982	0.5431	0.16643E 07	
7	22.5000	292.8272	144.9976	0.4952	0.14869E 07	
8	37.5000	278.1731	113.2839	0.4072	0.11617E 07	
9	52.5000	246.2579	68.8532	0.2796	0.70606E 06	
10	67.5000	164.0231	15.8687	0.0967	0.16273E 06	
	1010.59509		2560.26416			
	0.10363E 08		0.39472			
	0.32126E 09		0.14516E 07			
	325.000000	1.308933	-0.356591		0.607330	445.000000
	445.000000	15.000000	18.000000		1.570681	0.000000
1	-67.5000	81.0817	0.3535	0.0044	0.36250E 04	
2	-52.5000	222.5375	55.7005	0.2503	0.57119E 06	
3	-37.5000	269.3898	111.8972	0.4154	0.11475E 07	
4	-22.5000	289.2386	143.5374	0.4963	0.14719E 07	
5	-7.5000	297.1097	160.6558	0.5407	0.16475E 07	
6	7.5000	297.1097	160.6613	0.5407	0.16475E 07	
7	22.5000	289.2386	143.5476	0.4963	0.14720E 07	
8	37.5000	269.3898	111.9045	0.4154	0.11475E 07	
9	52.5000	222.5375	55.7093	0.2503	0.57128E 06	
10	67.5000	81.0817	0.3531	0.0044	0.36211E 04	
	944.32031		2318.71484			
	0.96836E 07		0.40726			
	0.29051E 09		0.15363E 07			
	354.000000	1.264642	-0.409211		0.607330	445.000000
	445.000000	15.000000	19.000000		1.570681	0.000000
1	-67.5000	38.5633	0.0000	0.0000	0.00000E 00	
2	-52.5000	211.7881	46.4623	0.2194	0.47645E 06	
3	-37.5000	266.5581	101.7321	0.3817	0.10432E 07	
4	-22.5000	288.8509	143.3987	0.4964	0.14705E 07	
5	-7.5000	297.5413	160.4846	0.5394	0.16457E 07	
6	7.5000	297.5413	160.4907	0.5394	0.16458E 07	
7	22.5000	288.8509	143.4095	0.4965	0.14706E 07	
8	37.5000	266.5581	101.7517	0.3817	0.10434E 07	
9	52.5000	211.7881	46.4702	0.2194	0.47653E 06	
10	67.5000	38.5633	0.0000	0.0000	0.00000E 00	
	904.19983		2206.60352			
	0.92722E 07		0.40977			
	0.28744E 09		0.15906E 07			

Table 4.6 Legend for Suntec-Hexcel Performance Estimate

Value	Legend
52.000000	Day of Year
445.000000	T average (°F)
1.432317	Sunrise, Sunset angle(radian)
15.000000	No. rows (80 feet each)
-0.196074	Declination angle(rad.)
18.000000	Spacing between rows (feet)
0.607330	Latitude(r)
0.000000	Angle from N/S orientation(r)
445.000000	T average (°F)
0.000000	Tilt angle(r)

	Hour Angle (degrees)	I Direct Normal (BTU/hr/ft^2)		Efficiency	Collected (BTU/hr)
1	-67.5000	185.4349	38.0882	0.2054	0.38564E 06
2	-52.5000	263.3479	103.0478	0.3913	0.10434E 07
3	-37.5000	293.0748	117.2070	0.3999	0.11867E 07
4	-22.5000	306.6578	110.3295	0.3598	0.11171E 07
5	-7.5000	312.2303	104.5754	0.3349	0.10588E 07
6	7.5000	312.2303	104.5754	0.3349	0.10588E 07
7	22.5000	306.6578	110.3295	0.3598	0.11171E 07
8	37.5000	293.0748	117.2070	0.3999	0.11867E 07
9	52.5000	263.3479	103.0478	0.3913	0.10434E 07
10	67.5000	185.4349	38.0882	0.2054	0.38564E 06

Value	Legend
946.49561	Collected (BTU/ft^2/day)
0.95833E 07	Collected (BTU/day)
0.26833E 09	Collected (BTU/month)
2721.49170	Energy available to collector (BTU/ft^2/day)
0.34779	Daily Efficiency
0.16014E 07	Receiver Heat Loss (BTU/day)

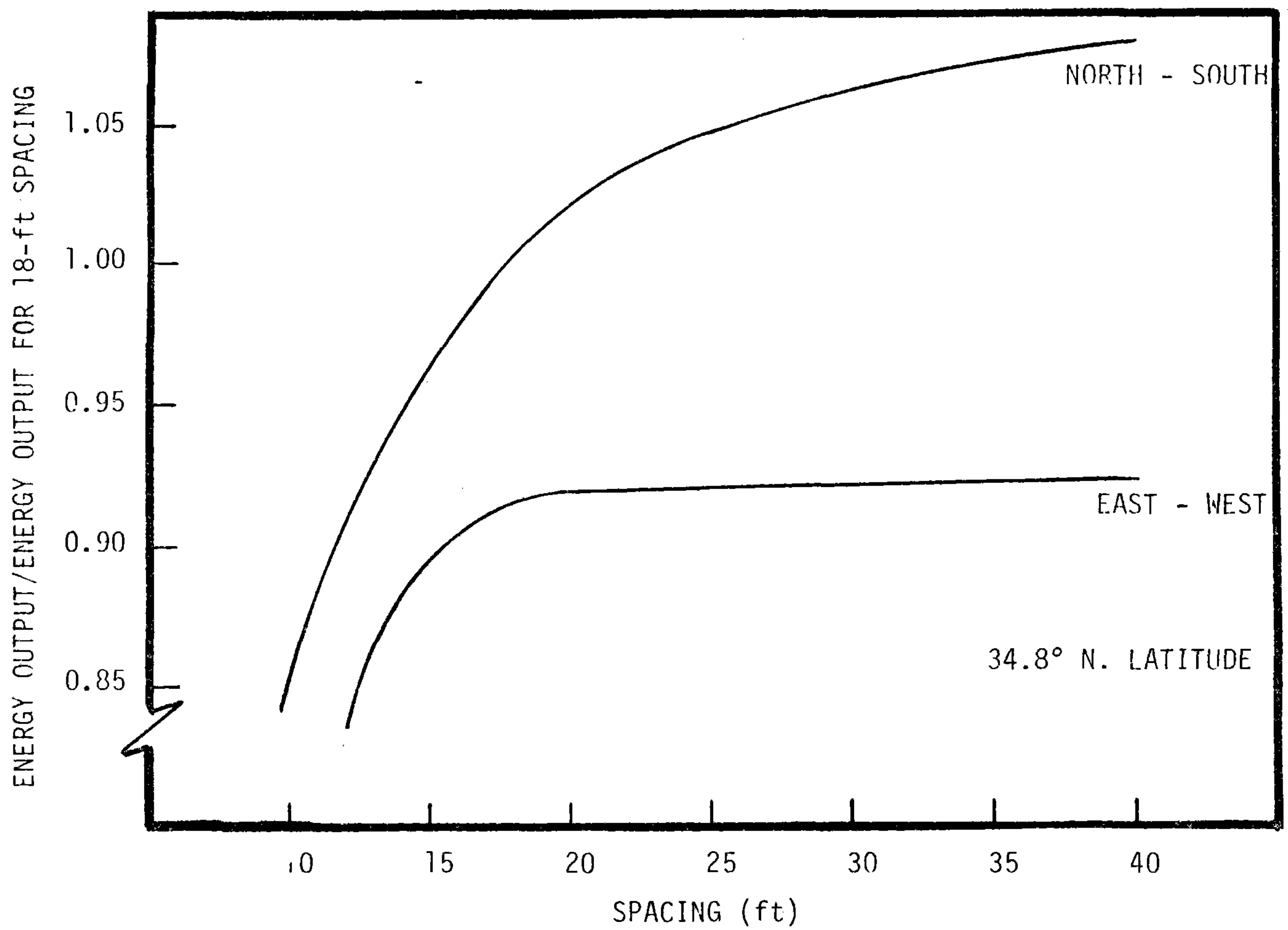


Figure 4.7 Effect of Spacing on Yearly Output

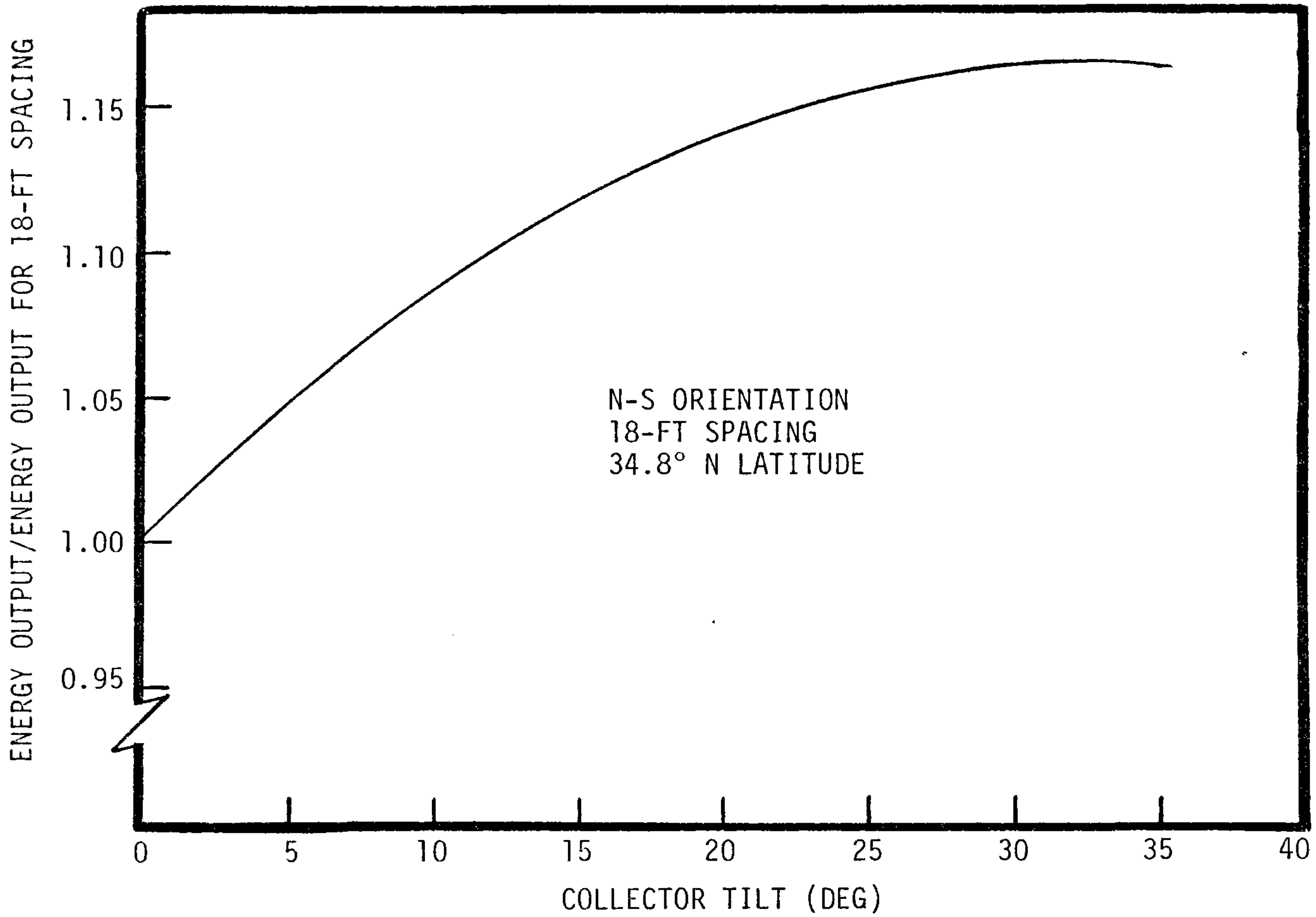


Figure 4.8 Effect of Tilt on Yearly Output

- Accept demand signal (contact closure indicating demand for heat).
- Accept flow signal (contact closure indicating sufficient flow of heat-transfer fluid in collector).
- Provide signal to start flow through collectors.
- Sense fluid temperature (exceeding a set temperature causing automatic collector shutdown or defocus).
- Sense presence of ac power (power failure causes automatic collector shutdown using backup power supply).
- Sense solar intensity (sufficient solar intensity required for collector operation. Set point is adjustable from 300 to 800 W/m^2).
- Activate time delay (3 to 10 min) in shutting down collector in case of solar intensity falling below set point.
- Sense wind speeds (collector shuts down automatically when average wind speed exceeds 30 mph for more than 30 s).

4.7.2 Environmental Conditions

The control system is capable of operating in or surviving the following environmental conditions in any combination.

- Ambient operating temperatures from -40 to 140°F.
- Relative humidity to 100 percent.
- Rainfall of 4 in.
- Snowfall accumulations to 100 in./season, 24 in./storm, 3 in./h.
- Ice accumulations of 2 in./storm, 1 in./h.
- Hail stones up to 0.5 in. diameter at terminal velocity in operating mode, 1.5 in. diameter at terminal velocity in the stowed (nonoperational) mode.
- Sunshine at intensities up to 1100 W/m^2.
- Sand and dust conditions in desert areas.

- Fungus.
- Wind speeds up to 100 mph including wind blown debris.
- Lightning strikes which may occur because of collector location.

4.7.3 Master Controller (One Per System)

The master controller provides functional and system status signals to each of the drive controllers. The basic functions of the master controller are:

- Provide a flow command signal to the fluid loop with the presence of sufficient sunlight (assuming all safety requirements are met)
- Send a search signal to each of the drive controllers upon receiving a ready signal from the fluid loop
- Sense flow through the collectors via flow meter
- Sense ac power and in its absence switch over to the backup power supply
- Accept a user-generated demand signal for solar heat
- Sense wind speed.

A control logic flow chart for the master controller is shown in Figure 4.9.

4.7.4 Drive Controller (One Per Drive Motor)

Each module has a separate drive controller which provides sun tracking commands to the drive motors in response to feedback signals from the tracker tubes. Each drive controller can be operated in either an automatic or manual mode, with the latter mode being used for individual module alignment. Two

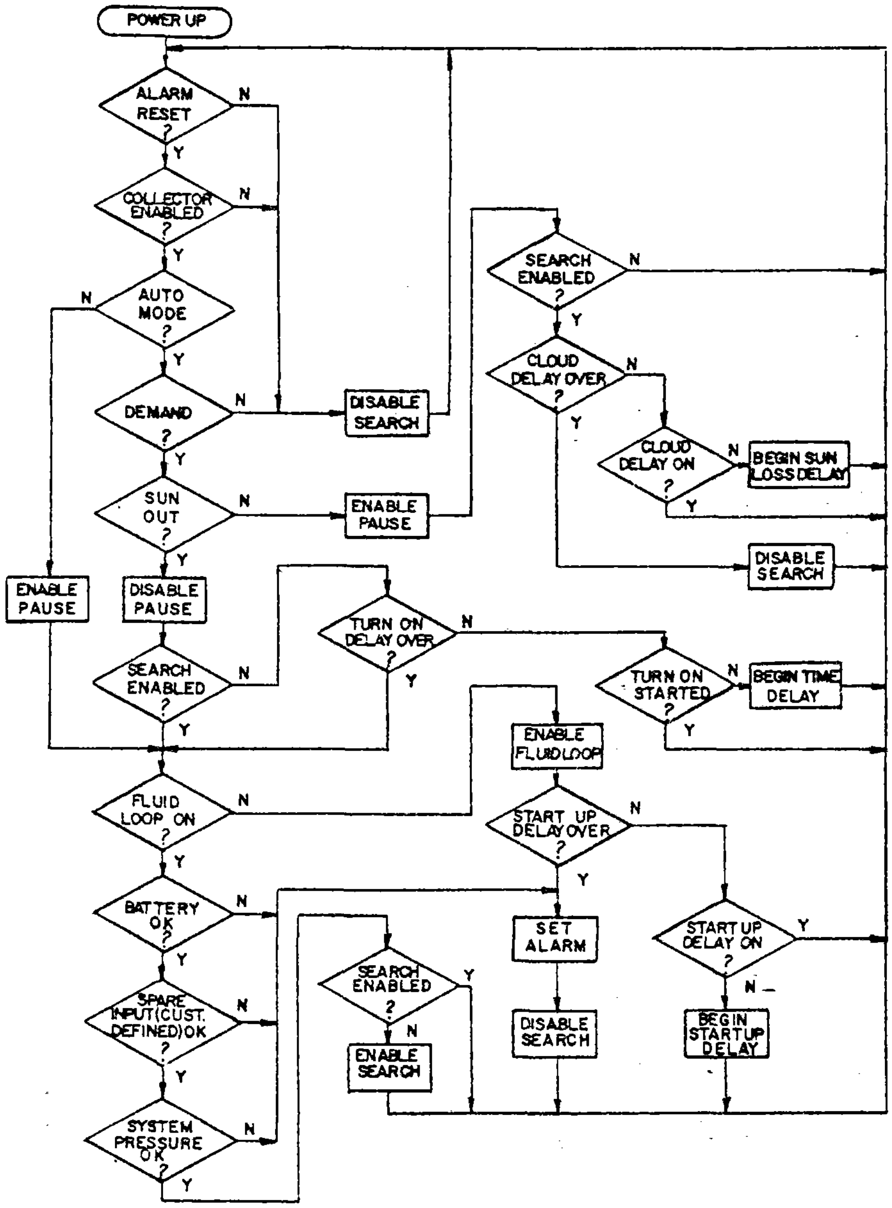


Figure 4.9 Master Controller Logic Flowchart

tracker tubes are positioned across the receiver aperture for each module and provide a null balance feedback signal to the drive controllers that keep the reflected sunlight centered in the receiver aperture throughout the day.

The tracker tubes can be replaced with a pair of drive motor shaft sensors that provide the feedback signal. In this case, the controls calculate the sun's location based on externally set (hour, day, month, latitude, longitude) and internally maintained parameters. With this information, the controls can aim the reflectors and the sun's reflected image precisely enough to meet the requirements.

A control logic flow chart for drive controller is given in Figure 4.10.

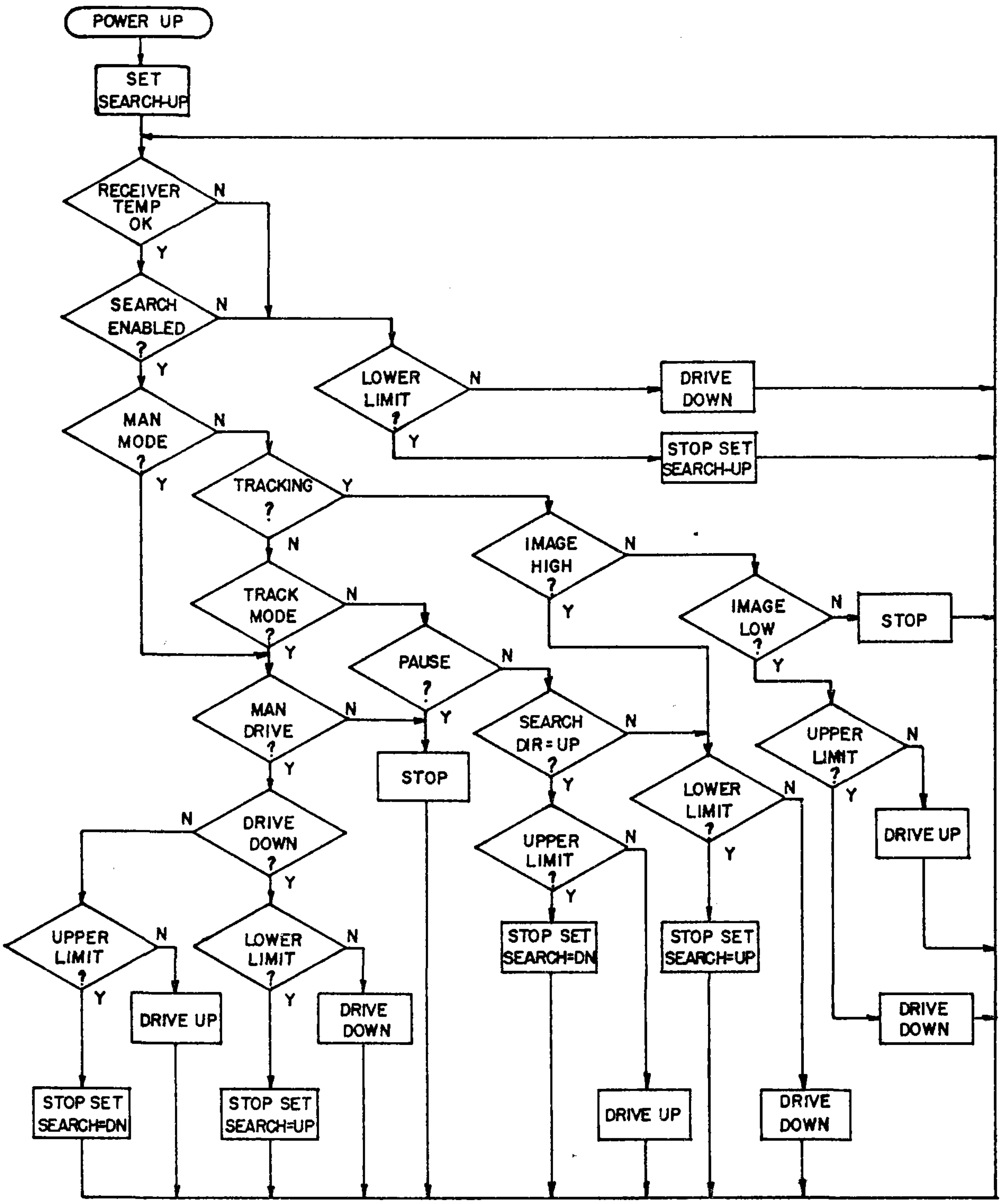


Figure 4.10 Drive Controller Logic Flowchart

SECTION 5
SYSTEMS ANALYSIS

Section 5

SYSTEMS ANALYSIS

5.1 GENERAL

A detailed systems analysis of the selected solar process steam concept is presented in this section. The economic model utilized in this system analysis is described in Subsection 6.2 of this report. The annualized cost of a unit net thermal energy produced by the solar system is used as a basis in this economic model for making optimal design decisions. All parasitic losses, thermal and electric, were considered in computing the net energy output. Other maintenance, repair, and insurance costs were considered in determining annualized costs.

The design decision areas discussed in this section include:

- Thermal storage
- Collector orientation
- Collector spacing
- Heat-transfer fluid
- Piping circuitry
- Operating temperatures
- Piping size
- Control parameter.

The calculations of solar collector thermal output for various collector orientations, spacings, and fluid temperatures through the absorber were made by using the Suntec computer program described in Subsection 4.6. The piping losses were computed by using FWDC-developed computer models. These computer models have the flexibility to treat varying pipe sizes and lengths. The monthly average daytime ambient temperatures shown in Table 4.2 are used. The model has the capability to analyze the constant flow rate situation in which the collector outlet temperature varies with insolation variation.

5.2 THERMAL STORAGE

Thermal storage systems are generally expensive. Thus, a more economically viable solar steam system is one which does not need thermal storage facilities. The need for thermal storage in a hybrid solar process steam system depends on:

- Steam capacity of the solar system
- Steam demand of the process
- Effects of solar system transients on the total system and the process.

The solar steam system to be installed at the Dalton plant will contain 9930 ft^3 of collector area. At peak insolation conditions, it will generate approximately 1500 lb/h steam.

The solar process steam system is designed to supply steam for the continuous stripping operation in Plant 2 of the Dalton plant. The steam required by this operation is approximately 4000 lb/h. Therefore, if the solar steam supply is suddenly cut off because of a cloud cover, the fossil-fueled boiler would have to take the full load. The existing boiler at the plant can pick up

$$\frac{9930}{15 \times 9} = 73.55 \text{ ft/row}$$
$$= 18.39 \text{ ft/module}$$

the full load in about 10 min. During these 10 min, the total steam pressure would be somewhat lower than the required 150 lb/in^2g which would have no significant effect on the stripping operation.

Based on these facts, the solar process steam system does not contain any thermal storage.

5.3 COLLECTOR ORIENTATION

The Suntec-Hexcel collector may be oriented along an east-west direction tracking sun-elevation or along north-south direction tracking the sun-hour. In north-south orientation, the collector output may be further increased by tilting it southward.[7] The orientation of the collectors affects their daily and annual thermal performance.

For 9930 ft^2 collector aperture area, the direct normal insolation available is plotted in Figure 5.1 for an average clear day in December, March, and June. Direct normal insolation available on a typical clear day of each month throughout the year is shown in Figure 5.2. Energy delivered by the collectors for various collector orientations was computed by the Suntec computer program. Typical average clear day collector output for east-west, 0 deg tilt; north-south, 0 deg tilt; and north-south 10 deg tilt are shown in Figure 5.3. Annual collector output for east-west orientation with no tilt and north-south orientation with tilt angles ranging from 0° to 34.8° latitude are shown in Figure 5.4. The results in Figure 5.4 show that the north-south orientation collects about 9 percent more energy than an east-west orientation when the collectors are mounted horizontally. However, Figure 5.3 shows that north-south orientation

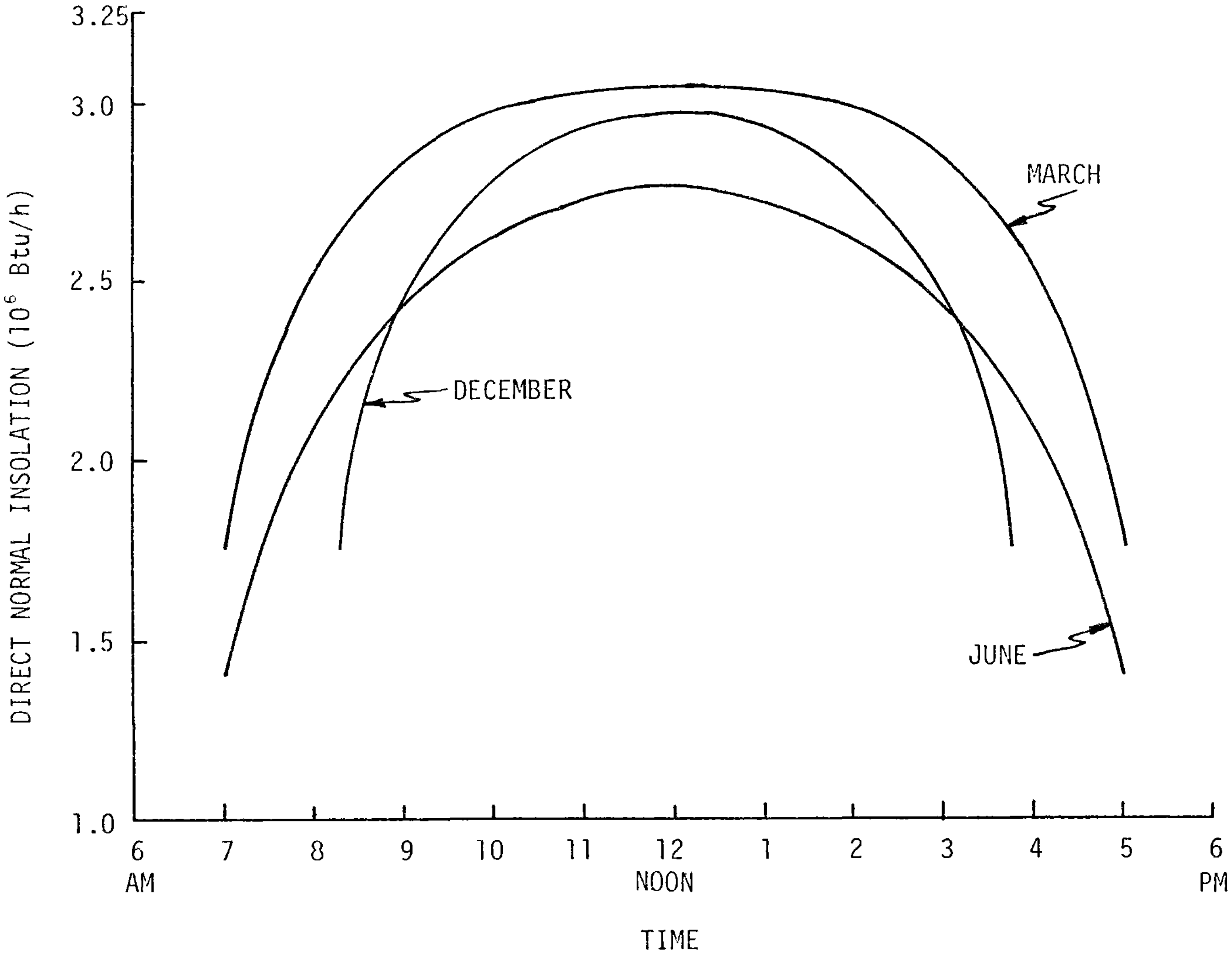


Figure 5.1 Average Clear Day Direct Normal Insolation Hourly Variation for 9930 ft^2 Collector Area

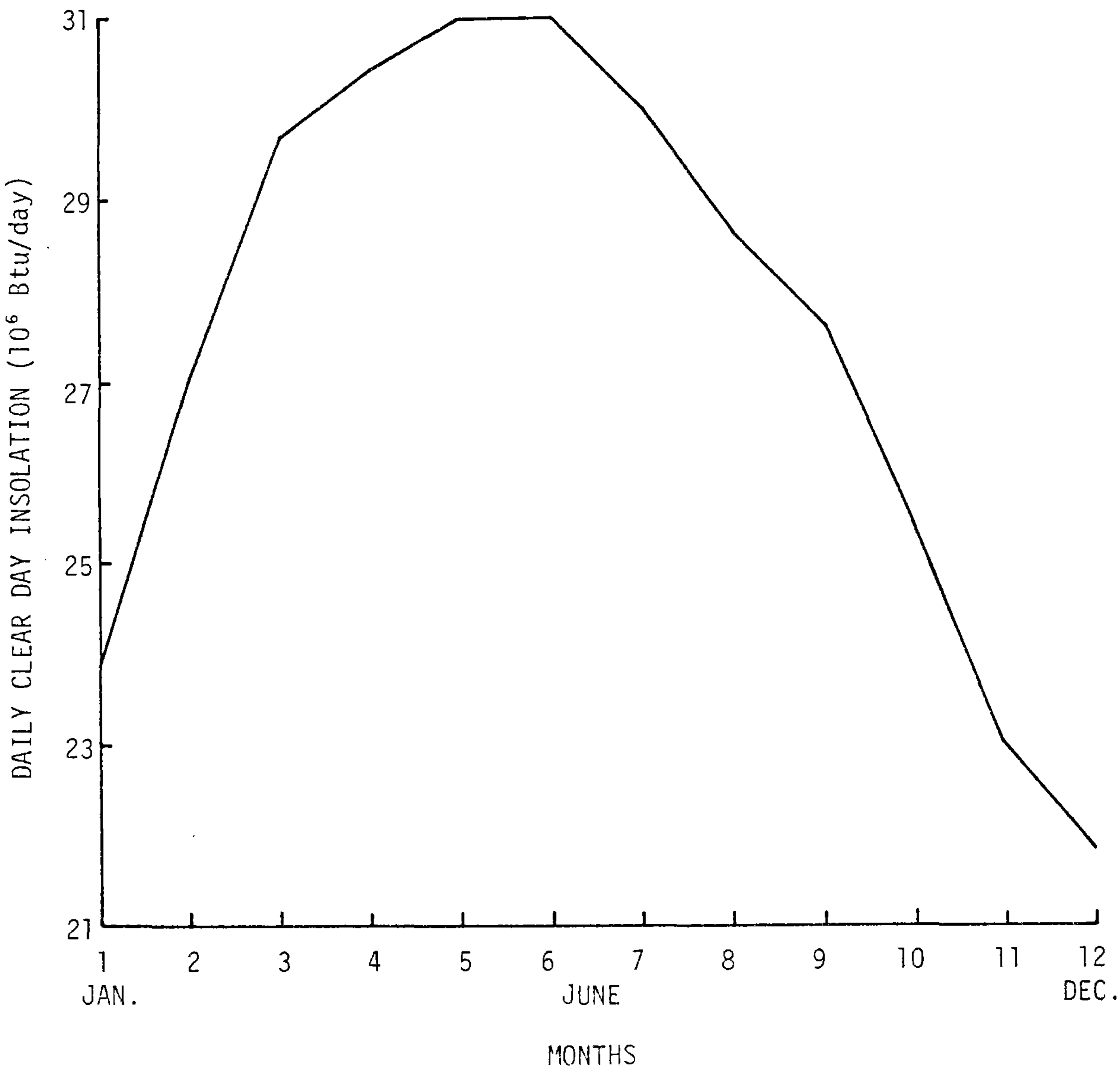


Figure 5.2 Daily Average Clear Day Direct Normal Insolation for 9930 ft^2 Collector Area

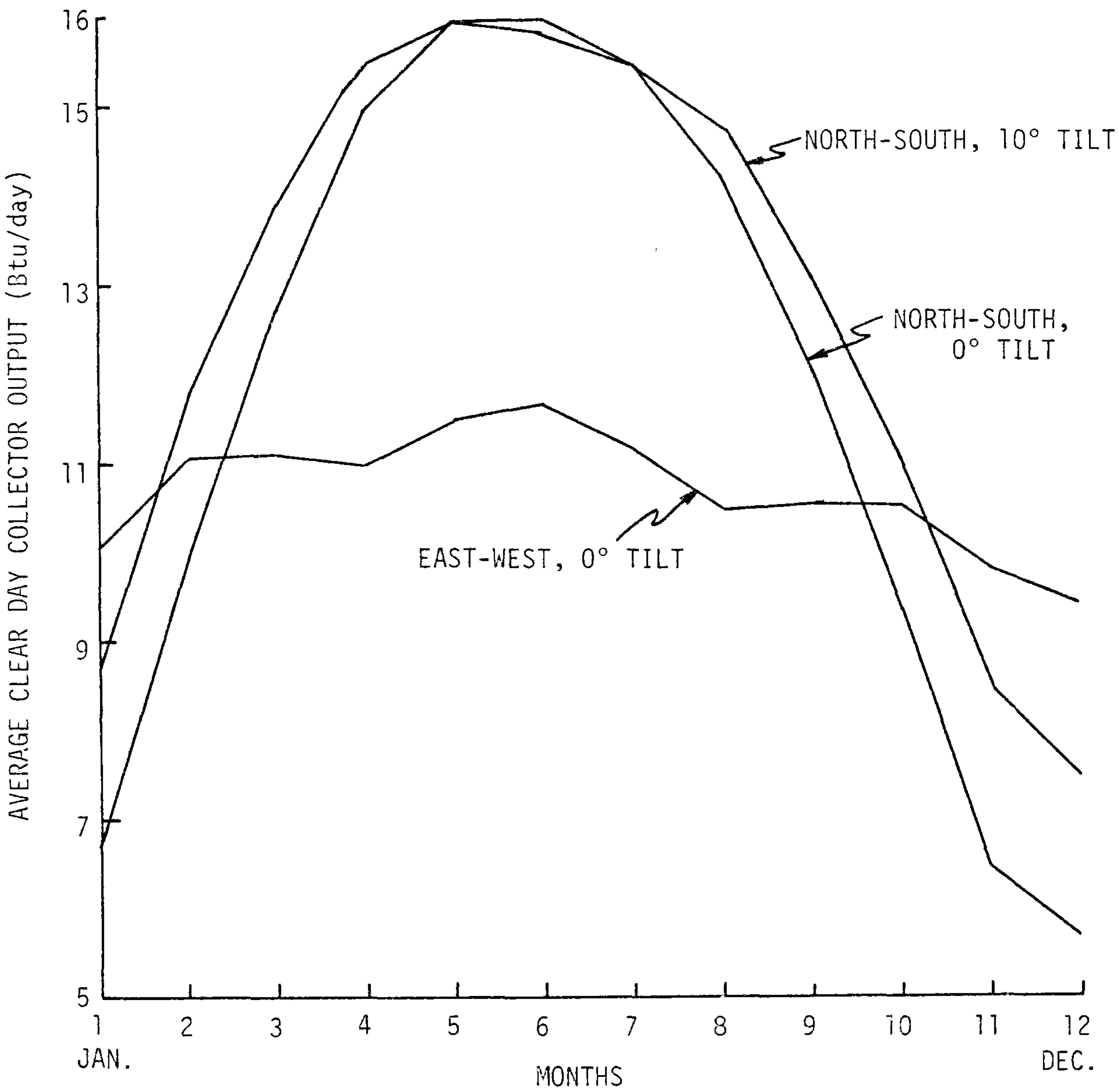


Figure 5.3 Daily Collector Energy vs. Collector Orientation

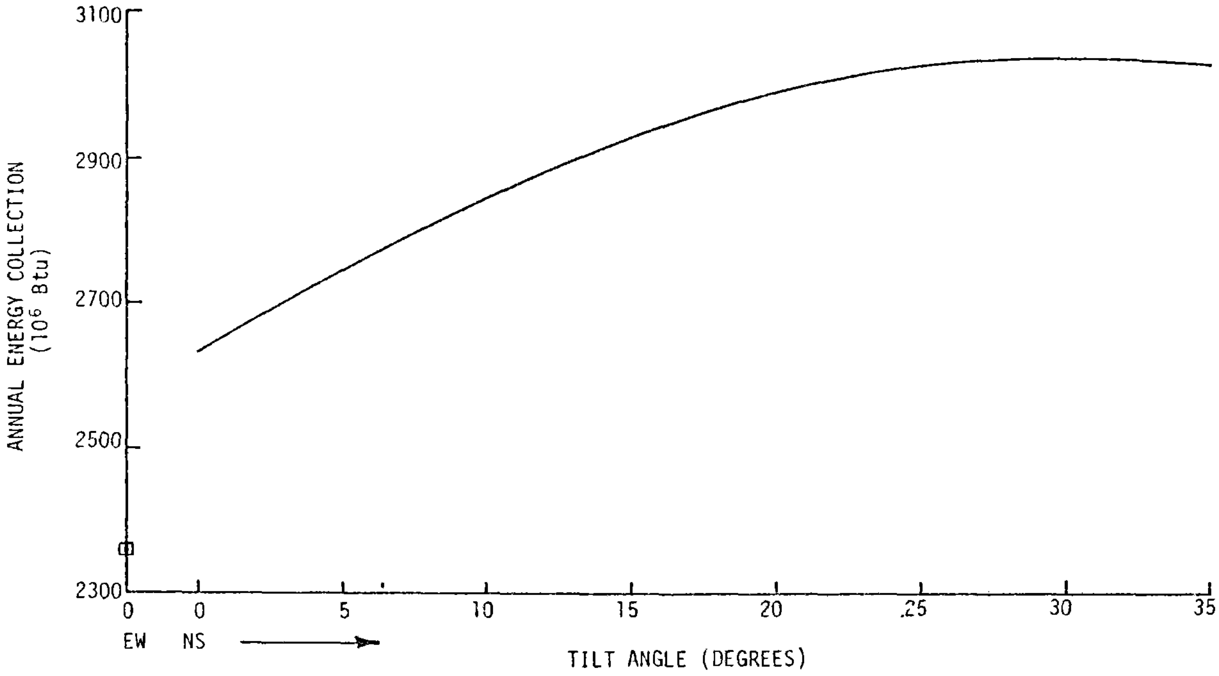


Figure 5.4 Annual Collector Energy Output for Various Collector Orientations

collects more energy during summer months and less energy in winter months than east-west orientation. Thus, east-west orientation yields a more uniform energy output throughout the year. The objective of the present project is to maximize the annual solar energy production. Therefore, north-south orientation is preferable to east-west orientation.

The results in Figure 5.4 also show that as the collectors in north-south orientation are tilted, the annual collected energy increases to a peak at approximately 30 deg tilt. A 30 deg tilt angle yields about 15.3 percent more annual energy than the horizontal north-south orientation.

The cost to install collectors is the lowest in the horizontal plane. Fortunately, the site selected for the collectors is on a small hill facing south. Therefore, if a particular tilt angle can be established only by a cut-and-fill operation, the cost of land preparation will not be affected significantly. If earth from elsewhere must be brought in, land preparation costs will begin to rise significantly. The estimated cost of land preparation for east-west orientation and north-south orientation with tilt angles varying from 0 to 34.8 deg is given in Table 5.1. The net effect on the total cost of the system from land preparation, foundation, piping layout, etc., is also indicated in Table 5.1. The energy produced by the collectors is included in this table. Constant parasitic losses are assumed for all cases. The cost-effectiveness values for different orientations are determined by using Equation 6.4 and are presented in Table 5.1.

Table 5.1 Cost-Effectiveness vs. Collector Orientation

Collector Orientation (deg)	Cost of Land Preparation ($)	Total Excess Cost as Compared to E-W ($)	Energy Calculations			Cost Effectiveness ($/$10^6$ Btu)
			Collector Array Output (10^6 Btu)	Excess Over E-W Orientation (%)	Parasitic Energy (10^6 Btu)	
E-W, 0	43,000	0	2359	0.0	340	32.75
N-S, 0	43,000	0	2631	8.9	360	29.12
N-S, 5	47,000	5,000	2752	14.0	360	27.89
N-S, 10	49,000	7,000	2842	18.3	360	26.97
N-S, 15	89,000	49,000	2936	21.6	360	27.90
N-S, 20	109,000	71,000	2992	23.9	360	28.29
N-S, 25	144,000	108,000	3023	25.2	360	29.59
N-S, 30	179,000	143,000	3033	25.6	360	31.02
N-S, 34.8	209,000	173,000	3028	25.4	360	32.40

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DATE: June 1979

The results in Table 5.1 show that 10 deg tilt in north-south orientation is the most cost-effective configuration, and therefore this configuration was selected for the solar steam system.

5.4 COLLECTOR SPACING

The spacing between adjacent collector rows affects both the cost of the solar steam system as well as its thermal performance. An increase in the spacing between adjacent collectors:

- Increases the total land area required, thereby increasing the land capital and preparation costs
- Increases the total amount of piping required, thereby increasing the piping capital cost, piping thermal losses, overnight thermal losses, and the pressure drop in the fluid loop
- Decreases the collector losses due to shading, thereby increasing the total energy collected.

These effects for the collector row spacing varying from 12 to 27 ft were determined. The annual collector energy output is plotted in Figure 5.5. The collector output increases quite sharply as the spacing is changed from 12 to 18 ft but the rate of this increase slows down thereafter. An 18-ft spacing yields an increase of 12.6 percent in collector output as compared to 12 ft. However, an additional increase of only 6.6 percent is achieved by increasing the collector row spacing to 27 ft. The relative increase in the total cost of the system varies approximately linearly with respect to the collector row spacing. This relative cost increase over 12-ft spacing is also shown in Figure 5.5.

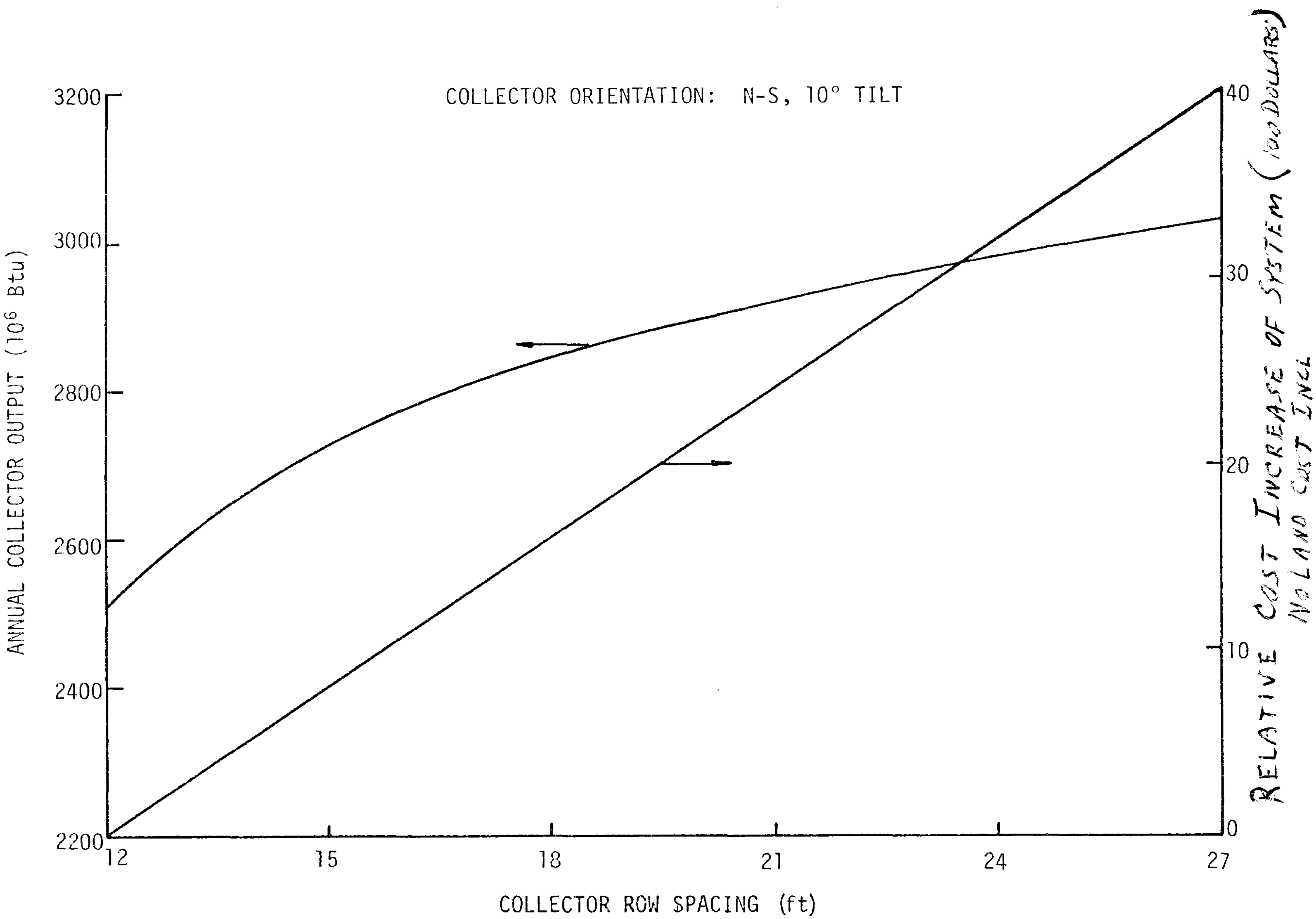

Figure 5.5 Annual Collector Output and Relative Increase in System Cost vs. Collector Row Spacing

The parasitic thermal as well as electrical losses are plotted in Figure 5.6. These parasitic losses also vary linearly with respect to the collector row spacing. Pump energy, piping losses, and overnight heat losses are also shown in Figure 5.6.

Cost-effectiveness of various collector row spacing values is computed by using Equation 6.4 derived in Subsection 6.2. A plot of the cost-effectiveness vs. collector row spacing is presented in Figure 5.7. The results in Figure 5.7 indicate that the collector spacing of 21 ft is the most cost-effective. However, 18-ft spacing was selected for the solar steam system was 18 ft because:

- Its cost-effectiveness is practically indistinguishable from 21-ft spacing
- It requires a smaller initial capital than 21-ft spacing
- It is significantly more cost-effective than 15-ft spacing.

5.5 HEAT-TRANSFER FLUID

Cost factors that must be considered in selecting the heat-transfer fluid are:

- Initial charge of fluid
- Replacing or reconditioning thermally decomposed fluid
- Heating and/or recirculating fluid on cold nights to keep it from becoming too viscous in the morning, i.e., to keep it "pumpable"
- Pump power requirements.

A comparison of the relevant properties and costs of a number of promising heat-transfer fluids is presented in Table 5.2. The maximum thermal

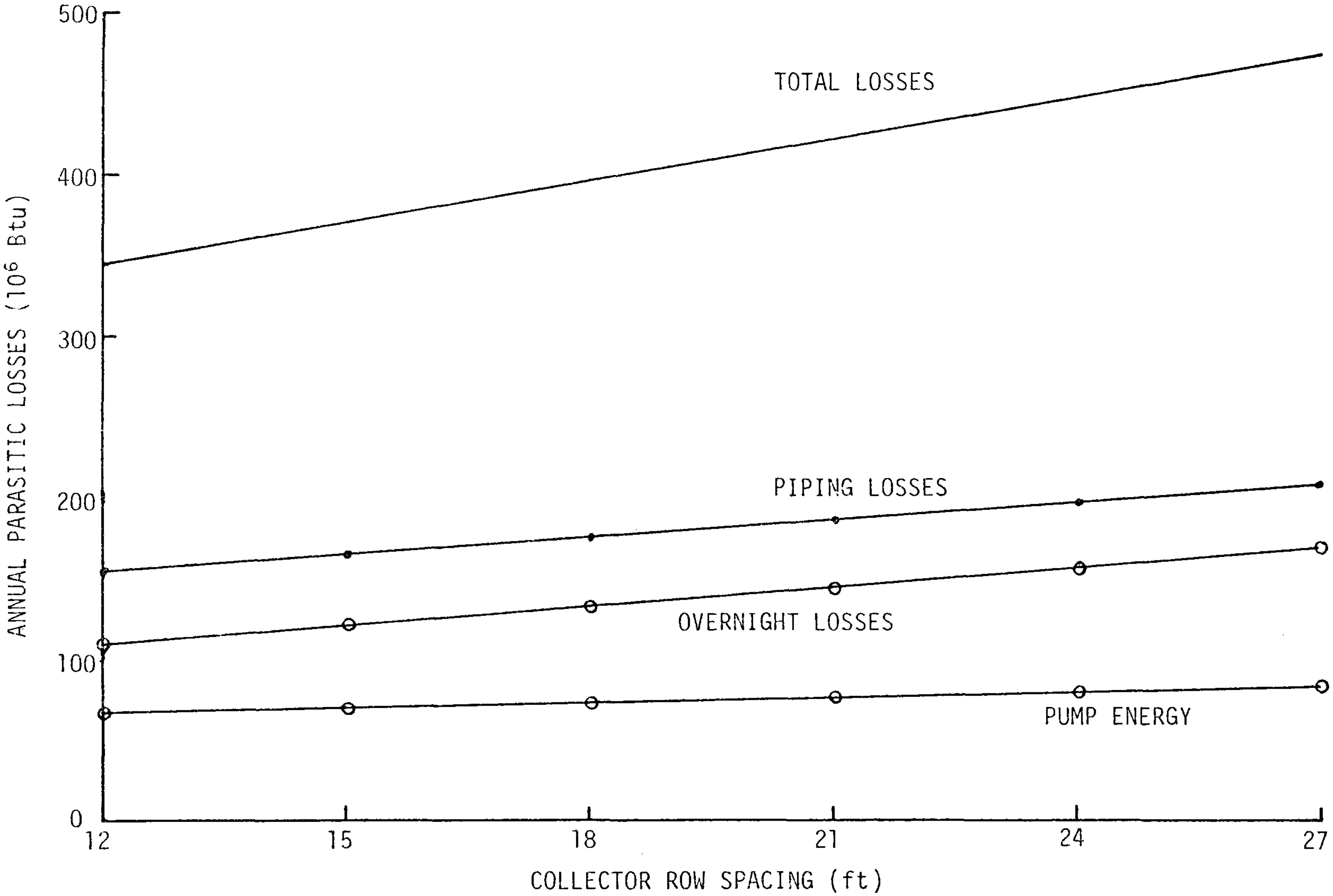

Figure 5.6 Parasitic Losses vs. Collector Row Spacing

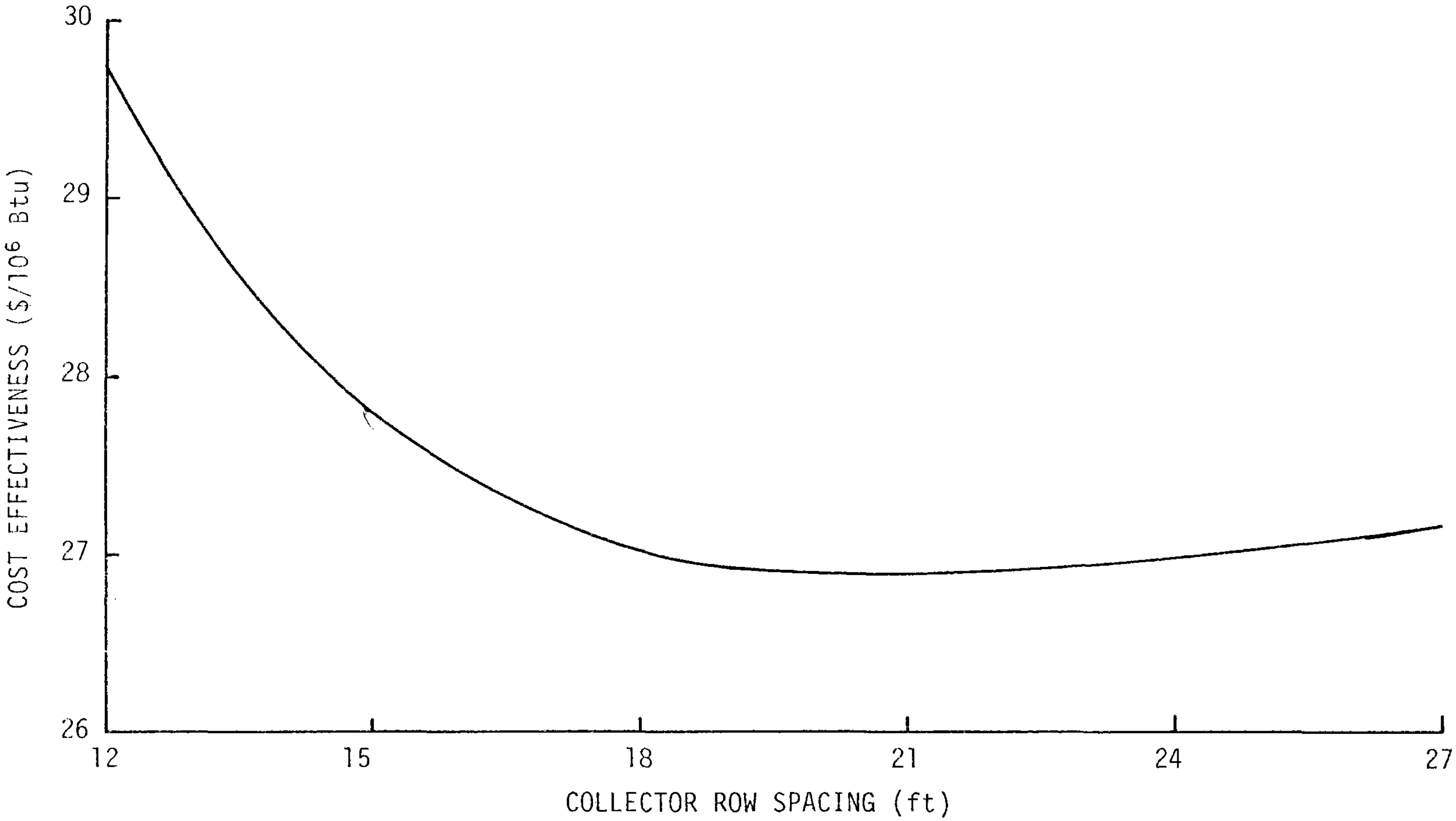

Figure 5.7 Cost Effectiveness vs. Collector Row Spacing

Table 5.2 Comparison of Heat-Transport Fluids

Fluid	Manufacturer	Maximum Thermal Stability Temperature* (°F)	Minimum Pumping Temperature (°F)	Specific Heat† (Btu/lb°F)	Viscosity† (ft^2/h)	Density† (lb/ft^3)	Cost ($/gal)
Dowtherm G	Dow Chemical	640	20	0.478	0.0258	60.00	9.53
Dowtherm LF	Dow Chemical	530	-25	0.527	0.0157	55.68	9.15
Dowtherm J	Dow Chemical	540	-100	0.595	0.0082	44.11	6.69
Caloria HT-43	EXXON	500	30	0.600	0.0577	45.60	1.53
Therminol 55	Monsanto	500	25	0.611	0.0402	47.30	3.31
Therminol 60	Monsanto	525	-35	0.543	0.0238	54.60	9.21
Therminol 66	Monsanto	560	40	0.534	0.0382	55.00	10.47

*For a 30-year lifetime.
†At 400°F.

stability temperature values in this table correspond to an acceptable upper limit of 10 percent decomposition level of the fluid in 214 exposure weeks. The total number of exposure weeks are computed on the basis of 0.5 exposure hour per operating hour, 8 operating hours per day, and 300 days per year of operation.

From the thermal stability point of view, all of the heat-transfer fluids would be adequate if the maximum temperature of the fluid is maintained below 500°F. However, if a maximum fluid temperature of 525°F appears to be most cost-effective from other system considerations, only Caloria HT-43 and Therminol-55 would be unsuitable. If Caloria HT-43 or Therminol-55 were used at 525°F, they would need to be replaced approximately every 10 years.

Caloria HT-43 is the least expensive of the heat-transfer fluids listed in Table 5.2. However, it becomes highly viscous at ambient temperatures, reaching a viscosity of 300 cP at about 30°F. Piping and receiver temperatures can drop below 30°F on cold nights, making it extremely difficult to get the Caloria circulating properly in the morning. Therefore, it would be necessary to use heat tracing or to heat and recirculate the fluid during the night. It was estimated that an additional capital cost of $2,350 would be incurred for heat tracing. As indicated in Table 5.2, the use of Dowtherm LF, Dowtherm J, or Therminol-60 would eliminate the need for heat tracing. The extra initial cost of these three fluids would be $2,286, $1,548, and $2,304, respectively as compared to Caloria HT-43. Therefore, the use of Dowtherm LF, Dowtherm J, or Therminol-60 would be more cost-effective than Caloria based solely on the initial capital cost. If the energy consumed in heat-tracing operation is taken into account, these fluids will be even more cost-effective than Caloria HT-43.

The pumping power depends on the viscosity of the fluid. Dowtherm J has the lowest viscosity at 400°F and thus would require the least pumping power and have the lowest operating cost. Dowtherm LF is the next best candidate fluid from the pumping power standpoint.

Considering all factors mentioned above, the best heat-transfer fluid is Dowtherm LF. Dowtherm LF has the following advantages:

- Maximum Temperature - Can be operated at temperatures up to 530°F without needing replacement for 30 years.
- Minimum Temperature - Minimum pumping temperature is -25°F. Would need no heat tracing or hot fluid recirculation during the night.
- Cost-Effectiveness - Cheaper than Therminol-60. More cost-effective than Caloria HT-43.
- Pumping Power - Requires less pumping power than all but Dowtherm J. The difference in pumping power is estimated to be less than 5 percent.
- Low Vapor Pressure - Vapor pressure at 600°F is 20 lb/in^2g and at 525°F is 3 lb/in^2g. In comparison, vapor pressure of Dowtherm J at 525°F is 80 lb/in^2g. The nitrogen at the plant site is available at 45 lb/in^2g. Hence, additional pressurizing equipment and controls would be required if Dowtherm J was to be used.
- Toxicity - Dowtherm LF is a mild skin irritant and a low toxicity fluid. Any leakage is detected easily by its characteristic smell.
- Autoignition - Autoignition temperature of 1020°F is substantially higher than the system operating temperatures.
- Oxidation Stability - Dowtherm LF after exposure to oxygen exhibits greatest thermal stability.
- Cost Sharing - Dow Chemical Company will furnish the required amount of Dowtherm LF at no expense to the project.

5.6 PIPING CIRCUITRY

The solar collectors are located about 110 ft north of the solar boiler house. The solar collector field occupies about 80 ft x 265 ft of land area. Three alternate piping circuits were considered. These are schematically shown in Figure 5.8. These three alternate schemes will be briefly described and their advantages and disadvantages listed. The final piping circuitry is then selected on the basis of its cost-effectiveness.

5.6.1 Scheme 1

As shown in Figure 5.8(A), the heat-transfer fluid is fed to the inlet manifold at the northwest corner and the hot fluid is taken from the outlet manifold at the southeast corner of the collector field. The main advantage of this scheme is that it equalizes the fluid flow rate through each of the collector rows. However, the disadvantage of this scheme is that it requires 265 ft of additional piping which would result in greater piping heat losses and overnight cool-down losses.

5.6.2 Scheme 2

As shown in Figure 5.8(B), in this scheme the heat-transfer fluid is fed to the inlet manifold at the northeast corner and the hot fluid is taken from the outlet manifold at the southeast corner of the collector field. The primary advantage of this scheme is that is minimizes both the piping heat losses as well as overnight cool-down losses. However, in order to obtain equal flow rates through each of the collector rows, a number of restriction orifices must be designed and installed in the piping circuitry.

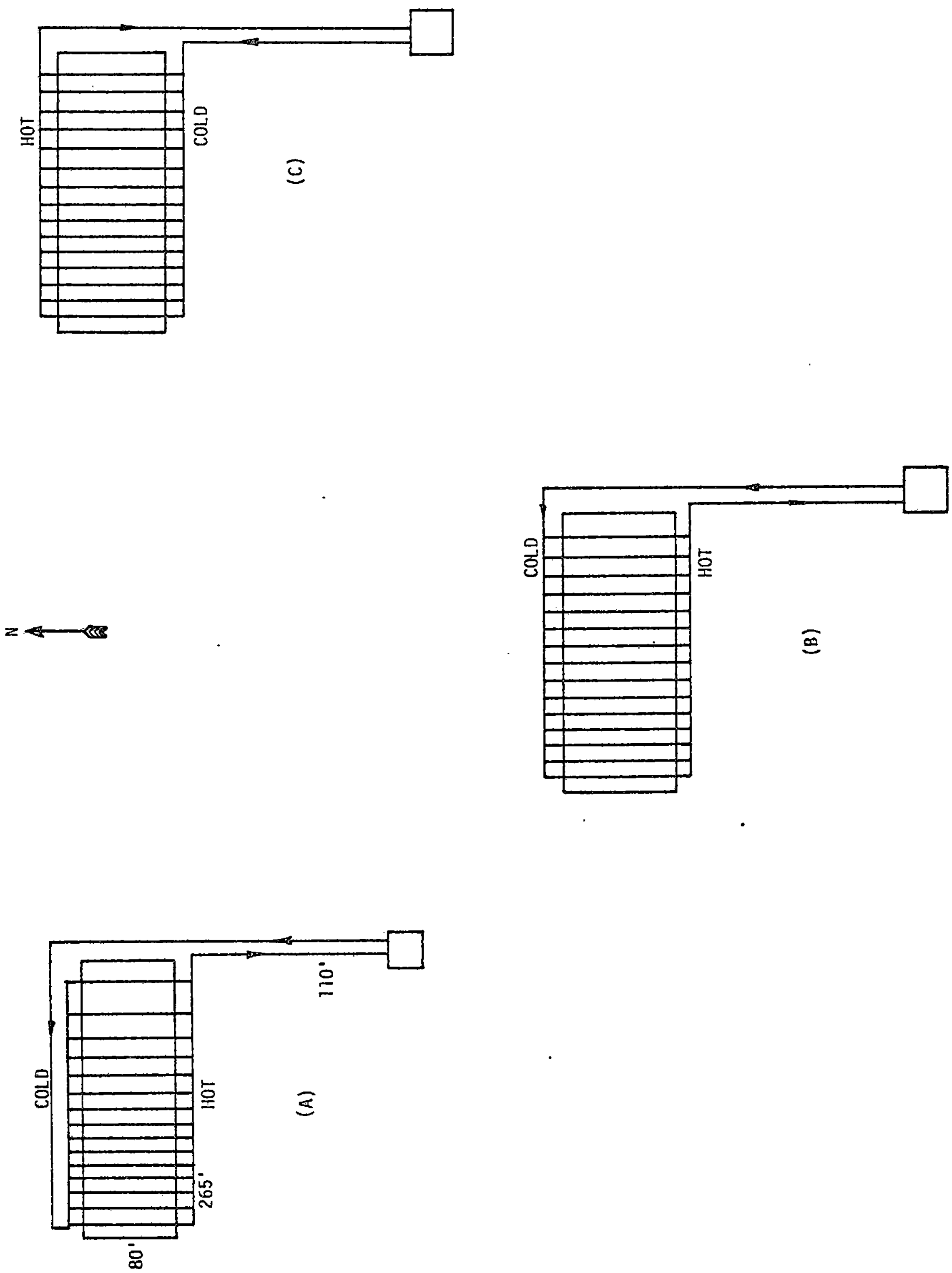

Figure 5.8 Schematic of Alternate Piping Schemes

Since the collector field is tilted facing southward, the circulating pump in this scheme would have to work against the natural circulation tendency of the fluid.

5.6.3 Scheme 3

This scheme, shown in Figure 5.8(C), is identical to Scheme 2 except that the fluid flow direction is reversed. The advantage of this scheme is that the circulating pump is assisted by the natural circulation tendency of the fluid, thereby reducing the pump parasitic energy. However, the piping heat losses in this case are higher than those in Scheme 2 because the pipe containing hot fluid is longer and that containing colder fluid is shorter by 80 ft.

5.6.4 Comparison of the Three Alternate Schemes

A comparison between the three alternate piping schemes is presented in Table 5.3. As mentioned earlier, the piping heat losses, the overnight thermal losses, and the pump parasitic energy in Scheme 1 are considerably higher than the other two schemes. In addition, even the capital cost of extra piping in Scheme 1 is greater than the cost of restriction orifices needed in Schemes 2 and 3. Schemes 2 and 3 are similar except that the piping losses involved in Scheme 3 are about 2 percent more than those in Scheme 2. Although Scheme 3 takes advantage of the natural circulation tendency of the fluid, the reduction in pump energy is not sufficient to offset the extra piping losses involved in this scheme. This difference, though small, is shown by the cost-effectiveness calculations. Scheme 2 was chosen for the solar plant.

Table 5.3 Cost-Effectiveness of Three Alternate Piping Circuits

Piping Circuitry Alternate	Piping Losses (10^6 Btu)	Overnight Losses (10^6 Btu)	Pump Parasitic Energy (10^6 Btu electric)	Extra Cost ($)	Cost Effectiveness ($\$/10^6$ Btu)
				Piping	
Scheme 1 [Figure 5.8(A)]	216.8	164	25.9	6,800	28.05
				Restriction Orifices	
Scheme 2 [Figure 5.8(B)]	175.8	130	18.3	3,500	26.84
Scheme 3 [Figure 5.8(C)]	179.7	130	18.0	3,500	26.89

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5.7 OPERATING TEMPERATURES

Selection of optimum fluid operating temperatures necessitates consideration of collector efficiency, piping heat losses, pump parasitic energy, and boiler and pump capital costs. Since the steam is to be generated at 368.4°F (or 155 lb/in^2g), the boiler outlet fluid temperature must be greater than 368.4°F. The boiler inlet fluid temperature must be greater than the outlet fluid temperature. The maximum limit on the fluid temperature is dictated by its thermal stability. For Dowtherm LF, this limit is 530°F. Thus, the design regime, in which an optimum set of operating temperatures must be determined, is defined.

5.7.1 Energy Production and Losses

Solar collector efficiency decreases with an increase in the average temperature of fluid in the receiver. A variation of annual collected energy with respect to the average fluid temperature is shown in Figure 5.9 for east-west; north-south, 0 deg tilt; and north-south, 10 deg tilt orientation.

The piping heat losses increase as the boiler inlet or outlet temperature is increased. A plot of annual piping losses with respect to boiler inlet and outlet temperatures is shown in Figure 5.10. The overnight heat losses would remain approximately unaffected by the fluid operating temperatures. These heat losses are assumed to be 130×10^6 Btu for the computations in this subsection.

The pump parasitic energy depends on the fluid flow rate which varies almost linearly with the temperature differential across the boiler. The annual

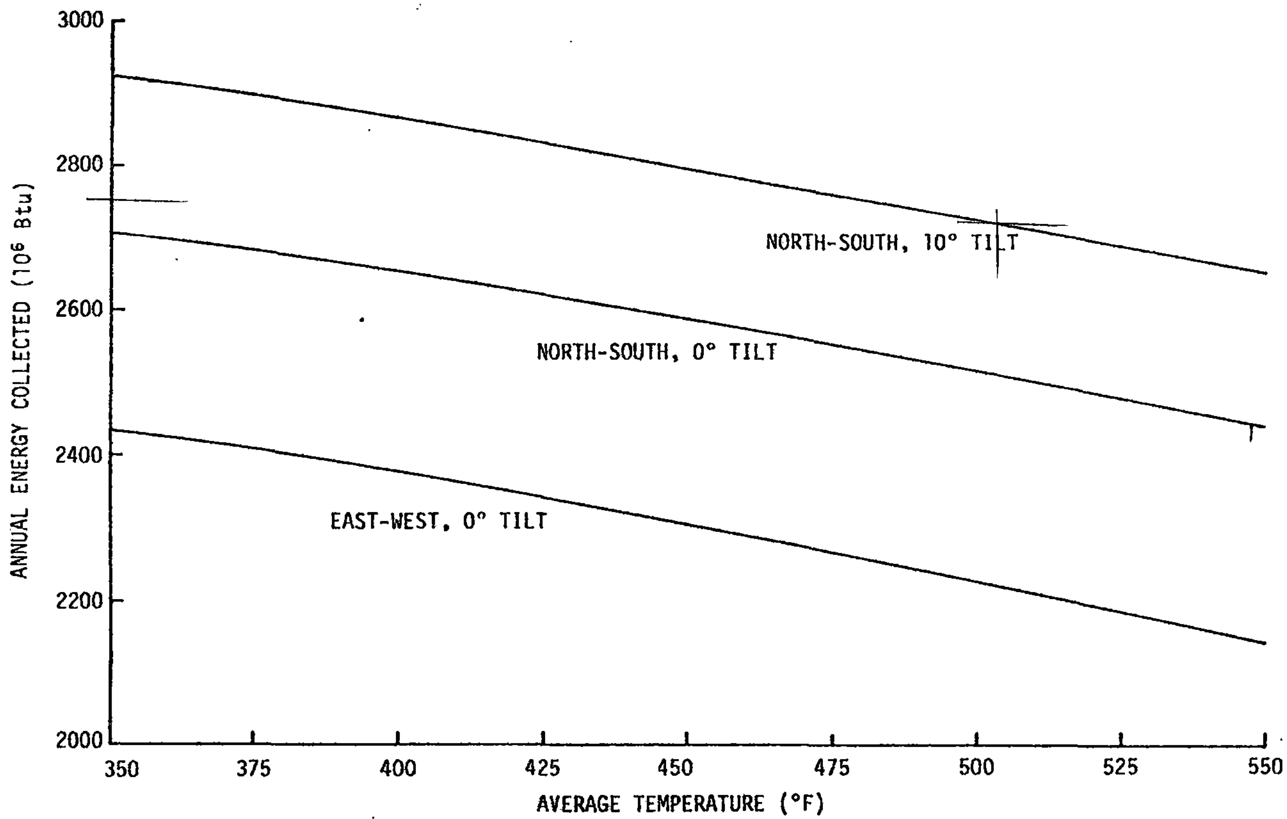

Figure 5.9 Annual Thermal Energy Collected vs. Average Heat-Transfer Fluid Temperature

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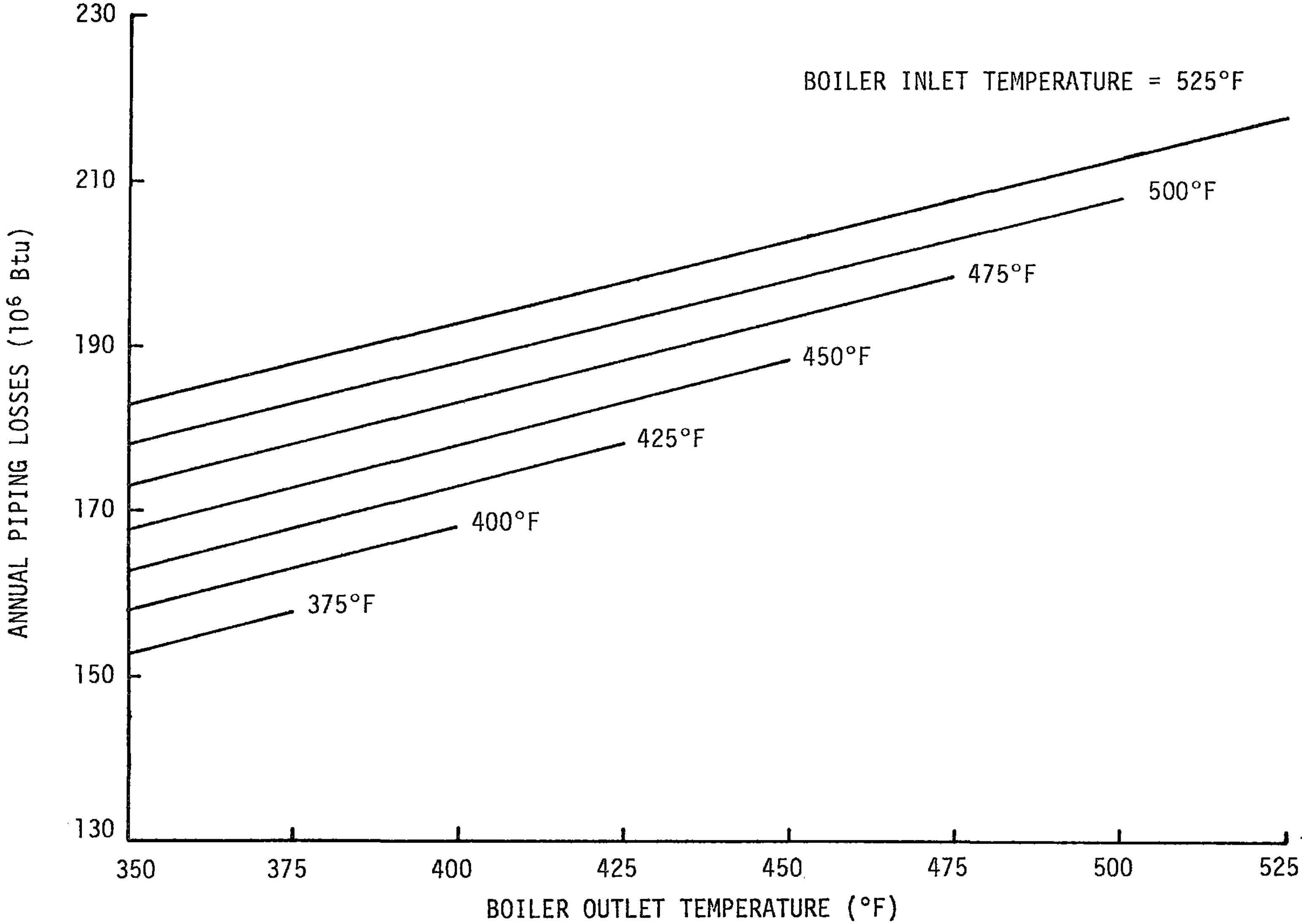

Figure 5.10 Annual Piping Losses vs. Boiler Inlet and Outlet Temperatures

pump parasitic energy for various boiler inlet and outlet temperatures is presented in Figure 5.11. This figure indicates that as the boiler outlet temperature approaches the boiler inlet temperature, the pump energy approaches an infinitely large value.

5.7.2 Effects on System Cost

The required boiler surface areas for various fluid temperatures across the boiler are plotted in Figure 5.12. This figure indicates that the boiler surface area decreases as the boiler inlet and outlet temperatures are increased. Thus, the inlet/outlet temperature combination of 525°F/500°F yields the smallest boiler, whereas 425°F/370°F yields the largest. The feedwater temperature of 205°F and the steam temperature of 368.4°F was assumed for these calculations. As the boiler surface area increases, the boiler cost per square foot of area decreases.

The pump cost varies in direct proportion to its required duty.[8] As indicated by Figure 5.11, a decrease in the temperature differential across the boiler requires a larger pump, increasing the pump capital cost. Thus, for a constant value of boiler inlet temperature, the boiler cost decreases and the pump cost increases with an increase in boiler outlet temperature.

5.7.3 Cost-Effectiveness of Operating Temperatures

The cost-effectiveness of various operating temperatures was determined in accordance with Equation 6.4 given in Subsection 6.2. A summary of these cost-effectiveness values is shown in Figure 5.13. The results in Figure 5.13 indicate that for a constant boiler inlet temperature, the cost-effectiveness

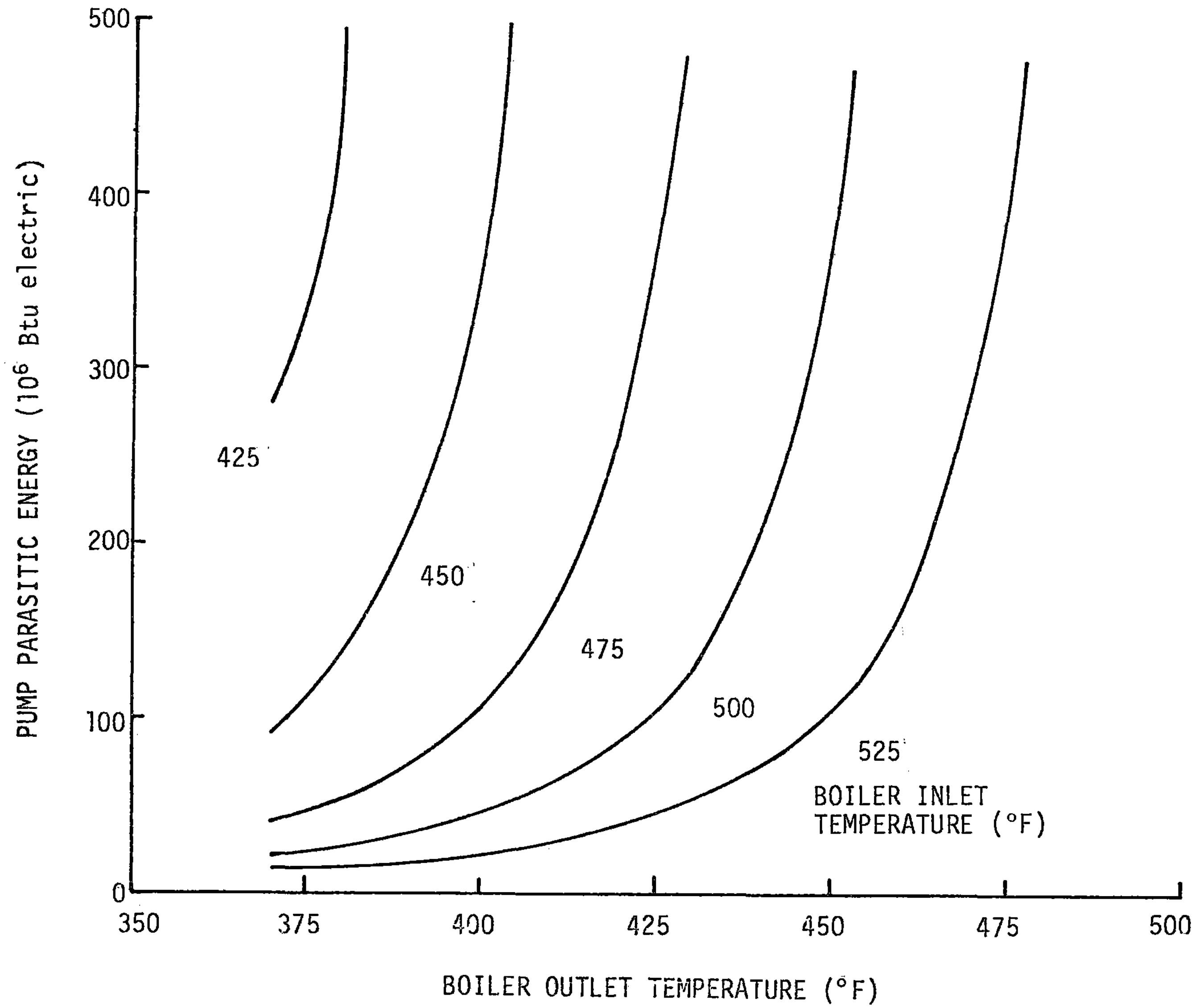

Figure 5.11 Pump Parasitic Energy vs. Boiler Inlet and Outlet Temperatures

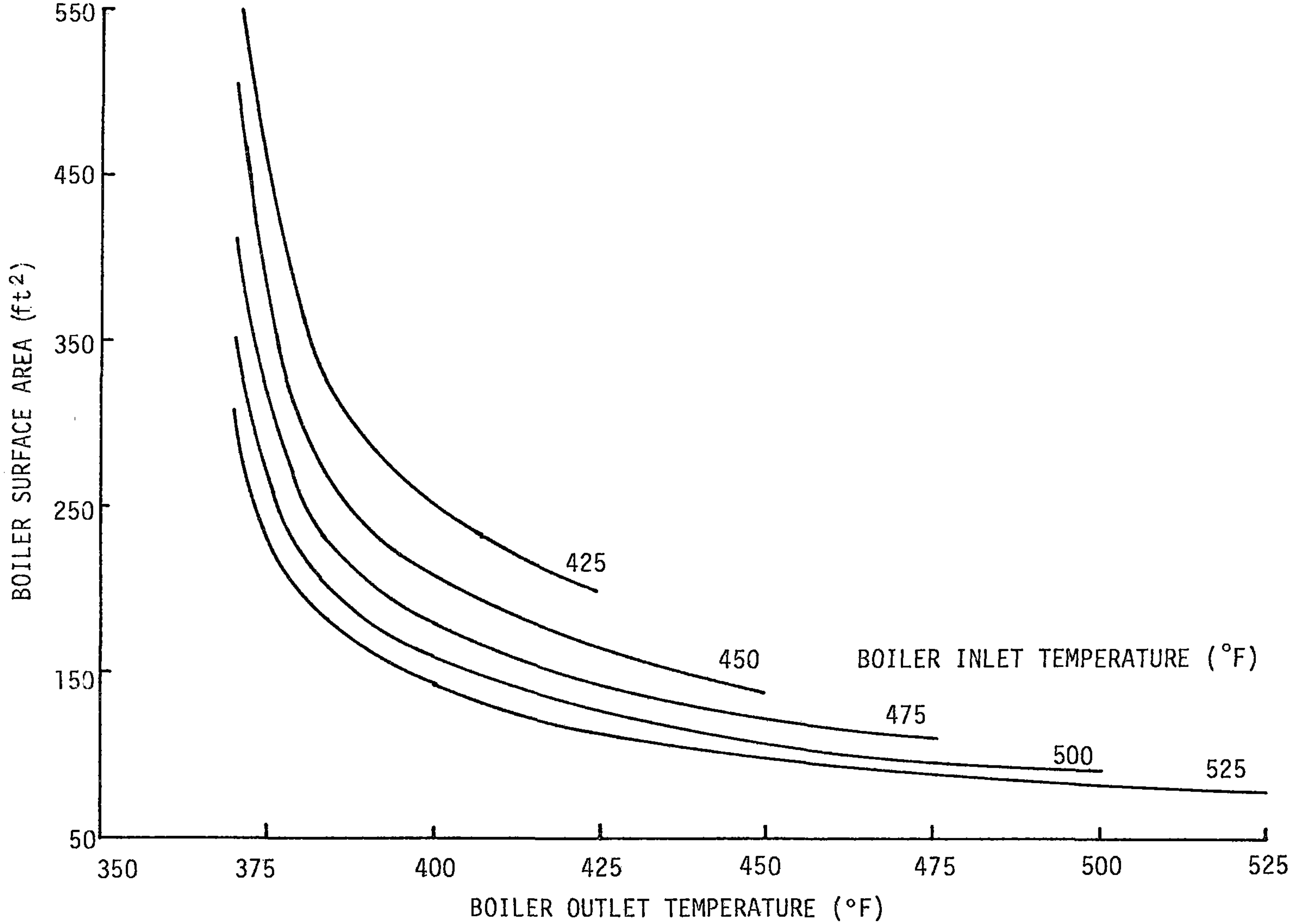

Figure 5.12 Boiler Surface Area Requirement vs. Boiler Inlet and Outlet Temperatures

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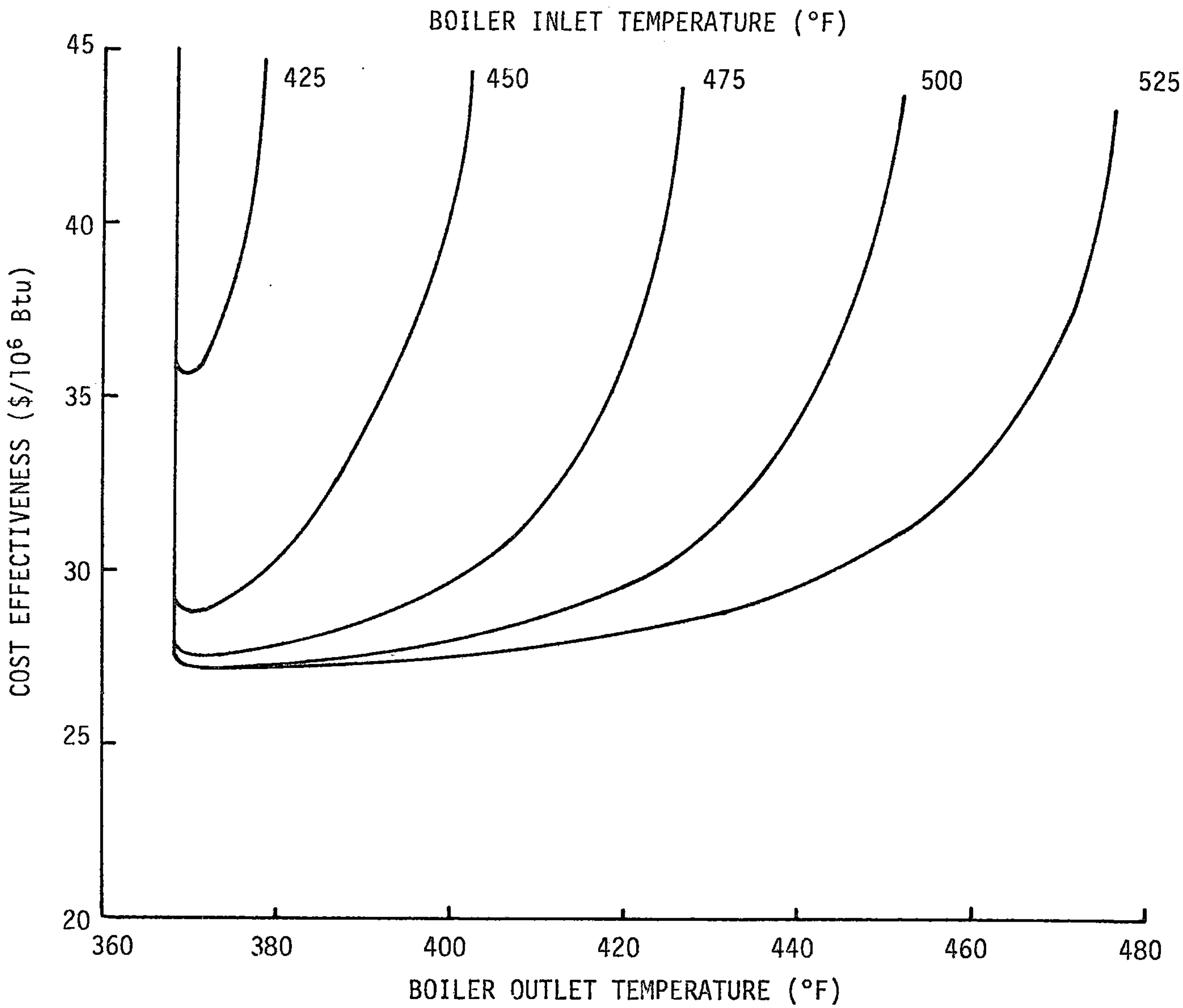


Figure 5.13 Cost Effectiveness vs. Operating Temperatures

decreases to a minimum at an approximate boiler outlet temperature of 370°F and then becomes infinitely large as this temperature approaches 368.4°F. The results also indicate that cost-effectiveness is relatively insensitive to the boiler inlet/outlet temperature regime between 475°F/370°F to 525°F/390°F. The operating temperatures selected for the Dalton solar plant are 510°F/375°F because:

- They are well within the most cost-effective temperature regime
- The vapor pressure of Dowtherm LF at 510°F is about 15 lb/in^2a
- The initial capital cost is reduced.

5.8 PIPE SIZE

Selection of satisfactory pipe size requires consideration of piping, overnight and pump parasitic losses as well as piping and pump capital costs. The nominal diameter of the pipe considered ranged from 1 to 3-1/2 in.

The annual piping and overnight thermal losses for various pipe sizes are plotted in Figures 5.14 and 5.15. As the pipe size increases, these losses also increase. A summary of the cost-effectiveness evaluation of the various pipe sizes is given in Table 5.4.

The fluid velocity variation with respect to pipe size was determined. Fluid velocity adversely affects the piping support structure and the pressure drop in the pipe. Standard industrial practice is to keep the fluid velocity below 10 ft/s.

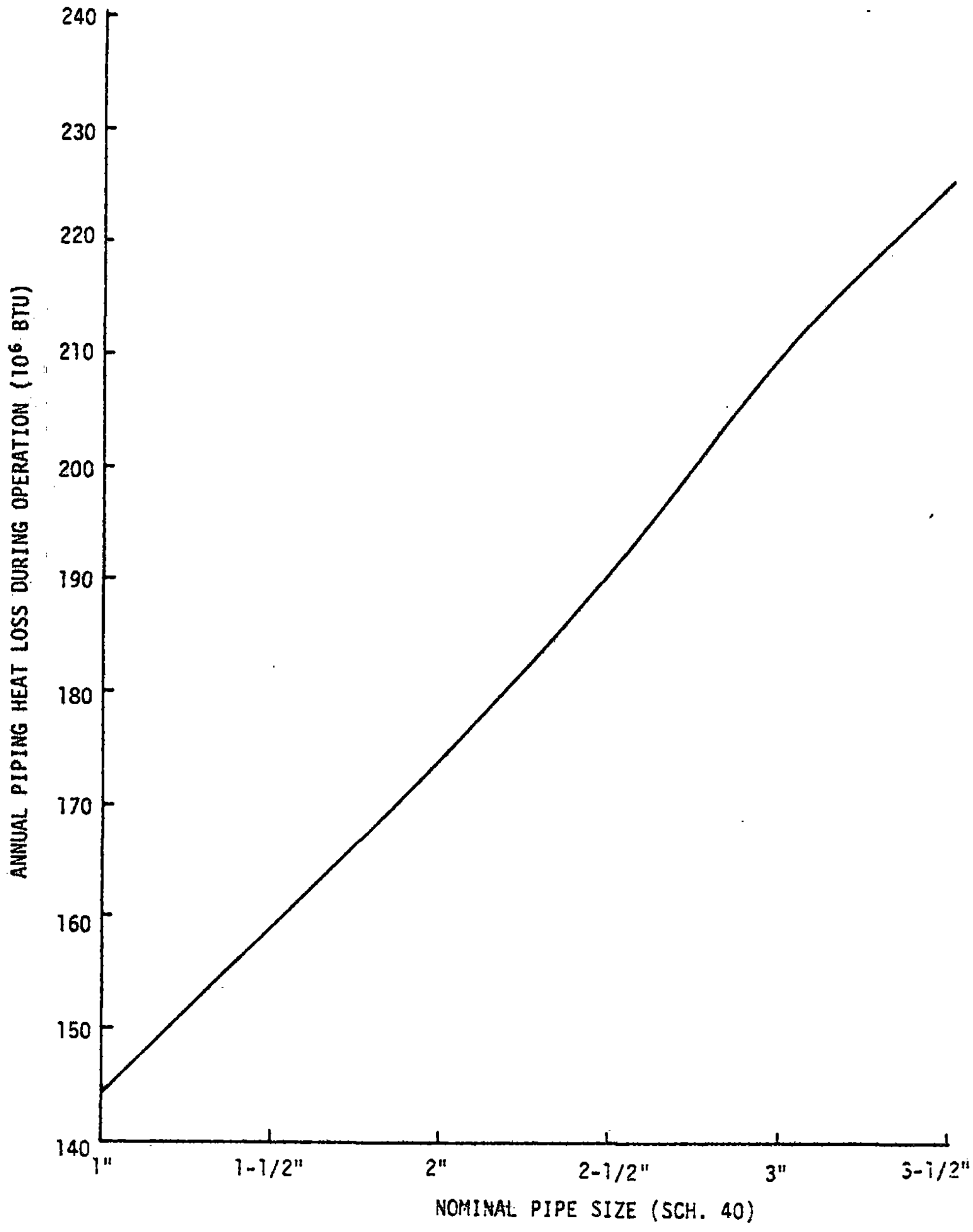


Figure 5.14 Piping Losses vs. Nominal Pipe Size

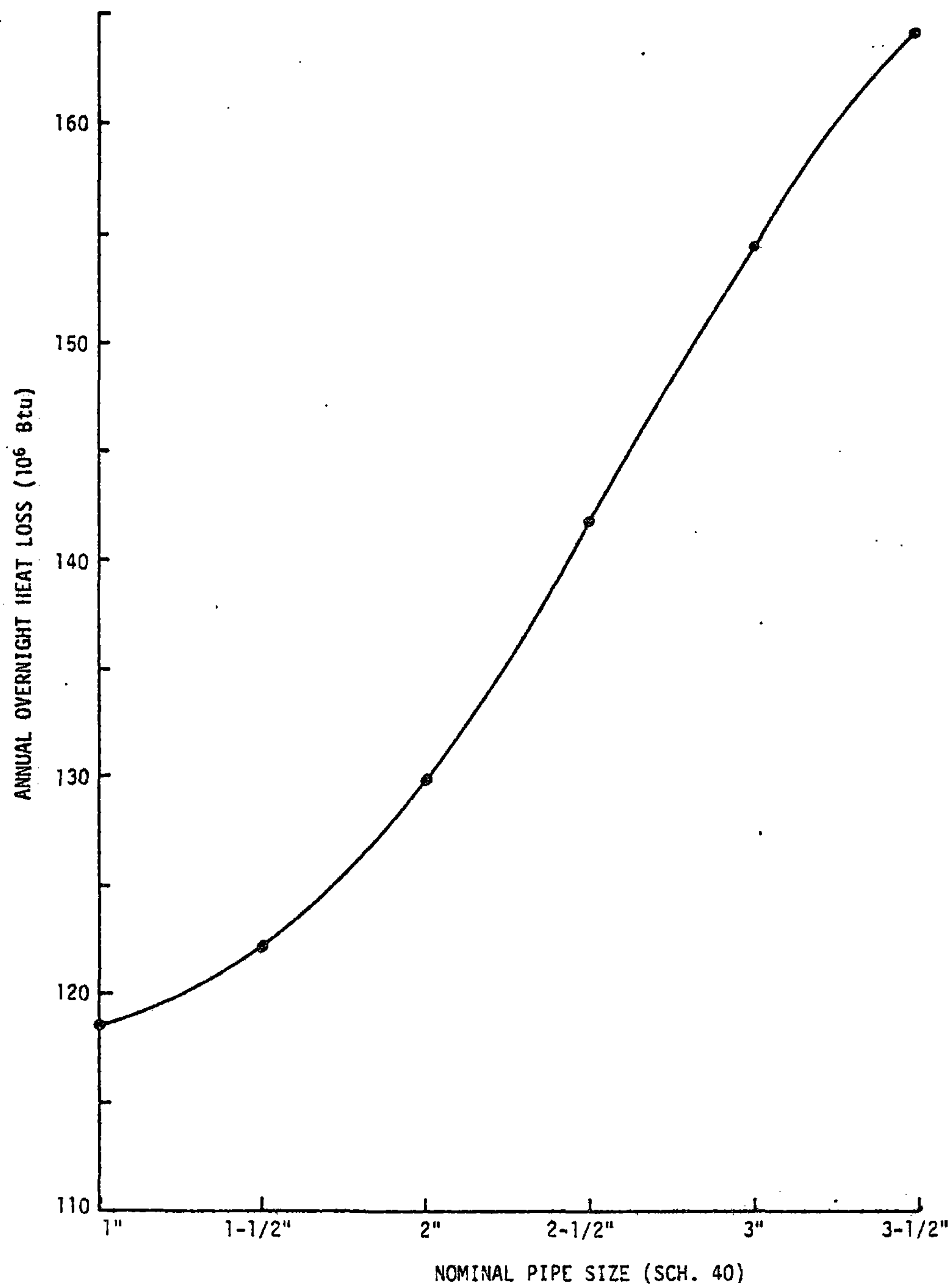


Figure 5.15 Overnight Losses vs. Nominal Pipe Size

Table 5.4 Cost-Effectiveness vs. Pipe Size

Nominal Pipe Diameter (in.)	Fluid Velocity (ft/s)	Relative Pump Power	Cost Difference from Base ($)			Cost Effectiveness ($/$10^6$ Btu)
			Installed Insulated Piping	Pump	Net ΔI_o (Pump + Piping)	
1	21.17	6.18	-1650	+1550	-100	32.19
1-1/2	8.98	1.63	-800	+450	-350	26.82
2	5.45	1.00	Base	Base	Base	26.66
2-1/2	3.82	0.81	+1300	-125	+1175	26.87
3	2.51	0.71	+2400	-200	+2200	27.20
3-1/2	1.85	0.68	+4300	-250	+4050	27.61

Cost-effectiveness of the various pipe sizes was computed by using Equation 6.4 developed in Section 6.2. The relative pump power required and its effect on the pump capital cost[8] are also listed in Table 5.4. This table indicates that the cost-effectiveness is not very sensitive to pipe sizes of about 2 in. However, since 2 in. nominal diameter is the most cost-effective size, it was selected for the solar steam system.

5.9 CONTROL PARAMETER

There are three methods of controlling the heat-transfer fluid loop of the solar steam system. A schematic of these three methods is shown in Figure 5.16 and described below.

5.9.1 Flow Control

The flow rate of the heat-transfer fluid is maintained constant as shown in Figure 5.16(A). Thus, any reduction in the solar insolation would lower the collector outlet temperature. The average temperature of the fluid in the collector would decrease. Therefore, the collectors would operate at slightly higher efficiency. Also, the piping thermal losses would be less because of lower fluid temperatures.

In the actual system, the flow rate will be maintained approximately constant by using a constant-speed pump. Thus, this scheme would essentially have no active control element in the heat-transfer fluid loop. The solar steam system, in this case, would be controlled only by the boiler control.

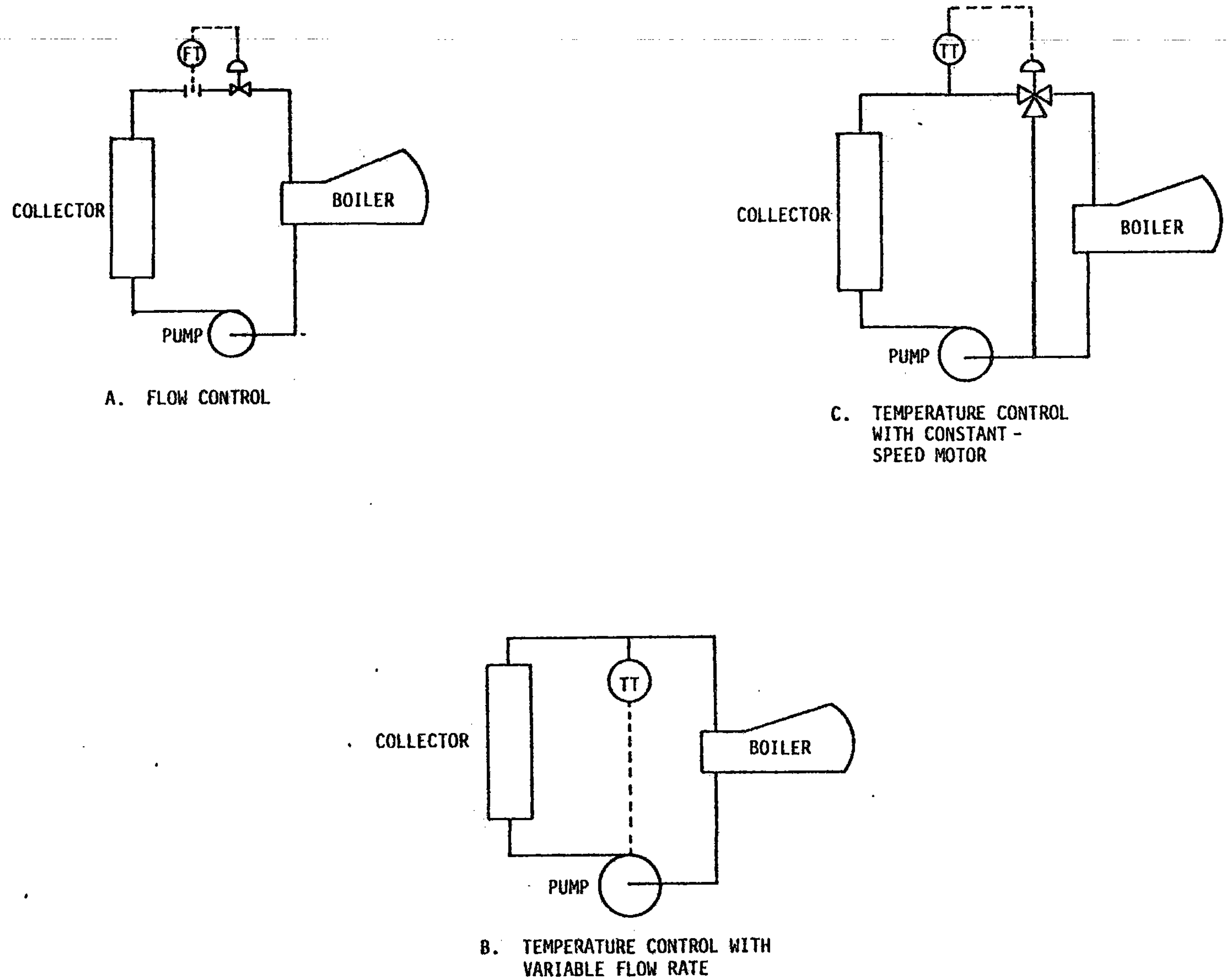


Figure 5.16 Schematic of Various Control Methods

5.9.2 Collector Outlet Temperature Control With Variable Flow Rate

The collector outlet temperature is maintained constant by varying the flow rate of the fluid which is controlled by a variable speed pump motor as shown in Figure 5.16(B). In this scheme, the average temperature of the fluid in the collector remains approximately constant during operation. The primary advantage of this system is that there is a reduction in the pump parasitic energy. However, the annual collector output would be lower than that in the flow control scheme and the capital cost of the system would be higher because ofadditional control equipment and an expensive variable-speed pump motor. The piping heat losses will also be slightly higher in this case because of higher fluid temperatures.

The major drawback of this scheme is that lower fluid flow rates would adversely affect the thermal resistance of the absorber tube. This would decrease the collector efficiency to a greater degree.

5.9.3 Collector Outlet Temperature Control With a Constant-Speed Motor

A constant-speed motor is used and the collector outlet temperature is maintained constant by controlling the fluid flow rate through the boiler as shown in Figure 5.16(C). A three-way control valve is used to bypass the remaining flow across the boiler. Thus, the flow rate through the collectors remains constant.

In this scheme, any reduction in the solar insolation would increase the bypass flow rate, thus increasing the collector inlet temperature. The average temperature of the fluid through the collectors would increase. Therefore, the collectors would operate at lower efficiency. The piping heat losses will also be highest in this scheme.

5.9.4 Control Parameter Selection

The piping heat losses depend on the fluid temperature in the piping. For a typical clear day in June, the piping losses for the three control schemes are shown in Figure 5.17. This figure shows that for Scheme 1, the piping losses are maximum at noon when the fluid temperature is highest. Since the fluid temperatures in Scheme 2 are maintained constant, the piping losses remain unchanged during the day. The piping losses in Scheme 3 are minimum at noon when the fluid temperature is lowest. The daily average clear day piping losses for the three control schemes are shown in Figure 5.18.

The effect of various control schemes on the annual thermal output of the collectors and the annual piping losses is shown in Table 5.5. Scheme 3 can be readily eliminated in favor of Scheme 1 because it:

- Yields about 2 percent less energy on an annual basis
- Involves greater capital cost because of additional control equipment.

Scheme 2 produces about 38 x 10^6 Btu less energy than Scheme 1 which will be compensated by the reduction in pump power consumption. Therefore, the two schemes would displace approximately the same amount of fossil energy. Scheme 1 was selected because it:

- Involves no control element in the heat-transfer fluid loop
- Provides a simpler system and therefore is more reliable.

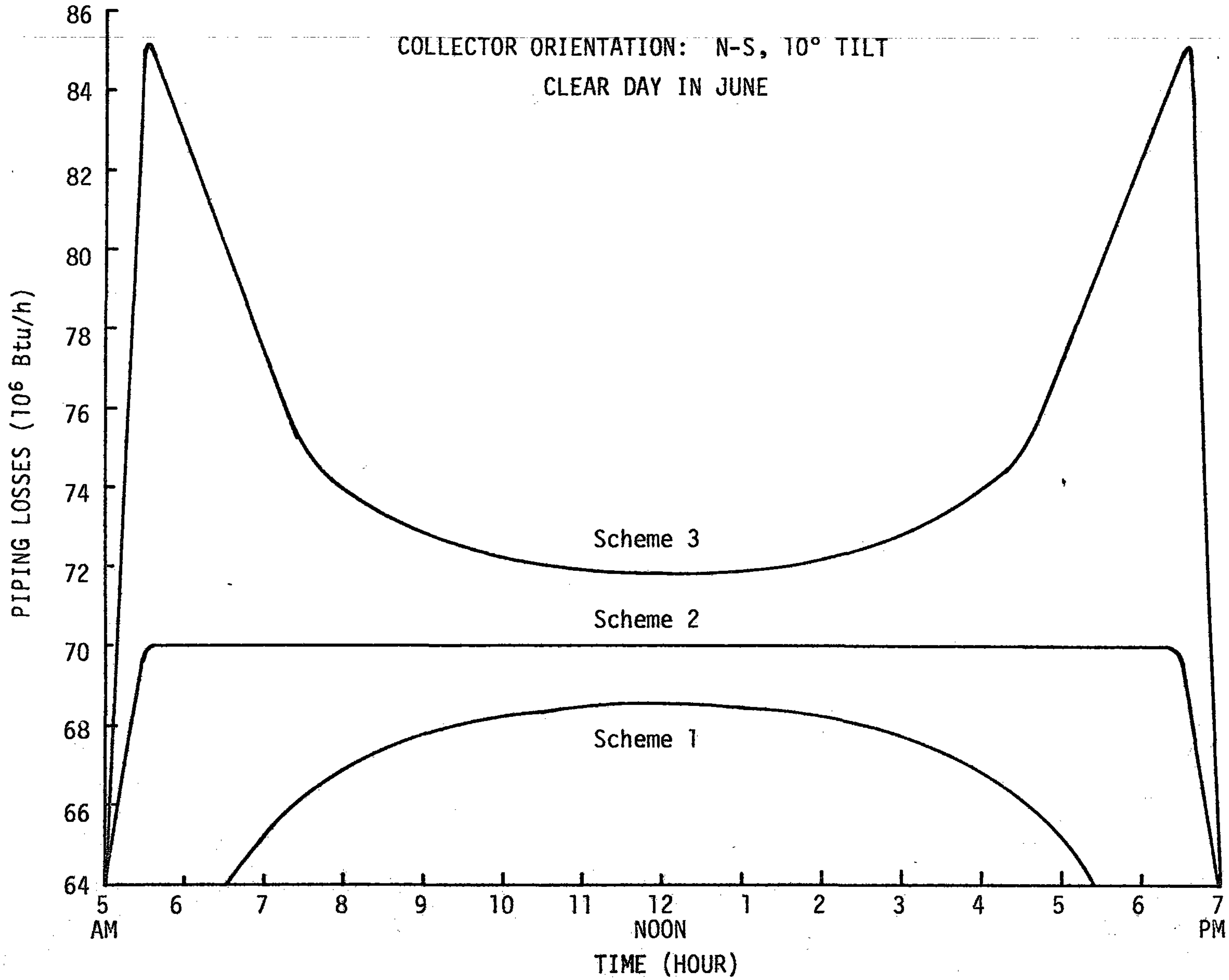


Figure 5.17 Daily Variation of Piping Losses on a Typical Clear Day in June for Various Control Schemes

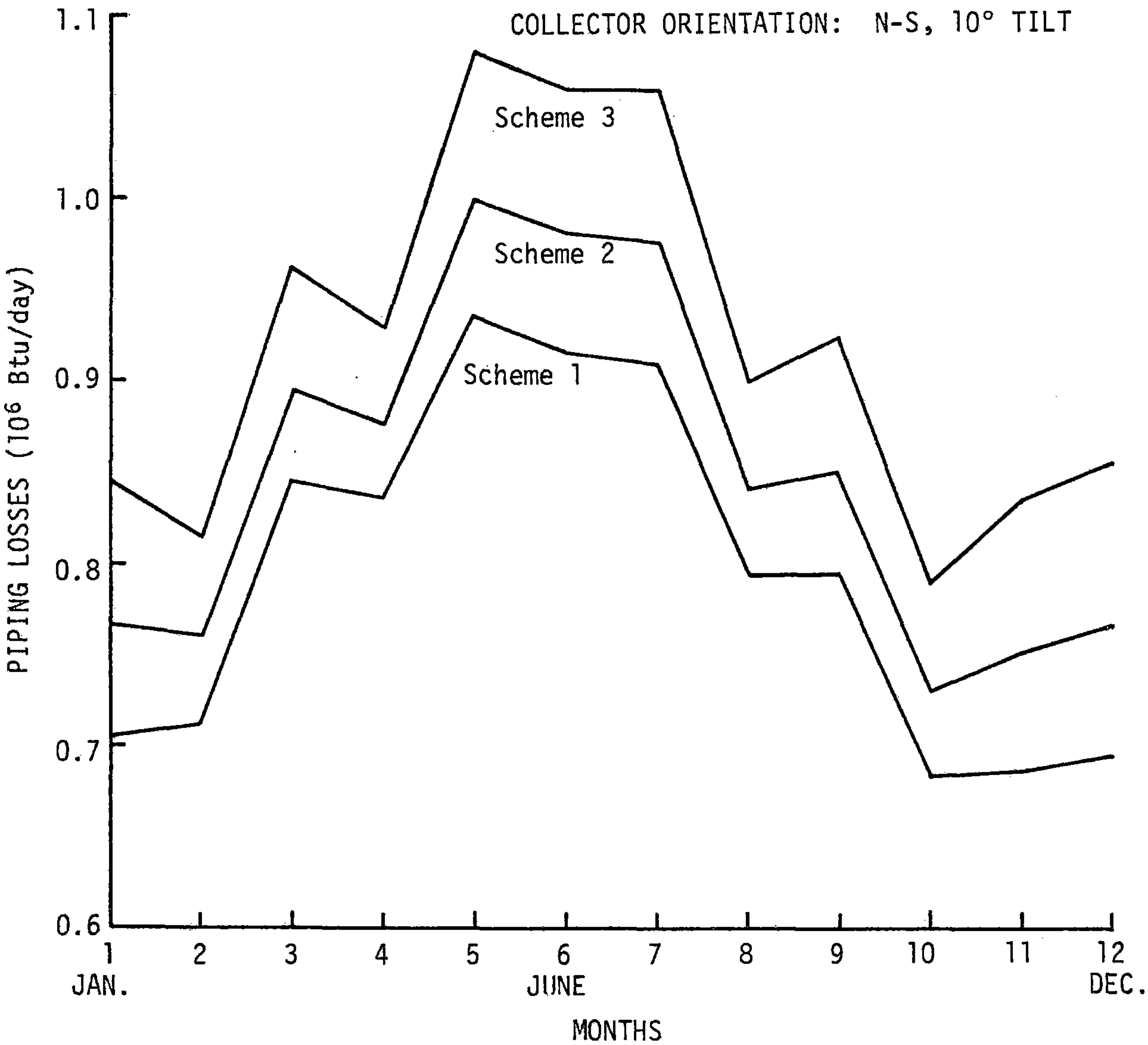


Figure 5.18 Daily Average Clear Day Piping Losses for Various Control Schemes

Table 5.5 Annual Collector Thermal Performance and Piping Losses vs. Control Parameter (10^6 Btu)

Performance Criteria	Collector Orientation		
	East-West	North-South (0 deg tilt)	North-South (10 deg tilt)
Flow Control Case			
Piping Losses	154	174	176
Collector Output	2359	2631	2842
Variable-Speed Pump Motor			
Piping Losses	167	188	188
Collector Output	2319	2599	2806
Constant Flow Rate Through Collectors			
Piping Losses	182	206	204
Collector Output	2256	2563	2776

5.10 STEAM PRODUCTION CALCULATIONS

The amount of steam generated by the solar steam system is computed in this subsection. The optional parameters determined in earlier subsections are assumed for these calculations. The assumptions are:

- Thermal storage: None
- Collector area: 9930 ft^2
- Collector location: Dalton, Georgia
- Collector orientation: North-south with 10 deg tilt
- Latitude: 34.8° north
- Collector spacing: 18 ft

- Heat-transfer fluid: Dowtherm LF
- Piping circuitry: Shown in Figure 5.8(B)
- Pipe size: 2 in. nominal diameter
- Control parameter: Flow rate maintained constant
- Feedwater temperature: 205°F
- Steam pressure: 150 lb/in^2g.

For these assumptions, the steam enthalpy rise = 1196 - 174 = 1022 Btu/lb.

The energy available for steam generation and the amount of steam generated is derived below. The computer program used for these calculations has been described elsewhere in the report.

- Peak Energy - Peak energy collection occurs at noon on a typical clear day in April.
  - Peak energy collected: 1.61×10^6 Btu/h
  - Pipe losses: 71.7×10^3 Btu/h
  - Net energy available: 1.54×10^6 Btu/h
  - Peak steam production: 1500 lb/h
- Daily Energy - The maximum energy on an average clear day is available in the month of May.
  - Energy collected: 15.9×10^6 Btu/day
  - Piping losses: 0.9×10^6 Btu/day
  - Net energy available: 15.0×10^6 Btu/day
  - Daily steam production: 14,680 lb/day

A plot of daily steam production on a typical clear day of each month is shown in Figure 5.19.

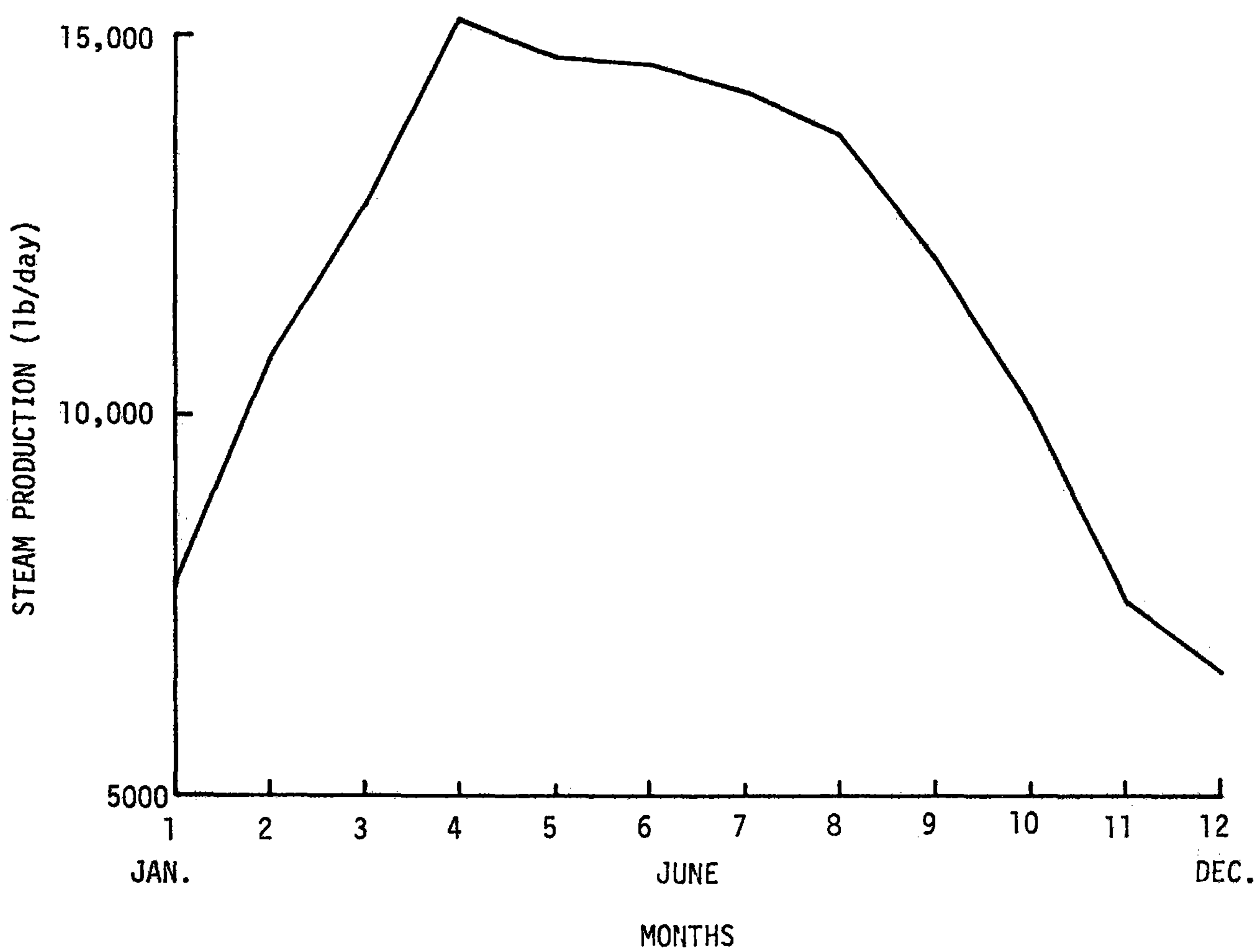


Figure 5.19 Daily Average Clear Day Steam Production

- Annual Energy
  - Energy collected: 2842×10^6 Btu/yr
  - Piping losses: 176×10^6 Btu/yr
  - Overnight losses: 130×10^6 Btu/yr
  - Net energy available: 2536×10^6 Btu/yr
  - Annual steam generation: 2.5×10^6 lb/yr

SECTION 6

ECONOMIC ANALYSIS

Section 6

ECONOMIC ANALYSIS

6.1 GENERAL

The objectives of the economic analysis are:

- To develop a cost-effectiveness model on the basis of which alternative design concepts can be evaluated and optimum design decisions made
- To evaluate the economic attractiveness of the solar steam system to the process industry.

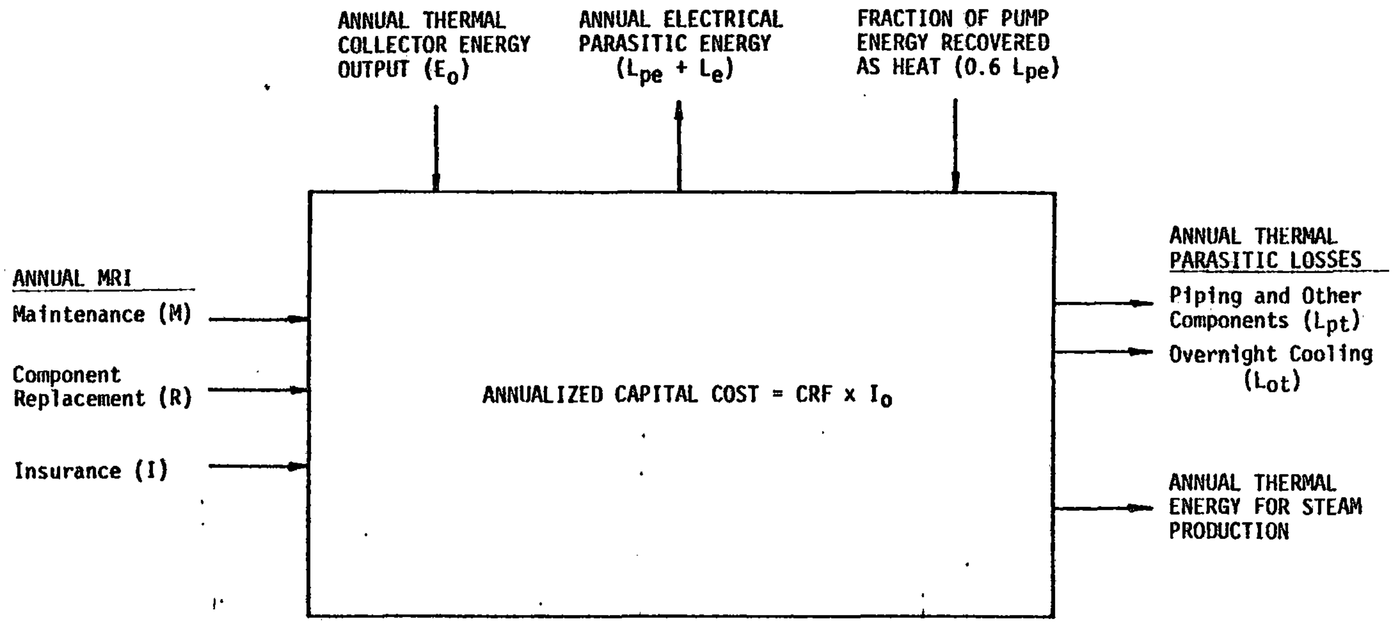
Theoretically, the two objectives listed above can be treated by a single economic model. However, from a practical standpoint it is not convenient. Standard industrial life-cycle costing techniques normally used by industry involve assumptions regarding interest rate, fuel cost escalation rate, inflation rate, investment tax credit, taxes and annual maintenance, component replacement, and insurance premium costs. The economic evaluation then predicts the annual rate of return on the solar investment on which the industry can base the economic attractiveness of the solar steam system.

On the other hand, a simplified economic model is more convenient for use in the evaluation of alternative design concepts and to make design decisions. In this section, such a simplified economic model is developed first. A detailed economic analysis of the FWDC/Dow solar steam system is then presented. The sensitivity of various parameters to the rate of return is also shown.

6.2 ECONOMIC MODEL USED IN SYSTEMS ANALYSIS

The annualized cost of a unit of net annually generated thermal energy was used as a cost-effectiveness criterion in the systems analysis. The economic model used is depicted in Figure 6.1. The total annual cost includes the annualized capital investment and annual maintenance, component replacement, and insurance costs. The net annually generated thermal energy is obtained by subtracting all the parasitic thermal and electric losses from annual thermal energy output of the collectors. Due to pump inefficiency, the fraction of the electrical parasitic energy that is recovered by the system as low-grade heat is added to this net energy. The electric parasitic losses represent high-grade energy and therefore must be converted into equivalent fossil energy. A multiplication factor of three is used for this conversion.

The idea of accounting for the electrical parasitic energy in the calculation of net solar thermal energy is different from that used in standard life-cycle cost analysis.[9] In a standard life-cycle economic analysis, the annual cost of electric parasitic energy is treated as operating costs and added to annualized cost. For solar system designs, where the primary objective is to displace the use of nonrenewable fossil energy, the electric parasitic energy should not be considered as an operating cost but should be debited against solar energy collected. The cost-effectiveness expression based on this economic model is derived in Subsection 6.2.1.



$$\text{COST EFFECTIVENESS} = \frac{CRF \times I_o + M + R + I}{E_o - [L_{pt} + L_{ot} - 0.6\, L_{pe}] - 3[L_{pe} + L_e]}$$

Figure 6.1 Economic Model Used in Systems Analysis

6.2.1 Derivation of Cost-Effectiveness Expression

ANNUALIZED COST

Initial capital investment ($) = I_o

Annual interest rate = i

Expected equipment life (yr) = n

Assume that the initial capital is also amortized over n years*

$$\text{Capital recovery factor (CRF)} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (6.1)$$

Annualize capital cost ($/yr) = $I_o \times CRF$

Annual maintenance cost ($/yr) = M

Annual replacement cost ($/yr) = R

Annual insurance cost ($/yr) = I

NET ENERGY PRODUCED BY SOLAR SYSTEM

Annual thermal energy output of collectors = E_o

Thermal losses in piping and other components = L_{pt}

Thermal losses from overnight cooling = L_{ot}

Fraction of pump energy recovered as heat = $0.6\ L_{pe}$

Annual thermal energy available for steam production =

$$E_o - \left(L_{pt} + L_{ot} - 0.6L_{pe}\right) \quad (6.2)$$

*The effect of amortizing the initial capital over a different time period than the expected equipment life is considered in Subsection 6.3.

Annual electric parasitic energy consumed by:

circulating pump motor = L_{pe}

tracking motors and controls = L_e

Thermal energy equivalent of the annual electric parasitic energy $= 3(L_{pe} + L_e)$

Net energy produced by solar system =

$$E_o - \left(L_{pt} + L_{ot} - 0.6L_{pe}\right) - 3\left(L_{pe} + L_e\right) \quad (6.3)$$

COST-EFFECTIVENESS

$$\text{Cost-effectiveness} = \frac{CRF \times I_o + M + R + I}{E_o - \left(L_{pt} + L_{ot} - 0.6L_{pe}\right) - 3\left(L_{pe} + L_e\right)} \quad (6.4)$$

ASSUMPTIONS MADE IN SYSTEMS ANALYSIS

Annual interest rate (i) = 0.1

Assume equipment life (n) = 20

Capital recovery factor (CRF) =

$$\frac{0.1(1 + 0.1)^{20}}{(1 + 0.1)^{20} - 1} = 0.11746$$

Maintenance, replacement, and insurance costs (M + R + I)($/yr) = $7,400

For evaluating alternating design concepts, the capital cost of the base concept was assumed to be $500,000.

The total annualized cost for the base concept =

$$500{,}000 \times 0.11746 + 7{,}400 = \$66{,}130/\text{yr}$$

The cost difference between an alternate concept and the base concept was then estimated as ΔI_o.

The total annualized cost for the alternate concept =

$$66{,}130 + 0.11746\Delta I_o \tag{6.5}$$

In the net energy calculations, the annual collector thermal energy output was determined by considering insolation, site latitude, collector spacing, collector orientation, and average receiver temperature (described in Section 4). For calculating the annual electrical energy consumed, it was assumed that the solar steam system operates for an average of 8 hours-a-day and 300 days per year.

The estimated parasitic electrical energy consumed by tracking motors, controls, and circulating pump is:

$$L_e = 1309.5 \text{ kWh/yr} = 4.47 \times 10^6 \text{ Btu electric/yr} \tag{6.6}$$

$$L_{pe} = 6.1N \times 10^6 \text{ Btu electric/yr} \tag{6.7}$$

where:

N is the horsepower of the pump motor.

6.2.2 Comparison Between the Selected Economic Model for System Analysis and Standard Economic Model

As described earlier in this section, the primary difference between the selected economic model for systems analysis and a standard economic analysis[9] lies in the manner the electrical parasitic energy is treated. In the selected economic model, thermal energy equivalent to electrical parasitic energy is credited against the collected solar energy. Thus, this model uses the total displaced fossil energy as a basis for the effectiveness of the solar steam system design.

In the standard economic analysis, the annual cost of the electrical parasitic energy is added to the annualized cost. The two methods give identical results if the cost of the electrical parasitic energy, in terms of equivalent thermal energy, is assumed to be the same as the cost of solar energy. Attaching any lower cost value to this parasitic energy reduces its weightage. This would decrease the sensitivity of the solar system to the consumed electrical parasitic energy.

6.3 LIFE-CYCLE ECONOMIC ANALYSIS

6.3.1 Introduction

The objective of this analysis is to evaluate the economic attractiveness of solar steam systems to process industries. In particular, the influence of tax incentives, cost-sharing, capital structure, depreciation method, reductions in the costs of solar steam systems and fuel price, and other inflation rates will be examined to identify those circumstances in which solar steam generation would be economically attractive to industry.

The analysis is performed using a discounted cash flow technique. While traditional methods for the assessment of the profitability of invested capital (rates of return on an original investment, a depreciated investment on the pay-back period for such capital, etc.) depend on arbitrarily chosen methods of estimating depreciation as an operating cost, the determination of the profitability of a process through the estimation of the Discounted Cash Flow Rate of Return on Equity can be made without such subjectivity:[10] discounted cash flow analysis inherently makes provision for the recovery of capital expenditures. Implicit in discounted cash flow analysis is the concept of the time value of money: an interest rate reflecting the risk associated with the project and the alternative uses to which money can be put is to be paid upon the capital invested. Alternatively stated, a discount factor is used to reduce a potential future sum of money to its present value--the use of a discount factor also reflects the uncertainty of predicted future cash flow.

To perform the calculations, an in-house computer program was used.[11] This program provides for considerable flexibility in the handling of investments, capital structures, operating expenses, and taxes. Provision is made for Federal and state income taxes, and revenue and local property taxes as well as for insurance costs. Federal income tax calculations allow for the investment tax credit, tax-loss carry forward calculations, several methods for calculating depreciation allowances and various other options. An additional feature of this computer program is its ability to handle varying rates of inflation, both in the overall rate and in rates specific to capital, feedstock, operation, and maintenance costs and in the price of the "product," in this case the value of the fossil fuel replaced by solar energy. This ability is particularly relevant to the analysis of solar projects where a high capital cost is combined with low operating costs. In addition other criteria of profitability are provided: the maximum net outlay, the discounted break-even point (years to a zero net present value at an interest rate of 10 percent per annum) and the equivalent maximum investment period.

6.3.2 Data for the Economic Analysis

The following data and conditions were examined in the economic analysis.

6.3.2.1 Capital Costs. The fabrication and construction costs used for this life-cycle economic analysis is $700,000. This includes all equipment, land preparation, foundation, installation, electrical, and supervision costs. The control equipment and the instrumentation necessary to operate the system are also included.

6.3.2.2 Capital Structure. Debt to equity ratios of 1:1 and 0:1 were examined. Interest rates on debt of 6 and 10 percent per annum were considered. Unless otherwise stated, 100 percent equity funding is assumed.

6.3.2.3 Tax Credits. Tax credits of 20 to 80 percent of the depreciable capital investment were considered. It should be noted that a 60 percent tax credit is equivalent to a 50 percent capital cost sharing arrangement combined with a 10 percent investment tax credit and a special 10 percent solar investment tax credit. Unless otherwise stated, a tax credit of 20 percent is assumed.

6.3.2.4 Federal Taxes. A Federal income tax rate of 46 percent is assumed. It is further assumed that the parent corporation has other tax liabilities against which negative taxes can be charged.

6.3.2.5 State and Local Taxes. State tax in Georgia is 3 percent. Local taxes are 1 percent in the Whitfield County in which Dow Chemical Company's Dalton plant is located.

6.3.2.6 Depreciation Method. Sum of years digits, double declining balance with conversion to straight line and straight line depreciation methods were considered. A depreciation life of 20 years is assumed for the entire system. Unless otherwise stated, a sum of years digits depreciation method is used.

6.3.2.7 Start-Up Date. A start-up date of January 1981 is assumed.

6.3.2.8 System Lifetime. Lives of 20, 25, and 30 years were considered. Unless otherwise stated, a life of 30 years is assumed.

6.3.2.9 Working Capital Requirements. Assumed to be $1,000.

6.3.2.10 Insurance Costs. Fred S. James Insurance Company of Boston, Massachusetts, provides the insurance coverage for the existing facilities at Dow Chemical's Dalton, Georgia, plant. According to an estimate submitted by the Fred S. James Insurance Company, an adequate property damage and liability insurance for the additional solar steam system would cost $1,000 per year.

6.3.2.11 Operating Costs. The manpower required to operate the solar steam system is assumed to be negligible. The operating costs of the solar energy system result from the electrical power required to operate the circulating pump, the collector tracking motors, and the control system. The power consumed is estimated on daily basis first. The annual electrical power consumption is determined by assuming 300 days per year operation. Based on a current electric rate, at Dalton, Georgia, of 27 mils/kWh, the results are tabulated in Table 6.1.

6.3.2.12 Maintenance Costs. It is expected that the solar steam system would require a minimal of maintenance expenses. The estimated annual man-hours and costs for maintaining the solar steam system are presented in Table 6.2. A labor rate of $12.00 per hour is used for the cost computations.

6.3.2.13 Replacement Costs. 30 percent of the initial major component cost is used as a basis to estimate the annual component replacement cost. It is assumed that with the development of solar market, the cost of solar collectors will be reduced. A factor of 0.7 is assumed.

Solar Collectors	$140,000
Boiler	8,000
Circulating Pump	3,000
Dump Tank	8,000
Miscellaneous (including piping, insulation valves, etc.)	26,300
TOTAL	$185,300
30%	55,600
Annual for 20 years	2,780

6.3.2.14 OMRI (Operating, Maintenance, Replacement, Insurance)

Insurance	$1,000
Operating	180
Maintenance	3,240
Replacement	2,780
TOTAL	$7,200

Table 6.1 Operating Costs for Solar Steam System

Item	Consumption per day (Wh)	Annual Consumption (kWh)	Current Cost ($)
Circulating pump	17,700	5310	144
Tracking motors	2,565	770	21
Master control	300	90	3
Drive control	1,500	450	12
TOTAL	22,029	6610	180

Table 6.2 Maintenance Cost

Item	Man-hours	Cost ($)
Circulating pump	10	120
Solar collectors	200	2,400
Boiler	20	240
Controls	40	480
TOTAL	270	3,240

6.3.2.15 Product Value. In this analysis it is assumed that the product is the equivalent oil (costlier fossil fuel used) that is not consumed as a result of the use of solar energy.

6.3.2.16 Inflation Rates. Inflation rates of between 7 and 17 percent per annum in the cost of oil and electricity were considered. The other inflation rates were set at 7 percent per annum.

6.3.3 Result of the Analysis

The critical parameters in this study were found to be the capital costs, the capital structure, the availability of tax credits or cost sharing, and the escalation rates of energy costs above the rates of inflation in other costs. This is to be expected. Solar energy systems combine high capital costs with low operating costs and an "income" generated from the replacement of fossil fuel as an energy source. These parameters will now be examined in greater detail.

6.3.3.1 Effect of Capital Costs. The influence of capital cost on the expected rate of return on equity is shown in Figure 6.2. The estimated capital cost is $500,000 once mass production and installation of collectors and their controls, and piping is achieved. A capital cost of $400,000 is the most optimistic estimate of the costs of such a distributed collector system.

6.3.3.2 Effect of Tax Credits. The influence of tax credits was examined assuming equity funding for the solar steam system. A 10 percent rate of return on equity was achieved with an 80 percent tax credit at an assumed annual

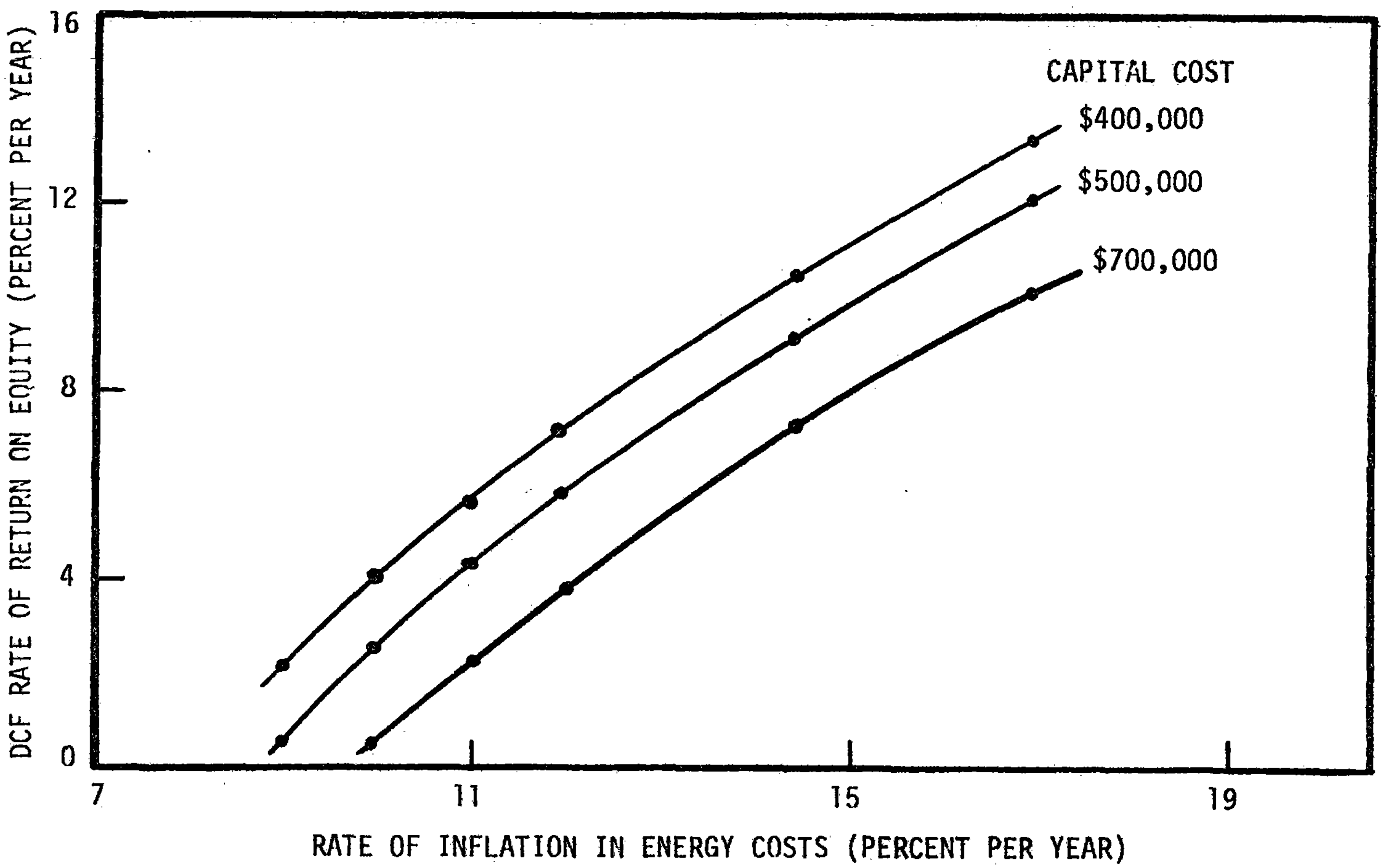


Figure 6.2 Influence of Capital Cost Upon Rate of Return on Equity

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rate of inflation in oil costs of 9.6 percent. With a 20 percent tax credit, an annual rate of inflation in oil costs of 16.8 percent is required if a 10 percent rate of return on equity is to be achieved. The results are shown in Figure 6.3.

6.3.3.3 Effect of Capital Structure. Analyses to determine the discounted cash flow rate of return on equity at debt to equity ratios of 1:1 and 0:1 were made. Interest rates on debt of 6 percent per annum (representative of funding through the issuance of tax-free bonds) and of 10 percent per annum (commercial loans) were considered. A greater rate of return on equity was achieved at the lower debt interest rate. With debt funding at 6 percent, and with an annual inflation rate in energy costs exceeding 11.3 percent, the rate of return on equity was more than that obtained with 100 percent equity funding. A 10 percent per annum rate of return on equity was achieved at a 12.8 percent per annum inflation rate for fuel assuming debts at 6 percent. The results of the study upon debt: equity ratio and debt interest rate are presented in Figure 6.4.

6.3.3.4 Effect of Depreciation Method. Though the sum of years digits depreciation method was found to give a higher rate of return on equity than both double declining balance and straight line depreciation methods, the differences between these depreciation methods are small: 0.8 percent per annum between the best and worst. The influence of depreciation method upon the discounted rate of return on equity was found to be negligible.

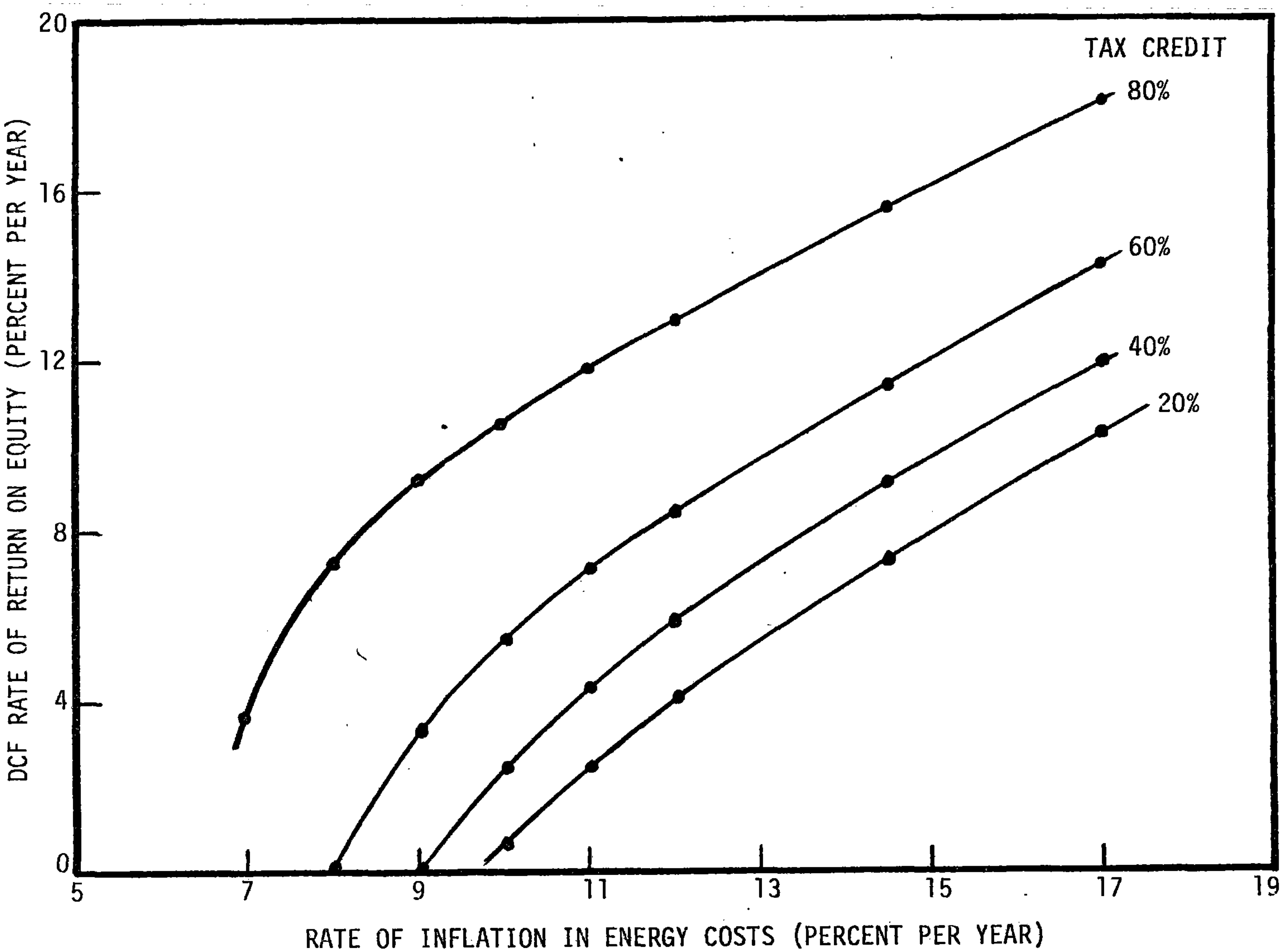

Figure 6.3 Impact of the Size of Tax Credits Upon the Rate of Return of Equity

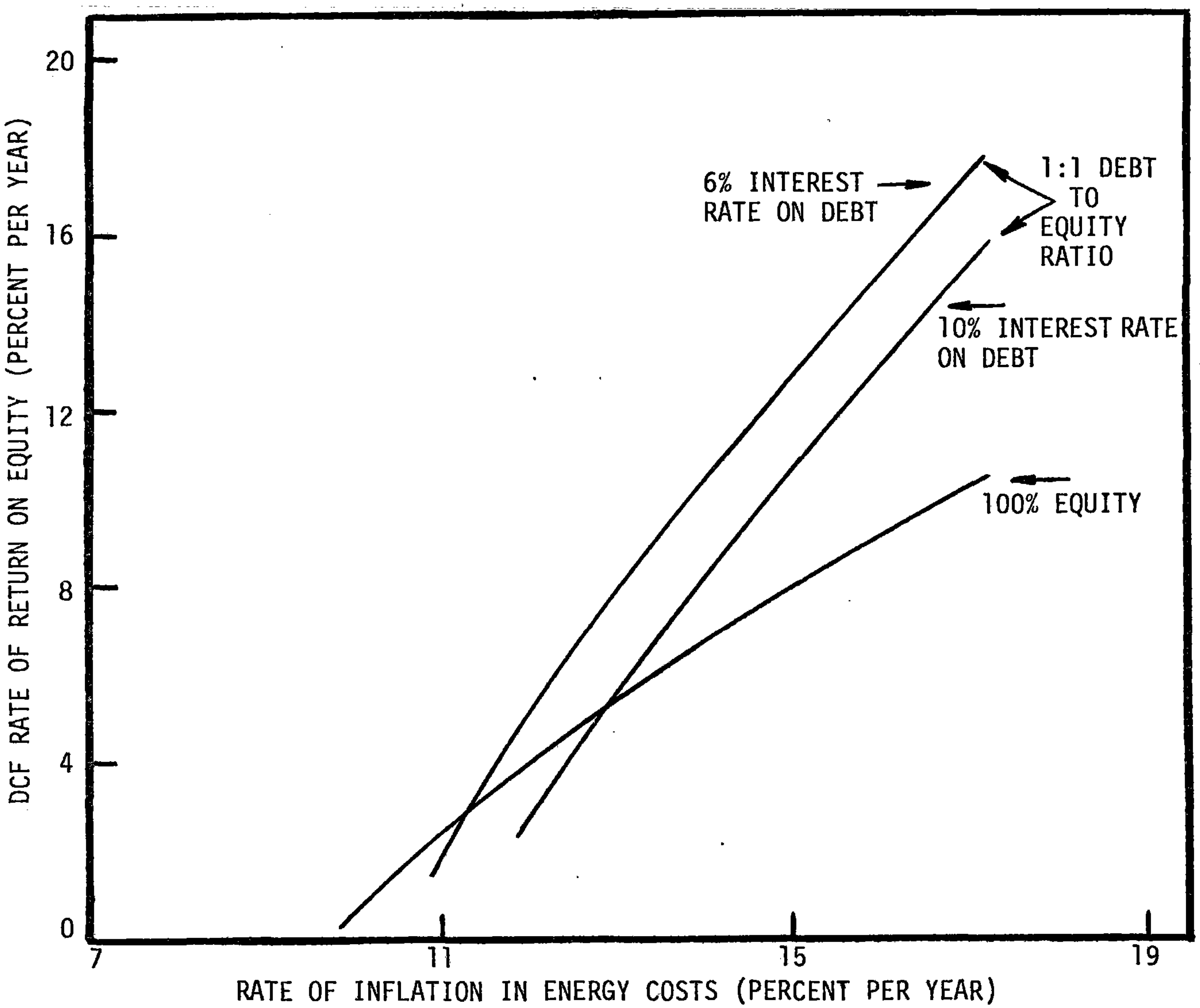

Figure 6.4 Impact of Use of Debt as a Source of Capital

6.3.3.5 Effect of System Lifetime. As the system lifetime is extended, the anticipated rate of return on equity increases provided the rate of inflation in fuel costs exceeds the overall rate of inflation and other specific inflation rates. The results of the study on system life span are presented in Figure 6.5.

6.3.4 Conclusions

A discounted cash flow analysis technique has been used to examine the influence of capital costs, tax incentives, cost-sharing, capital structure, depreciation methods, and inflation rates upon the rate of return on equity anticipated for solar steam systems.

Any conclusions that can be drawn as to the scenarios in which solar steam systems will be economically attractive to process industries must be accompanied by a critical evaluation of the assumptions made in those scenarios. In particular, the economic viability of solar steam systems requires fuel cost inflation rates to be greatly in excess of the overall rate of inflation over the 20 to 30 year life of the project. While it is anticipated that such a discrepancy in inflation rates will persist in the near future whether or not such discrepancies will continue over the entire life of the system and whether or not such discrepancies would lead to process modifications that would require less or no steam are moot points.

If these assumptions can be made, then it would appear that if we were to define our criteria of economic attractiveness as the ability to generate 10 percent per annum rate of return on equity, the solar steam systems will be

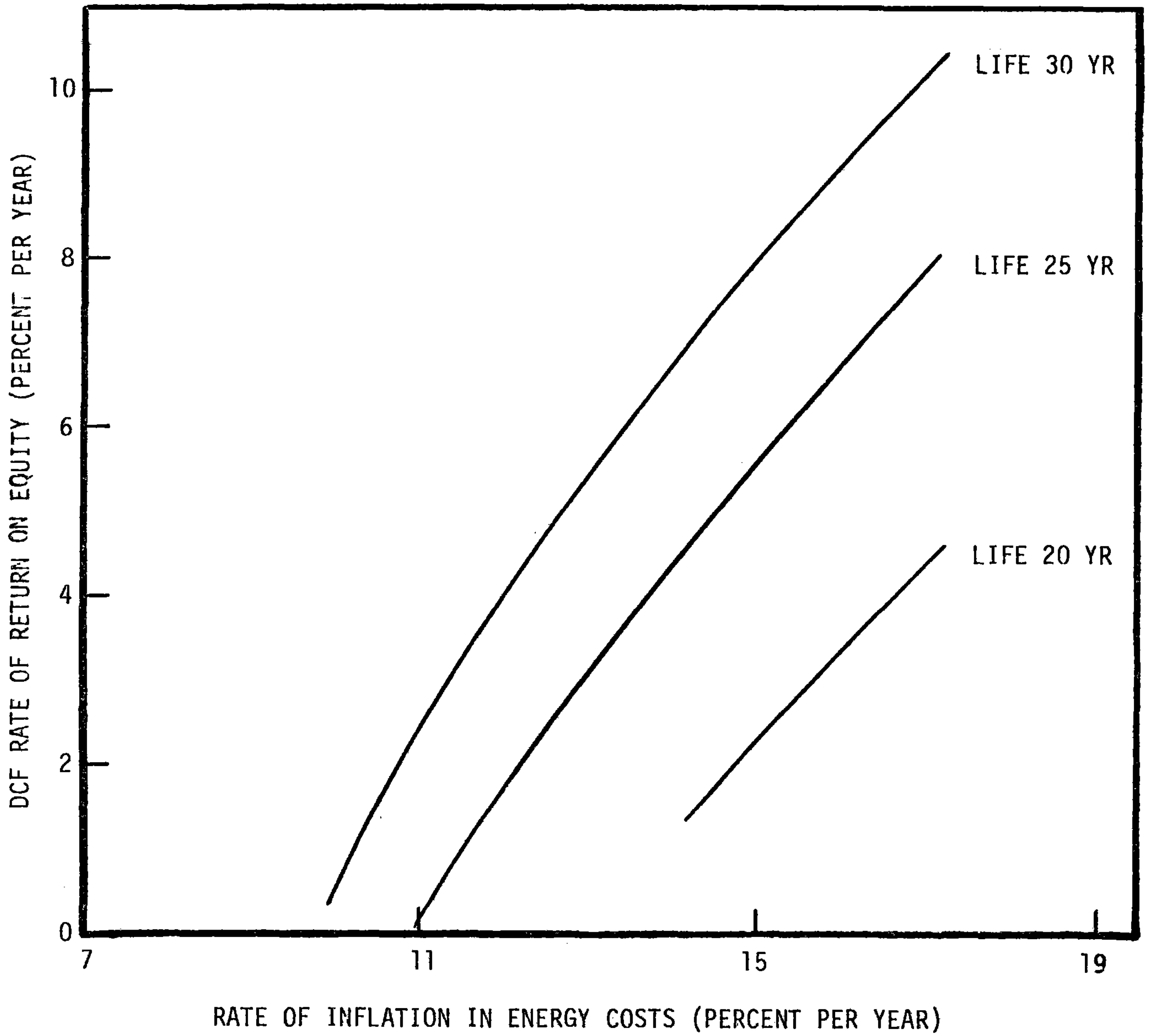

Figure 6.5 Impact of System Life Upon Rate of Return on Equity

economically attractive given a combination of tax credits or low interest debt funding and a rate of inflation in fuel costs that exceeds the overall inflation rate. These conclusions are graphically shown in Figure 6.6.

To the above, it should be added that there may be other special circumstances where solar steam systems are viable, e.g., where there are stringent environmental controls imposed upon emissions.

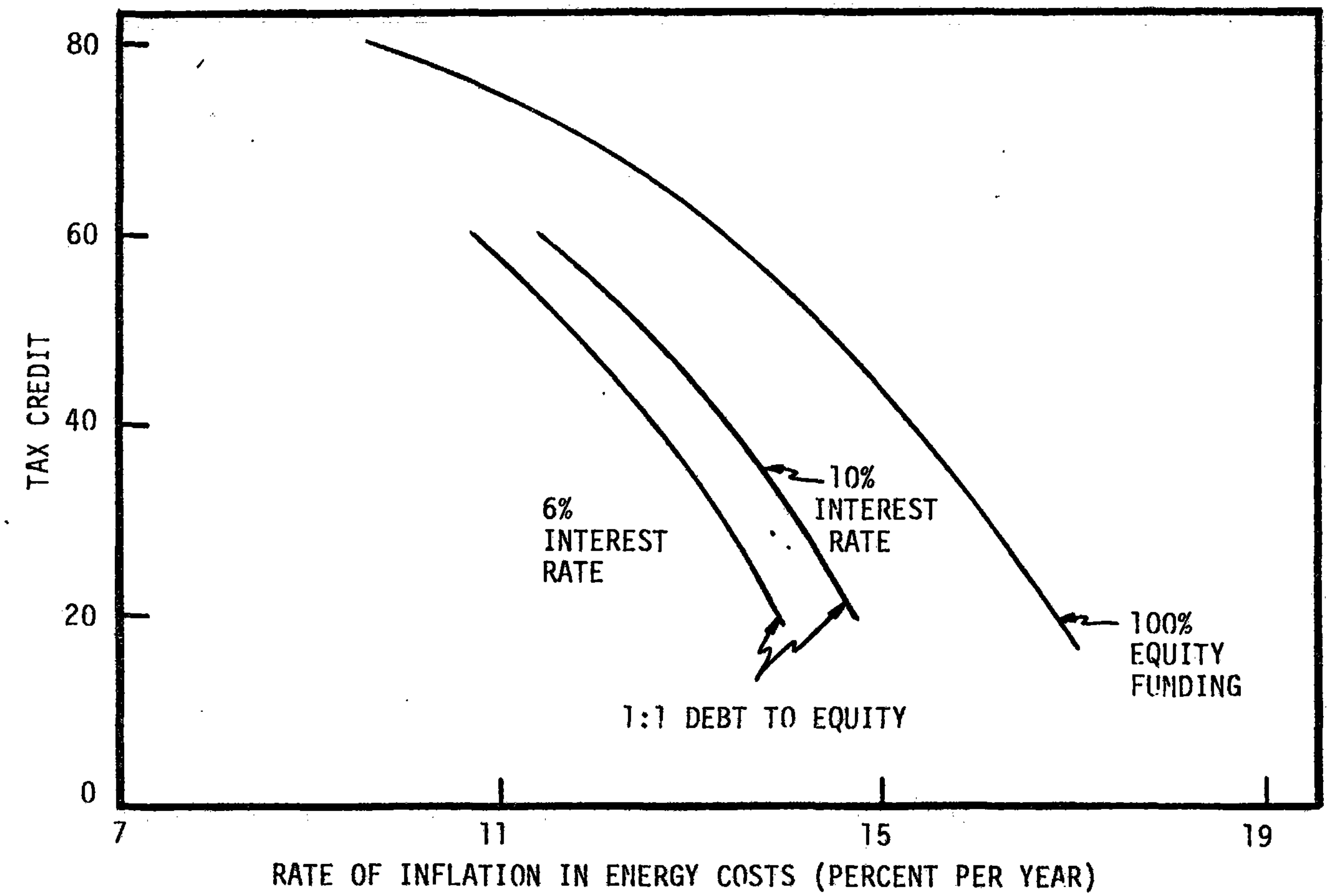

Figure 6.6 Circumstances in Which Solar Steam Systems Are Economically Viable

SECTION 7

DETAIL DESIGN OF SOLAR PROCESS STEAM SYSTEM

Section 7

DETAIL DESIGN OF SOLAR PROCESS STEAM SYSTEM

7.1 PROCESS DESIGN

The design of the other process equipment and the basis for its selection is discussed in this section. Complete specifications and drawings of the equipment are given in Appendix A. This section also includes a discussion of the Dowtherm piping system.

The basic parameters from which the equipment specifications were derived are:

- Maximum heat absorption during peak mid-day insolation of 1.7×10^6 Btu/h
- Boiler feedwater from existing boiler house at minimum temperature (205°F) and pressure (190 lb/in^{2}g)
- Saturated steam from solar system at minimum pressure (150 lb/in^{2}g)
- Dowtherm LF temperature from collectors (510°F) and to collectors (375°F).

Besides the solar collectors, the process equipment includes the following items, outlined in Subsections 7.1.1 to 7.1.5.

7.1.1 SG-101 Steam Generator

At the maximum heat absorption rate of 1.7 Btu/h, this unit will generate 1662 lb/h of 150 lb/in^{2}g steam. SG-101 is a kettle-type exchanger in which a 16-in.-diameter removable bundle of U-tubes is inserted into a 30-in.-diameter shell about 13 ft 6 in. long.

Boiler feedwater at 205°F enters the shell side and is vaporized to produce 150 lb/in^{2}g saturated steam. Sufficient disengaging space is left above the tube bundle to minimize liquid carryover in the product steam.

The U-tube bundle includes 30 U-tubes, resulting in 60 holes in the tube sheet. To maintain a satisfactory inside film convective heat-transfer coefficient, 1-in.-O.D. x 10 BWG tubes are used and arranged in 6 passes of 10 tubes each. The overall clean coefficient is 175.5 Btu/h/ft^2/°F, and after allowing for a steamside fouling factor of 0.0005 and a Dowtherm LF-side fouling factor of 0.001, the service or design coefficient is 138.9 Btu/h/ft^2/°F.

All-steel construction is specified and all other pertinent information can be found in the boiler requisition in Appendix A.

7.1.2 TK-101 Dowtherm LF Accumulator Tank

This tank has three basic functions:

- Stores Dowtherm for addition to the system on start-up initially or after repairs
- Accepts expansion of Dowtherm LF as the cold system heats up
- Contains the total inventory of the system if necessary.

The tank is 4 ft in diameter by 8 ft long and has a volume of 110 ft^3. The total system has a volume of about 37 ft^3.

If charged with 37 ft^3 of cold Dowtherm LF, expansion will be about 11 ft^3 requiring 48 ft^3 of volume if the system must be emptied. Thus, with no allowance for reserve in the tank, it will be about 44 percent full when containing one system charge of hot Dowtherm LF.

Although Dowtherm LF is pumpable down to -25°F, the tank is fitted with a steam coil. This permits testing of other heat-transfer fluids if later desired. It can also be used to keep Dowtherm LF warm for extended periods of cold weather with no sunshine.

All-steel construction is specified; other design details are included in Appendix A.

7.1.3 P-101 Dowtherm Circulating Pump

Based on the properties of Dowtherm LF, peak heat absorption of 1.7 x 10^6 Btu/h, Dowtherm to the collectors at 375°F, and returned at 510°F, the normal pumping rate is 52 gal/min.

With the physical arrangement as illustrated in the drawing included in Subsection 7.6, the system pressure drop dictates a design differential head of 84 ft. At the design pumping rate of 57 gal/min. The hydraulic horsepower is 1.1 at an efficiency of 60 percent will consume 1.8 bhp. Further design details are provided in Appendix A.

An in-line pump designed for a maximum temperature of 500°F is specified in all steel construction.

7.1.4 P-100 Dowtherm Charge Pump

A simple steel gear pump with 3 hp electric motor is furnished to change Dowtherm from storage drums to TK-101. It pumps 10 gal/min against 100 lb/in^2g.

7.1.5 Dowtherm Piping System

The physical characteristics of the Dalton plant dictated locating the collector field about 100 ft from the process equipment. The items are housed along with the control panel in a 20 x 25 ft building adjacent to the existing boiler house. These features may be seen on the detail drawings included in Subsection 7.6.

As described in Subsection 5.6, in order to minimize heat losses from the Dowtherm circulation piping, the hot (510°F) line returning from the collectors will be run from the southeast corner of the collector field directly to the solar boiler house and the cold (375°F) line is run to the northeast corner of the collector field.

Thus, the feed and return headers to the field enter and leave from the east side causing a distribution problem. This is overcome by installing a series of restriction orifices in each collector feeder to maintain constant flow in each of the 15 collector rows. These items range from a 5/16-in.-diameter orifice at the inlet end to a 1-in. hole in a 1.049-in. I.D. pipe at the next-to-last cell near the west end of the field.

7.2 ENGINEERING DESIGN PACKAGE

The detail design package was developed in accordance with Foster Wheeler standard practices. Dow Chemical and Foster Wheeler worked together to prepare the design, and in some cases, Dow specifications were used as the basis for the preparation of job specifications. Subsections 7.3 through 7.6 plus Appendices A through D contain the complete engineering design package for the Phase II procurement and erection of the solar steam generating facility.

For Phase II, Foster Wheeler is prepared to immediately send out equipment and subcontract requisitions for inquiry and bidding, and then to place purchase orders. When certified vendor prints are received, the design drawings will be checked and the final details will be added.

The solar collector package is the major portion of the new equipment. The detailed design of the collector area is based on drawings supplied by Suntec Systems, Inc. The layout of the solar boiler house is based on Foster Wheeler equipment designs. The exact dimensions of the required equipment will not be determined until the certified vendor prints are received after purchase in Phase II.

The design drawings in Subsection 7.6 detail the installation of equipment plus the necessary civil, piping, instrumentation, and electrical work which will be undertaken to complete the installation. These design details are based on the Dow Chemical's drawings of the Dalton plant. The required erection work is detailed in subcontract requisitions given in Subsection 7.7, which are supplemented by the design drawings and job specifications. The foundation design is included in Appendix D.4.

7.3 ENGINEERING FLOW DIAGRAM AND LINE CLASSIFICATION LIST

The engineering flow diagram, shown in Figure 7.1, illustrates all of the process equipment and instrumentation. This drawing provides a description of the plant and is therefore one of the basic documents on which the detailed design is based. The equipment and instrument symbols are based on Foster Wheeler standards. The instrument numbering system is in accordance with those

FIGURE 7.1 ENGINEERING FLOW DIAGRAM OF SOLAR STEAM SYSTEM

(Included in a Separate Package With This Report) suggested in Reference 12. The line classification list for the engineering flow diagram is shown in Table 7.1.

Figure 7.1 assumes that an analog data acquisition system is used for performance testing and evaluation. The diagram will be modified if an on-line computerized system is used.

7.4 EQUIPMENT LIST

The equipment list (Table 7.2) includes all items which have an item number, not including instruments, and provides a cross-reference to Figure 7.1 and the equipment requisitions presented below in Appendix A.

7.4.1 Equipment Requisitions

The equipment requisition defines the process and mechanical specifications for each piece of equipment and is supplemented by job specifications which have been developed in accordance with Foster Wheeler standards to cover general mechanical details. The job specifications are presented in Appendix D. In Phase II, the appropriate commercial documents will be issued along with the requisition to form an inquiry package which is sent to the vendors. Upon selection of an equipment vendor, the requisition is converted into a "purchase requisition" which reflects the details of the equipment being purchased. Equipment requisitions are included in Appendix A.

7.5 INSTRUMENT LIST

The instrument list has been included to provide identification of the instruments which are shown in Figure 7.1; requisitions for instruments will be

Table 7.1 Line Classification List

FORM NO. 135 905

FOSTER WHEELER ENERGY CORP. PROCESS PLANTS DIVISION | CONTRACT: 11-60863 | SECTION | LINE CLASSIFICATION LIST | FLOW SHEET NUMBER & REVISION: 60863-1-50-1 REV. A | PAGE 1 OF 1

REVISION	ORIGINAL	1	2	3	4	5	6	7	8	9	10	11
DATE	5/1/79											

LINE NUMBER SIZE	SERIAL		SPEC	LINE EXTREMITIES FROM	TO	OPERATING TEMP °F.	OPERATING PRESS PSIG	DESIGN TEMP °F	DESIGN PRESS PSIG	INSULATION TYPE	INSULATION THK	PLAN OR ISOMETRIC DRAWING NO	PIPE WALL THK	FLU CAT	REMARKS
2"	P	0101	B1	SC-101/115	SG-101	600	30			HC	2½				
2"	P	0102	B1	SG-101	P-101	350	30			HC	2½				
2"	P	0103	B1	TK-101	P0102B1	350	30			HC	2½				
2"	P	0104	B1	P-101	SC-101/115	350	30			HC	2½				
1"	N	0105	A	TIE-IN	TK-101	AMB	60			NI	–				
3"	SM	0106	Ad	SG-101	TIE-IN	366	150			HC	2½				
1"	BF	0107	A	TIE-IN	SG-101	205	180			HC	1½				
1"	SL	0108	Ad	SM0106Ad	TK-101	250	15			HC	1½				
1"	D	0109	Ad	TK-101	DRAIN	250	15			PP	1½				
1"	P	0110	B1	P-102	TK-101	AMB	30			NI	–				
1"	P	0111	B1	P0104-B1	SC-101/115	350	30			HC	1½				
1"	P	0112	B1	P0104-B1	TK-101/DRUMS	500	30			PP	1½				
(5) ← – – SEE NOTES LINE CLASSIFICATION LIST INDEX ——→						(1)	(1)	(1)	(1)		(2)		(3)		(4)

FOSTER WHEELER DEVELOPMENT CORPORATION

REF.: ET-78-C-03-2199
DATE: June 1979

Table 7.2 Equipment List

FORM NO. 135 904

FOSTER WHEELER ENERGY CORP. PROCESS PLANTS DIVISION	CONTRACT 11-60863 SECTION:	EQUIPMENT LIST	NAME OF UNIT: Solar Steam Generation	PAGE 1 OF 1

CLIENT: U.S. Department of Energy
LOCATION: Dow Chemical Company Dalton, GA

REVISION	ORIGINAL	1	2	3	4	5
DATE	4/20/79					

CLASS	ITEM NO.	DESCRIPTION	CFD	REQ'N NO.	P. O. NO.		REV
TANKS	TK-101	Accumulator Tank	1	1142-A			
EXCHANGERS	SG-101	Kettle Boiler	1	1219-A			
PUMPS	P-101	Circulating Pump	1	1311-A			
	P-102	Dowtherm Charge Pump	1	1213-A			
PACKAGE SYSTEMS	SC-101 thru SC-115	Solar Collectors (15 Rows)	1	1929-A			
	A-101	Collector Control Package	1	1929-A			
	A-102	Dowtherm Drum Rack	1	1919-A			

prepared during the Phase II procurement work. An instrument list is included in Appendix B.

7.6 DESIGN DRAWINGS

Detailed design drawings (Figures 7.2 through 7.13)* have been prepared for the site work and installation of equipment, building, piping, and instruments at the Dow Dalton plant. These drawings are based on drawings provided by Dow Chemical Company showing the existing terrain and buildings.

7.7 SUBCONTRACT REQUISITIONS

Subcontract requisitions include a technical description of the materials to be supplied and the work to be performed by the subcontractors. The subcontracted work will be divided into four work packages: mechanical, electrical, insulation and painting, and site preparation and foundation. The narrative part of each requisition is supplemented by what Foster Wheeler calls a "B Requisition" which provides Foster Wheeler's drawings, job specifications, and vendor drawings to the subcontractor. As the drawings are revised or new drawings issued, only the B Requisition is updated, not the entire requisition. The subcontract requisitions are included in Appendix C.

7.8 SAFETY EVALUATION

A failure modes and effects analysis was performed on the solar industrial process steam plant. A failure modes and effects analysis is an extensive

*Figures 7.2, 7.6, and 7.7 are included as a separate package with this report. Figures 7.3 to 7.5 and 7.8 to 7.13 are being prepared.

survey of the failure logic of a process. As such, it is applicable in both reliability and safety analyses. In a failure modes and effects analysis, the consequences of component failures, operator errors, and disturbances to process conditions are determined and their criticality and severity assessed. Corrective action is usually obvious.

To facilitate the analysis, checklists of commonly occurring component failures are used. Other failure modes are identified from previously performed analyses and failure reports from operating facilities and pilot plants.

The result of the failure modes and effects analysis is a survey of the failure behavior of the system and recommendations for corrective action to enhance safety or reliability. The analysis, for the solar steam system, reported in the form prescribed by MIL STD 1929, is presented in Appendix E.

The following are the principal points of concern identified in the analysis together with a description of the steps being taken to resolve these matters or recommendations for steps to enhance the safety and reliability of the unit.

7.8.1 Release of an Organic Heat-Transfer Fluid to the Atmosphere

The release of an organic heat-transfer fluid to the atmosphere creates the risk of fire if ignition sources are present, and toxic damage to the environment. In addition, autoignition of the heat-transfer fluid is possible if catalyzed by insulation. Accordingly, the following measures have been taken in the design to minimize the likelihood and consequences of a release:

- The collector area is diked to prevent the run-off of spilled heat-transfer fluid.
- Adequate fire protection facilities cover the collector area.
- Closed-cell insulation will be utilized on pipes to minimize the possibility of the autoignition of leaking heat-transfer fluid.
- Pipe valves will be installed on the bottom of pipes to prevent the draining of release fluid into the insulation.
- Low-flow and low-level alarms and shutdowns are provided that will protect against the loss of fluid from the system through failures in lines and valves and the accidental opening of drains, etc.
- Steps have been taken to protect against overheating and overpressurization of the system, both of which are possible causes of the release of heat-transfer fluid. These steps will be discussed later.

The release of heat-transfer fluid is not believed to pose a significant health hazard. However, ingestion will cause sickness, skin contact may cause irritation, and exposure to vapors is irritating at levels of 10 ppm or higher. Accordingly, extraordinary measures are not called for with respect to the handling of fluid release.

7.8.2 Overpressurizing the System

Overpressurizing the system can result in damage to equipment and the release of hot, flammable liquids. One potential cause of overpressurization is the thermal expansion of liquid in an isolated solar collector. A second cause arises from the expansion of the fluid as the operating temperature is raised. A third cause is the introduction of water into the system through boiler leaks or prior to start-up. Accordingly, the following steps have been taken:

- Pressure relief valves will be installed between the valves which isolate each collector. These must discharge to a safe area should they prematurely open while the plant is in service, releasing heat-transfer fluid.
- An expansion tank and a nitrogen purge is provided. The latter will serve to maintain pressure and vent steam.
- A pressure relief valve has been installed on the expansion tank should the purge malfunction.
- A pressure indicator is placed on the expansion tank. It is recommended that this indicator be placed in clear view of the operator or that the pressure be indicated on the control panel.

7.8.3 Overheating the Collectors

Should the flow of fluid through a collector be reduced through partial blockage or be stopped by pump failure or valve closure, overheating of the collector can occur under high heat-flux conditions. As a result of overheating, thermal stresses can damage the equipment and the heat-transfer fluid can decompose, forming sluggish tars and even coke after long exposures. Should the collector be isolated and exposed to a high heat flux, overpressurization of the collector may result.

The likelihood of the collectors overheating will be diminished by stowing them if:

- Power to the pump is lost
- Fluid flow is low
- Collector temperatures are excessive.

7.8.4 Hot Fill

The introduction of cold heat-transfer fluid into a hot collector, or vice versa, will create thermal stresses that may damage the collectors. This possibility should be recognized and stressed in the operating manual.

7.8.5 Corrosion

Corrosion may be a problem if water contaminates the heat-transfer fluid. This water will be vented from the expansion tank. It should be noted that organic heat-transfer fluids are incompatible with copper and aluminum at temperatures exceeding 400°F. These metals should not be utilized in the design.

SECTION 8

OPERATION: PERFORMANCE TESTING AND EVALUATION

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OPERATION: PERFORMANCE TESTING AND EVALUATION

8.1 INTRODUCTION

The instrumentation, data acquisition system, and procedures used in conducting performance testing and evaluation of the solar steam system are described in this section. The instrumentation and data acquisition system are designed to:

- Determine the monthly and annual energy delivered by the solar steam system for steam production.
- Determine the system's monthly and annual steam production.
- Determine the solar collector system's monthly and annual use of electrical parasitic energy.
- Determine the amount of fossil fuel saved by the solar system monthly and annually.
- Determine collector array efficiency on an "instantaneous," daily, monthly, and annual basis.
- Measure the thermal performance of the boiler.
- Measure piping and overnight thermal losses.
- Determine changes in system's operational characteristics including degradation over the life of the system. Correlate performance changes with maintenance.
- Determine long-term reliability in terms of materials, component, and system performance.

Three data acquisition systems were evaluated:

- Real-time minicomputer-based data acquisition system. This system is specified by Solar Energy Research Institute in Reference 12.

- Electronic data logger with off-line computer performance evaluation.
- Analog data acquisition system. The appropriate signals in this option are conditioned to suit the system requirements and are recorded on chart recorders.

A comparative evaluation of the three alternatives was performed and the final selection made.

8.2 PERFORMANCE CALCULATION PROCEDURE

The instruments used for the performance evaluation are shown on the Engineering Flow Diagram (Figure 7.1). The following measurements will be recorded on a continuous basis throughout the day.

- Direct normal insolation, I001
- Wind speed, V001
- Ambient temperature, T001
- Collector inlet header temperature, T100
- Collector outlet header temperature, T101
- Steam pressure, P400
- Feedwater temperature, T400
- Electrical power to collectors, EP101
- Electrical power to circulating pump, EP600
- Boiler inlet fluid temperature, T403
- Boiler outlet fluid temperature, T401
- Fluid flow rate, W400.

The performance of the system will be calculated as follows:

- Boiler Heat Losses - During the operational testing period, the boiler will be completly isolated under hot conditions. A record of the boiler pressure with time will be made. The total water content in the boiler, ambient temperature, and boiler pressure vs. time curve will be used to establish the boiler heat losses. These will be designated as L_B.

- Energy Delivered to Water by Solar Steam System

  Energy delivered to water (Btu/h), $E_1 = E_2 - L_B$
  and $E_2 = Cp \times W400 \times (T403 - T401)$

  where

  Cp = Specific heat of Dowtherm LF

  L_B = Boiler heat losses

- Amount of Steam Generated - Having calculated the energy delivered to water by the solar system (E_1), the amount of steam generated is calculated as follows:

  $$\text{Amount of steam produced (lb/h)} = \frac{E_1}{h_{fg} + Cp_1(T_{Sat} - T400)}$$

  where

  h_{fg} = Heat of vaporization of water at the pressure P400

  T_{Sat} = Saturation temperature corresponding to the pressure P400

  Cp_1 = Specific heat of water

  A redundant check of the amount of steam generated will be provided by a feedwater flow totalizer.

- Collector Array Efficiency

  $$\text{Collector Array Efficiency } (\eta) = \frac{E_3}{I001}$$

  and $E_3 = Cp \times W400 \times (T101 - T100)$

- Electrical Parasitic Losses

  Total electrical parasitic losses = EP101 + EP600

- Piping Thermal Losses - The piping losses are computed by subtracting the heat delivered to the boiler from the heat collected in the solar collectors. Thus,

  Piping Losses = $E_3 - E_2$

- Overnight Thermal Losses - The overnight thermal losses will be measured by determining the cumulative value of energy E_3, from the time between collector start-up and the onset of steam generation.

8.3 INSTRUMENTS FOR PERFORMANCE EVALUATION

A summary of all instruments mounted on the system is presented in Table 8.1. The sensors selected meet the instrument specification provided in References 13 and 14. All sensors deliver signals which can be used by the data acquisition system for data processing.

8.4 DATA ACQUISITION SYSTEMS

8.4.1 Minicomputer-Based Data Logging and Reduction

The minicomputer-based, data acquisition, data logging, retrieval, and analysis system is designed to perform the following functions:

- Collect data from the transducers at a rate of approximately 7 seconds for any point
- Prepare a log on magnetic tape for input to the data processing system
- Prepare a hard copy log of operating variables either at fixed times of the day, or on a continuous basis in an easy-to-read format
- Scan and compare the "alarm" variables for out-of-limit conditions and print or display them

Table 8.1 Instrument List of Performance Evaluation

Type	Tag No.	Service	Remarks
Pressure transmitter	PT-400	Boiler drum	Two-wire 4 to 20 mA dc output, low-displacement type, weather-proof construction
Temperature transmitters	TT-001	Ambient temperature including radiation shield	All temperature primary elements are RTEs, two-wire, 4 to 20 mA dc output, complete with well and weatherproofed, integrally mounted transmitters
	TT-100	Collector array inlet	Matched pair for temperature difference
	TT-101	Collector array outlet	Matched pair for temperature difference
	TT-400	Boiler feedwater	Matched pair for temperature difference
	TT-401	Dowtherm boiler inlet	Matched pair for temperature difference
	TT-403	Dowtherm boiler outlet	Matched pair for temperature difference
Flow transmitters	WT-100	Dowtherm circulating flow	Rampo target meter Foxboro model
	WT-400	Feedwater flow	DP cell with integral orifice, both flow meters, two-wire, 4 to 20 mA dc output
Level transmitter	LT-400	Boiler drum level	Two-wire, 4 to 20 mA dc output, complete with upper drum reservoir

Table 8.1 Instrument List of Performance Evaluation (Cont)

Type	Tag No.	Service	Remarks
Power transducer	EPT-101	Circulating pump power (W)	
	EPT-600	Collector controls/ tracking power (W)	
Solar intensity transducer	IT-001	Direct normal insolation	Eppley Model PSP pyrehliometer with sun tracker
Wind speed transducer	VT-001	Wind speed	Weather measure Model W101-P-DC/540

- Provide continuous display of selected variables if necessary
- Perform the necessary analysis of the data in real-time.

The minicomputer is a multitasking real-time system. This system has the inherent ability to perform 100 percent of all data reduction and analysis on-site without support of an off-site computer. Advantages of this system are:

- Complete real-time and off-line analysis of data is possible at the site.
- System storage and data processing capabilities permit long-term testing.
- Data reduction cost is lower.
- Manpower requirements for data acquisition and data reduction are lower.
- Data acquisition and reduction can be automatic.
- Has provision for future direct digital control.
- Has capability to alarm data points.
- A large amount of data can be gathered over a arbitrarily long time period.
- All information collected is computer compatible and can be evaluated and analyzed very rapidly. The results can be used as feedback for manual- or computer-controlled adjustments on experimental parameters.
- Once the system is installed, relatively little effort and investment is required to collect additional useful data.
- Excellent graphical capabilities can be built into the system.
- The data logger is a stand-alone unit and can be programmed to log and monitor the alarm requirements even when the computer system is down. Therefore, no elaborate back-up system is required.
- The use of a data logger as a front end greatly makes the system economical.

- The system is general and not dedicated, accepting a wide range of inputs.
- The interactive mode of operation reduces training of operator personnel.

8.4.1.1 System Hardware. The computer data acquisition system is shown in Figures 8.1 and 8.2. It consists of a control unit (minicomputer), data logger (analog to digital converter), printer, video display, hard copy unit, disks, magnetic tape, and Teletype.

Control Unit: The control unit is the minicomputer which is comprised of three sections: a central processing unit (CPU), memory, and an input/output (I/O) section. The I/O section is the means by which the minicomputer communicates with a variety of devices called peripheral equipment. The minicomputer accepts data only in digital form.

Under program control from the minicomputer, the input from the data logger is transmitted by cable to the memory in the CPU. All applicable software can be recalled from memory when needed for real-time data reduction and analysis. Data reduction is accomplished automatically and stored temporarily on disk and transmitted later to magnetic tape.

The CPU will be a Data General NOVA 4/C computer with 48K word memory. It has four accumulators, 16-level programmed priority interrupt, extended stack facility, direct memory access data channel, asynchronous interface, power fail/ auto restart, and auto program load. The NOVA 4 has a full-memory cycle time of

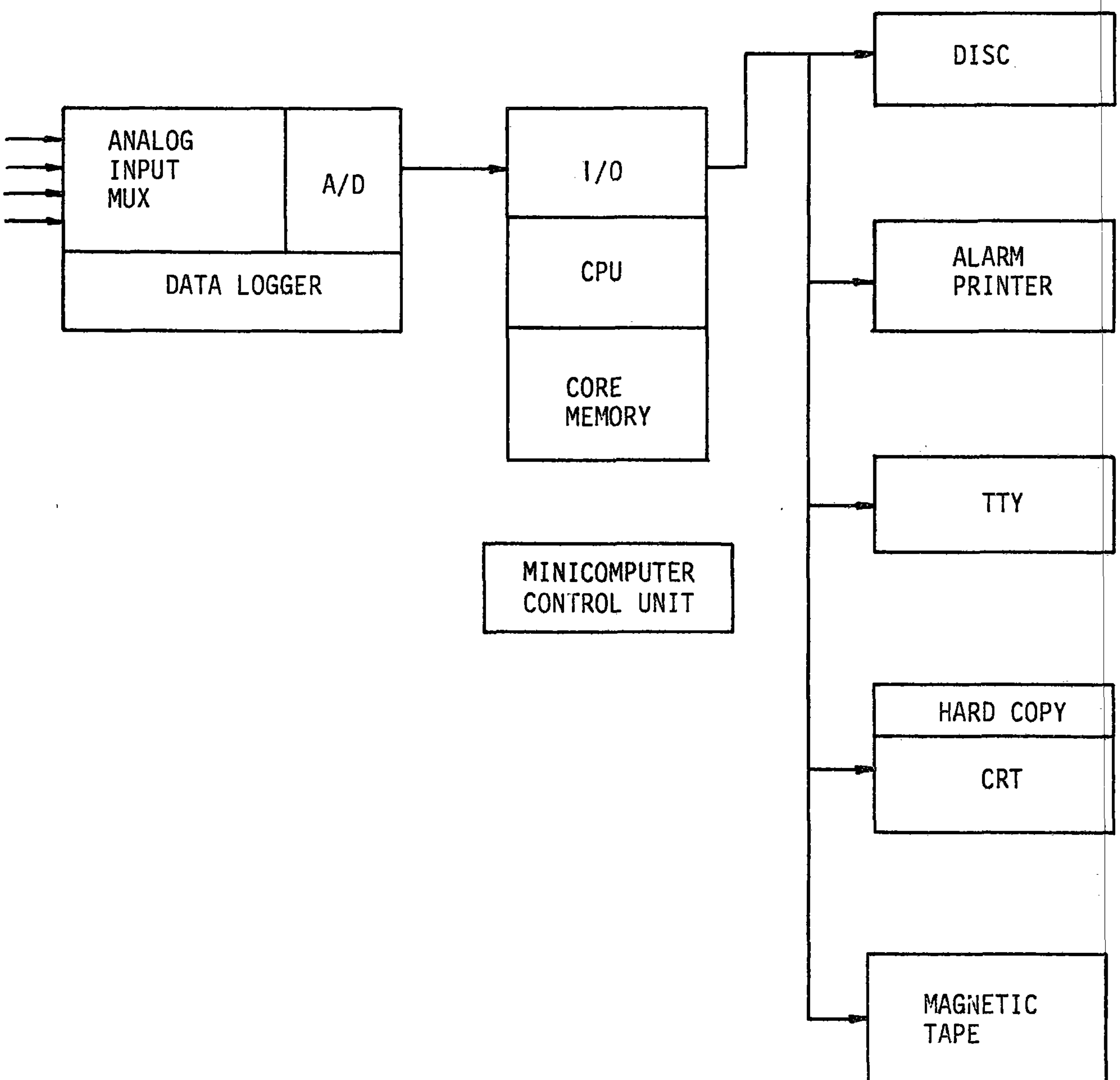

Figure 8.1 Schematic Diagram--Computer Data Acquisition System

FIGURE 8.2 COMPUTER DATA ACQUISITION SYSTEM

(Being Prepared)

400 ns. In NOVA 4, a real-time clock and battery back-up provide power to retain the contents of the memory during a power failure. NOVA 4 has front panel key locknut.

Analog to Digital Converter (A/D): This is comprised of the Analog Multiplexer (MUX) and A/D. Using solid-state switches, the MUX connects the analog inputs to the A/D converter. A/D converts analog input signals to digital code. The A/D subsystem will be a Doric 230A process monitor. The subsystem can be comprised of one main frame with 200 input points. This system includes:

- 200 points of analog input, thermocouples, and voltages
- 64 alarm set points
- 0.1 deg or 1.0 uv resolution
- Point and data display
- Internal clock (hours-minutes-seconds)
- Internal strip printer for alarm printout
- Thermocouple reference junction and linearization
- Terminal and computer interface
- Common mode rejection of 140 db at 60 Hz.

The Doric 230A system is completely programmed and controlled through minicomputer.

Commands can be edited on-line and listed without interrupting a scan sequence. The Doric 230A will also operate as a stand-alone unit with front-panel control after initialization.

Individual points can be assigned up to 36 functions, e.g., thermocouple type, degrees Fahrenheit or Centrigrade, voltage range and linear dc volts, point skip and alarm, set point value, as well as alarm scan delay. For convenience, group programming can also be performed.

Up to 32 different individual alarm set points can be programmed and up to four assigned to each point. With optional memory expansion, up to 64 alarm set points may be programmed. Data are printed when an alarm set point is exceeded and again when it returns to a within-limits condition. This prevents repeated alarms, yet indicates precisely what happened and when. Alarm scan delay allows an alarmed point to be ignored 3 times before output indication, preventing nuisance alarms from sensors with spurious outputs.

The scan sequence is also completely programmable: first point, last point, scan interval from one second to 24 hours, continuous scan, scan and log alarmed points only, scan and log alarm transitions only. Alarm status summary listing on demand provides a listing of current alarm conditions. With the Doric 230A system operating in a scan sequence, individual points within a scan can be selected and logged without interrupting the sequence.

Optional control features include a three-digit day calendar, alarm relay and acknowledgment panels, automatic range, subinterval scanning (where certain points can be scanned more frequently than others), and point address conversion.

The Doric 230A system provides several data output devices in the basic configuration. A large (0.6-in.) planar display provides visual indication of time in hours, minutes, and seconds; and when scanning, provides point identification and point data. Also, an internal thermal printer provides a hard copy record of all data with push-button printer on/off control.

The Doric 230A can display or print without disturbing data acquisition or magnetic tape output.

Any channel or group of channels can be accessed and displayed on a timed basis.

Printer: Data General terminal printers will handle all printout including timed alarm printout. The printer has 96 characters with 60-character-per-second printing speed. A 40-character print buffer ensures no data will be lost during carriage returns. The terminal printer uses a standard keyboard for data input.

Video Terminals: The 6053 video terminal is an operator-oriented, alphanumeric display manufactured by Data General. It consists of a detached keyboard, a pedestal-mounted video monitor that can be positioned in two planes, and a Teletype-compatible asynchronous communications interface with 10 switch-selectable speeds up to 19.2 K baud. The terminal can be connected directly to the computer at distances up to 1500 ft, or to modems via a standard RS-232-A interface for remote applications.

Diskettes: The Data General Model 6030 diskette system provides flexible mass storage. The subsystem includes two drives, power supplies, a controller, diskette, and cable sets. Each drive contains a single spindle for one 315-K-byte diskette.

All data are initially stored on diskette and then transferred to magnetic tape. Up to 8 hours of data are stored on one diskette. Eight hours of actual test data are available for real-time analysis data reduction.

Magnetic Tape: Data General's magnetic tape subsystems provide serial access storage and can be used in computational, instrumentation and control, data processing and communications applications. All transports feature self-loading vacuum columns designed to protect tape-stored data from damage. Transports process tape at 75 ips, and record and read data at 800 bpi (9 track). This device provides a permanent record of data for archival storage and future data analysis. It is also used for creating back-up of all programs.

8.4.1.2 System Software. All data acquisition, reduction, and analysis programs are written in Advanced FORTRAN V in an interactive mode of operation. All commands to the computer regarding data acquisition changes or analysis are in conversational English. This mode of operation greatly reduces operator training time.

All programs are run on the real-time multitasking concept. Tasks are separate programs running in parallel, thereby efficiently utilizing system resources. The tasks gain control of the resources on the basis of the predetermined priority assigned to them. The following six tasks can be run at any given time. These tasks are listed in order of priority.

Task 1: This task is called by the main program from disk to initiate and set up all Doric A/D subsystem operating parameters. All commands to Doric are stored in a disk file named DORCAM. Task 1 reaches the file line-by-line and issues the command automatically to Doric. Task 1 waits for Doric response before issuing the next command. Operators have the option of printing the dialogue between the computer and Doric. The following commands are issued by the computer to Doric in Task 1:

- Set date and time.
- Set test title for printout identification.
- Skip all appropriate channels.
- Assign one of the 32 functions available to each of the 200 analog channels.
- Enable alarms for each of the 200 analog channels.
- Set the scan delay to 1 for the 4 alarms on each of the 200 analog channels. This means the alarmed point can be ignored once before output indication preventing nuisance alarms from sensors with sporadic outputs.
- Set alarm limits for each of the 200 analog channels.
- Turn the printer on.
- Start continuous alarm scan.

After the initialization is complete, Task 1 kills itself, thereby releasing its space to subsequent tasks.

Task 2: After Task 1 is killed, the main program calls in Task 2. This task collects all the record data points. Task 2 reads the disk file DORCAM 2 and issues the random access command to Doric for all the record data points. Doric responds by returning the channel accessed and its value at the rate of 3 channels per second. The alarm scan continues uninterrupted in the Doric, while points are being random accessed.

Task 3: This task provides data reduction. Data collected by Task 2 are reduced to the proper form. This involves converting some of the data from millivolts to engineering units based on the user-supplied linear and nonlinear conversion curves. All the data are finally packed in compact form and stored on the disk file DATASTOR. Each complete scan requires two blocks (512 words) of disc space. The two blocks contain the starting time and date of scan, ending time and date of scan, the channel number, and the values of all the record data points.

Every time the blocks are written on DATASTOR, Task 3 writes the ending time and date of scan with the block number of data stored on another disk file called DATATABLE. This is a seven-word record file. The first six words of each record are the time and date of scan and the seventh word is the block number of DATASTOR. The first record of DATATABLE is always the date, time, and block number of the most recent record of the DATASTOR. (DATATABLE is the catalogue of information in DATASTOR and can contain up to 8 hours of test data in a circular file concept). Since DATASTOR is a random-access file, DATATABLE can be used to access any DATASTOR record very quickly. For example, to locate data at any given time and date, a quick search of DATATABLE locates the starting block number of the required data. Knowing the block number, the data is now directly accessed from DATASTOR.

Task 4: This Task 4 is the communication task, and is the only task by which the operator can command the computer to do the operations he desires. Task 4 is initiated through the keyboard. Once initiated, the task asks the operator to type the following two operations:

- Change Doric Values - All commands to the computer are in conversational English. The computer asks a series of questions, and the operator types the appropriate answers. The computer also checks the answers for typographical errors and repeats the question if it has encountered any. The following are some of the on-line changes that can be made to the data acquisition task:
  - Set limits on any transducer.
  - Disable alarms.
  - Enable alarms.
  - Check status of any transducer.
  - Change the scan delay for any alarm.
  - Disable a point from logging.
  - Enable a disable point to be logged.
  - Random access any point and display it once every second.
  - Disable the random access.
  - Display up to six groups of data or display any group of data desired by the operator. The data is updated every 90 seconds.

  In all these above commands the operator identifies the operation by transducer Tag ID rather than by the computer channels to which the transducers are attached. The program keeps a cross-reference file "DFILEI," which correlates the transducer Tag ID with the channels.

- Shut System Down - When the operator types in this option all data collected are dumped into the magnetic tape and the files are released and closed.

Task 5: Main Program Call in Task 5. Task 5 keeps track of time and every 4 hours dumps its data from the disk to the magnetic tape. Task 5 creates a disk file called TAPE FILE which contains the latest date and time of the data that has been dumped and the available magnetic tape file. After the dump is completed, Task 5 updates TAPE FILE to reflect the new dump.

Since the magnetic tape can only have 99 files, Task 5 keeps track of the tape file that contains the dumped data. If the tape file exceeds 99, Task 5 informs the operator to rewind the old tape and load a new one.

If Task 5 encounters the end of a tape during the dumping process, it informs the operator to load a new tape, rewinds the old tape, and starts the dump again on the new tape when ready.

Task 5 also checks to ensure that the tape end is aligned and that the word rings are on. The operator is informed if corrective action is required. During the dumping cycle, Task 5 checks for any bad tape. If bad tape is encountered, it tries to write over it 3 times. If it fails, it informs the operator of the steps for corrective action.

Task 6: This is the performance analysis task using both the collected data and data supplied by the operator.

8.4.1.3 Minicomputer System Cost. The cost of the minicomputer system can be broken into five categories. The price quoted for each category is based on current information available. These categories, their estimated labor cost where applicable, and a brief description of the equipment or services included are detailed below.

- Hardware Cost - This includes all computer and peripheral equipment costs. The estimated minicomputer hardware costs are detailed in Table 8.2. The prices quoted are for the computer system hardware only and do not include the cost of the transducers and wiring from the transducers to the computer input junction box.
- Integration and Installation - Labor cost of this work is estimated to be 300 man-hours.
- Software - The labor cost to develop computer programs is estimated to be 400 man-hours.
- Materials and Supplies - Costs of the magnetic tapes, paper, and disks is estimated to be $800 per year.
- Maintenance - This includes the cost of parts and labor for maintenance of the computer and peripheral equipment. Normally, a flat fee is charged by the equipment manufacturer. However, it is recommended the service contract be made with the equipment supplier for better and faster service. Suppliers normally charge 1 percent of the hardware cost per month. This fee would then be approximately $400 per month.

8.4.2 Electronic Data-Logger With Off-Line Computer

This system utilizes a basic electronic data logger with hard copy and magnetic tape data output. This type of data logger is commonly used to gather large amounts of field data at a power plant or other similar installation for the following reasons:

- They are inexpensive
- They can be moved from plant to plant as testing needs dictate with minimum effort
- They can be set up to accommodate many different types of field inputs.

Table 8.2 Minicomputer Hardware Costs

64K WORD MINICOMPUTER	$15,750
Memory management	
Auto program load	
Power fail restart	
Real-time clock	
Hardware with multiply, divide, and floating point processor	
AUXILIARY EQUIPMENT	
Dual diskette system	3,900
Dasher video terminal	1,900
60 cps dasher line printer	2,600
ULM5 asynchronous line controller	1,400
Magnetic tape subsystem	9,900
One bay cabinet	950
A/D SUBSYSTEM	5,600
Doric 230A data logger	
40-channel analog input	
Thermal printer display board	
16-bit resolution	
ANNUNCIATOR	500
DORIC SPECIAL FUNCTION	890
TOTAL	$43,480

The typical function of a data logger is to acquire data in a format which can be later input to a computer for data reduction and analysis. For this application, some of the disadvantages of a data logger are:

- For many test programs and lengthy data sets, it may be several days before all data can be reduced
- This method affords little opportunity to identify faulty instrumentation inputs during a test
- It does not allow a thorough evaluation of plant operating conditions during a test
- It is susceptible to error.

8.4.2.1 Hardware. The hardware consists of the Doric 230A data logger and cassette magnetic tape data output.

The Doric 230A is a microprocessor-based data logger that meets the requirements of the solar steam system. It can measure a wide variety of analog signals: thermocouples, RTDs, voltage, current, or resistance. It can also monitor digital data and record sequences of events with millisecond resolution.

The 230A is supplied as a complete, self-contained data logging system, with its own 28-key touch panel (as easy to use as a touch-dial telephone), nine-digit LED readout, built-in alphanumeric thermal printer, and convenient carrying handle. A typical system with up to 100 analog inputs weighs less than 30 lb and occupies less than 1-1/2 ft^3.

The 230A can be equipped with EIARS-232-C or 20 mA current loop capabilities. The interface can be used to connect 230A mainframes to a process computer to provide an efficient, economical "front end" capability--under complete control of the computer. It achieves high accuracy and scanning speeds, and low installation costs, by distributing the data acquisition function into 20-point analog modules and separate plug-in cards for digital data.

Each analog Front End Module (FEM) is equipped with its own scanning multiplexer, preamplifier, and precision analog-to-digital converter. Compact and self-contained, the FEMs can be plugged directly into the 230A or located close to the source of the analog signals. Low cost, four-wire cables can then be used to transmit the digital output for distances up to 1 mile without any loss of data due to common mode voltage or electrical noise.

Up to five 20-point FEMs can be plugged in or connected to the 230A mainframe. A satellite chassis can accommodate an additional five FEMs for a total capacity of 200 analog inputs for each logger. The analog-to-digital converter in each FEM uses dual slope integration with automatic zeroing to achieve 1 μv resolution (0.5 μv for a high-sensitivity option) at a scanning rate of 2.85 points per second for each analog module, or 28.5 points per second for a system with a full complement of 10 FEMs.

Thermocouple break detection and reference junction compensation are performed in each FEM. Standard scaling and linearization functions are calculated by the microprocessor in the 230A mainframe. Alarms and arithmetic functions are provided as plug-in options.

Reference-junction compensation is obtained by digitizing the output of a transistor connected as a transdiode. After linearization in three straight-line segments, the digital compensation is incorporated into the millivolt-to-temperature calculation.

A two-digit code identifies the function for each analog input. Recorded temperature data can be in degrees Fahrenheit or Centigrade. Other measurements are expressed as percentage (for current inputs), millivolts, volts, or ohms. An engineering-units option allows the user to specify two alpha-characters such as lb and assign them to any point in the system.

Optional arithmetic functions can also be added to the system. These include scaling, offset, difference between points, running average for single points, single-point deviation from a group average, and custom arithmetic functions.

All of the arithmetic processing is performed before the data are stored in the 230A memory. Stored data are updated with each scanning cycle and are immediately available for front-panel display or demand logging. Each data update can be checked for alarm conditions. If alarm set points have been programmed, assigned relays are activated and an alarm log momentarily interrupts any other log in progress.

Up to three different timed-interval logging sequences can be programmed, plus demand and alarm logging. Each logging output can be directed to one or more recording or display devices.

Logging can be programmed for 1-minute to 24-hour intervals and can be programmed as individual points, or several sequential groups of points.

The standard 230A mainframe includes a built-in thermal printer that produces a 12-column alphanumeric record on roll or fan-fold paper at a minimum print rate of 2.5 lines per second. As an option, a connector can be installed on the back panel for connection to any standard RS-232-C or 20 mA current loop terminal, line printer, or magnetic tape cassette unit.

Up to three additional I/O cards can be added for interfacing the unit to a process computer, punched or magnetic tape equipment, or telephone modem.

Optional alarm cards and relay panels can be added to the 230A to provide monitoring and alarm capability. The additions allow the operator to establish up to 63 unique alarm set points. These set points can be assigned by two-digit code numbers to specific analog and digital input points such as high, low, or high/low alarm conditions.

Electromechanical relays, packaged 16 to a panel are also identified by a two-digit code and can be independently assigned, not only to a specific point, but to one of set points for a given point.

The result is a complete matrix of assignable alarm conditions and relays. More than one relay can be assigned to a specific alarm condition, and several inputs can share an alarm condition or relay.

8.4.2.2 System Software. All the data collected on tapes will be analyzed by off-line minicomputers. All programs will be in Fortran language. The performance calculations required are described in Subsection 8.2.

8.4.2.3 Electronic Data Logger System Cost. As for the previous system, the costs are broken into five categories:

- Hardware Cost - The following is the hardware cost of the data logging system. The prices quoted are for the data logger system hardware cost only and do not include the cost of the transducers and wiring.

Doric data logger	$ 5,600
Annunciator	500
Special function memory	295
Cassette recorder	1,700
Terminal	1,400
Point average (special function)	495
Alarm	695
Three-slot memory special function alarm	1,895
TOTAL	$13,175

- Software Cost - This includes the cost for program development and rental charge for the off-line computer system.

Program development	200 man-hours
Data preparation	100
Computer run including terminal rental	$5,000

- Integration and Installation Cost - The labor cost for system installation and integration is estimated to be 150 hours.

- Material and Supplies - The cost of magnetic tape and paper is estimated to be $500 per year.

- Maintenance - Monthly maintenance costs are estimated to be $100 per month.

8.4.3 Analog Data Acquisition System

In this approach, signal conditioning devices are utilized to perform the necessary computations, and chart recorders are used to make continuous recordings. The signal conditioning devices are listed in Table 8.3. The recording equipment is listed in Table 8.4. These chart recorders and totalizers can be effectively utilized to assess system performance instantly at any time. The formal data processing for reporting purposes will be done at the end of each month by Foster Wheeler personnel.

In addition to the instruments listed in Tables 8.3 and 8.4, an annunciator will be needed to alarm various upset conditions. These conditions are listed in Table 8.5.

An error analysis of this system showed that the expected rms error value is well below the 6 percent limit specified in Reference 12.

8.4.3.1 Analog System Costs. The material cost of all equipment shown in Tables 8.3, 8.4, and 8.5 is $20,000. The installation costs would be 200 man-hours. Estimated annual cost of materials and supplies would be $500 and maintenance is expected to cost $100 per month.

8.4.4 Comparison Between the Three Data Acquisition Systems

The various capital, installation, and maintenance costs involved in the three data acquisition systems are summarized in Table 8.6. The final selection will be made after the discussions with DOE personnel at the Design Review Meeting.

Table 8.3 Instrument List - Signal Conditioning Devices

Tag No.	Service	Remarks
EPY-101	Collector array power	MV/I
EPY-600	Circulating pump power	MV/I
HFY-100	Collector array Btu calculator	Multiplier
HFY-400	Boiler input Btu calculator	Multiplier
IY-001-A	Direct normal insolation	MV/I
IY-001-B	Direct normal insolation	Adjustable delay (average)
TDY-100	Collector array ΔT	Two input summer
TDY-402	Boiler ΔT	Two input summer
VY-001	Wind speed	MV/I
WY-100	Dowtherm flow	Square root extractor with low-level cutoff
WY-400	Feedwater flow	Square root extractor with low-level cutoff
ηY-001	Collector efficiency calculator	Divider
LSL-400	Boiler water level low	Dual alarm switch with DPDT contacts
LSH-400	Boiler water level high	Dual alarm switch with DPDT contacts
WSL-100	Dowtherm flow low	Dual alarm switch with DPDT contacts
WSLL-100	Dowtherm flow cut off	Dual alarm switch with DPDT contacts
LYLL-400	Boiler water cut off	DPDT contacts

Table 8.4 Instrument List - Recording Devices*

Type	Tag No.	Service	Remarks
Totalizers	EPQI-101	Circulating pump power (kWh)	Six-digit, shelf-mounted, 3 in. x 6 in. nominal size, two counters per module
	EPQI-600	Collector power (kWh)	
	HFQI-100	Collector energy (Btu)	
	HFQI-400	Boiler energy (Btu)	
	WQI-400	Feedwater (lb)	
Chart Recorders*	VR-001	Wind speed	Two pen
	TR-001	Ambient temperature	Two pen
	IR-001	Direct normal insolation	Two pen
	ηR-001	Collector efficiency	Two pen
	TR-100	Collector inlet temperature	Three pen
	TR-101	Collector outlet temperature	Three pen
	HFR-100	Collector energy absorbed (Btu/h)	Three pen
	WR-100	Dowtherm flow	Two pen, one spare
	TR-400	Feedwater temperature	Two pen
	WR-400	Feedwater flow	Two pen
	PR-400	Steam pressure	Two pen
	TR-402	Boiler ΔT, Dowtherm	Two pen
	TR-401	Boiler outlet temperature	Three pen
	TR-403	Boiler inlet temperature	Three pen
	HFR-400	Boiler heat absorbed (Btu/h)	Three pen
	EPR-101	Circulating pump power (kW)	Two pen
	EPR-600	Collector power (kW)	Two pen

*All are shelf-mounted, 6 in. x 6 in. nominal size, strip chart, 0.5 percent accuracy, felt-tip pens, 0.75 in./h chart speed, adjustable pen damping, 1 to 5 v signals.

Table 8.5 Instrument List - Annunciator

Tag No.	Service	Remarks
LAL-400	Boiler level low	Solid-state annunciator with 10 alarms, test and acknowledge push button, horn, sequence standard, remote electronics
LAH-400	Boiler level high	
LALL-400	Boiler level low low (system shut down)	
LAL-800	Dump/expansion tank level low	
WAL-100	Dowtherm flow low	
WALL-100	Dowtherm flow low low (system shut down)	
XL-100-A	System on	
XL-100-B	System off	

Table 8.6 Comparison of Alternate Data Acquisition System Costs

Data Acquisition System	Hardware ($)	Software*		Installation*		Yearly Material and Supply Costs ($)	Yearly Maintenance Costs ($)
		Man-Hours	($)	Man-Hours	($)		
Computerized	43,500	300	6,000	400	8,000	800	4,800
Electronic Data Logger	13,200	300	6,000	150	3,000	500	1,200
Analog	20,000	---	---	200	4,000	500	1,200

*At $20/man-hour.

8.5 OPERATING AND MAINTENANCE MANUAL

After the equipment vendors' prints and operating information has been received by Foster Wheeler during Phase II, an operating and maintenance manual will be prepared. The manual will provide a general description of the plant, the basis for the design, and a description of the process flow. Another section will be devoted to operating conditions and process controls. Safety features including alarms and trips will also be covered. Other sections include descriptions for initial start-up, normal start-up, and normal and emergency shutdowns. The project drawings will be presented as well as a summary of the major equipment and vendor information. The normal maintenance schedule and requirements will also be included. The operating and maintenance manual is a valuable tool, not only to the operators and owners, but to anyone wishing to gain an understanding of the design and operation of this solar installation.

SECTION 9

PHASE II
PLANS AND SCHEDULE

Section 9

PHASE II - PLANS AND SCHEDULE

A discussion of the plans and schedule for performance of Phase II - Fabrication and Installation is given in this section.

9.1 CONSTRUCTION APPROACH

Foster Wheeler Energy Corporation (FWEC), the major United States operating subsidiary of Foster Wheeler Corporation, is one of the world's largest architect-engineering firms and has extensive experience in design, construction, and providing management services for large process plants in the United States and abroad. FWEC has expertise in direct hire through international agreements with the building and construction trades (AFL-CIO), construction management with labor subcontracted to local contractors, cooperative agreements with open shop constructors, and various combinations of these. FWEC will assume the primary responsibility for procurement and construction of the solar process steam plant. These responsibilities include procurement of equipment, execution of the construction program, directing and coordinating subcontract work, employment of local craftsman and laborers as required, disposition and utilization of construction materials and equipment, and plant operational testing and start-up.

The staff of Dow Chemical's Dalton plant will participate significantly in carrying out the construction program. The experience of Dalton plant personnel with the local labor force and subcontractors will be utilized to facilitate procurement, installation, construction, and system operation.

FWDC will assume the overall project responsibility. FWEC will provide a project engineer who will coordinate the engineering design review and construction work. The project engineer will spend part of his time supervising construction at the plant site. The Dow Chemical plant manager will provide a plant engineer to assist Foster Wheeler in construction supervision. The project manager and the project administrator will visit the site periodically to review the construction schedule and prepare monthly progress and cost reports to ensure realistic monitoring of all facets of construction.

Appropriate inspection procedures will be implemented for controlling all operations in the field to ensure compliance with tests and specifications and to produce a properly functioning installation. The inspection procedures will include:

- Inspection of delivered materials and equipment
- Review of qualifications and certification of workers
- Checks on the adequacy of the storage facility
- Inspection of the installation with reference to design drawings and specifications
- Field testing of pipes, equipment, welds, and equipment alignment.

9.2 CONSTRUCTION SCHEDULE

The anticipated construction schedule is shown in Figure 9.1. The date of contract award has been assumed to be August 1, 1979. The Phase II work will continue for 12 months. The long-lead items will be ordered immediately following contract award. All procurement will be completed by January 31, 1980.

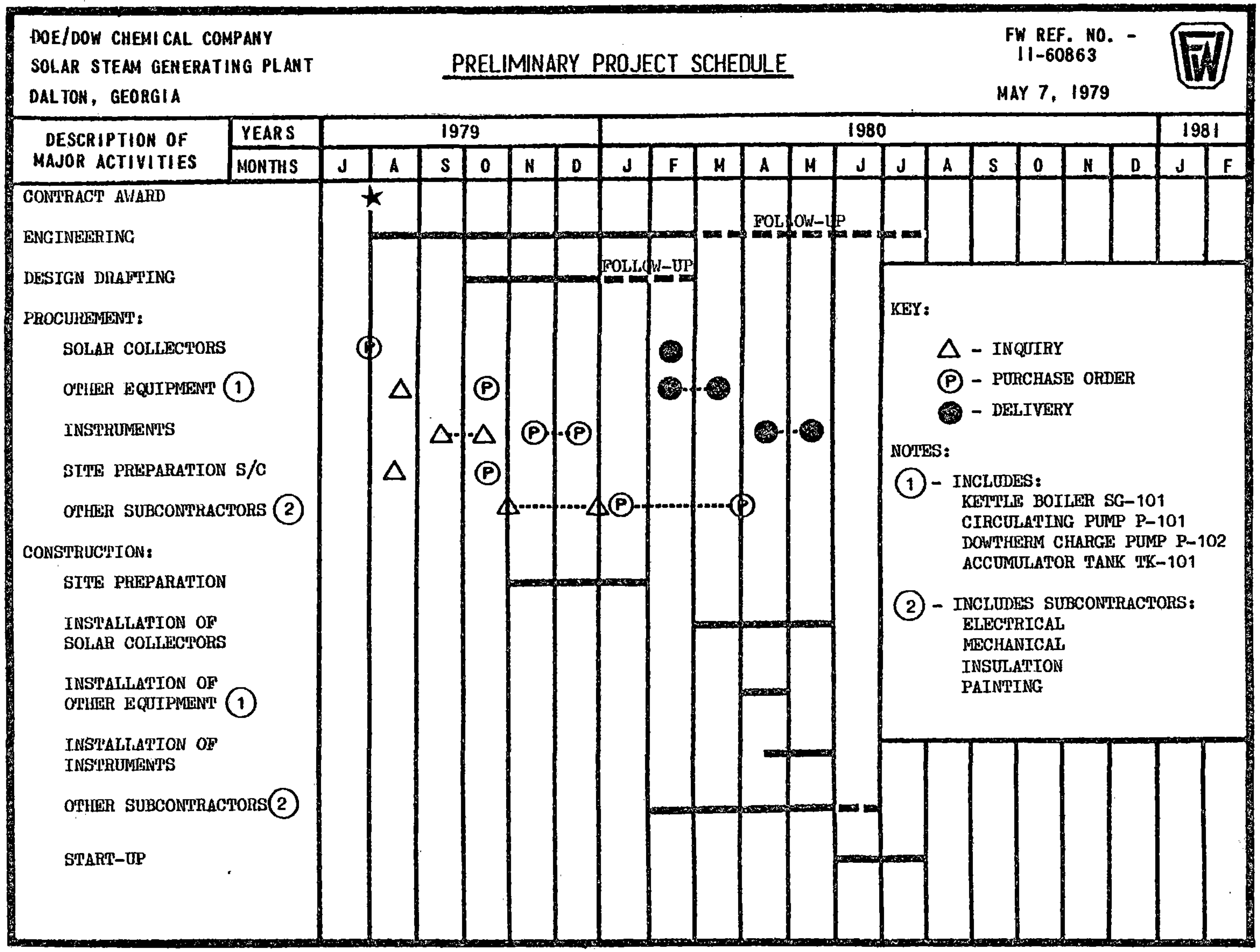

Figure 9.1 Preliminary Project Schedule

REF.: ET-78-C-03-2199
DATE: June 1979

System installation is planned between February 1 through May 31, 1980. By July 31, 1980, the solar process steam plant will be ready for performance testing and evaluation.

9.3 CONSTRUCTION SEQUENCE

1. Order solar collectors.
2. Send out equipment requisitions for bids.
3. Send out site-preparation and foundation subcontract requisitions for bids.
4. Prepare instrumentation details and requisition.
5. Send instrumentation requisition for bids.
6. Order equipment.
7. Select subcontractor for site-preparation and foundation.
8. Update detail drawings for piping and electrical work.
9. Send out subcontract requisitions for electrical and mechanical work, insulation, and painting.
10. Site-preparation begins.
11. Foundations are laid for solar collectors, solar boiler building, equipment, and piping. One month is allowed for foundations to settle.
12. Order instruments.
13. Select subcontractors for mechanical and electrical work, insulation, and painting.
14. Solar collectors and other equipment are delivered to site.
15. Mechanical subcontractor begins installation. Collector, equipment, and piping installation will begin simultaneously. The piping, valves, fittings, control devices, and monitoring equipment will be installed starting within the solar boiler house and extending to connection of the solar collectors.

16. Install instruments.
17. Install electrical wiring and controls.
18. Prepare operating and maintenance manual.
19. Align collectors.
20. Perform operational testing, including leak tests on piping.
21. Install insulation and complete painting.
22. Begin start-up and ensure system balancing and proper functioning of the system, its controls, and the monitoring system.
23. Solar system ready for performance, testing, and evaluation.

SECTION 10
REFERENCES

Section 10

REFERENCES

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9. W. C. Dickinson and H. J. Freeman, "An Economic Methodology for Solar-Assisted Industrial Process Heat Systems: The Effect of Government Incentives," Lawrence Livermore Laboratory, UCRL-52254, June 1977.

10. F. A. Holland, et al., "Introduction to Process Economics," John Wiley and Sons, London, 1974.

11. D. J. Allen, "PRP-FW: A Computer Program for Economic Analysis," Foster Wheeler Development Corporation, EST-78-3, August 1978.

12. C. F. Kutscher, "Data Acquisition and Analysis Guidelines for IPH Demonstration Projects," transmitted from Solar Energy Research Institute to Foster Wheeler Development Corporation, on March 30, 1979.

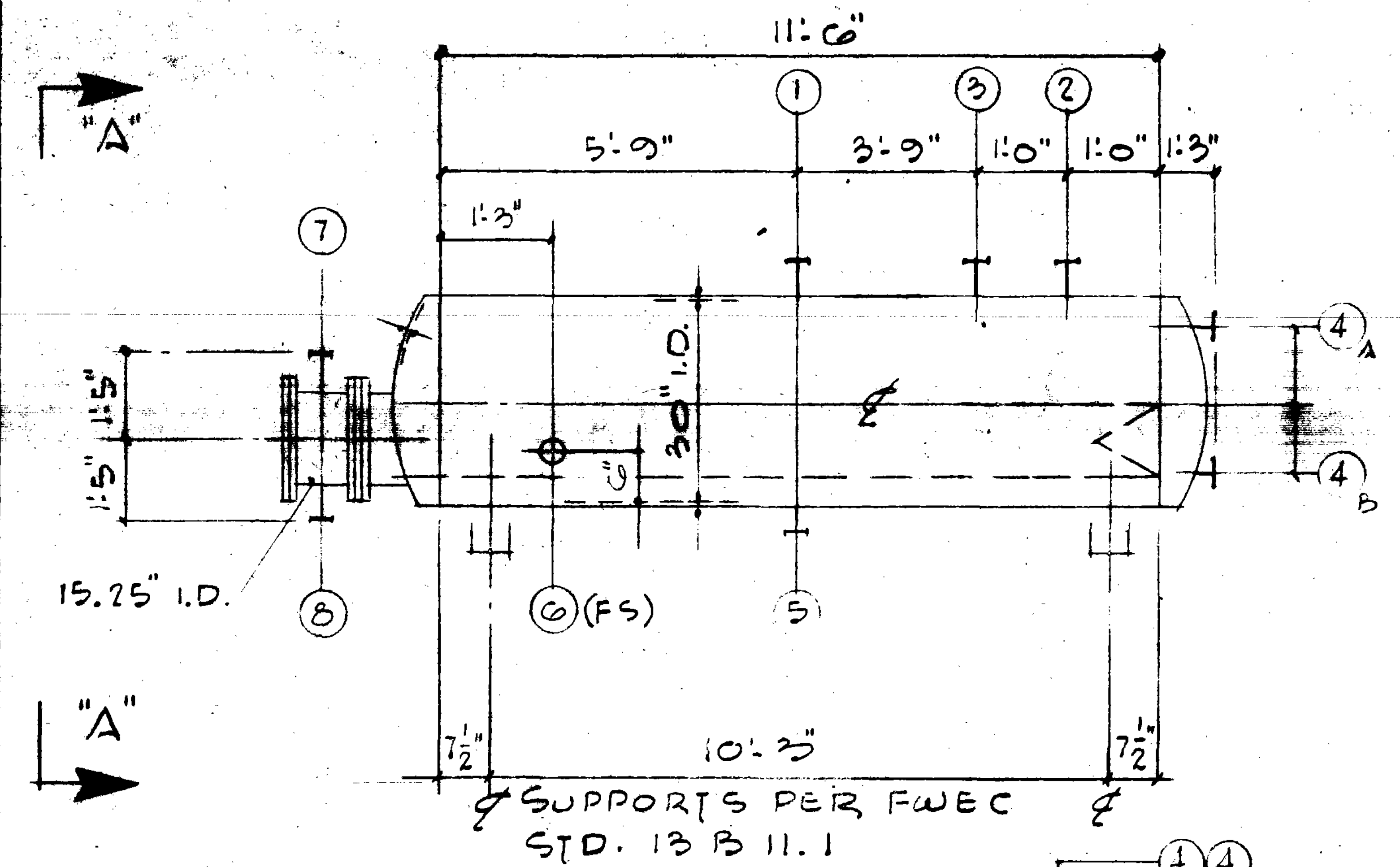
13. "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program," National Bureau of Standards NBSIR 76-1137, August 1976.

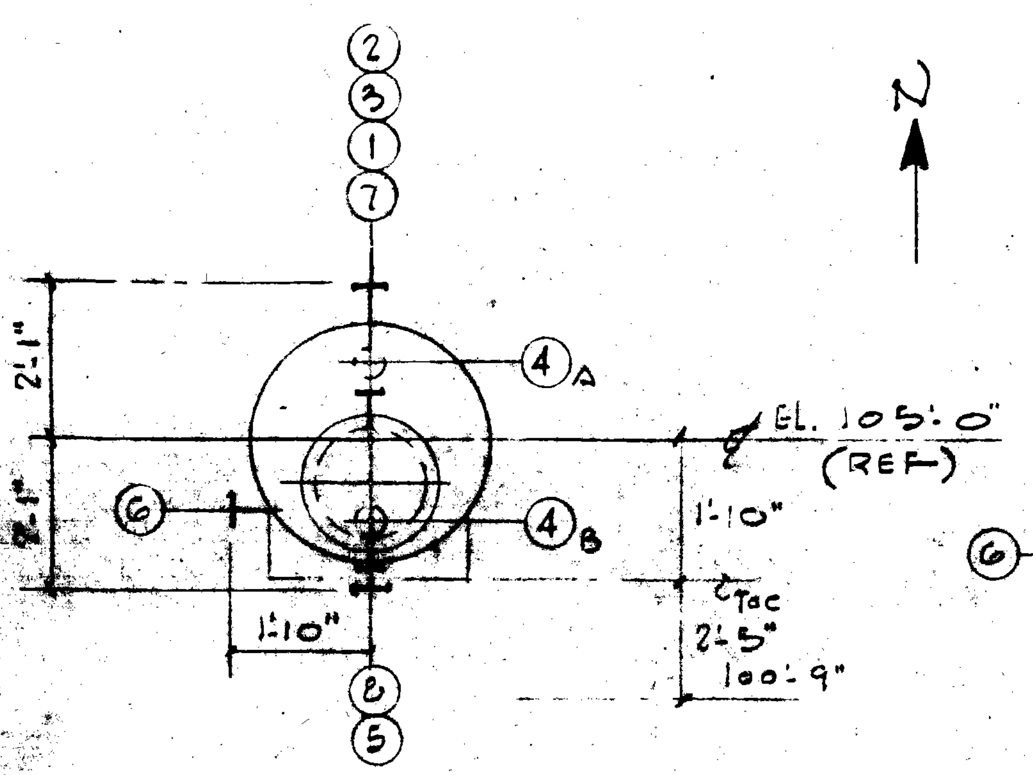
14. "Instrumentation Installation Guidelines," IBM Corporation, SOLAR/0001-77/15, November 1977.

15. H. E. Auld and P. F. Lodde, "Study of Low-Cost Foundation/Anchor Designs for Single-Axis-Tracking Solar Collector Systems," Sandia Laboratories, SAND78-7048, January 1979.

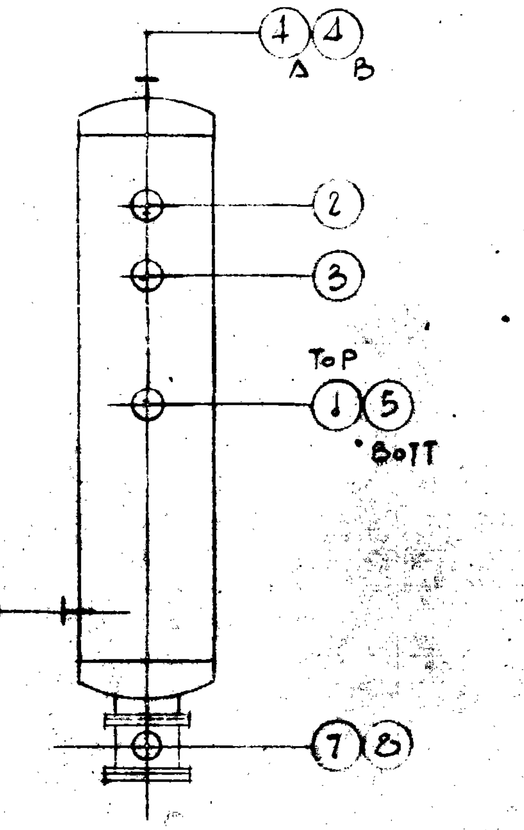
16. "Soil Boring Exploration," Soil Test Report for Dalton, Georgia, solar steam plant site, prepared by Peabody Testing Services, Inc., Chattanooga, Tennessee, March 1979.

APPENDIX A
EQUIPMENT REQUISITIONS





VIEW "A-A"



ORIENTATION PLAN

FORM (135) 59A

RELEASES

DWG. REV.	DATE	ISSUED FOR
	DATE OF ORDER	(A) PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		(B) ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS, FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		(C) VENDOR'S DRAWING RETURNED
		(D) FIELD CONSTRUCTION
		(E)

NOZZLE CHART

CONN. NO.	SIZE	USAS. RATING	SERVICE	NO. REQD
1	3"	150# RF	STEAM OUTLET	1
2			PT	1
3	3/4"		PSV	1
4	1½"	150# RF	LG-LC	2
5	1"	150# RF	DRAIN/BLOWDOWN	1
6	2"	150# RF	BFW INLET	1
7	2"	300# RF	DOWTHERM IN	1
8	2"	300# RF	DOWTHERM OUT	1

PRELIMINARY

REV.	DATE	BY	DESCRIPTION

REVISIONS

VESSEL DATA

1	ITEM NO: SG-101 NO. REQ'D: ONE	
2	SERVICE: KETTLE BOILER	
3		
4	DIAMETER:	
5	TANGENT LENGTH:	
6	OPER. PRESSURE: NORM.:	PSI
7	(ABOVE LIQUID LEVEL) MAX.:	PSI
8	DESIGN PRESSURE:	PSI
9	OPER. LIQUID HOLD-UP PRESS:	PSI
10	OPER. PRESS. DROP THRU VESSEL:	PSI
11	MAX. RELIEVING PRESS. @ TOP HD.:	PSI
12	MAX. OPER. TEMPERATURE:	
13	DESIGN TEMPERATURE:	
14	SPECIFIC GRAVITY (PROCESS FLUID):	
15	CODE: STAMPED:	
16	P.W.H.T.: FOR CODE: FOR PROCESS:	
17	RADIOGRAPHED:	
18	JOINT EFFICIENCY:	
19	CORROSION ALLOWANCE: SHELLS: HEADS:	
20	MAT'L., SHELL:	
21	MAT'L., HEADS:	
22	MAT'L., SUPPORTS:	
23	TYPE OF HEADS:	
24	EXTERNAL BOLTING:	
25	INTERNAL BOLTING:	
26	GASKETS:	
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE	
28	PAINT:	
29	INSULATION:	
30	SHIPMENT:	
31		
32	EMPTY WGT.:	LBS
33	WATER WGT.:	LBS
34	TRAYS WGT.:	LBS
35	INSULATION WGT.:	LBS
36	GUNITE WGT.:	LBS
37	OPER. LIQUID WGT.:	LBS
38		
39		
40		
41	HYDROTEST: SHOP: FIELD:	PSI
42	GAGE LOCATION:	
43	MAX. ALLOW. PRESS. (NEW & COLD):	PSI
44	LIMITED BY:	
45		

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

DRAWN	EDC	CONTRACT NO: 11-60863
CHECKED		REQUISITION NO:
APP'VED		

KETTLE BOILER (SG-101)
U.S. DOE CONTRACT Nº ET-78-C-03-2199
AT DOW CHEMICAL Co.
DALTON GEORGIA

DRAWING NO: 60863.

THIS DWG. WAS:

file 4.1.13

FOSTER WHEELER

Solar Production of Industrial Process Steam Ranging in Temperature From 300°F to 500°F at Dow Chemical Company's Latex Manufacturing Plant in Dalton, Georgia

Dr. Gopal D. Gupta
Head, Systems Engineering and Analysis Section

Engineering Science and Technology Department
Foster Wheeler Development Corporation

For presentation at the
Solar Industrial Process Heat Conference
Oakland, California
October 31 to November 2, 1979

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM AT DOW CHEMICAL COMPANY'S DALTON, GEORGIA, LATEX MANUFACTURING PLANT

G. D. Gupta, Program Manager
Foster Wheeler Development Corporation
Livingston, New Jersey 07039
Phone - 201-533-2189

ABSTRACT

This solar system is designed to generate industrial process steam at 1034 kPa (150 lb/in²) gage for Dow Chemical Company's Latex Manufacturing Plant in Dalton, Georgia. The project, funded by the U.S. Department of Energy, is intended to develop a demonstration unit consisting of 929 m^2 (10,000 ft^2) of solar collector surface area. Dowtherm LF is used as the intermediate heat-transfer fluid which is circulated in the primary loop through Suntec-Hexcel parabolic trough collectors to a boiler and then back to the collectors via a circulating pump. The system is expected to generate 2677 GJ (2536 x 10^6 Btu) annually.

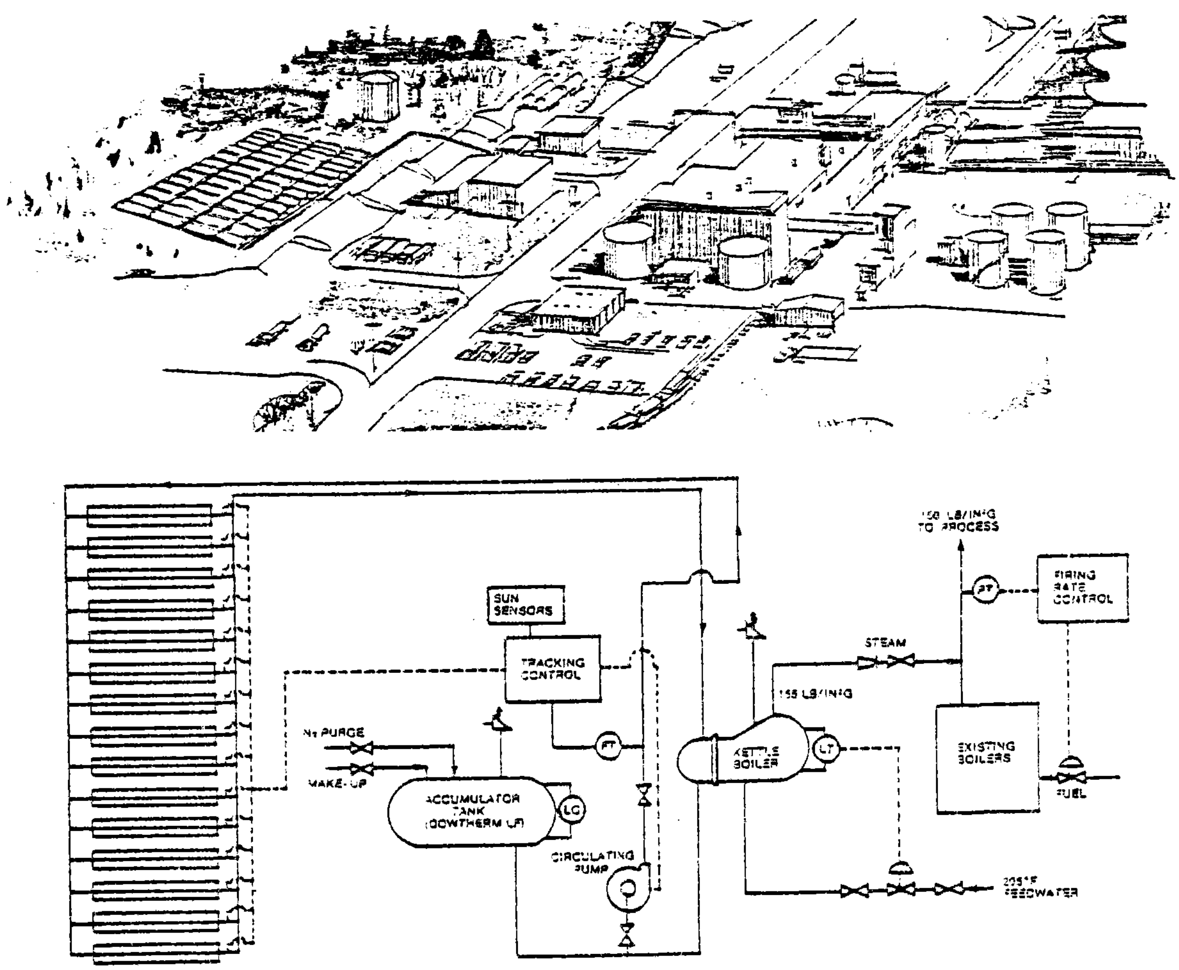


FIGURE 1 ARTIST'S CONCEPTION AND SCHEMATIC OF SOLAR STEAM SYSTEM AT DOW'S DALTON PLANT

INTRODUCTION

Work on this solar industrial process steam project began on September 30, 1978. The primary objective of Phase I (Contract No. ET-78-C-03-2199), was to design a cost-effective solar steam generating system. Other objectives were to predict system performance; conduct a safety evaluation, environmental impact assessment, and economic analysis; and promote the project to industry and the general public.

Phase I work was completed on June 30, 1979, and a final design report was submitted to DOE. Funding for Phase I was $194,000. No major problems were encountered during the design and analysis phase of the project.

Work on Phase II - Fabrication and Installation (Contract No. DE-AC03-78CS32199), began on September 30, 1979. During this phase, the solar steam plant will be fabricated and installed in accordance with the approved design and performance specifications developed under the Phase I contract. Fabrication and installation is expected to be completed by September 30, 1980. Funding for this phase is $801,098.

SYSTEM SUMMARY

The solar process steam system shown in Figure 1 has the following features:

- System Description - The heat-transfer fluid circulates through the collectors and boils water in a kettle boiler to produce steam. An accumulator tank connected to the fluid loop serves both as an expansion tank and dump tank. No overnight freeze protection is required.

- Collector - Suntec-Hexcel parabolic trough collector manufactured by Suntec Systems, Inc.; sun-hour tracking; north-south orientation with 10-deg tilt facing south; 15 rows; 923 m^2 (9930 ft^2) collector area; smooth absorber tube with smooth inner plug.

- Storage - None required.

- Boiler - Kettle type; boiler surface area 23 m^2 (250 ft^2); fitted with pressure relief valve, low-level alarm, and level transmitter to feedwater flow-control valve.

- Circulating Pump - Centrifugal, with single-speed 2.24 kW (3-hp) motor.

- Accumulator Tank - 1.2 m (4 ft) diameter x 2.4 m (8 ft) long; fitted with pressure relief valve, level gage, and low-level alarm; nitrogen purge.

- Heat-Transfer Fluid - Dowtherm LF manufactured by Dow Chemical Company.

- Piping*

- Collector inlet:	50 mm	(2 in.) Sch. 40
- Collector outlet:	50 mm	(2 in.) Sch. 40
- No heat tracing		
- Feedwater piping:	25 mm	(1 in.) Sch. 40
- Steam outlet piping:	76 mm	(3 in.) Sch. 40

- Design Conditions

- Dowtherm LF		
-- Boiler inlet temperature:	265°C	(510°F)
-- Boiler outlet temperature:	190°C	(375°F)
-- Fluid flow rate:	0.22 m^3/min	(57 gal/min)
-- Nitrogen pressure:	207 kPag	(30 lb/in^2g)
- Steam/Water		
-- Feedwater inlet temperature:	95°C	(205°F) 170°F ΔT
-- Steam outlet pressure:	1034 kPag	(150 lb/in^2g)
-- Peak steam flow rate:	680 kg/h	(1500 lb/h)

- Thermal Performance

- Annual thermal collector output:	2998 GJ	(2842 x 10^6 Btu)
- Annual piping thermal losses:	186 GJ	(176 x 10^6 Btu)
- Annual thermal losses from overnight cooling:	137 GJ	(130 x 10^6 Btu)
- Annual parasitic losses in collector tracking motors and automatic control system:	472 GJ	(447 x 10^6 Btu) electric

- Solar Steam Production

- Annual thermal energy available for steam production:	2677 GJ	(2536 x 10^6 Btu)
- Estimated annual solar steam production:	1.1 x 10^6 kg	(2.5 x 10^6 lb)
- Percentage of steam supplied by solar steam system:		
-- At peak solar conditions:		37.5
-- Annual:		7.1

*Restriction orifices are installed on the absorber risers near the inlet manifold.

Canada
Foster Wheeler Limited; St. Catharines, Ontario
England
Foster Wheeler Power Products; London
Mexico
Foster Wheeler Mexicana, S.A.; Mexico City
Saudi Arabia
Foster Wheeler Middle East Services; Riyadh
Spain
Generadores de Vapor Foster Wheeler, S.A.; Barcelona
U.S.A.
Foster Wheeler Boiler Corporation
Foster Wheeler Development Corporation
Foster Wheeler Energy Corporation
Foster Wheeler Solar Development Corporation
Livingston, N. J.

FOSTER WHEELER

PRINTED IN U.S.A.

Gopal Gupta
Bob Goshak Consultant

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM RANGING IN TEMPERATURE FROM 300°F TO 550°F

(PHASE 1)

DOE CONTRACT NO. ET-78-C-03-2199

CONCEPTUAL DESIGN REVIEW
PRESENTATION AT SERI, COLORADO
JANUARY 23, 1979

GOPAL D. GUPTA, PROGRAM MANAGER
FOSTER WHEELER DEVELOPMENT CORPORATION
12 PEACH TREE HILL ROAD
LIVINGSTON, NJ 07039

OBJECTIVES OF PHASE 1

- DESIGN A COST-EFFECTIVE SOLAR STEAM GENERATING SYSTEM, USING STATE-OF-THE-ART TECHNOLOGY, FOR DOW CHEMICAL'S DALTON PLANT
- PREDICT SOLAR STEAM PLANT PERFORMANCE
- CONDUCT A SAFETY EVALUATION AND AN ENVIRONMENTAL IMPACT ASSESSMENT
- CONDUCT AN ECONOMIC ANALYSIS
- PROMOTE THE PROJECT IN INDUSTRY AND GENERAL PUBLIC

DESIGN BOUNDARIES

1. COLLECTOR AREA = 10,000 FT^2

2. DOW CHEMICALS' DALTON, GEORGIA PLANT REQUIREMENTS:

   STEAM AT PRESSURE = 150 PSIG

   TEMPERATURE = 366^0F

   FEEDWATER AVAILABLE AT TEMPERATURE = 205^0F

3. INTERFACE WITH EXISTING FOSSIL-FUEL BOILER SOLAR TRANSIENT SHOULD NOT AFFECT THE PLANT OPERATION.

DESIGN DECISION AREAS

1. TYPE OF COLLECTOR - FLAT PLATE, STATIONARY CONCENTRATING, ONE AXIS TRACKING, FULLY TRACKING, CENTRAL TOWER RECEIVER
2. WITH OR WITHOUT STORAGE
3. USE OF INTERMEDIATE FLUID
4. DIRECT BOILING OR FLASHING
5. OPERATING CONDITIONS
6. CONTROL PARAMETERS/PHILOSOPHY

CONCEPT COMPARISON OF DISTRIBUTED COLLECTOR SYSTEMS

Concept	Concentration Ratio	Maximum Fluid Outlet Temperature (°F)	Concept Features
Segmented reflector in planar array. Fixed receiver. Sun-elevation.	35-40	675	• Stationary receiver • Stationary structure • Large, continuous collector rows • Moving segmented reflector • Low power drive system.
Cylindrical parabola. Receiver mounted to reflector. Sun-elevation or sun-hour tracking.	40-70	675	• Moving receiver • Moving reflector • Long, continuous rows • High performance potential.
Cylindrical parabola. Receiver stationary. Sun-elevation or sun-hour tracking.	30-50	675	• Stationary receiver • Moving reflector • Long, continuous rows • High-performance potential.
Point focus parabola. Moving receiver. Two-axis tracking.	300 or higher	700 or higher	• Moving receiver • Moving reflector • Moderate collector area per driven module • High concentration ratio, high temperature capability • Can operate above 1000°F with liquid metals • Highest performance potential.

Table 2.2 Cost-Effectiveness of Various Collector Systems

Collector System	Relative Thermal Performance at Noon*			Costs ($/ft²)§	Relative Cost	Net Cost Effectiveness¶
	Claimed Efficiency (%)	Demonstrated Efficiency (%)†	Relative Collector Area Needed			
SLATS	61.5	54.5	1.00	28.00	1.00	1.00
HEXCEL	62	61.5	0.89	26.50	0.95	0.84
Solar Kinetics	63	53	1.03	29.00	1.04	1.07
Acurex	53	Not Available	1.03	30.50	1.09	1.12
Del-Jacobs	62	60	0.91	26.50	0.95	0.86

*Based on 392°F Fluid Outlet Temperature.
†Sandia Laboratory Reports, References 1 and 2.
§Costs include collector, freight, foundation, and installation.
¶Based on total relative cost of collector per ft² area for the same thermal output at noon.

COLLECTOR

SLATS - MANUFACTURED BY SUNTEC SYSTEMS

- SMALL BUSINESS
- NONPARABOLIC TROUGH COLLECTOR
- COST-EFFECTIVENESS
- FIXED RECEIVER
- MICROPROCESSOR CONTROLS
- MAINTAINABILITY

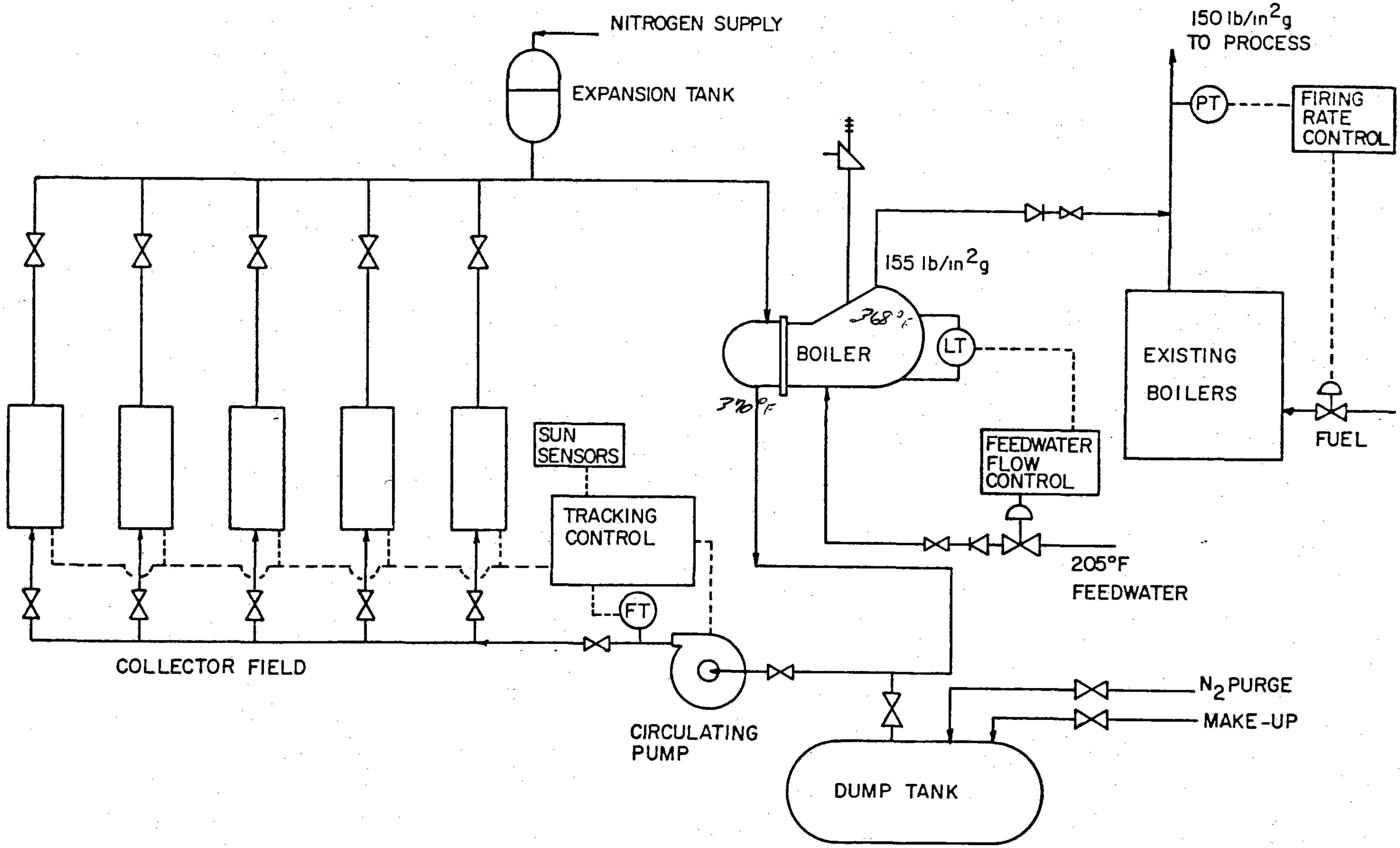
STORAGE VS. NO STORAGE

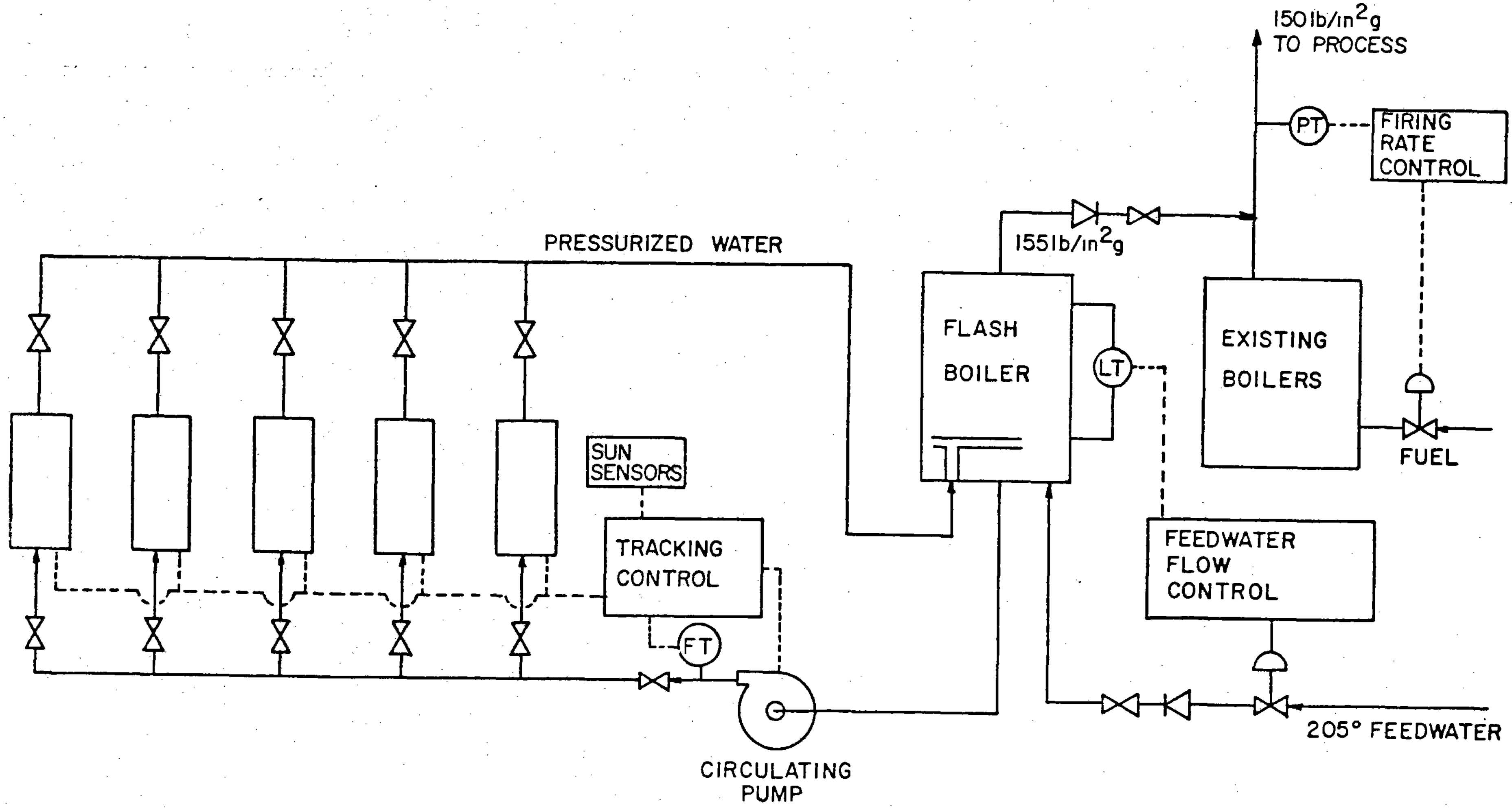
- SOLAR STEAM SYSTEM CAPACITY
  - 1600 LB/H
- PROCESS STEAM DEMAND
  - 4000 LB/H
- INTERFACING EFFECTS AND PROBLEMS
  - INSIGNIFICANT

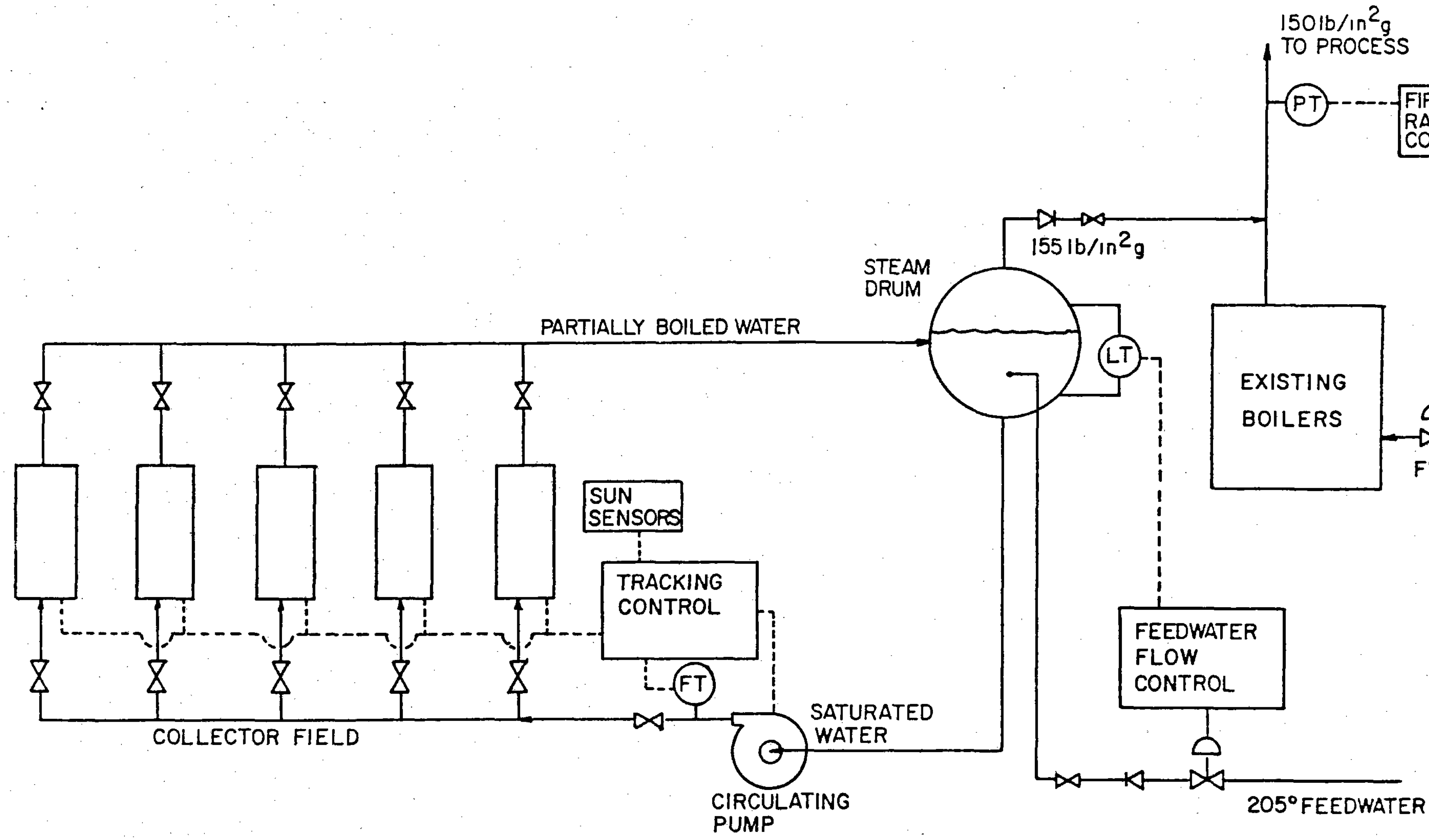
DECISION - NO STORAGE

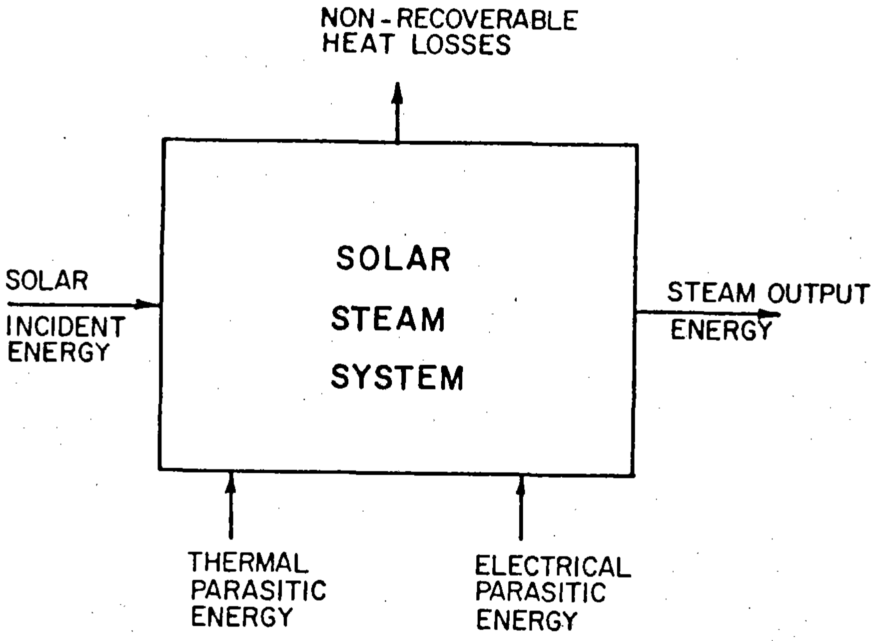
ALTERNATE SYSTEM CONCEPTS

- SYSTEM ALTERNATE 1
  - INTERMEDIATE
  - BOILER FOR STEAM GENERATION
- SYSTEM ALTERNATE 2
  - PRESSURIZED WATER
  - FLASH TANK
- SYSTEM ALTERNATE 3
  - BOILING IN COLLECTOR


NITROGEN SUPPLY
EXPANSION TANK
150 lb/in²g
TO PROCESS
PT
FIRING
RATE
CONTROL
155 lb/in²g
368°F
BOILER
LT
370°F
EXISTING
BOILERS
FUEL
SUN
SENSORS
FEEDWATER
FLOW
CONTROL
TRACKING
CONTROL
205°F
FEEDWATER
FT
COLLECTOR FIELD
N2 PURGE
MAKE-UP
CIRCULATING
PUMP
DUMP TANK


150 lb/in²g
TO PROCESS
PT
FIRING
RATE
CONTROL
PRESSURIZED WATER
155 lb/in²g
FLASH
BOILER
LT
EXISTING
BOILERS
FUEL
SUN
SENSORS
TRACKING
CONTROL
FT
FEEDWATER
FLOW
CONTROL
205° FEEDWATER
CIRCULATING
PUMP

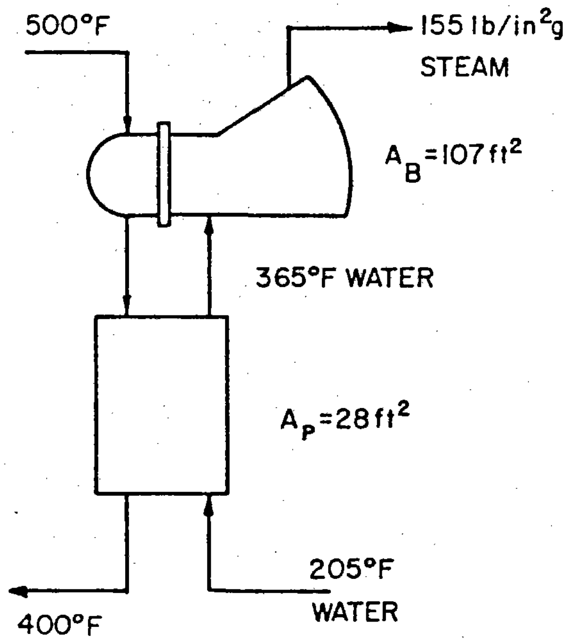

150 lb/in²g
TO PROCESS
PT
FIRING
RATE
CONTROL
155 lb/in²g
STEAM
DRUM
PARTIALLY BOILED WATER
LT
EXISTING
BOILERS
FUEL
SUN
SENSORS
TRACKING
CONTROL
FT
FEEDWATER
FLOW
CONTROL
SATURATED
WATER
COLLECTOR FIELD
CIRCULATING
PUMP
205° FEEDWATER



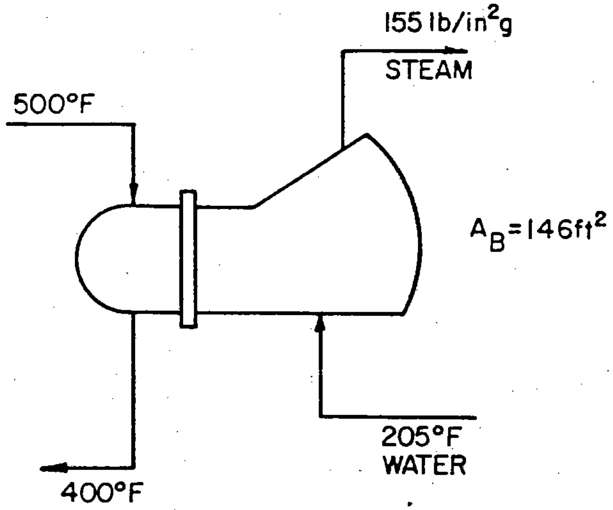
$$\text{COST-EFFECTIVENESS} = \frac{\text{TOTAL INSTALLED COST}}{\text{NET ANNUAL ENERGY OUTPUT}}$$

NET ANNUAL ENERGY OUTPUT = STEAM OUTPUT ENERGY − (THERMAL + 3 x ELECTRICAL) PARASITIC ENERGY

PREHEATER



COST = $3645



COST = $ 3270

SELECTED - NO PREHEATER OPTION

HEAT TRANSPORT FLUID

- INITIAL CHARGE OF FLUID
- REPLACING THERMALLY DECOMPOSED FLUID
- FREEZE PROTECTION
- PUMPING POWER
- SAFETY CONSIDERATIONS

Table 3.1 Comparison of Heat-Transport Fluids

Fluid	Manufacturer	Maximum Thermal Stability Temperature* (°F)	Minimum Pumping Temperature (°F)	Specific Heat† (Btu/lb°F)	Viscosity† (ft^2/h)	Density† (lb/ft^3)	Cost ($/gal)
Dowtherm G	Dow Chemical	640	20	0.478	0.0261	60.00	8.50
Dowtherm LF	Dow Chemical	530	-25	0.520	0.0166	55.54	8.86
Dowtherm J	Dow Chemical	540	-100	0.595	0.0450	44.36	6.00
Caloria HT-43	EXXON	500	30	0.600	0.0577	45.60	1.25
Therminol 55	Monsanto	500	25	0.620	0.0455	47.87	2.75
Therminol 60	Monsanto	525	-35	0.543	0.0238	53.30	6.90
Therminol 66	Monsanto	560	40	0.530	0.0350	53.70	8.48

*For a 30-year lifetime.
†At 400°F.

HEAT TRACING VS. FLUID COST

ESTIMATED COST OF HEAT TRACING = $2,200

AS COMPARED TO CALORIA HT-43, ADDITIONAL COST OF USING:

DOWTHERM LF	=	$2,660
DOWTHERM J	=	$1,660
THERMINOL 60	=	$1,980

SAFETY RELATED HEAT TRANSFER FLUID PROPERTIES

FLUID	FLASH POINT (^oF)	AUTOIGNITION TEMPERATURE (^oF)	TOXICITY		
			SKIN CONTACT	INGESTION	8H THRESHOLD LIMIT VALUE
DOWTHERM G	305	1030	MILD IRRITANT	LOW	N.A.
DOWTHERM LF	260	1020	"	"	~1 (BASED ON SMELL)
DOWTHERM J	145	806	"	"	10
CALORIA HT-43	425	---	"	"	N.A.
THERMINOL 55	350	675	"	"	N.A.
THERMINOL 60	310	835	NONE	"	N.A.
THERMINOL 66	354	705	MILD IRRITANT	"	N.A.

N.A. - NOT AVAILABLE

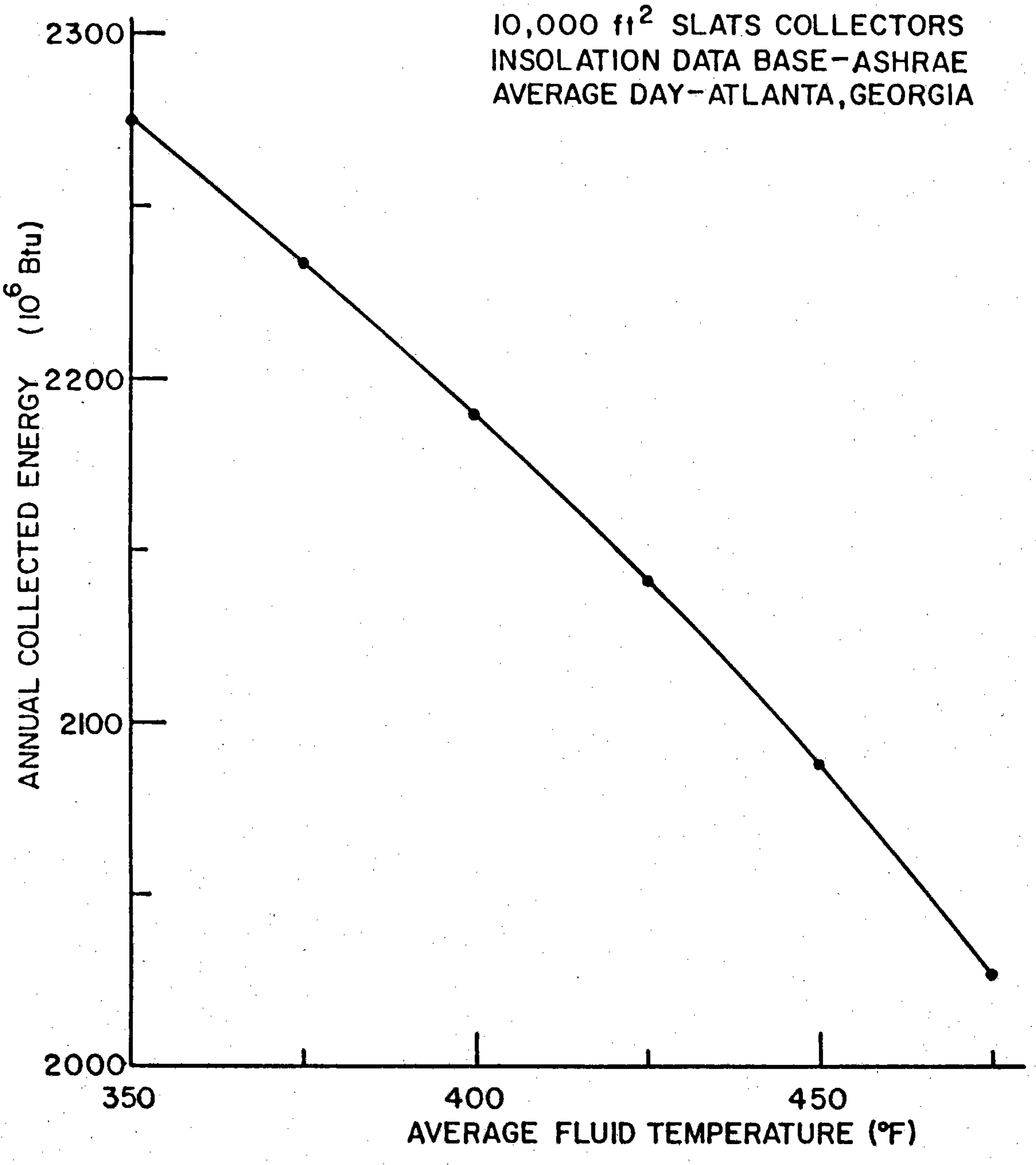


Figure 3.2 Annual Collected Energy Variation With Average Fluid Temperature Through the Collector

Table 3.2 Fluid Temperature Effect on Boiler Cost, Pump Cost, and Collector Efficiency

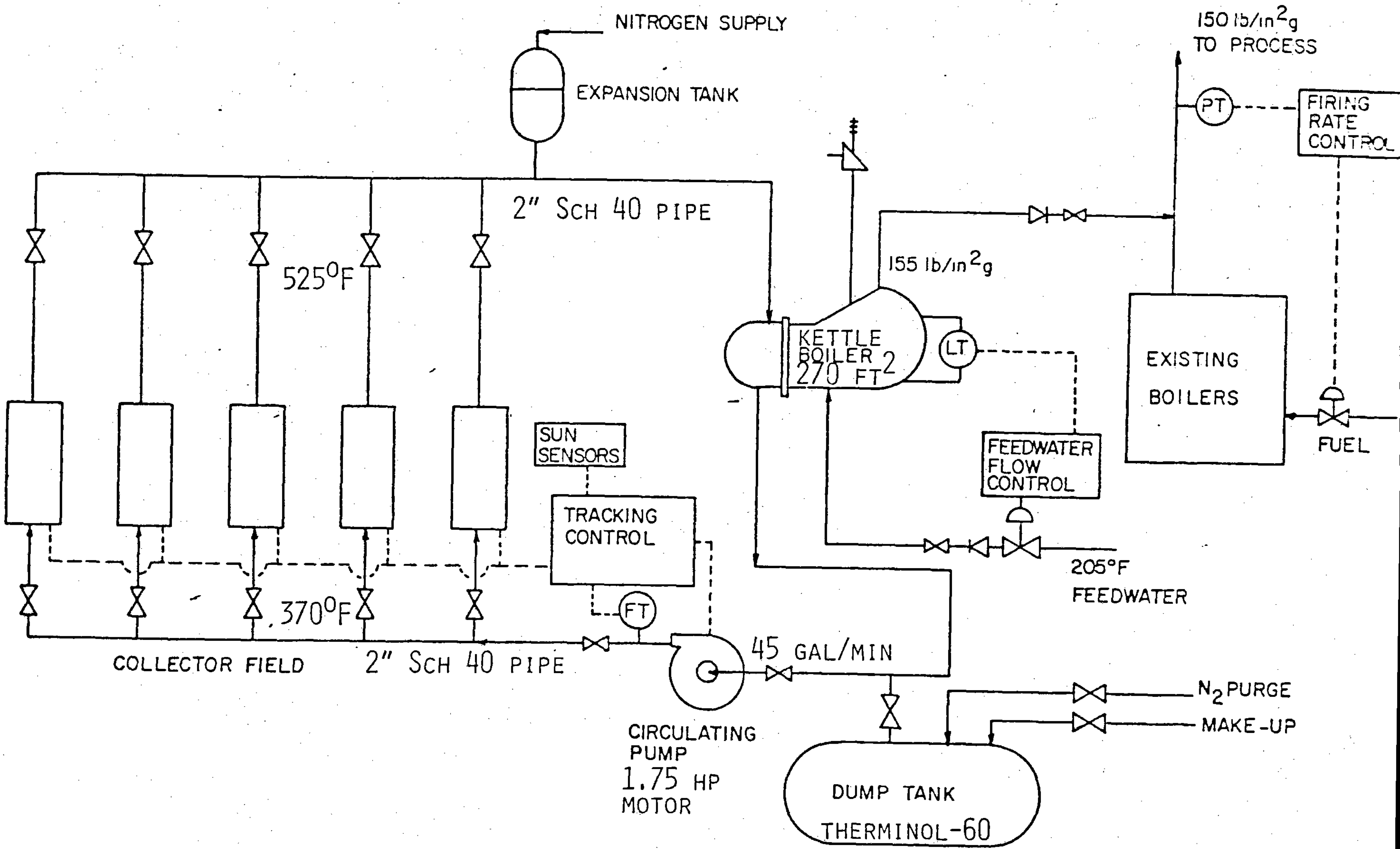
Boiler Inlet Temperature (°F)	Boiler Outlet Temperature (°F)	Cost Difference From Base ($)			Annual Energy Collected (10^6 Btu)	Relative Pump Power	Unit Cost of Net Annual Thermal Energy Collected ($/$10^6$ Btu)
		Boiler	Pump	Net (Pump + Boiler)			
450	380	+2050	+650	+2700	2162	3.04	165.6
	400	+800	+1550	+2350	2140	8.27	245.6
475	380	+1410	+50	+1460	2135	1.20	150.5
	400	+300	+600	+900	2115	2.40	162.6
	420	-140	+1300	+1160	2093	6.02	210.5
500	380	+970	-450	+520	2110	0.58	146.9
	400	Base	Base	Base	2087	1.00	151.7
	420	-460	+450	-10	2064	1.93	162.0
	440	-770	+950	+180	2038	4.52	194.8
525	380	+590	-750	-160	2082	0.33	146.5
	400	-260	-500	-760	2058	0.51	149.5
	420	-670	-250	-920	2032	0.85	154.2
	440	-980	+300	-680	2008	1.58	163.2
	460	-1190	+750	-440	1984	3.49	187.2

Table 3.3 Cost-Effectiveness vs. Boiler Outlet Temperature (Boiler Inlet Temperature = 525°F)

Boiler Outlet Temperature (°F)	Cost Difference From Base ($)			Annual Energy Collected (10^6 Btu)	Relative Pump Power	Unit Cost of Net Annual Thermal Energy Collected ($/$10^6$ Btu)
	Boiler	Pump	Net (Pump + Boiler)			
400	-260	-500	-260	2058	0.51	149.5
380	+590	-750	-160	2082	0.33	146.5
375	+885	-775	+110	2087	0.30	146.1
370	+1970	-800	+1170	2093	0.27	145.9
369	+2590	-800	+1790	2094	0.27	146.2

Table 3.4 Cost-Effectiveness vs. Pipe Size

Nominal Pipe Diameter (in.)	Fluid Velocity (ft/s)	Cost Difference From Base ($)			Relative Pump Power	Unit Cost of Net Thermal Energy Produced ($/$10^6$ Btu)
		Installed Insulated Piping	Pump	Net (Pump + Piping)		
1	16.7	-1650	+1550	-250	11.73	170.21
1-1/2	7.1	-800	+450	-450	1.92	146.86
2	4.3	Base	Base	Base	1	145.35
2-1/2	3.0	+1300	-125	+1075	0.75	145.47
3	2.0	+2400	-200	+2050	0.64	145.77



ANNUAL THERMAL ENERGY PRODUCED = 2093×10^6 BTU

ANNUAL PUMP ENERGY CONSUMED = 10.7×10^6 BTU ELECTRIC.

FREEZE PROTECTION

- OVERNIGHT DRAINING; ELECTRIC HEAT TRACING; PREHEATING THE RECEIVER BEFORE START-UP
  - CONSUME 1,350 KWH/HR (4.6 MMBTU/YR)
  - CAPITAL COST $2,200

- HEATING AND RECIRCULATING WATER
  - CONSUME 25.9 MMBTU/YR
  - CAPITAL COST $300

SELECTED SECOND METHOD: - FLOW RATE 1.5 GAL/MIN
- USE EXISTING FEEDWATER PUMP

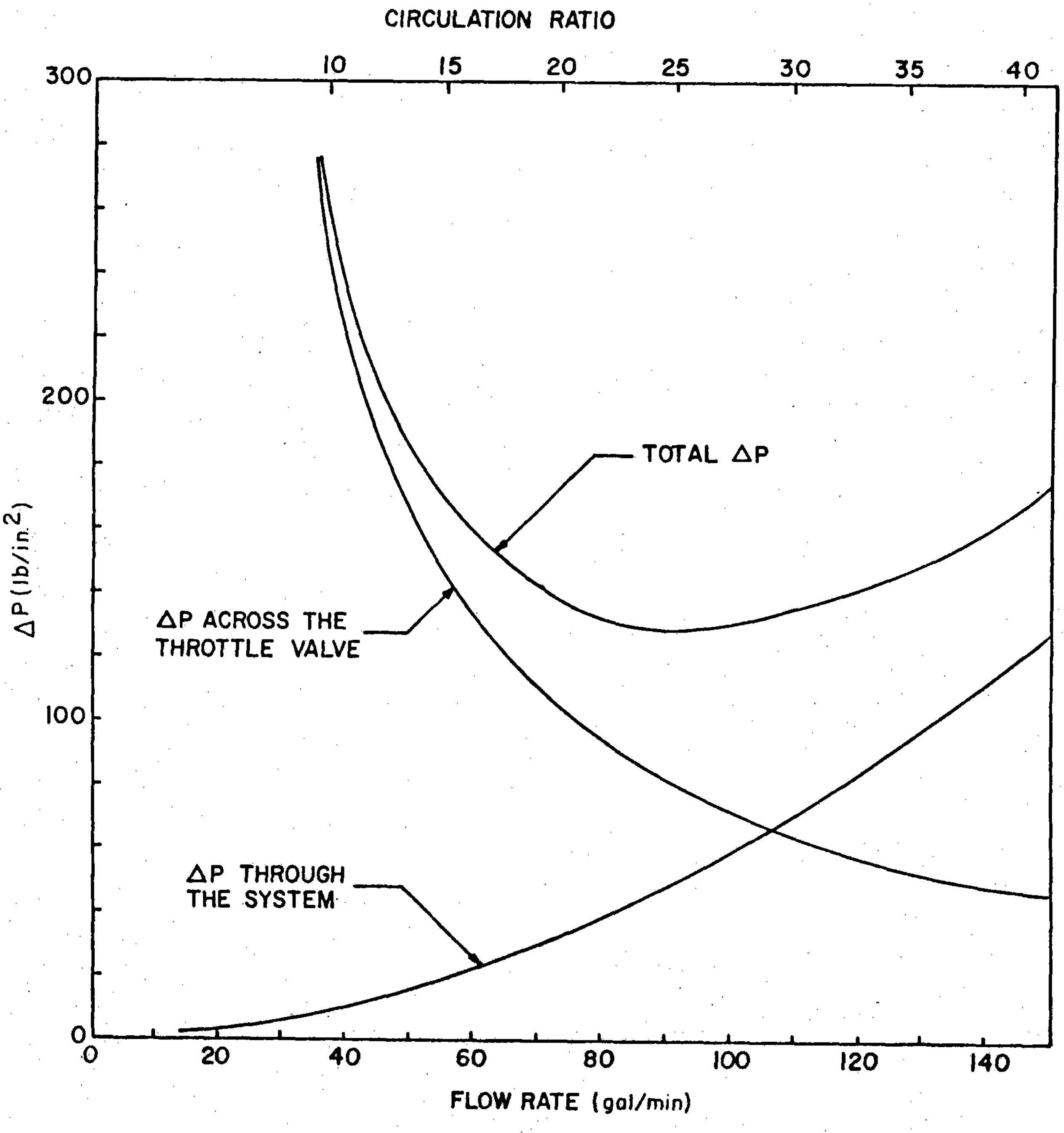


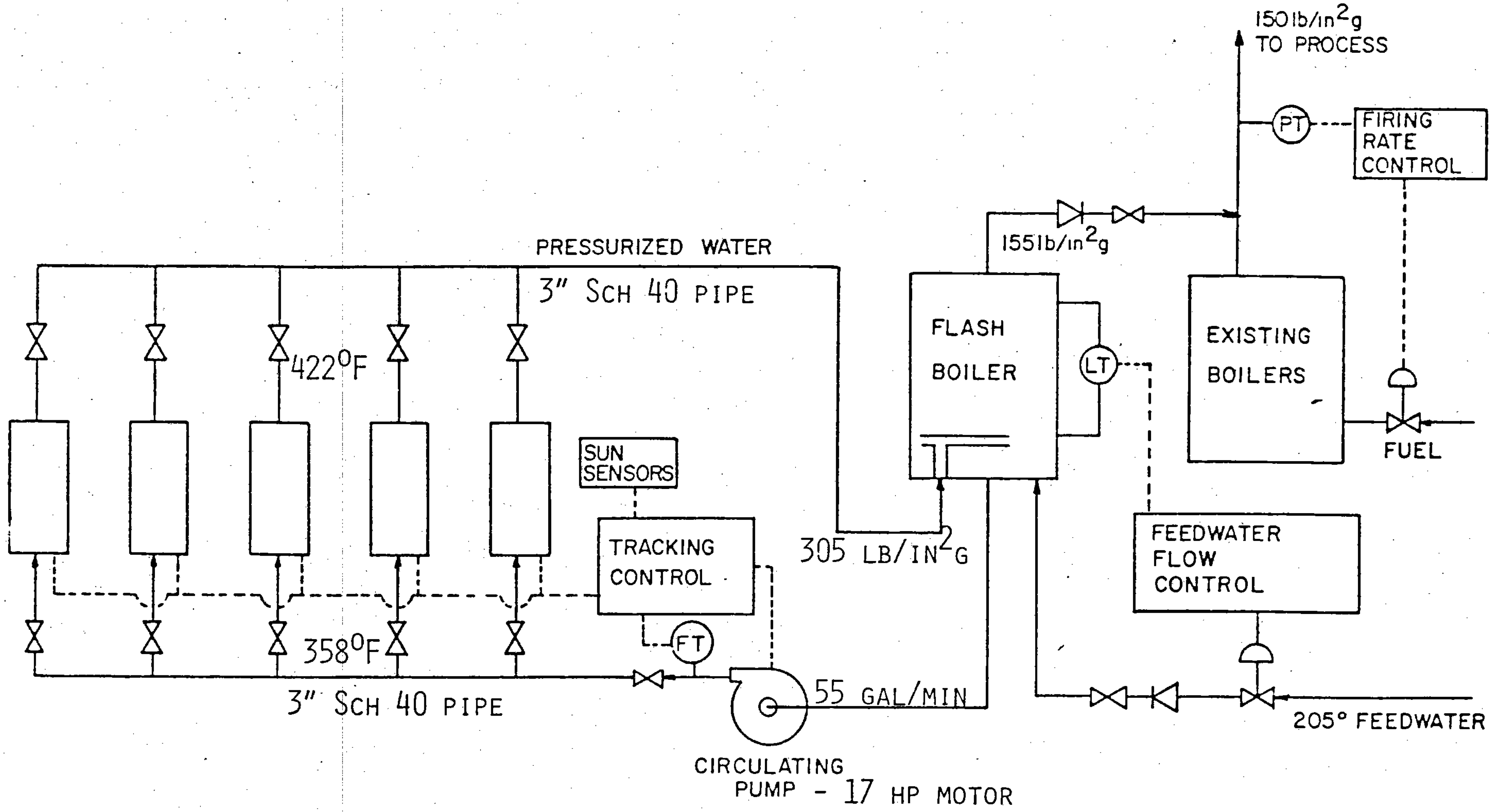
Figure 3.4 Pressure Drop vs. Circulation Ratio (Flow Rate)

Table 3.5 Cost Effectiveness of Various Circulation Ratios

Circulation Ratio	Flow Rate (gal/min)	Collector Performance: Average Temperature (°F)	Collector Performance: Annual Collected Energy (10^6 Btu)	Circulating Pump: Relative Pump Power	Circulating Pump: Pump Cost Difference ($)	Cost per Net Thermal Energy Generated Annually ($/$10^6$ Btu)
10	37	400	2189	0.80	-150	161.8
15	55	390	2206	0.78	-200	159.6
20	73	384	2216	0.85	-100	161.3
25	92	381	2223	1.0	Base	166.3
30	110	379	2226	1.25	+200	176.4

Table 3.6 Cost-Effectiveness vs. Pipe Size

Nominal Pipe Diameter (in.)	Fluid Velocity (ft/s)	Cost Difference From Base ($)			Relative Pump Power	Unit Cost of Net Thermal Energy Produced ($/$10^6$ Btu)
		Installed Insulated Piping	Pump	Net		
1	20.42	-1600	+835	- 765	2.4	210.55
1-1/2	8.66	- 800	+ 85	- 715	1.17	164.13
2	5.26	Base	Base	Base	1.0	159.66
2-1/2	3.68	+1300	- 85	+1215	0.95	158.92
3	2.41	+2400	-465	+2235	0.92	158.64
3-1/2	1.78	+4300	-240	+4060	0.91	159.32
4	1.38	+6050	-290	+5760	0.907	160.13



ANNUAL THERMAL ENERGY PRODUCED = 2206×10^6 BTU

ANNUAL PUMP ENERGY CONSUMED = 104×10^6 BTU ELECTRIC

FREEZE PROTECTION ENERGY CONSUMED = 25.9×10^6 BTU

ADVANTAGES OVER SYSTEM ALTERNATES 1 AND 2

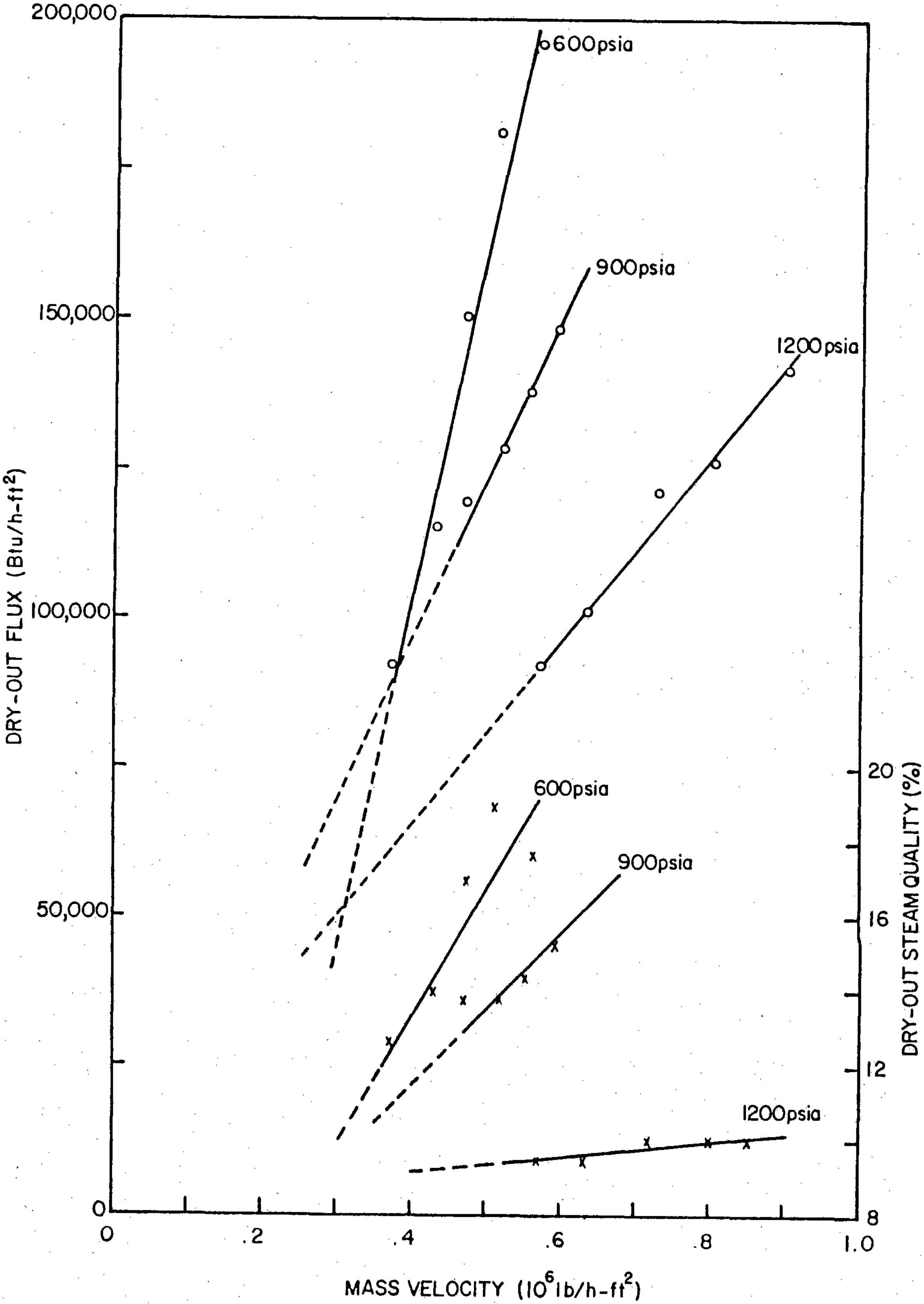
- ELIMINATES MANY COMPONENTS USED IN SYSTEM 1.
- COLLECTOR AVERAGE TEMPERATURE IS THE LOWEST. HIGHEST COLLECTOR EFFICIENCY.
- PUMP SIZE MUCH SMALLER THAN SYSTEM 2. SIMILAR TO SYSTEM 1.

DISADVANTAGES

- LARGER PIPE SIZE
- FREEZE PROTECTION
- NEED CONSIDERATION OF:
  - DRY-OUT
  - CORROSION
  - FLOW IMBALANCE/INSTABILITY

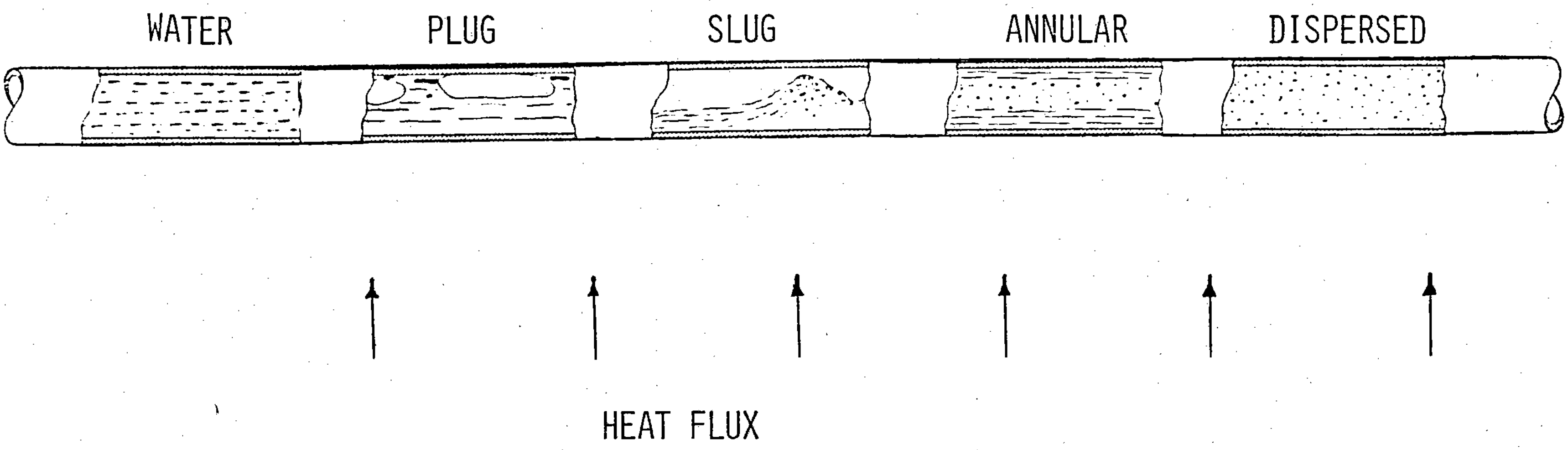
DESIGN DECISIONS

- CIRCULATION RATIO
- NUMBER OF PARALLEL COLLECTOR ROWS
- RECEIVER CONFIGURATION
- PIPING SIZES



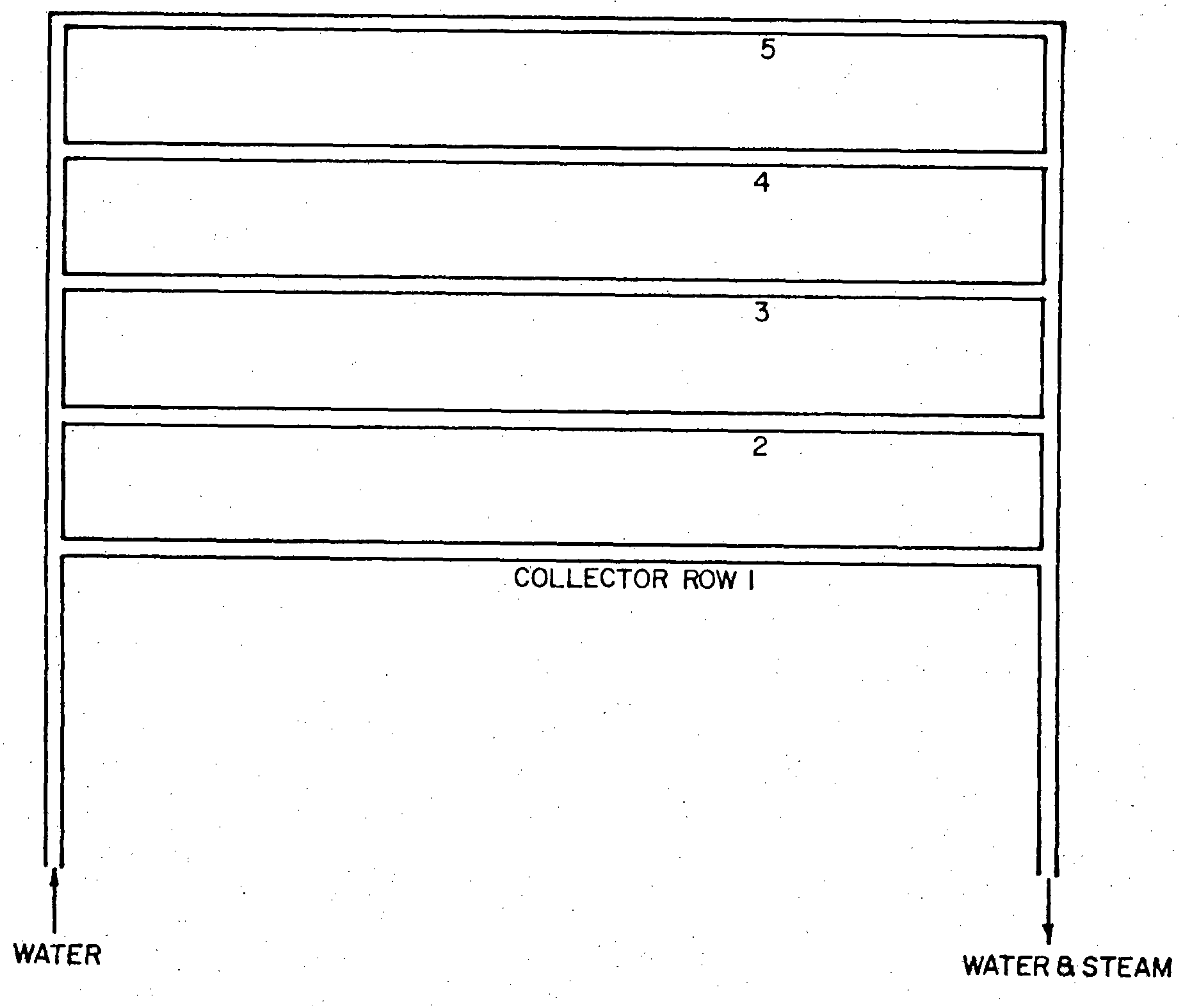
RESULTS OF PURNELL & NOVAK

CORROSION



FLOW INSTABILITY

$\Delta P = f$ (FLOW RATE, STEAM QUALITY)



CIRCULATION RATIO

CIRCULATION RATIO	FLOW RATE (GPM)	AVERAGE TEMPERATURE THROUGH COLLECTOR (°F)	STEAM QUALITY AT COLLECTOR OUTLET (%)
10	37	365	9.9
20	73	366	4.8
25	92	367	3.6
30	110	368	2.8
50	185	370	1.7

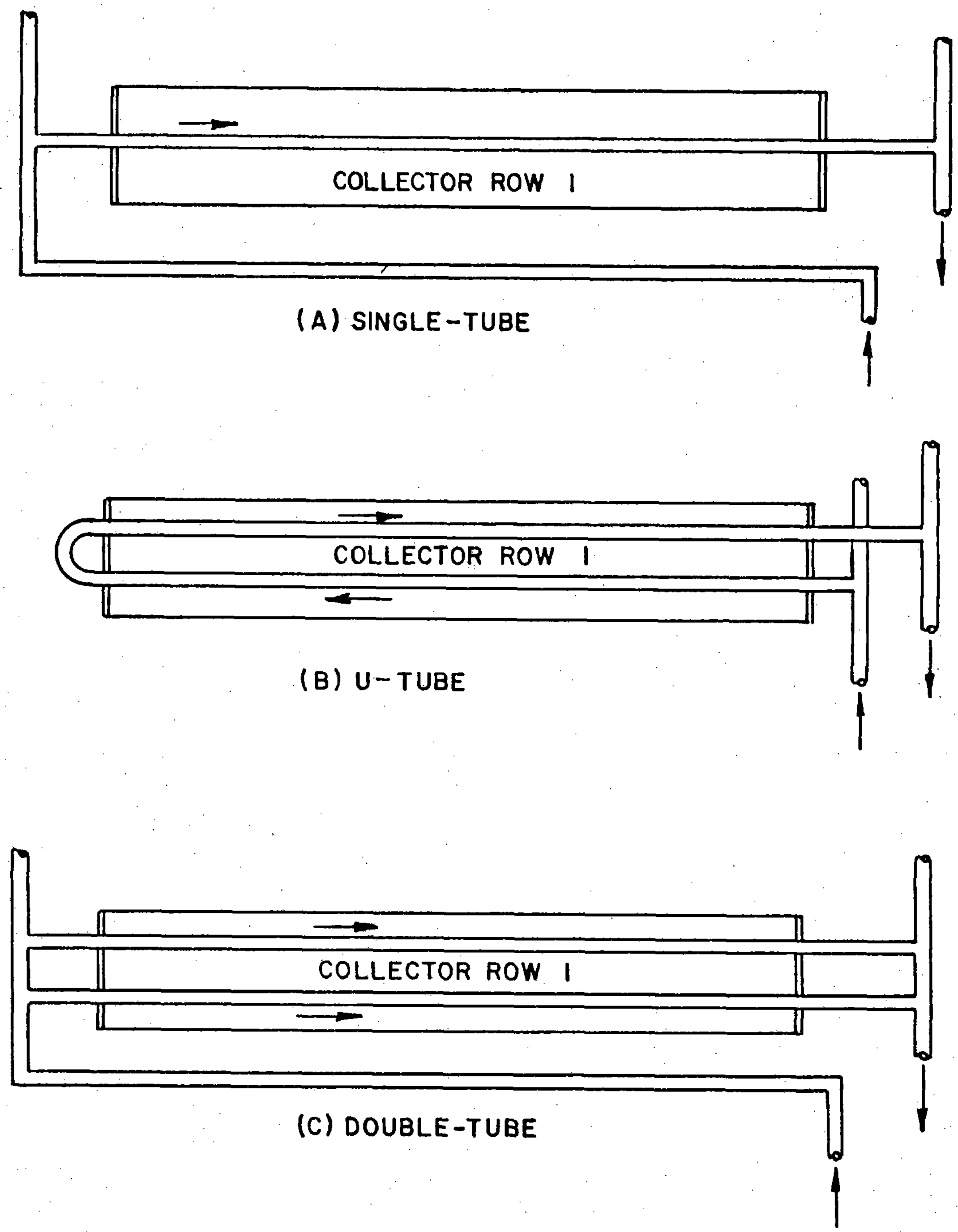
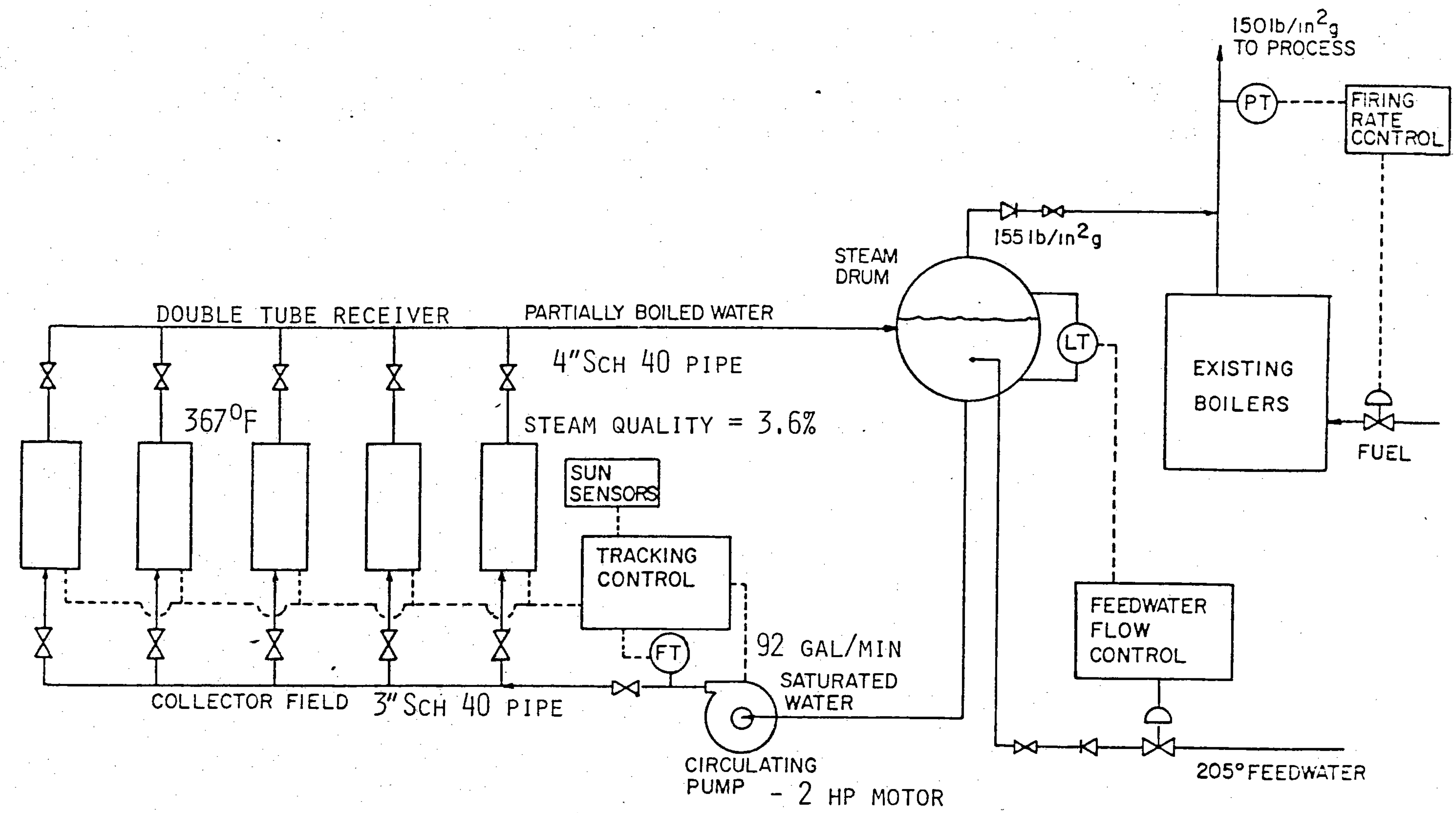


Figure 3.6 Alternate Receiver Configurations

ALTERNATE RECEIVER TUBE CONFIGURATIONS

RECEIVER TUBE CONFIGURATION	PIPING AND RECEIVER TUBE COST DIFFERENCE FROM BASE ($)	RELATIVE PUMP POWER	UNIT COST PER NET THERMAL ENERGY PRODUCED ($/$10^6$ BTU)
SINGLE-TUBE	BASE	1.0	141.76
U-TUBE	-600	1.21	143.40
DOUBLE TUBE	+1800	0.72	140.24



ANNUAL THERMAL ENERGY PRODUCED = 2247×10^6 BTU

ANNUAL PUMP ENERGY CONSUMED = 12.2×10^6 BTU ELECTRIC

FREEZE PROTECTION ENERGY CONSUMED = 25.9×10^6 BTU

Table 3.12 Comparison of the Three Alternate System Concepts

Concept	Cost Difference From Reference of $300,000 ($)	Annual Energy Produced (10^6 Btu)	Parasitic Power* (10^6 Btu Thermal)	Cost Effectiveness† ($/$10^6$ Btu)
System Alternate 1 (Oil)	+40,400	2093	32.1	165.17
System Alternate 2 (Flash Tank)	+31,000	2206	337.9	177.19
System Alternate 3 (Collector Boiling)	+35,600	2247	62.5	153.63

*Includes operation and freeze protection.
†Unit cost of net annual thermal energy produced.

DESIGN PARAMETERS TO AVOID PROBLEMS

DRY-OUT

- MASS VELOCITY ABOVE 400,000 LB/H-FT^2
- STEAM QUALITY BELOW 5%
- ELIMINATE HEAT FLUX ON TOP OF THE TUBE

CORROSION

- AVOID STRATIFIED OR DISPERSED FLOW REGIME
- MORNING, EVENING, AND OVERNIGHT CONDITIONS HELP WITHOUT ANY DEPOSITS

FLOW INSTABILITY

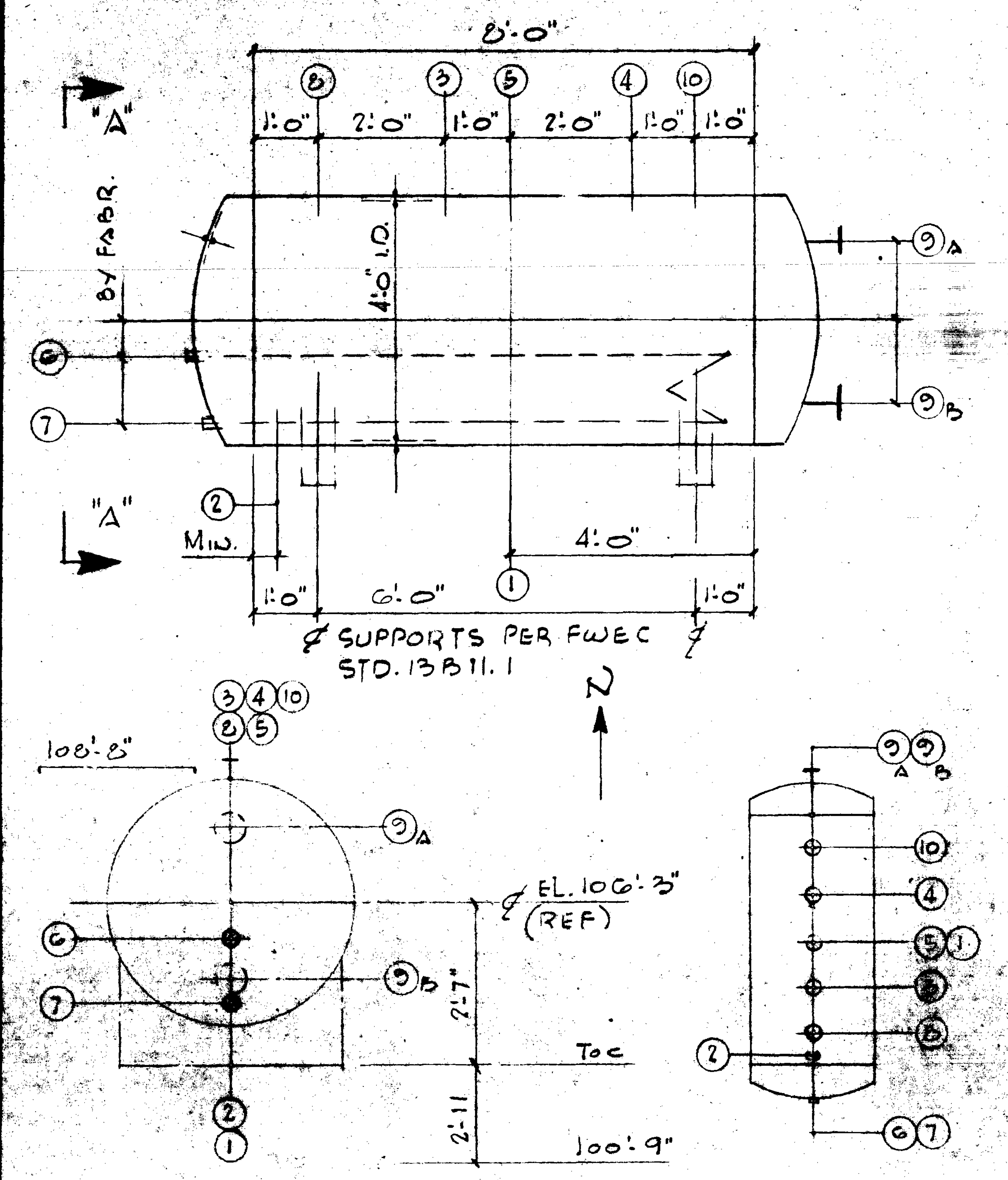
- ADEQUATE CONTROL SYSTEM
- PROPER OPERATING PROCEDURE

ENVIRONMENT IMPACT ASSESSMENT

- HISTORICAL
- TOPOGRAPHY AND SOILS
- HYDROLOGY AND WATER QUALITY
- ODOR
- AIR QUALITY
- NOISE
- VISUAL
- COMMUNITY SERVICES AND FACILITIES
- WILDLIFE

PRELIMINARY SAFETY ANALYSIS

- RELEASE OF ORGANIC FLUID TO ATMOSPHERE
- OVERPRESSURIZING THE SYSTEM
- OVERHEATING THE COLLECTORS
- CORROSION
- BOILER HAZARDS



VIEW "A-A"

ORIENTATION PLAN

RELEASES

DWG. REV.	DATE	ISSUED FOR
	DATE OF ORDER	(A) PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		(B) ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS. FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		(C) VENDOR'S DRAWING RETURNED
		(D) FIELD CONSTRUCTION
		(E)

NOZZLE CHART

CONN. NO.	SIZE	USAS. RATING	SERVICE	NO. REQ'D
1	2"	300#RF	SYSTEM IN/OUT	1
2	1"	6000#CPLG	FILL - DRAIN	1
3	1"	6000#CPLG	VENT	1
4	1"	6000#CPLG	INERT GAS IN	1
5	3/4"	6000#CPLG	PI	1
6	1"	6000#CPLG	STEAM	1
7	1"	6000#CPLG	COND	1
8	1½"	150#RF	PSV	1
9	2"	150#RF	GG	2
10	2"	300#RF	PUMP DOWN	1

PRELIMINARY

REV.	DATE	BY	DESCRIPTION

REVISIONS

VESSEL DATA

1	ITEM NO: TK-101 NO. REQ'D: ONE	
2	SERVICE: DOWTHERM STORAGE	
3	TANK	
4	DIAMETER: 4'-0" I.D.	
5	TANGENT LENGTH: 8'-0"	
6	OPER. PRESSURE: NORM.: 30	PSIG
7	(ABOVE LIQUID LEVEL) MAX.: 40	PSI
8	DESIGN PRESSURE: 50	PSI
9	OPER. LIQUID HOLD-UP PRESS:	PSI
10	OPER. PRESS. DROP THRU VESSEL:	PSI
11	MAX. RELIEVING PRESS. @ TOP HD.: 50	PSI
12	MAX. OPER. TEMPERATURE: 550	
13	DESIGN TEMPERATURE: 600°	
14	SPECIFIC GRAVITY (PROCESS FLUID): .9	
15	CODE: ASME VIII STAMPED: YES	
16	P.W.H.T.: FOR CODE: FOR PROCESS:	
17	RADIOGRAPHED:	
18	JOINT EFFICIENCY:	
19	CORROSION ALLOWANCE: SHELLS: HEADS:	
20	MATL., SHELL: SA 283 GR. C	
21	MATL., HEADS: SA 283 GR. C	
22	MATL., SUPPORTS:	
23	TYPE OF HEADS: ASME	
24	EXTERNAL BOLTING:	
25	INTERNAL BOLTING:	
26	GASKETS:	
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE	
28	PAINT:	
29	INSULATION: YES	
30	SHIPMENT:	
31		
32	EMPTY WGT.:	LBS
33	WATER WGT.:	LBS
34	TRAYS WGT.:	LBS
35	INSULATION WGT.:	LBS
36	GUNITE WGT.:	LBS
37	OPER. LIQUID WGT.:	LBS
38		
39		
40		
41	HYDROTEST: SHOP: FIELD:	PSI
42	GAGE LOCATION:	
43	MAX. ALLOW. PRESS. (NEW & COLD):	PSI
44	LIMITED BY:	
45		

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

DRAWN	FDC	CONTRACT NO: 11-60863
CHECKED		
APP'VED		REQUISITION NO:

ACCUMULATOR TANK (TK-101)
U.S. DOE CONTRACT No ET-78-C-03-2199
AT DOW CHEMICAL Co.
DALTON GEORGIA

DRAWING NO: 60863.

THIS DWG. WAS:

FORM (135) 50A

FOSTER WHEELER DEVELOPMENT CORPORATION

REF.: ET-78-C-03-2199
DATE: June 1979

REQUISITION

FOSTER WHEELER ENERGY CORPORATION

PAGE 1 OF 1

CLIENT U.S. DEPT. OF ENERGY	CONTRACT NO. 11-60863	REQUISITION NO. 60863-1311 A	DATE 5-11-79
SITE DOW CHEMICAL CO. DALTON, GA	ITEM NO. P-101	C1	C4
MATERIAL CENTRIFUGAL PUMP	NO. REQ'D. ONE	C2	C5
SERVICE CIRCULATING PUMP		C3	C6
MFR	MODEL SIZE		

No.		
1	OPERATING CONDITIONS, EACH PUMP	PERFORMANCE
2	LIQUID DOWTHERM — U. S. GPM RATED 55	PROPOSAL CURVE NO.
3	PUMPING TEMP DEG F 375 — U. S. GPM NORMAL 50	SPEED RPM — NO. STAGES
4	MAX. P.T. DEG F 500 — MAX SUCTION PSIG 50	NPSHR, FT (H2O) — MIN CONT GPM
5	S. G. AT PT 0.906 — DISCH. PRESS. PSIG 65	SHUTOFF HD. FT — % EFF @ RATED GPM
6	VAP. PRESS., PSIA @ PT 3.5 — SUCT. PRESS., PSIG 32	BHP @ RATED GPM — MAX BHP
7	VISC @ PT. CP 0.45 — DIFF PRESS., PSI 33	IMPELLER DIA. IN — RATED — MAX — MIN
8	CORR./EROS. FROM — DIFF. HEAD, FT 84	MAX. ALLOW. CASING PSIG/DEG F /
9	NPSH AVAIL. FT 25 +	HYDROSTATIC TEST PRESS. PSIG
10	PCT & SIZE SOLIDS — (MEAS. TO [ ] ℄ PUMP [ ] ℄ SUCT FLG)	MAX POSSIBLE DISCH PRESS PSIG
11	CONSTRUCTION	ROTATION FACING COUPLING [ ] CW [ ] CCW
12	CASING SPLIT [ ] AXIAL [X] RADIAL	CONNECTIONS — SUCTION — DISCHARGE
13	CASING VOLUTE [X] SINGLE [ ] DOUBLE [ ] DIFFUSER	SIZE, INCHES
14	CASING SUPPORT [ ] FOOT [ ] CENTERLINE	RATING/FACING — 300# RF — 300# RF
15	[ ] BRACKET [X] VERTICAL IN-LINE	LOCATION — IN-LINE — IN-LINE
16	CASING CONNS. [X] VENT [X] DRAIN [ ] GAUGE [ ]	DRIVER
17	IMPELLER TYPE CLOSED	FURNISHED BY [X] PUMP MFR [ ] OTHERS
18	IMPELLER MTG. [ ] BETWEEN BRGS [X] OVERHUNG	MOUNTED BY [X] PUMP MFR [ ] OTHERS
19	WEAR RINGS [X] CASING [X] IMPELLER [X] INLET [X] BACK	[X] MOTOR: ITEM NO. P-101 TYPE INDUCTION
20	BEARINGS-TYPE: RADIAL (IN MOTOR) THRUST (IN MOTOR)	HP — RPM — FRAME NO.
21	BEARINGS-LUBE: [ ] RING [ ] FLOOD [ ] FLINGER	ENCL. TEFC INSUL. B S.F. 1.0
22	[ ] OIL MIST [ ] PRESSURE LUBE	MFR — V 460 PH 3 HZ 60
23	COUPLING: MFR PUMP MFR TYPE RIGID SPACER	FLA — LRA — LUBE
24	DRIVER HALF MTD BY [X] PUMP MFR [ ] DRIVER MFR [ ] OTHERS	THRUST (VERT) LB — UP — DOWN
25	SHAFT SEAL TYPE [ ] PACKING [X] MECHANICAL	[ ] TURBINE: ITEM NO. — MFR.
26	PACKING MFR. TYPE — SIZE — NO. RINGS	REFER TO PAGE — , ATTACHED
27	SEAL MFR. MODEL CRANE 9B TYPE	TESTS — REQUIRED — WITNESSED — CERTIFIED
28	MFR. CODE — API CODE BSTXL (1)	SHOP INSPECT [X]
29	BASEPLATE [ ] EXTENDED FOR DRIVER [ ] DRAIN RIM	PERFORMANCE [X] [ ] [X]
30		NPSHR [ ] [ ] [ ]
31	WATER COOLING & SEAL FLUSH PIPING	HYDROTEST [X] [ ] [X]
32	WATER COOLED [ ] BEARINGS [ ] STUFFING BOX JACKET	[ ] [ ] [ ]
33	[ ] GLAND [ ] PEDESTALS	MATERIALS - API CLASS S-5
34	C. W. PLAN — , WITH [ ] CS [ ] SS [ ] TUBING [ ] PIPE	CASING C.S. — IMPELLER C.S.
35	TOTAL COOLING WATER REQUIRED, GPM	SHAFT 12 CHR. — SLEEVE 12 CHR.
36	SEAL FLUSH, PLAN 11, WITH [X] CS [ ] SS [ ] TUBING [X] PIPE	WEAR RINGS 12 CHR. — GLAND C.S.
37	EXT. FLUSH LIQUID @ DEG F GPM PSIG	
38	AUX. SEAL PLAN 61 WITH C.S. PIPE PLUGS	BASEPLATE NONE
39	ACCESSORIES FURNISHED BY PUMP MFR	WEIGHTS, LBS EACH
40	[X] SEAL FLUSH PIPING [ ] STEAM JACKETING	PUMP — BASEPLATE
41	[ ] COOLING WATER PIPING [ ]	MOTOR — TURBINE
42	[ ] OIL PIPING [ ]	SITE & UTILITIES
43	[ ] MINIMUM FLOW ORIFICE [ ]	[ ] INDOORS [X] OUTDOORS
44	NOTES: (1) X = ASBESTOS GASKETS.	AMBIENT 100 DEG F MAX TO 0 DEG F MIN
45		CL — GR — DIV — [X] NON-HAZARDOUS
46		ALT. FT — COOLING WATER SOURCE
47		DEG F: IN. OUT: PSIG IN. OUT
48		
49		DOCUMENTS
50		[X] 60863-1300A [X] STD-38A6
51		[X] STD-31A1 [X] STD-97A1
BY	RTI — P.O. NO.	VENDOR

FORM NO 135-302

FOSTER WHEELER CORPORATION
110 SOUTH ORANGE AVENUE, LIVINGSTON, NEW JERSEY

ROTARY PUMPS
MATERIAL REQUISITION

FOR U.S. DEPT. OF ENERGY
SITE DOW CHEM. CO. DALTON, GA. F.W. REF. 11-60863
ITEM NO. P-102 MOTOR DRIVE ✓ TURBINE DRIVE
SERVICE DOWTHERM CHARGE PUMP
PUMPS MFR.
SIZE & TYPE NO. REQ'D. ONE
GENERAL NOTES REQUISITION 60863-1300A IS AN INTEGRAL PART OF THIS REQUISITION

REQUISITION NO.	DATE
60863-1313-A	4-24-79

SUPERSEDED BY

CHG.		CHG.	
C1		C4	
C2		C5	
C3		C6	

OPERATING CONDITIONS

LIQUID DOWTHERM — US GPM @ P.T. NORMAL — DES. 10
DISCH. PRESS. PSIG 100
PUMP TEMP. °F 90 (110 MAX) — SUCT. PRESS. PSIG 0
SP. GR. @ P.T. 1.04 — DIFF. PRESS. PSI 100
VAP. PRESS. @ P.T. PSIA NIL — NPSH AVAIL. @ P.T. - FEET 25+
VISC. @ P.T. CKS 3.2
CORR./EROS. DUE TO

CONSTRUCTION & MATERIALS

CASING - MOUNTING (CENTERLINE) (FOOT ✓) (BRACKET) (VERTICAL)
SPLIT (AXIAL) (RADIAL)
TYPE (GEAR, VANE, SCREW, ETC.)
TAPPED OPENINGS (VENT) (DRAIN ✓) (GAGE CONNS.)

NOZZLES	SIZE	ASA RATING	FACING	POSITION
SUCTION		150 #	FF	SIDE
DISCHARGE		150 #	FF	SIDE

BEARINGS-RADIAL (INT.)(EXT.) THRUST (INT.)(EXT.) TYPE BALL OR ROLLER
BEARING LUBRICATION OIL
COUPLING & GUARD MFR STD — BASEPLATE DRIP RIM
PACKING
MECH. SEAL TYPE 9 — MFR. J. CRANE
TIMING GEARS - (INT.)(EXT.)

MATERIAL CODE CASING I — INTERNALS S

	INTERNALS	SYMBOL	REMARKS
I - CAST IRON	ROTOR (S)		
B - BRONZE	LINER		
S - STEEL	SLEEVE (PACKED)		
C - 11-13% CHROME	SLEEVE (SEAL)		
A - ALLOY	SHAFT		
H - HARDENED	TIMING GEARS		
F - FACED			
X			

PERFORMANCE

PROPOSAL CURVE NO.
NPSH REQ'D - (WATER) - FT.
MECH. EFF. — BHP
PUMP RPM
MAX. BHP — @ R.V. SET. - PSIG
REL. VALVE (BUILT IN) (EXT.) BY PUMP MFR.
ROTATION FACING COUPLING END
WATER COOLING NONE
BEARINGS — PED.
STUFF. BOX — GLAND
TOTAL WATER REQ'D.-GPM
STEAM JACKETS-CASE NONE
STUFF. BOX
STEAM REQ'D.-LB./HR.
JACKET STEAM PSIG — TEMP °F
EXHAUST PSIG
JACKET MAX. ALLOW. W.P. PSIG
FLUSHING
AUX. PIPING

SHOP TESTS	REQUIRED	WITNESSED
RUNNING PERF.	YES	
NPSH	NO	

HYDROSTATIC PSIG
MAX. ALLOW. W.P. PSIG °F
WEIGHTS: PUMP — BASE
MOTOR — TURBINE — GEAR

MOTOR DRIVER BY PUMP MFR.
ITEM NO. P-102 — MTD. BY P. MFR
HP — RPM — FRAME
MFR.
TYPE INDUCTION — INSUL. B
ENCL. TEFC — TEMP. RISE °C
VOLTS/PHASE/CYCLES 460/3/60
BEARINGS BALL — LUBE GREASE
F.L. AMPS. — L.R. AMPS.
SERVICE FACTOR 1.0

TURBINE DRIVER BY
ITEM NO. — MTD. BY
HP — RPM — MAT'L.
MFR. & TYPE
INLET STEAM PSIG — TEMP. °F
EXHAUST
STEAM RATE - F.L. — #/SHP/HR
BEARINGS — LUBE

NOZZLES	SIZE	ASA RATING	FACING	POSITION
INLET				
EXHAUST				

SPEED REDUCER BY
MFR. — RATIO
AGMA S.F. — RATED HP
TYPE — MECH. EFF.

MFR. FINAL DATA (AS BUILT)
TEST CURVE NO.
OUTLINE DWG. NO.
SECTIONAL DWG. NO.
SEAL DWG. NO.
PUMP SERIAL NO.

EQUIPMENT TO BE IN ACCORDANCE WITH: 60863-1300A ; ENG. STD.-38A6 ; ENG. STD-57A1
NOTES:

FORM 135-30

REQUISITION
FOSTER WHEELER ENERGY CORPORATION

PAGE 1 OF 6

CLIENT U.S. Department of Energy CONTRACT NO. 11-60863	REQUISITION NO.		DATE	
SITE Dow Chemical Co., Dalton, GA ITEM NO.	60863-1929-A		4-26-79	
MATERIAL SC-101 thru SC-115 and A-101	C1		C4	
OR Solar Collector Package Including Controls	C2		C5	
SERVICE	C3		C6	

I. GENERAL

The vendor shall supply and deliver to the jobsite fifteen (15) rows (modules) of solar collectors and the associated controls to make a complete system as described herein. Each module shall be an 80' long line-focusing parabolic trough collector, Model SH-1655, as manufactured by Suntec Systems, Inc. Each 80' module shall consist of four (4) nominally 20' collector (reflector) assemblies, supported from a steel torque tube mount with steel leg stanchions for ground foundation.

II. APPLICABLE DOCUMENTS

The equipment shall be furnished in accordance with the applicable provisions of the latest revisions of the following Codes and specifications:

A. National, State and Local Requirements

1. State and local requirements

2. OSHA

3. NEC

B. Foster Wheeler Specifications

1. 60863-1300A General Notes for Mechanical Equipment

2. 60863-92A1 Preparation for Shipment

III. VENDOR SCOPE OF SUPPLY

The Vendor shall supply:

A. Fifteen (15) rows of Suntec Model SH-1655 solar collector modules as described in Suntec Drawing #1000505. These line-focusing parabolic trough collector modules are described in detail in Section-Technical Specifications below. Modules will arrive at the jobsite in appropriate sub-assembly component parts for ease of installation.

B. One (1) field master controller.

BY	P.O. NO.	SUPPLIER

FORM NO 135-901

FW

REQUISITION

FOSTER WHEELER ENERGY CORPORATION PAGE 2 OF 6

CHANGE NO.	DATE 4-26-79	REQUISITION NO. 60863-1929-A

III. VENDOR SCOPE OF SUPPLY (Continued)

C. Fifteen (15) module controllers (one per row).

D. One (1) set of collector field battery D.C. power source and battery charging device.

E. One (1) reproducible and three (3) copies of module assembly, equipment drawings, field layout drawings and other technical data.

F. Three (3) copies of a Suntec Operation and Maintenance Manual complete with spare parts lists.

G. Make available, in accordance with its current rates therefore, field engineering and/or supervision, also in accordance with a mutually agreeable proposal and schedule for such additional costs.

H. Five (5) man days, including one trip and necessary per diem, for engineering supervision of at least one (1) row installation.

IV. PURCHASER SCOPE OF SUPPLY

The Purchaser shall supply:

A. A properly prepared site including all necessary supports and structures for storing, mounting and supporting the vendor supplied equipment.

B. All installation labor, hardware, equipment, and services to receive, store, interconnect, assemble, wire, construct, and install the vendor supplied equipment. Such effort shall include all plumbing and electrical labor and materials.

C. All required installation, test, and operation utilities and fluids and associated equipment in the required quantities and quality to adequately and safely operate the vendor supplied equipment.

D. Provide and install all necessary process or external controls, and control signals including connection to vendor equipment at designated points of tie-in.

E. Provide and install flexible line (hoses, etc.) assemblies at each end of each row for interconnecting the module row or rows with field piping.

F. Provide and install, as necessary, pressure relief devices and air vents at the end of each row.

G. Provide and install on vendor provided welded tees on each row end any necessary drainage taps, fluid temperature/pressure devices, or other Purchaser desired instrumentation.

FORM NO. 135-902

REQUISITION

FOSTER WHEELER ENERGY CORPORATION

CHANGE NO.	DATE 4-26-79	REQUISITION NO. 60863-1929-A

V. TECHNICAL SPECIFICATIONS

The vendor shall supply a linear focusing parabolic trough solar collection system. The collector system shall consist of Model SH-1655 collector modules, each nominally 80' in length composed of:

- Four (4) collector assemblies
- Receiver assembly
- Module drive unit
- Module tracking and controls
- Module structure and support

Each 80' module is described on Suntec Drawing #1000505 and discussed herein.

A. Collector Assembly

Each 20' collector assembly consists of four (4) 2.98 meter (9.75 feet) long by 1.41 meters (4.83 feet) wide panels of aluminum honeycomb mounted on a torque tube. The honeycomb, with front and back skins of 0.05 cm thickness, has a reflective, surface attached on the concave side. The surface is an aluminized acrylic such as 3M company's FEK 224 or equal. The panels, when mounted to the torque tube, provide a parabolic trough assembly having a rim angle of 72° and a collector aperture of approximatley 15.2 m^2 (165 ft^2). Each assembly requires field installation (concrete filled by installer) of two (2) painted steel counterweight elements as balance ballast. Two (2) painted steel mirror support beams per assembly provide seating for the panel adjustment bolts used in fine tuning the field reflector focusing. Each 80' row module requires three (3) nominal 20' assemblies and one (1) 29'-9½" assembly at the drive mount stanchion location (reference Drawing #1000505). Steel items are shop tooled and fixtured for proper alignments and high quality fabrication to insure a quality image on the absorber tube.

FORM NO. 115-912

REQUISITION
FOSTER WHEELER ENERGY CORPORATION
PAGE 4 OF 6

CHANGE NO.	DATE 4-26-79	REQUISITION NO. 60863-1929-A

V. TECHNICAL SPECIFICATIONS (Continued)

B. Absorber (Receiver) Assemblies (Reference Drawing #1000505)

Each Model SH-1655 module requires an absorber assembly located at the 36" focal length, from the reflector surface, and running the entire length of the nominal 80' module. The absorber tubing (piping) shall terminate at each end of the module in suitable fittings for customer attachment of flexible connectors.

The absorber assembly consists of:

- absorber riser weldment
- absorber support clamp and rod
- absorber housing and strap
- absorber insulation
- absorber glass cover

The painted steel riser weldment accurately spaces the absorber assembly from the torque tube and supports the absorber while providing minimal shadow effects to the reflective surface.

The absorber tubes are smooth bore, carbon steel tubes (ASTM A178 or equal) suitable for use with the customer supplied pressure of 40 atmospheres and an internal working temperature of 270°C. Receiver tubes are supplied to the field in nominal 10' lengths for field welding into continuous flow piping per each 80' module length. The tubes are coated with a selective coating of high absorptance and low emissivity suitable for the proposed service such as a continuous surface of black chrome on a nickel sulfate substrate (similar to Sandia/Hexcel tests). Ten foot long plugs are furnished and are to be inserted inside the coated tubing to produce an annular flow in the receiver.

The aluminum absorber housing with fiberglass insulation are factory supplied to the field for simple field assembly to the riser via the U-bolt, strip, support clamp and rod, to form the continuous 80' module length.

Welded steel tee fittings will be provided for customer supply and installation of pressure relief devices, drainage taps and/or instrumentation.

FORM NO. 135-302

REQUISITION

FOSTER WHEELER ENERGY CORPORATION

CHANGE NO.	DATE 4-26-79	REQUISITION NO. 60863-1929-A

V. TECHNICAL SPECIFICATIONS (Continued)

C. Drive Assembly

The single-axis tracking concept provides for driving the reflector assemblies via DC motor drives. Each 80' module is driven by a single motor-chain drive assembly as shown on Suntec Drawing #1000505. The DC motors are hard wired by the customer to the remotely located and environmentally protected Suntec battery set. The DC motors (456 watts max.) are driven during their tracking and stowing maneuver by the 24 VDC source. The source also is provided with an on-line trickle charge connected to the customer supplied 110-120 VAC source at Suntec designated point of tie-in.

The motor-chain drive sprocket combination are field mounted at the drive stanchion location and connected via the drive chain to the torque tube drive sprocket. Drive control signals and monitoring are accomplished through the module controller at the drive stanchion mounting locations.

D. Tracking and Control Systems

The Suntec (or equal) control system provides the sun tracking and collector assembly drive control commands for operation of the collector field system. The control program of:

- focus
- defocus
- stow

is based on control commands for thermal demand, changes in load, time sequence requirements, or process security conditions (low flow, weather, wind, power failure, or no load). The standard Model SH-1655 module is supplied with a Delavan Electronics Corporation control subsystem (or euqal). This subsystem includes Sun-Trak sun sensors, total field solar illumination (hemispherical direction insolation) sensor and wind sensor. (Tracking drive is accomplished via the 3.3 Drive Assembly for each 8' module.) Appropriate control, operation, and drive logic and instructions are included.

FORM NO. 135-902

REQUISITION

FOSTER WHEELER ENERGY CORPORATION

CHANGE NO.	DATE 4-26-79	REQUISITION NO. 60863-1929-A

V. TECHNICAL SPECIFICATIONS (Continued)

D. Tracking and Control Systems (Continued)

The Suntec Model SH-1655-ACS includes a microprocessor control system. This advanced unit is covered in Alternates and Options, Section 9.0 of this porposal.

E. Structure and Mounts

The Suntec collector module is supported from the ground, deck or roof by suitable customer designed and supplied foundations or other structures. The reflector assemblies are supported at each end of the module and at approximate 20' intervals (Drawing #1000505) by stanchions (5 per 8' module). This factory jig-welded steel stanchion is field set and J-bolted to the customer support. The torque tube is appropriately supported through a Suntec thrust bearing with pipe roller supports at the remaining stanchions.

VI. INSTALLATION SUPERVISION

The vendor shall include five (5) man days including one round trip and necessary per diem expenses for services of an installation supervisor. The vendor shall also include a per diem quotation for additional installation supervision.

FORM NO. 135-902

APPENDIX B
INSTRUMENT LIST

INSTRUMENT LIST

Pressure Devices

Type	Tag No.	Service	Remarks
Locally Mtd. Pressure Gages	PI-100	Dowtherm Circulating Pump Disch. Press.	All 4½" nominal size bourdon tube with blow-out back or disc. and solid front
	PI-800	Dowtherm Makeup Pump Disch. Press.	
	PI-801	Expansion Tank Steam Coil Press.	
	PI-802	Expansion Tank Vapor Press.	
Pressure Transmitter	PT-400	Boiler Drum	Two wire 4-20 Ma. D.C. Output, low displacement type, weatherproof construction.

Temperature Devices

Type	Tag No.	Service	Remarks
Locally Mtd. Temp. Indicator	TI-102	Individual Collector Bank Outlet Temp.	All Bimetallic strip type complete with well, dial reading, fixed stem.
	TI-103		
	TI-104		
	TI-105		
	TI-106		
	TI-107		
	TI-108		
	TI-109		
	TI-110		
	TI-111		
	TI-112		
	TI-113		
	TI-114		
	TI-115		
	TI-116		
	TI-800	Expansion Tank Dowtherm Temp.	
Temperature Transmitters	TT-001	Ambient Temp. Inc. Radiation Shield	All 2-wire, 4-20 Max. D.C. output complete with well + weatherproof
	TT-100	Collector Array Inlet	Matched Pair for Temp. Difference
	TT-101	Collector Array Outlet	
	TT-400	Boiler Feedwater	
	TT-401	Dowtherm, Boiler Outlet	Matched Pair for Temp. Difference
	TT-403	Dowtherm, Boiler Inlet	

Level Devices

Type	Tag No.	Service	Remarks
Level Glass	LG-400	Boiler Water Level	Inc. water columns & offset valves
	LG-800	Expansion Tank Level	Offset valves only
Level Switches	LSLL-400	Boiler Low Water Cutoff	External alarm contact
	LSL-800	Expansion Tank Low Level	SPST
Level Transmitter	LT-400	Boiler Drum Level	Two wire 4-20 Ma. D.C. Output, complete with upper drum reservoir

BRUNING 44-131 20427-2

FORM NO. 135-28M

Fig 7.2

THIS DRAWING SUPERSEDES
THIS DRAWING SUPERSEDED BY

LEGEND									
11 COOLING WATER SUPPLY	16 # EXHAUST STEAM	21 CONDENSATE	26 OILY OR DIRTY WATER SEWER	31 PUMPOUT	36 INERT GAS	41	46	51
12 COOLING WATER RETURN	17 POTABLE WATER	22 TREATED WATER	27 PROCESS SEWER	32 PURGE GAS	37 OILY SUMP	42	47	52
13 # H.P. STEAM	18 PLANT AIR	23 FUEL OIL	28 SANITARY SEWER	33 BLOWDOWN	38	43	48	53
14 # STEAM (INTERMEDIATE PRESS.)	19 INSTRUMENT AIR	24 FUEL GAS	29 FIRE WATER	34 FLARE	39	44	49	54
15 # L.P. STEAM	20 H.P. CONDENSATE	25 CLEAN WATER SEWER	30 FLUSHING OIL	35 TO ATMOSPHERE	40	45	50	55

NOTES
1. TEST WELLS CLOSE BY ALL TT POINTS.
2. HIGH TEMPERATURE FLEXIBLE HOSE INSTALLATION SHALL INCLUDE ADEQUATE PROTECTION FOR PERSONNEL.

ITEM NO.	P-101	P-102
SERVICE	CIRCULATING PUMP	DOWTHERM CHARGE PUMP
S.G. AT P.T.	0.9	1.04
DES. G.P.M. AT P.T.	57	10
DES. DIFF. P.S.I.	33	100
MAX. DISCH. P.S.I.G.	65	100
MATERIAL	C.S.	C.S.
INSULATION	NO	NO

ITEM NO.	SG-101
SERVICE	KETTLE BOILER
SHELL DES. P. & T.	200/400
TUBE DES. P. & T.	100/600
SURFACE	251 SQ. FT.
MATL. SHELL	C.S.
MATL. TUBE	C.S.
INSULATION	YES

ITEM NO.	TK-101	SC-101-115
SERVICE	ACCUMULATER TANK	SOLAR COLLECTORS
SIZE	4'-0"Ø×8'-0"	80' PER ROW
DES. PRESS-TEMP.	50/600	
OPER. PRESS-TEMP.	30/550	50/600
MATERIAL	C.S.	
INSULATION	YES	

REVISIONS

A	5-1-79	PHASE I DESIGN BASIS

ITEM NOS. THIS DWG.
P-101
P-102
SG-101
TK-101
SC-101 TO SC-115
A-101

ENGINEERING FLOW DIAGRAM
SOLAR STEAM GENERATING PLANT
U.S. DOE CONTRACT NO ET-78-C-03-2199
AT DOW CHEMICAL COMPANY
DALTON GEORGIA

EST. NO.		DRAWN BY: M.C.	4-13-79	SH. 1 OF 1
CONTRACT NUMBER	11-60863	DWG. NO.- 60863-1-50-1	B	

THIS DRAWING SUPERSEDES NOT ISSUED

Fig 7.1

BRUNING 40-5353 23763-3
FORM-135-29M REV.

NEW 15' ACCESS ROAD
EXPANSION TANK
SOLAR COLLECTOR FIELD
GRADE ELEV.
NEW 10' WIDE ACCESS ROAD (TYP)
5' WIDE SHOULDER (TYP)
PIPE CULV'RT
PLAN
EXIST. WATER TANK
BASE LINE
5'-0" PIPEWAY
DESIGN TEMP. 600°F
ELEVATION "A A"
SEE ENLARGED ELEV. (BELOW)
GRADE
SENSOR
PARABOLIC MIRROR
ROTATION
METAL FLEX HOSE
TRACKING CONTROL SYSTEM LOCATED AT CENTER STANCHION
ENLARGED ELEVATION - SOLAR CONCENTRATOR
STANCHION
SECTION "B B"
SEE ENLARGED ELEVATION
25 x 50 NEW SOLAR AUXILIARY BOILER HOUSE
EXIST. GARAGE HOUSE
EXIST. CONC. DRIVE
NEW 5' ACCESS WAY
FEEDWATER
EXISTING
STEAM
BOILER HOUSE
Preliminary
MARCH 15 1979
This Drawing is the Property of the
FOSTER WHEELER ENERGY CORPORATION
110 SOUTH ORANGE AVE., LIVINGSTON, N. J.
AND IS LENT WITHOUT CONSIDERATION OTHER THAN THE BORROWER'S AGREEMENT THAT IT SHALL NOT BE REPRODUCED, COPIED, LENT, OR DISPOSED OF DIRECTLY OR INDIRECTLY NOR USED FOR ANY PURPOSE OTHER THAN THAT FOR WHICH IT IS SPECIFICALLY FURNISHED. THE APPARATUS SHOWN IN THE DRAWING IS COVERED BY PATENTS.
EQUIPMENT ARRANGEMENT (HEX)
SOLAR STEAM SYSTEM PLANT
DEPARTMENT OF ENERGY (DOE)
DALTON, GEORGIA
DRAWN BY:
3-15-79
SCALE: 1"=10'-0" =1'-0"
EST. NO.
2-51-3436
DWG. NO-3436-1-018

Fig 7.7

Flow Devices

Flow Elements	WO-101 thru WO-115	Collector Flow Control	Orifice installed in tapped orifice flange with plugged & valve instrument conn.
Flow Transmitters	WT-100	Dowtherm Circulating Flow	All Two wire, 4-20 Ma. D.C. including orifice, orifi-e flange, etc. if required
	WT-400	Feedwater Flow	
Flow Totalizers	EPQI-101	Dowtherm Circulating Pump Power Kilowatt-Hours	All Six digit shelf mounting 3 x 6 nominal size. Depending on source may require V/F signal converter, two counters per module.
	EPQI-600	Collector Power Kilowatt - Hours	
	HFQI-100	Collector Heat Absorbed BTU's	
	HFQI-400	Heat Given up to boiler BTU's	
	WQI-400	Feedwater, Pounds	

Misc. Transducers

Power Transducer	EPT-101	Dowtherm Circulating Pump, Power in Watts	All Specific device a function of pump power requirements, current and/or voltage transformers may be required
	EPT-600	Collector Array Motor Power in Watts	
Intensity Transducer	IT-001	Sun Intensity	Eppley Model PSP
Wind Velocity Transducer	VT-001	Wind Velocity	Weather Measure Model W101-P-DC/540

Signal Conditioning Devices

Signal Conditioning Devices	EPY-101	Collector Array Power	MV/I
	EPY-600	Dowtherm Ciruclating Pump Power	MV/I
	HFY-100	Collector Array BTU Calculator	Mult.
	HFY-400	Boiler Input BTU Calculator	Mult.
	IY-001-A	Sun Intensity	MV/I
	IY-001-B	Sun Intensity	Adjustable Delay (Aug.)
	LSL-400	Boiler Water Level Low	Duel Alarm Switch
	LSH-400	Boiler Water Level High	DPDT Contacts
	TDY-100	Collector Array ΔT	Two Input Summer
	TDY-402	Boiler Input ΔT	Two Input Summer
	VY-001	Wind Velocity	MV/I
	WSL-100	Dowtherm Low Flow	Duel Alarm Switch
	WSLL-100	Dowtherm Low Flow Cut-Out	DPDT Contact
	EPY-101	Collector Array Power	MV/I
	EPY-600	Dowtherm Circulating Pump Power	MV/I
	HFY-100	Collector Array BTU	Mult.
	HFY-400	Boiler Input BTU Calculator	Mult.
	IY-001-A	Sun Intensity	MV/I

Signal Conditioning Devices (Continued)	IY-001B	Sun Intensity	Adjustable delay (Aug.)
	LSL-400	Boiler Water Level Low	Duel Alarm Switch
	LSH-400	Boiler Water Level High	DPDT Contacts
	TDY-100	Collector Array Δ T	Two input summer
	TDY-402	Boiler Input Δ T	Two input summer
	VY-001	Wind Velocity	MV/I
	WSL-100	Dowtherm Low Flow	Dual Alarm Switch
	WSLL-100	Dowtherm Low Flow Cut-out	DPDT Contact
	WY-100	Dowtherm Flow	Sq. RT. Extr. with low level cut-off
	WY-100	Feedwater Flow	Sq. RT. Extr. with low level cut-off
	NY-001	Collector Efficiency Calculator	Divider All signal conditioning devices to be mounted in the rear of the panel in racks with bussed power. Inputs and outputs (except for MU/I) 1-5 volts D.C.
Auxiliary Relay	LYLL-400	Boiler Low Water Level Cut-Out	Provides DPDT contact, one for alarm and one for interlock system mount on rear of panel
Recording Devices			
Recorders	VR-001	Wind Speed	Two Pen
	TR-001	Ambient Temp.	
	IR-001	Sun Intensity	Two Pen
	NR-001	Collector Efficiency	
	TR-100	Collector Inlet Hdr. Temp.	Three Pen
	TR-101	Collector Outlet Hdr. Temp.	
	HFR-100	Collector Array Absorption BTU/Hour	
Recorders (Continued)	WR-100	Dowtherm Flow	Two Pen
	Spare		
	LR-400	Boiler Drum Level	Three Pen
	TR-400	Feedwater Temp.	
	WR-400	Feedwater Flow	
	PR-400	Steam Pressure	Two Pen
	TR-402	Dowtherm T, Boiler	
	TR-401	Dowtherm Temp. Boiler Outlet	Three Pen
	TR-403	Dowtherm Temp. Boiler Inlet	
	HFR-400	Heat Absorbed by Boiler BTU/Hour	
	EPR-101	Collector Power, kilowatts	Three Pen
	EPR-600	Dowtherm Circulating Pump Power, kilowatts	
			All shelf mounted, 3 x 6 or 6 x 6 nominal size, strip chart, ½% accuracy, felt tip pens, 3/4" chart speed, adjustable pen dampering, 1-5 volt signals

Valve Devices

Control Valves	PCV-400	Steam to Expansion Tank Heating Coil	Self Contained Regulator
	PCV-800	Expansion Tank Max. N_2 Vent Press.	Self Contained Regulator
	PCV-801	Expansion Tank N_2 Supply Press.	Self Contained Regulator
	WV-400	Boiler Feedwater	Diaphragm operated singl?
Safety & Relief Valves	PSV-101 thru PSV-115	Collector Thermal Relief Valves	15 required
	PSV-400	Boiler Safety Valve	
	PSV-401	Boiler Dowtherm Thermal Relief	
	PSV-800	Expansion Tank Safety Valve	Set at higher press. than PCV-800
Annunciators	LAL-400	Boiler Drum Level Low	Annunciator with ten alarms, test and acknowledge push button, horn, sequence - std. solid state, remote electronics
	LAH-400	Boiler Drum Level High	
	LALL-400	Boiler Drum Level Low Level Cut-off	
	LAL-800	Expansion Tank Level Low	
	WAL-100	Dowtherm Flow Low	
	WALL-100	Dowtherm Flow Low Cut-Off	
	XL-100-A	System On	
	XL-100-B	System Off	
	Spare		
	Spare		

Controlling Devices

Controllers	LC-400	Boiler Drum Level	All Shelf mounted two mode, 3 x 6 nominal size, cascade/local switch, bumpless transfer. Accepts 1-5 volts D.C. input and has selectable 4-20 Ma or 1-5 volt D.C. output. To include a manual bypass capability implemented from the front of the panel.
	WC-400	Feedwater	

APPENDIX C
SUBCONTRACT REQUISITIONS

C.1 Mechanical Subcontract Requisition (Being Prepared)

C.2 Electrical Subcontract Requisition (Being Prepared)

c.3 Insulation and Painting Subcontract Requisition (Being Prepared)

C.4 Site Preparation and Foundation Subcontract Requisition (Being Prepared)

APPENDIX D
JOB SPECIFICATIONS

D.1 Vessels (Being Prepared)

D.2 Heat Transfer (Being Prepared)

D.3 Mechanical Equipment (Being Prepared)

D.4 Civil and Structural (Being Prepared)

D4.1 (Included)

D.5 Piping (Being Prepared)

D.6 Instrument (Being Prepared)

D.7 Electrical (Being Prepared)

D.8 Protective Covering (Being Prepared)

D.9 Administrative (Being Prepared)

FOSTER WHEELER DEVELOPMENT CORPORATION

JOHN BLIZARD RESEARCH CENTER
12 PEACH TREE HILL ROAD,
LIVINGSTON, NEW JERSEY 07039

BY GDG DATE 4/25/79 SUBJECT FOUNDATION DESIGN SHEET NO. 1 OF 6
CHKD. BY .... DATE .... FOR HEXCEL/SUNTEC COLLECTOR JOB NO. 9-41-4010

D.4.1 FOUNDATION DESIGN

FROM ANSI 58.1, DESIGN WIND LOAD FOR ATLANTA, GEORGIA SHOULD USE A WIND SPEED OF 80 MPH. ASSUME THE SAME WIND SPEED FOR DALTON, GEORGIA.

WIND LOADS ACTING ON THE FOUNDATIONS FOR VARIOUS COLLECTOR ORIENTATIONS ARE SHOWN IN FIGURE 4.1. REFERENCE (15) WAS USED FOR THIS FOUNDATION DESIGN. CYLINDRICAL CONCRETE PILES WERE SELECTED BECAUSE OF THEIR LOW INSTALLATION COSTS.

FOR THE WIND LOADS FOR ~~IN~~-OPERATION COLLECTOR ORIENTATIONS, FACTOR OF SAFETY USED IS ONE. THE MAXIMUM WIND LOADS DURING OPERATION MAY OCCUR AT $\theta = 0^\circ$. THESE LOADS ARE :

VERTICALLY UPWARD = 2950 LB.
VERTICALLY DOWNWARD = 2950 LB.
LATERAL = 1560 LB.
DEAD LOAD, DOWNWARD = 372 LB.

FOR THE WIND LOADS IN STOWED POSITION, FACTOR OF SAFETY USED IS THREE. THE WIND LOADS UNDER THIS CONDITION ARE SHOWN IN FIGURE 4-1, FOR $\theta = -90^\circ$ AS :

VERTICALLY UPWARD = −164 LB.
LATERAL = 520 LB.

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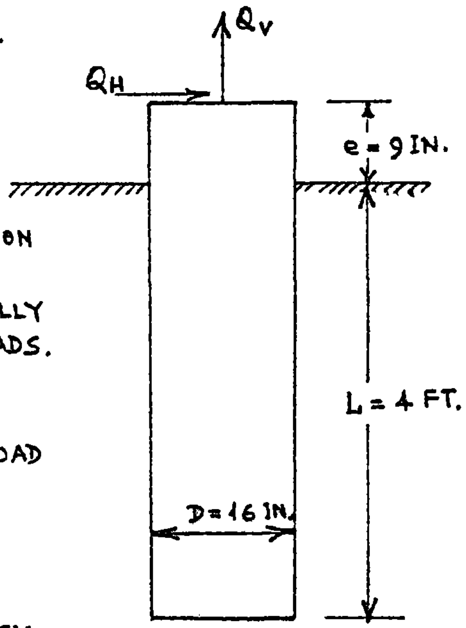
BY GDG DATE 4/25/79 SUBJECT FOUNDATION DESIGN SHEET NO. 2 OF 6
CHKD. BY .... DATE .... JOB NO. 9-41-4010

I DESIGN CONFIGURATION

THE SELECTED CYLINDRICAL PILE IS 16 INCHES IN DIAMETER AND 4 FEET 9 INCHES DEEP. 4 FEET OF THE PILE IS UNDERGROUND. THE FOUNDATION DESIGN IN THIS CASE IS GOVERNED BY THE VERTICALLY UPWARD AND LATERAL LOADS.



Q_V = VERTICALLY UPWARD LOAD
Q_H = LATERAL LOAD

FROM REFERENCE (15), THE CONCRETE PILE SHOULD SATISFY THE FOLLOWING EQUATION —

$$\frac{Q_V}{Q_{UV}} + \left(\frac{Q_H}{Q_{UM}}\right)^2 \leq 1 \qquad \text{...... (D-1)}$$

WHERE
Q_{UV} = GROSS ULTIMATE RESISTANCE FOR VERTICAL LOAD ALONE
Q_{UM} = GROSS ULTIMATE RESISTANCE FOR LATERAL LOAD ALONE

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BY GDG DATE 4/23/79 SUBJECT FOUNDATION DESIGN SHEET NO. 3 OF 6
CHKD. BY ______ DATE ______ JOB NO. 9-41-4010

II CALCULATION OF Q_{UV}

FROM REFERENCE (15),

$$Q_{UV} = \bar{r} \cdot A_s + W$$

WHERE

$\bar{r}$ = AVERAGE UNIT RESISTANCE TO UPLIFT

A_s = EMBEDDED SURFACE AREA

$= \pi D L = \pi \times \frac{16}{12} \times 4 = 16.75 \text{ FT}^2$

W = WT. OF THE CONCRETE PILE INCLUDING DEAD WEIGHT ACTING ON IT.

$= \frac{\pi D^2}{4}(L + e)\rho_c +$ DEAD LOAD

$= \frac{\pi}{4}\left(\frac{16}{12}\right)^2 \times 4.75 \times 150 + 372$

$= 995 + 372 = 1367$ LB.

ρ_c = DENSITY OF CONCRETE

$= 150 \text{ LB/FT}^3$

$\bar{r} = k_c C_U + \frac{1}{2} k_U \bar{\gamma} L \tan \delta$

WHERE

k_c, k_U = UPLIFT COEFFICIENTS

C_U = COHESIVE STRENGTH

= ½ UNCONFINED COMPRESSIVE STRENGTH

$\bar{\gamma}$ = EFFECTIVE UNIT WT. OF SOIL

δ = SKIN FRICTION PARAMETER

$= 0.6\,\phi$

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BY GDG DATE 4/25/79 SUBJECT FOUNDATION DESIGN SHEET NO. 4 OF 6
CHKD. BY .... DATE .... JOB NO. 9-41-4010

ϕ = ANGLE OF INTERNAL FRICTION

FROM REF. (15),

$$K_c = 0.5$$

$$K_U = 2.0$$

ASSUMING ϕ = 20 DEG.

δ = 12 DEG.

$\tan\delta = 0.213$

ASSUME $\bar{\gamma}$ = 100 LB/FT^3

FROM REF. (16),

$$C_U = 1500 \text{ LB/FT}^2$$

THEREFORE,

$$k = 0.5 \times 1500 + \frac{1}{2} \times 2 \times 100 \times 4 \times 0.213$$

$$= 750 + 85.2$$

$$= 835.2 \text{ LB/FT}^2$$

$$\therefore Q_{UV} = 835.2 \times 16.75 + 1367$$

$$= 15357 \text{ LB}$$

i.e. FOR THE VERICALLY UPWARD LOAD ALONE, THE FOUNDATION CAN TAKE 15357 LBS.

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BY GDG DATE 4/25/79 SUBJECT FOUNDATION DESIGN SHEET NO. 5 OF 6
CHKD. BY .... DATE .... JOB NO. 9-41-4010

III CALCULATION OF Q_{UM}

FROM REF. (15),

$$Q_{UM} = \frac{0.5\ \bar{Y}\ D\ L^3\ k_p}{e+L}$$

WHERE K_p = COEFFICIENT OF PASSIVE EARTH PRESSURE

$$= \frac{1+\sin\phi}{1-\sin\phi}$$

$$= \frac{1+0.342}{1-0.342}$$

$$= 2.04$$

$$Q_{UM} = 0.5 \times 100 \times \frac{16}{12} \times (4)^3 \times \left(\frac{2.04}{4.75}\right)$$

$$= 1832 \text{ LB.}$$

i.e. FOR THE LATERAL LOAD ALONE, THE FOUNDATION CAN TAKE 1832 LBS.

IV ACCURACY OF DESIGN

a. IN-OPERATION LOAD

$$Q_V = 2950 \text{ LB.}$$

$$Q_H = 1560 \text{ LB.}$$

FOSTER WHEELER DEVELOPMENT CORPORATION

JOHN BLIZARD RESEARCH CENTER
12 PEACH TREE HILL ROAD,
LIVINGSTON, NEW JERSEY 07039

BY GDG DATE 4/25/79 SUBJECT FOUNDATION DESIGN SHEET NO. 6 OF 6
CHKD. BY .... DATE .... JOB NO. 9-41-4010

$$\therefore \quad \frac{2950}{15357} + \left(\frac{1560}{1832}\right)^2 = 0.192 + 0.725$$

$$= 0.92$$

HENCE THE FOUNDATION SATISFIES THE IN-OPERATION LOAD REQUIREMENTS

b. STOWED LOADS

$$Q_V = 492 \text{ LB.}$$

$$Q_H = 1560 \text{ LB.}$$

$$\therefore \quad \frac{492}{15357} + \left(\frac{1560}{1832}\right)^2 = 0.032 + 0.725$$

$$= 0.757$$

HENCE THE FOUNDATION HAS A FACTOR OF SAFETY OF 3 FOR WIND LOAD IN STOWED POSITION

APPENDIX E

FAILURE MODES AND EFFECTS ANALYSIS SHEETS

Failure Modes and Effects Analysis Sheets (Being Prepared)