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EVALUATION OF A SULFUR OXIDE CHEMICAL HEAT STORAGE PROCESS FOR A STEAM SOLAR ELECTRIC PLANT

Joshua Dayan, Scott Lynn and Alan Foss

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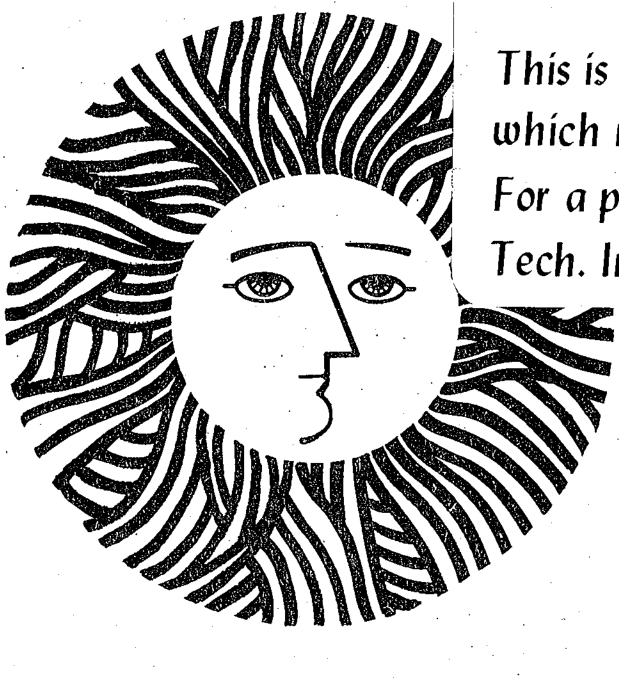

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EVALUATION OF A SULFUR OXIDE CHEMICAL HEAT STORAGE PROCESS FOR A STEAM SOLAR ELECTRIC PLANT[*]

Joshua Dayan, Scott Lynn, and Alan Foss

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SUMMARY

Economical energy storage is essential if solar power plants are ever to supply a significant fraction of the needs of a power grid. The purpose of this study was to develop and evaluate technically feasible process configurations for the use of the sulfur oxide system,

$$2\ SO_3 \rightleftarrows 2\ SO_2 + O_2,$$

in energy storage. The forward reaction for this system is endothermic and can be used to absorb energy. The reverse reaction is exothermic and releases the energy that has been stored. In this study the storage system is coupled with a conventional steam-cycle power plant. Heat for both the power plant and the storage system is supplied during sunlit hours by a field of heliostats focussed on a central solar receiver. When sunlight is not available, the storage system supplies the heat to operate the power plant.

In this report a technically feasible, relatively efficient configuration is proposed for incorporating this type of energy storage system into a solar power plant. Complete material and energy balances are presented for a base case that represents a middle range of expected operating conditions. Equipment sizes and costs were estimated for the base case to obtain an approximate value for the cost of the electricity that would be produced from such an installation. In addition, the sensitivity of the efficiency of the system to variations in design and operating conditions was determined for the most important parameters and design details.

In the base case the solar tower receives heat at a net rate of 230 MW_t for a period of eight hours. Daytime electricity is about 30 MW_e. Nighttime generation is at a rate of about 15 MW_e for a period of sixteen hours. The overall efficiency of converting heat into electricity is about 26%. A similar steam-cycle power plant without a storage system would operate at an efficiency of about 40%, but would have no nighttime capability. The total capital cost for the base case is estimated at about $68 million, of which about 67% is for the tower and heliostats, 11% is for the daytime power plant, and 22% is for the storage system. If the base case is compared to a daytime-only steam-cycle solar power plant, then about two-thirds of the cost of the heliostats and receiver must also be ascribed to the storage feature. The average cost of the electricity produced for the base case is estimated to be about 11¢/kW_e-hr.

I. INTRODUCTION

Some means of high-temperature heat storage for solar power plants is needed as a buffer against short-term interruption of insolation and as a heat source for operation after sundown. Reported here is the development and evaluation of a chemical process, integrated with the central receiver of a solar plant, that absorbs heat during the day by an endothermic chemical reaction, stores the heat as the internal energy of stable chemical compounds at ambient temperature, and releases heat when needed by reversal of the chemical reaction. The chemical reaction employed is the reversible, catalyzed reaction $SO_3 \rightleftarrows SO_2 + 1/2 O_2$.

The general idea of the storage process is that the sulfur-oxygen compounds are used as thermodynamic substances in a cyclic process. During the day, SO_3 is dissociated, absorbing heat, into SO_2 and O_2; during the night, the SO_2 and O_2 are recombined, releasing heat, to form SO_3, completing the cycle. One of the favorable characteristics of this chemical system is that SO_2 and SO_3 are storable as liquids at ambient temperature; oxygen, however, must be stored as a gas.

It is required by thermodynamics that heat be absorbed at a higher temperature than it is released in a system of this type. Two of the attributes of the sulfur oxide system are that the required heat-absorption temperature is technically attainable in current central receiver designs and that the heat-release temperature is suitable for the generation of power-plant quality steam. The storage system is therefore operated in parallel with a solar-heated steam power plant during daylight hours and supplies the heat for the power plant at night.

The objective of this work is the synthesis and evaluation of such a chemical storage system, integrated effectively with the central receiver and steam turbine portions of the plant. This involves the development of designs for the high- and low-temperature chemical reactors, heat recovery trains, and heat integration; evaluation of energy efficiency; and estimation of equipment size and costs. Attention is confined to storage-related portions of the plant; heliostat and central receiver designs, for example, are not a part of this work.

The process reported here has been developed for a single set of specifications and design parameters and may therefore be considered a "base-case" design. In addition, the sensitivity of the system performance to changes in the specifications and design parameters has been investigated and is treated in Chapter VII of this report. Two important specifications were set for the base case to fix its size and ability to function. The first is that the total thermal input to the central solar receiver was fixed at 230 MW_t, in accordance with the design by Boeing [5]. Second, the ratio of thermal inputs in the receiver for the daytime power plant and the storage system was set at 1.05, for reasons that are discussed in Chapter VIII. The temperature at which heat is dissipated to the environment is taken to be 60°C to reflect conditions met in a desert environment. In the base case, the storage system is charged during 8 hours of daylight and discharged during 16 hours of nighttime operation. The operations are assumed to be under constant insolation or load. The power output during daytime operation is about 31 MW_e. At night it would be about half that value for a constant rate of discharge. For the case where a larger power plant is desired the choice will have to be made between scaling up the Boeing receiver and installing multiples of the present design.

II. DAYTIME OPERATION: The Charging System

A. General Description of the Process

A detailed flow sheet for the high-temperature side, or charging side, of the process is shown in Figure 2.1. Properties and flow rates of each of the numbered streams are given for the base case in Table 2.1. To fully fix the conditions of all streams, the following set of five parameters must be specified; the values given here are for the base case:

Minimum discharge temp., T_{min}:	60°C
Maximum reactor wall temp., T_{max}:	880°C
Reactor feed-effluent ΔT, $(T_6 - T_5)$:	140°C
Reactor pressure:	40 atm
Distillation column pressure:	11 atm

The major components of the process are:

1) The receiver/high-temperature reactor (Figure 2.2): Sunlight reflected from the mirror field enters the aperture at the bottom of the receiver and is eventually absorbed by the process gas flowing through the receiver tubes. These tubes are coated internally with Fe_2O_3, which catalyzes SO_3 dissociation at high temperature. The process gas, at 40 atmospheres, absorbs the incoming heat mostly by reacting but also by rising in temperature.

2) Heat Exchanger 1: This heat exchanger transfers excess heat from the reactor exit gas to the incoming reactants. Thus, the sensible-heat rise experienced by the reaction gas in the reactor is used to preheat the reactor fuel to a temperature at which the catalyzed dissociation of SO_3 occurs quite rapidly.

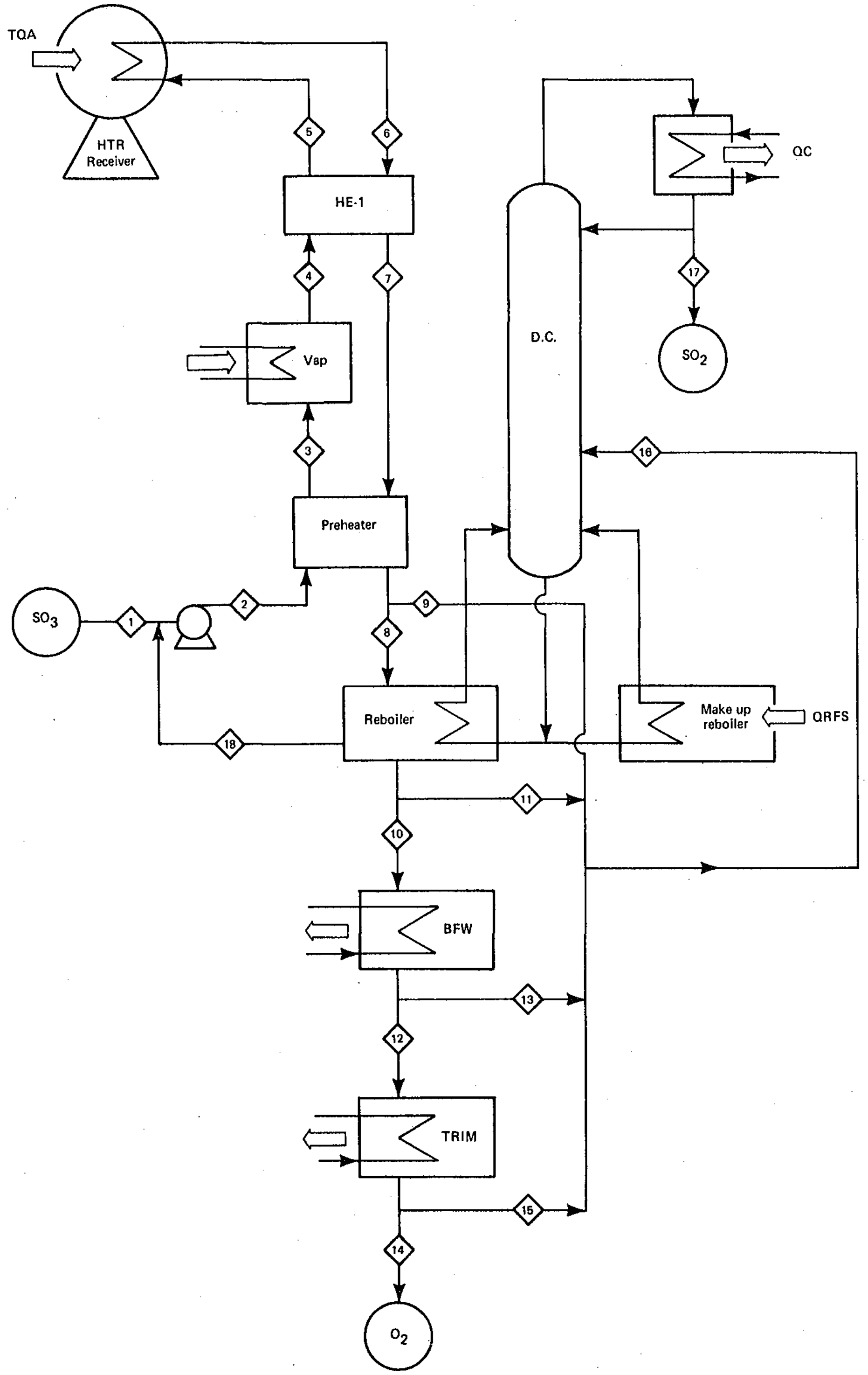

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Fig. 2.1. Flowsheet for the daytime (charging) storage process.

Table 2.1. Stream conditions and heat duties for the daytime high-temperature side.

		Concentration (Mole Fraction)						
Stream No.	State	O_2	SO_2	SO_3	Temp. (°K)	Pres. (Bar)	Flow (kmol/s)	Enthalpy (MJ/kmol)
1	l	0.00	0.07	0.93	362.	11.0	1.03	-30.02
2	l	0.00	0.03	0.97	375.	40.0	2.69	-28.00
3	l	0.00	0.03	0.97	443.	40.0	2.69	-11.13
4	g	0.00	0.03	0.97	443.	40.0	2.69	8.26
5	g	0.00	0.03	0.97	1007.	40.0	2.69	49.48
6	g	0.15	0.33	0.52	1148.	40.0	3.16	50.28
7	g	0.15	0.32	0.53	593.	40.0	3.16	15.24
8	g	0.19	0.36	0.45	418.	40.0	2.47	5.55
9	l	0.00	0.22	0.78	418.	40.0	0.69	-15.00
10	g	0.56	0.30	0.14	379.	40.0	0.85	2.97
11	l	0.00	0.38	0.62	379.	40.0	1.62	-20.96
12	g	0.77	0.20	0.03	343.	40.0	0.62	1.47
13	l	0.00	0.57	0.43	343.	40.0	0.23	-24.12
14	g	0.80	0.18	0.02	333.	40.0	0.59	1.12
15	l	0.00	0.65	0.35	333.	40.0	0.03	-24.12
16	l	0.00	0.36	0.64	391.	40.0	2.57	-18.78
17	l	0.00	0.99	0.01	334.	10.8	0.91	-17.81
18	l	0.00	0.01	0.99	383.	10.8	1.66	-26.63

Heat exchanger loads (MW_t)

HE-1	110.8
VAP	52.7
PREHEATER	44.9
REBOILER	45.2
STEAM REBOILER	11.3
BFW	1.6
TRIM	6.5
DIST. COND.	57.0

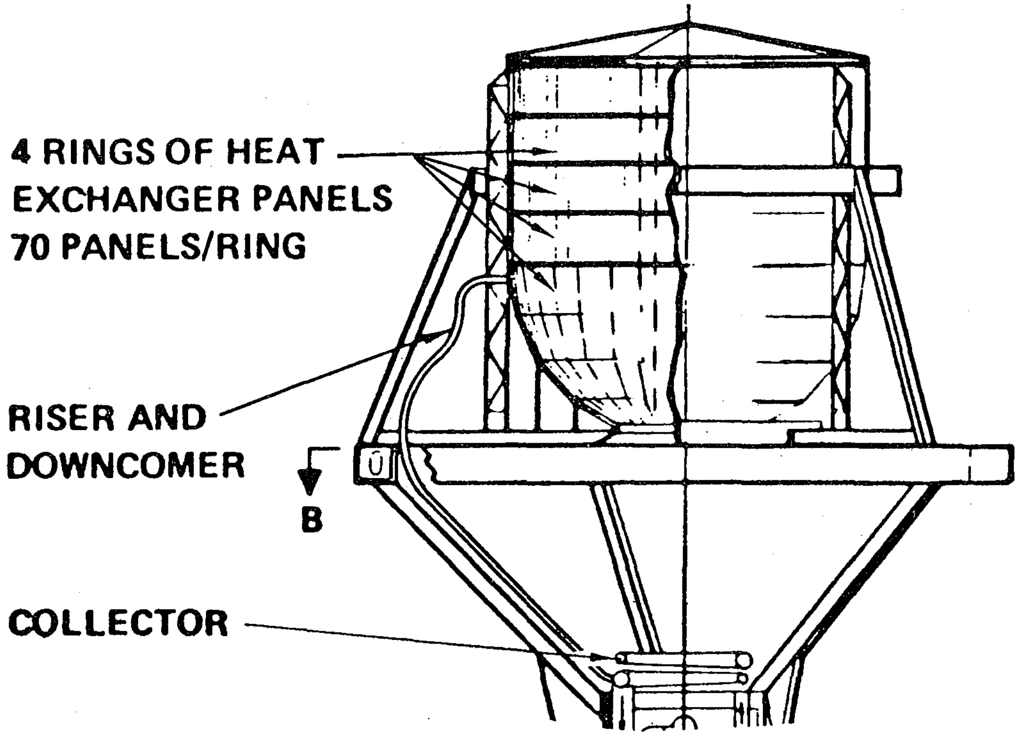

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Fig. 2.2. Boeing solar receiver (Ref. 5).

3) The Condensers: The main function of the condensers is to separate noncondensible oxygen from the liquid SO_2 and SO_3 before feeding the process stream to the distillation column. The heat of condensation is used to preheat liquid SO_3 feed and boiler feedwater and also to supply part of the reboiler duty for the distillation column.

4) The Distillation Column: Conversion of SO_3 in the high-temperature reactor is limited by equilibrium to 46.6% at the temperature and pressure proposed. The distillation column, operating at 11 atmospheres, separates SO_2 from the unreacted SO_3. The SO_2 is stored at near ambient temperature, while SO_3 is recycled to the high-temperature reactor.

5) SO_3 Vaporizer: This is the second largest source of heat input into the storage system (the solar collector is the largest). Steam is taken from the parallel solar power plant to vaporize the liquid SO_3.

6) The Parallel Power Plant (not shown in Fig. 2.1): While the storage system is charging, steam is also being generated in the receiver to produce power. Steam at intermediate pressure is taken from this plant to vaporize the liquid SO_3 and, if necessary, supply part of the heat required by the distillation column reboiler.

B. Detailed Design Considerations

Computer programs simulating the reactor, distillation column, and other components were integrated into one overall program for the entire system. Flow charts and a complete program listing are given in Appendix C. This program was used to determine heat duties for the various units, as well as to predict the effects of changing various design parameters. The design presented here evolved from several such calculations.

1. The Receiver. The receiver configuration utilized in this system is that proposed by Boeing (Fig. 2.3) [5] and is used here only to establish that tube wall temperatures and receiver temperatures are technically feasible. The receiver is situated at the top of a supporting tower 300 meters tall. This tower is located about in the middle of a more-or-less elliptically shaped mirror field. The tower is located to the south of the major axis of the ellipse because the sun does not pass directly overhead in non-tropical latitudes.

The mirrors reflect sunlight into the receiver through the aperture at the bottom. Incident energy is absorbed by the refractory brick lining the lower portion of the cavity, and is re-radiated to tubes located in the upper portion. This indirect transfer of heat reduces the possibility of hot spots occurring in the tubes. If the focused sunlight were directly incident upon the tubes, hot spots would be inevitable as a result of improper mirror aim.

In the Boeing design the heat exchanger tubes are arranged in four rows of 70 panels per row. Each panel consists of two offset columns of heat exchanger tubing (Fig. 2.4); there are 20 tubes on a panel, each tube having a total length of 9.5 meters. Each tube makes two passes: one from the inlet down to the bend, and a second pass close to the cavity insulation up to the outlet. The difference in path length is to provide proper tube expansion during thermal cycling.

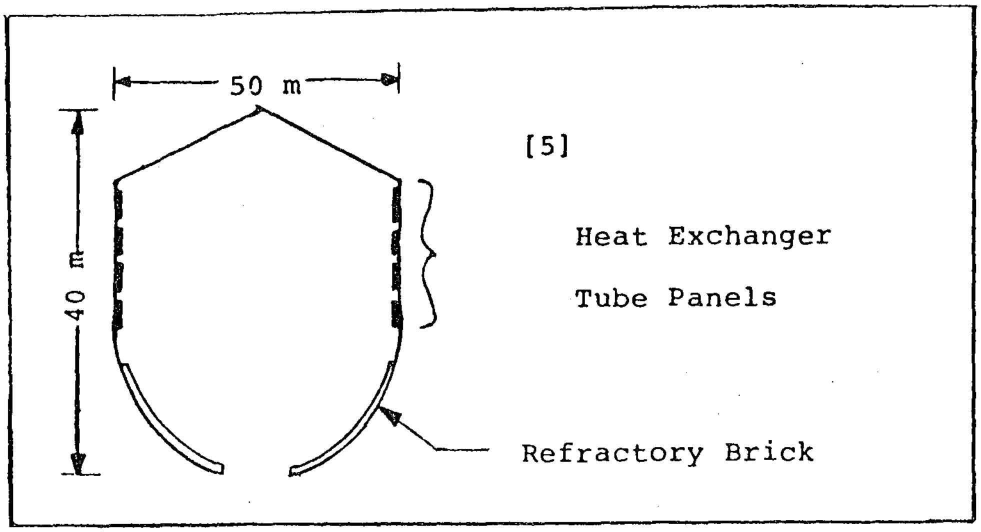

Fig. 2.3. Location of tube banks in Boeing solar receiver.

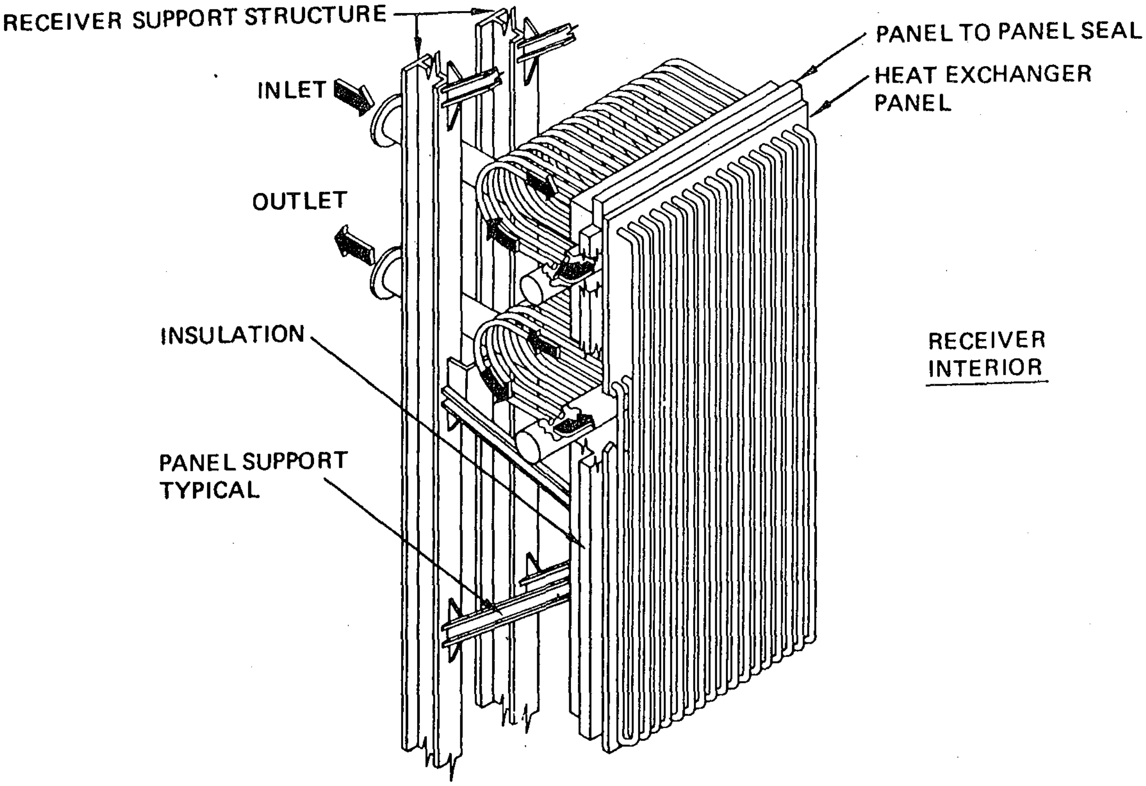

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Fig. 2.4. Heat exchanger tube panel (Ref. 5).

The Boeing design is capable of absorbing 230 MW_t and contains 5600 tubes. The present design for the base case calls for using 800 of the receiver tubes for the power plant and 4800 of them for the storage reactor in which SO_3 is dissociated. The power-plant tubes are subdivided to provide for boiling (460), superheating (240), and reheating. The storage-reactor tubes are connected to form 2400 pairs, each pair making a tube with an equivalent length of 19 m. This division of receiver tubes between power-plant duty and storage-reactor duty, 1 to 6, results in a ratio of solar heat input to the two systems of 1.05 to 1. The radiative thermal flux to the reactor tubes is much lower than that to the power plant tubes because the former operate at a much higher temperature than the latter.

The tubes are made of Haynes 188 alloy for reasons discussed in Chapter VI. The reactor tubes are coated on the inside with the Fe_2O_3 catalyst, and thus provide both heat-transfer area and catalyst support. Because the reaction occurs on the inner surface of the tube, heat-transfer resistance is minimal, mass-transfer resistance is significant. However, the primary factor controlling the fraction of SO_3 that can be dissociated is the maximum allowable tube-wall temperature, which is limited by the physical properties of Haynes 188 alloy.

Many simplifying assumptions were made during the computer modeling of the high-temperature reactor and are stated below. These assumptions may be eliminated as need for greater accuracy in calculations stimulates further work on the reactor design.

a. The model used for the reactor was a simple one-dimensional plug-flow model. Radial gradients in bulk temperature and concentration were ignored, as was axial diffusion. The high linear gas velocity (3 meters per second) and the high length-to-diameter ratio of the tubes indicates that the assumption is not too far removed from reality.

b. The reaction mixture at the tube wall was assumed to be at equilibrium. The reaction rate is limited by the turbulent convection of SO_2 away from the wall and into the bulk. This is an important assumption that finds some support in the results of experiments described in Chapter V.

c. The radiative source (refractory brick) temperature was assumed to be constant throughout the collector, and the heat flux through the tube walls was calculated using the usual fourth-power radiant heat-transfer relationship for black bodies. No attempt was made to calculate a shape factor or source temperature distribution.

d. The effect of re-radiation from the reactor tubes to the nearby colder steam boiler and superheater tubes was ignored. The tubes used for steam are identical to the ones that carry the sulfur oxides. The maximum outside wall temperature of the reactor tube wall is 880°C. The maximum outside tube wall temperature for the boiler, superheater and reheater are 380°C, 570°C and 570°C respectively. These temperatures are based upon the heat flux required to heat the steam, and upon the radiant heat-transfer relation mentioned above. The tubes can withstand a maximum operating temperature of 880°C based upon stress-rupture properties of Haynes 188 alloy.

A summary of experimental evidence that Fe_2O_3 catalyzes the dissociation of SO_3 is given in Chapter V. Considerations in the relation of materials of construction and specification of the maximum temperature of the receiver tubes are summarized in Chapter VI. The reactor model equations, parameters, and method of calculation are given in Appendix A; the computer program is in Appendix C.

The temperatures of the inside tube surface and of the bulk gas are plotted against reactor length in Figure 2.5 for the base case. Also plotted is the degree of conversion at the tube surface and in the bulk gas. In the base case the inlet bulk temperature and the maximum tube wall temperature were 730°C and 880°C, respectively. The amount of heat absorbed by the sulfur oxide stream was 112 MW_t. It will be noted that the equilibrium SO_3 conversion, at the inner tube surface near the reactor inlet, is significantly greater than the conversion of SO_3 in the bulk gas leaving the reactor. Greater conversion of the bulk gas could be obtained if a higher tube wall temperature were permissible. Alternatively, it could also be obtained by increasing the effective tube length (having more than two tubes in series) if the total radiation flux were decreased to avoid exceeding the maximum tube-wall temperature. The effect of the former approach is discussed in Chapter VIII.

2. Heat Exchanger 1. In this heat exchanger, high-temperature gas exiting from the receiver/reactor gives up heat to the incoming reactor feed gas. The area required for the heat exchanger is determined by the temperature difference (ΔT_{5-6}) between the two streams. In the base case this was set at 140°C. In Chapter VIII of the report, effects of changes in this temperature difference are studied. The temperature of the SO_3 entering HE-1 from the vaporizer, T_4, is set by the pressure of the system; it is the boiling point of liquid SO_3 at 40 atmospheres.

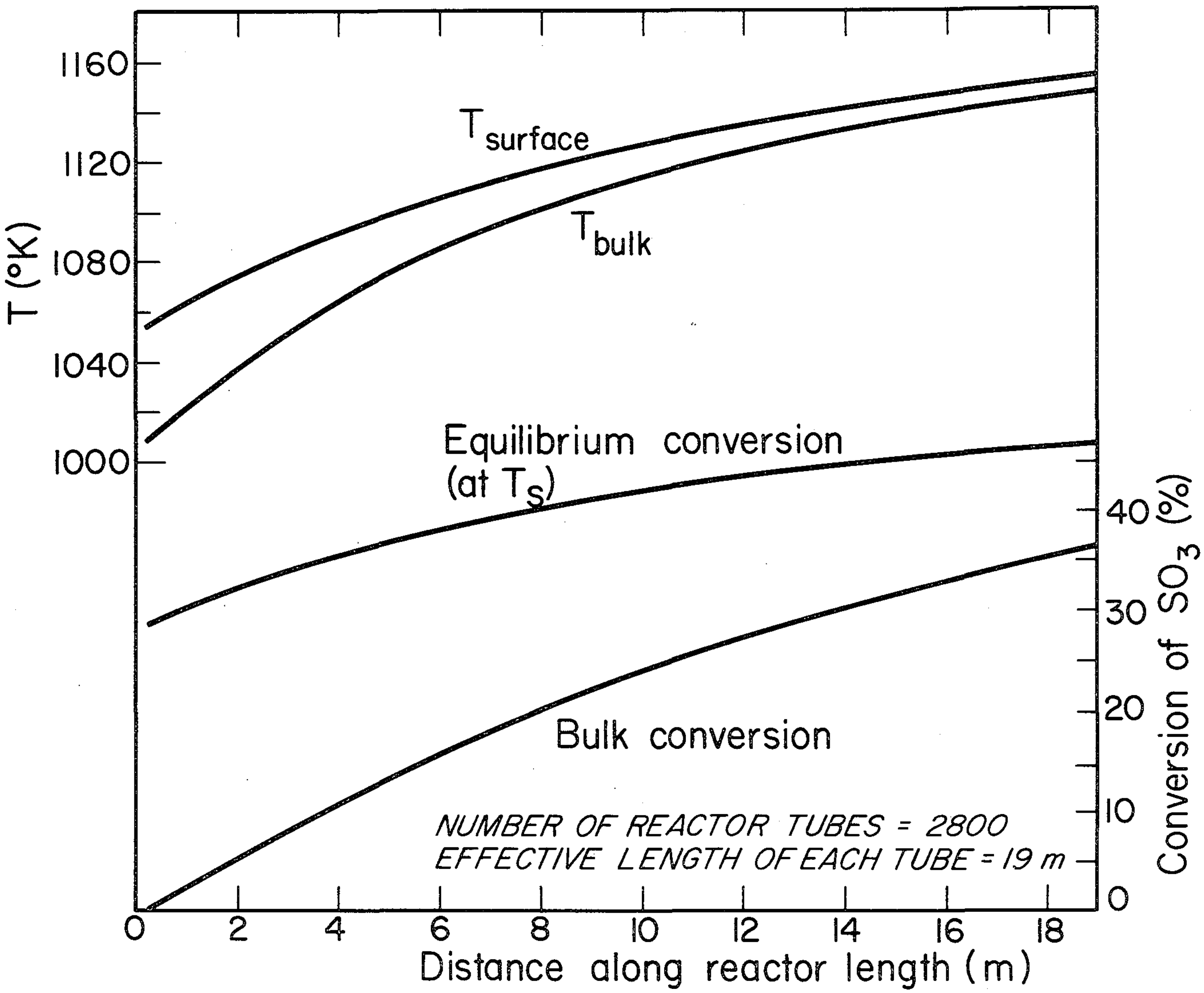

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Fig. 2.5. Temperature and conversion profiles along the reactor tubes.

The stream from the reactor leaves the exchanger at T_7, set by a heat balance around HE-1.

3. The Condensers: Condenser 1. The inlet temperature of the cool stream (T_2) is known from the SO_3 storage temperature and the temperature of the SO_3 recycle stream. The inlet temperature of the hot stream, T_7, is known from the HE-1 calculation. Thus the enthalpy, temperature, and the vapor/liquid split of the exit stream from the condenser may be calculated, using conventional condenser calculation techniques.

4. Reboiler. The gas stream from Condenser 1 flows through one side of this condenser. The other side acts as the reboiler for the SO_3-SO_2 distillation column. The exit temperature for the condensing side is set by the temperature approach (10°C) in the reboiler of the distillation column. This in turn sets the exit enthalpy and the vapor-liquid split for the condensing side. When the reboiler load exceeds the heat available in the process stream, the deficit is supplied by steam extracted from the turbines and fed to the make-up reboiler.

5. Boiler Feed Water Heater. This condenser supplies some of the heat required to preheat boiler feed water for the daytime power system. The rest of the heat must come from turbine steam extraction. The heat available in this unit, limited by the 10°C temperature approach, determines the ratio of power-to-storage heat input (see Chapter VII).

6. Trimmer. The system rejects some heat to the atmosphere through this cooler-condenser. The separation between oxygen and liquid sulfur oxides is completed here. Gas exiting from this unit goes to oxygen storage.

7. The Distillation Column. Liquids exiting from all four condensers are introduced into the distillation column. The column pressure is set at 10.8 atmospheres to allow condensation of the distillate at 60°C, the heat discharge temperature set for the base case. The liquid feed will partially flash when introduced. SO_3 (99% pure) leaves from the bottom and is recycled back to the high-temperature reactor. The distillate (99% pure SO_2) leaves from the top, going to the liquid-SO_2 storage vessels. The reflux rate was selected empirically because the operating lines are curved. Tray-to-tray calculations accounting for changes in the heat of vaporization confirmed the adequacy of this choice and showed that sufficient reflux was available to yield a normal pinch near the feedtray. The minimum reboiler heat duty was based on this reflux rate. Raoult's Law was used to calculate the vapor-liquid equilibria.

8. Make-up Reboiler. Additional heat for the reboiler is supplied by steam taken from the power system turbines and fed to this unit. It is desirable to minimize the steam extraction from the power system because the steam could be used to generate electricity. Storage-system designs that minimize the heat load on this unit and on the SO_3 vaporizer are preferable.

9. SO_3 Vaporizer. The SO_3 vaporizer uses heat from the parallel power plant, in the form of extraction steam, to convert the liquid SO_3 feed to the gas phase. There is no process stream with enough enthalpy, and at a high enough temperature, to vaporize all of the SO_3. Steam taken from the discharge of the intermediate-pressure turbines condenses at a convenient temperature for this purpose:

184°C, or approximately 12°C higher than the boiling point of the SO_3 stream. Hence SO_3 is vaporized by steam that has already performed work in the high- and intermediate-pressure turbines.

10. The Parallel Power Plant. This plant utilizes steam produced in the solar collector during the eight daylight hours. The turbine and steam cycle used are described in the next chapter, under "Electricity Generating System."

III. NIGHTTIME OPERATION: The Discharging System

A. General Description of Process

A detailed flow sheet for the low-temperature side, or discharging side, of the process is presented in Figures 3.1 and 3.2. Tables 3.1 and 3.2 give the stream conditions for the base case. The major process components are:

1) The Low-Temperature Reactors (LTR's): These five reactors are adiabatic beds packed with a supported V_2O_5 (vanadium pentoxide) catalyst, each followed by an adiabatic bed packed with a platinum catalyst. The reasons for this dual-bed design are detailed below.

2) LTR Heat Exchangers: The LTR heat exchangers are used to boil water and generate superheated steam at 144 atmospheres (2116 psi) and 35 atmospheres (510 psi), both at 538°C (1000°F). They have been arranged to obtain maximum steam generation per unit gas flow (0.354 kg of high-pressure steam per kg of SO_2-O_2 mixture processed), with a minimum of heat exchange area.

3) Electricity Generating System: A General Electric turbine design for high-back-pressure turbines has been modified for this system. The most important modification is the replacement of some steam extractions used for boiler feedwater preheat by process heat exchangers. The amount of steam fed to the low pressure turbines is thereby raised, increasing electricity production.

4) Heat Economizers: These units preheat boiler feedwater. They also preheat low-temperature reactor feed to the necessary ignition temperature of 420°C.

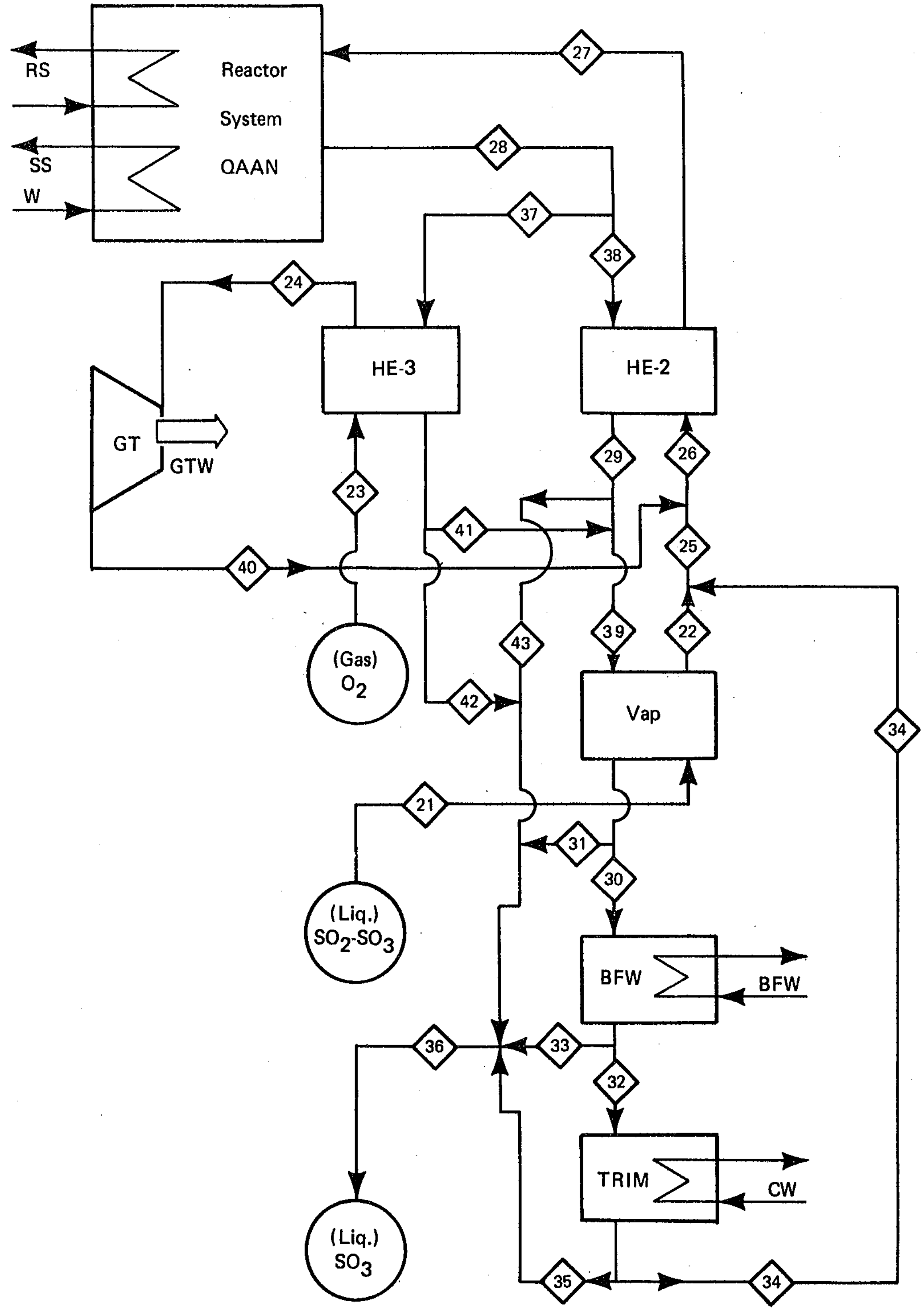

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Fig. 3.1. Flowsheet for the nighttime (discharge process).

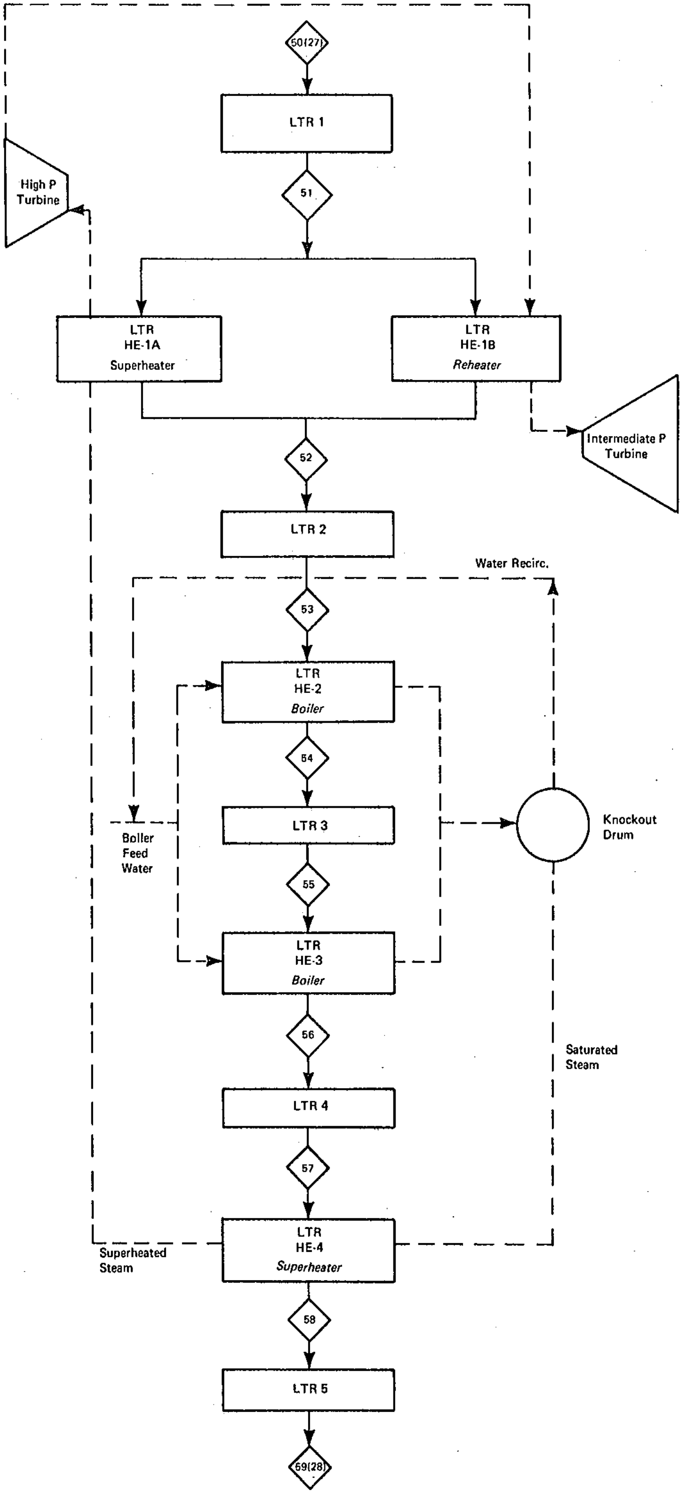

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Fig. 3.2. Low temperature reactor/heat exchange series.

Table 3.1. Stream conditions and heat duties for the nighttime operation of the low temperature side.

		Concentration (mole fraction)						
Stream No.	State	O_2	SO_2	SO_3	Temp. (°K)	Pressure (Bar)	Flow (kmol/s)	Enthalpy (MJ/kmol)
21	l	0.00	0.99	0.01	333.7	11.0	0.46	-17.81
22	g	0.00	0.99	0.01	333.7	11.0	0.46	1.46
23	g	0.80	0.18	0.02	333.0	40.0	0.29	1.12
24	g	0.80	0.18	0.02	573.0	40.0	0.29	9.30
25	g	0.01	0.99	0.01	333.7	11.0	0.46	1.46
26	g	0.32	0.67	0.01	354.7	11.0	0.76	2.14
27	g	0.32	0.67	0.01	693.0	11.0	0.76	16.37
28	g	0.01	0.07	0.93	777.1	11.0	0.52	30.95
29	g	0.01	0.07	0.93	400.8	11.0	0.42	5.62
30	g	0.01	0.09	0.89	382.0	11.0	0.28	4.48
31	l	0.00	0.03	0.97	382.0	11.0	0.24	-26.57
32	g	0.02	0.11	0.87	381.3	11.0	0.22	4.41
33	l	0.00	0.04	0.96	381.3	11.0	0.06	-26.61
34	g	0.71	0.11	0.18	333.0	11.0	0.01	1.22
35	l	0.00	0.11	0.89	333.0	11.0	0.21	-34.82
36	l	0.00	0.07	0.93	361.7	11.0	0.52	-30.18
37	g	0.01	0.07	0.93	777.1	11.0	0.10	30.95
38	g	0.01	0.07	0.93	777.1	11.0	0.42	30.95
39	g	0.01	0.07	0.93	400.8	11.0	0.52	5.62
40	g	0.80	0.18	0.02	396.2	11.0	0.29	3.20
41	g	0.01	0.07	0.93	400.8	11.0	0.10	5.62

Heat Exchanger Loads (MW_t)

HE-2	2.41	BWF	1.83
HE-3	10.76	Trimmer	8.36
Vaporizer	8.81	QAAN (heat available at night)	40.34
		Gas Turbine Work	1.80

Table 3.2. Stream conditions, heat loads, and conversion for the low-temperature reactor system.

Stream No.	Concentration (mole fraction) O_2	SO_2	SO_3	Temp. (°K)	Pressure (Bar)	Flow (kmol/s)	Reactor System (MJ/kmol)
50	0.32	0.67	0.01	693.0	11.0	0.76	16.37
51	0.22	0.48	0.29	1150.3	11.0	0.66	44.83
52	0.22	0.48	0.29	693.0	11.0	0.66	18.98
53	0.13	0.31	0.55	1016.3	11.0	0.60	42.06
54	0.13	0.31	0.55	693.0	11.0	0.60	21.36
55	0.06	0.17	0.76	912.2	11.0	0.55	38.59
56	0.06	0.17	0.76	693.0	11.0	0.55	22.32
57	0.02	0.09	0.90	815.4	11.0	0.53	33.43
58	0.02	0.09	0.90	752.3	11.0	0.53	28.80
59	0.01	0.07	0.93	777.1	11.0	0.52	30.95

Heat Exchanger Loads (MW_t)	
HE-1	17.16
HE-2	12.34
HE-3	8.41
HE-4	2.43
TOTAL	40.34

Reactor Conversions

$$\frac{\text{moles } SO_2 \text{ Converted}}{\text{moles } SO_2 \text{ fed}}$$

LTR-1	0.367
LTR-2	0.418
LTR-3	0.489
LTR-4	0.531
LTR-5	0.233

Total System Conversion = 0.932

B. Detailed Design Considerations

1. The Low-Temperature Reactors: Non-adiabatic reactors were considered before the decision to use adiabatic reactors was reached. Computer simulations showed, however, that the reaction was so fast, and heat transfer was so limited, that the system reached equilibrium conversion at a very small bed depth; the reaction occured almost adiabatically anyway. The reaction remained at equilibrium, temperature slowly dropping and conversion slowly increasing as heat was withdrawn. Because of this behavior, it seemed much more economical to use short reactor beds followed by heat exchangers, avoiding the problems associated with packed beds with tubes imbedded in them and decreasing the reactor volume and amount of catalyst required.

Each reactor actually consists of two reactors in series. The reason for this is the need to protect the V_2O_5 catalyst from thermal degradation. The first reactor is a very short bed of the vanadium catalyst, for which the exit temperature is 600^oC, and precedes a second bed of the high-temperature platinum catalyst, in which the reaction mixture achieves a 99% approach to equilibrium. Catalyst distributions are shown in Figure 3.3. The need for a platinum catalyst may be obviated, however, if the reactor feed contains appreciable amounts of SO_3, as would be the case were the distillation column not a part of the charging process. This process modification is discussed in Chapter VIII.

Platinum alone is not acceptable as a catalyst. The catalytic mechanism over Pt involves adsorption of the reactants, and this step is strongly temperature dependent [14,27]. Platinum gives an acceptable reaction rate only above 550^oC.

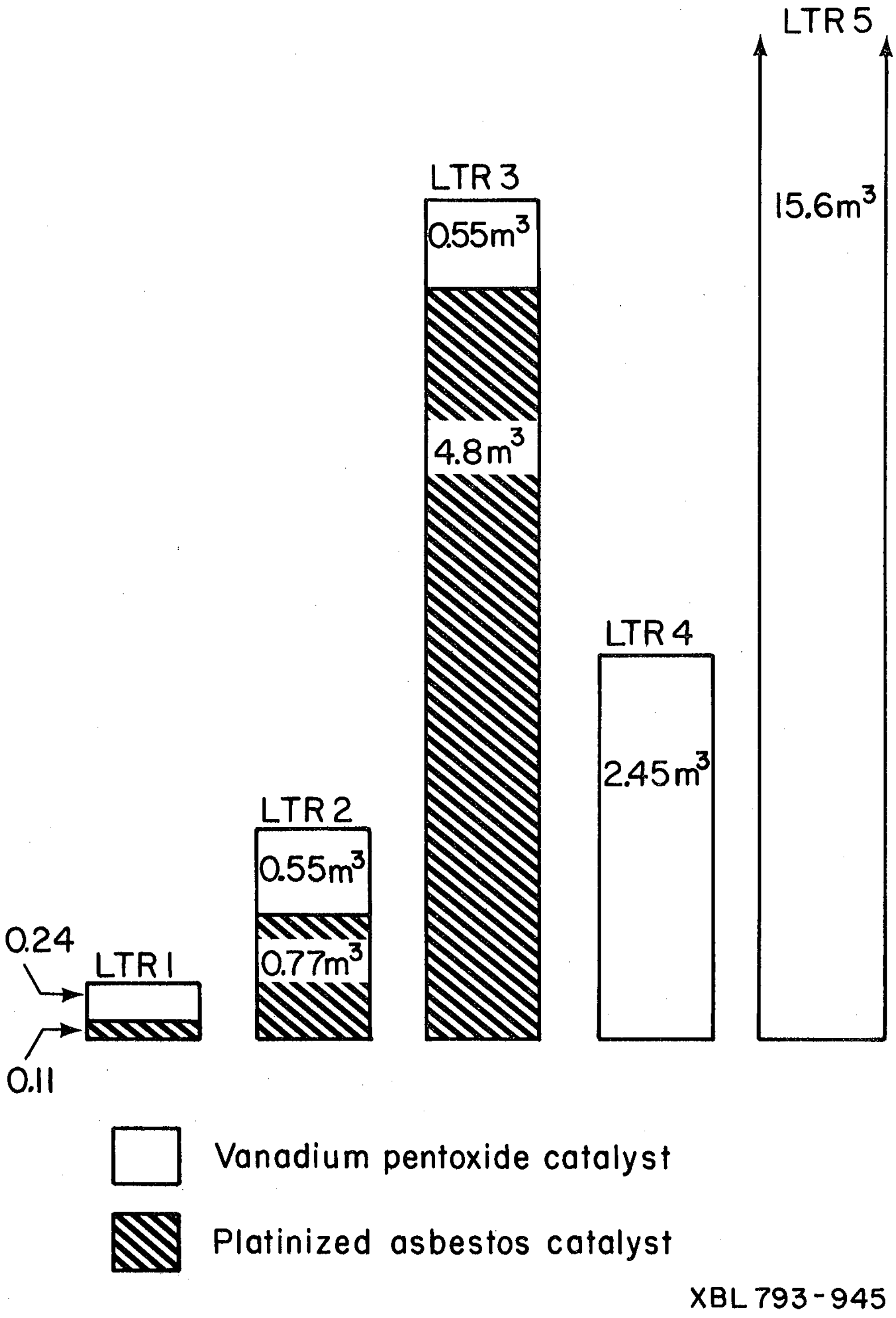

Fig. 3.3. Volume of low temperature reactor beds.

The vanadium beds were designed to achieve a temperature of 600°C, the maximum temperature for steady-state operation. The catalyst can withstand temperatures as high as 620°C for a short time. Thus there is some margin of safety: if the bed exit temperature exceeds 600°C, the bed inlet temperature may be decreased or the gas flow rate increased to return the exit temperature to the design point.

The platinum beds were designed for an inlet temperature of 550°C. This, too, includes a margin of safety. Fluctuations in flow rates and decline of the vanadium's activity with time may cause the temperature of the gas exiting from the vanadium bed to drop below 600°C. As long as the outlet temperature from the vanadium bed remains above 550°C, the length of the platinum bed is sufficient to achieve the designed level of final conversion. Reactors 4 and 5 never achieve a temperature of 600°C. Each consists, therefore, of only a single V_2O_5 packed bed; the high-temperature platinum beds are not required.

A computer program described in Appendix B has been developed in the course of this work to simulate a reactor bed packed with the vanadium catalyst. The most basic assumption of this program is that the kinetics, rather than heat and mass transfer, limit the reaction rate. The results indicate that such a bed achieves the ceiling temperature of 600°C very rapidly. The vanadium beds of Reactors 1, 2 and 3 are very short as a result. The total volume of V_2O_5 bed was estimated to be 0.84 m^3 per kg/sec of SO_2-O_2 mixture fed to the reactor sequence. This volume is based on a catalyst density of 680 kg/m^3. The actual volume may vary with catalyst density and approach to equilibrium, but these parameters have insignificant effect on total system cost.

2. LTR Heat Exchangers: LTR Heat Exchangers 1, 2, 3 and 4 perform the same functions that furnace boiler and superheater tubes serve in a conventional steam plant. The relative loads on the boiler, superheater, and reheater are fixed by the selection of turbine operation conditions.

All of the vapor generated by the boiler goes to the superheater. The amount of heat required to take the saturated vapor to the turbine inlet conditions is supplied in HE 4 and HE 1A.

The power system design calls for steam extractions between the various turbine stages to supply the additional heat required to preheat all of the boiler feedwater. Of the steam exiting from the high pressure turbine, 9.6% is extracted for this purpose. The flow rate within the steam reheater and the intermediate turbine is decreased to 89.8% of the flow through the superheater and the balance, 0.8%, is lost through seal leaks. Likewise, the flow rate through the low pressure turbine is reduced to 79% of the superheater flow. The ratios of the heat duties in the boiler, superheater, and reheater are 1.00/ 0.515/0.230.

The reactor/heat exchanger series may be designed graphically on a conversion-temperature diagram as shown in Figure 3.4. The heat exchanger duty is directly proportional to the length of the horizontal line representing it through the equation $Q=FC_p\Delta T$. Hence the reactor design consists of drawing diagonal lines representing the adiabatic reactors (the slope of these lines corresponds to the particular value of $-Cp/\Delta H_R$ at this reactor) and horizontal lines representing heat exchangers. The outlet temperatures of all the streams exiting the five reactors is determined by the reaction equilibrium. The first three streams are cooled in their respective heat exchangers to

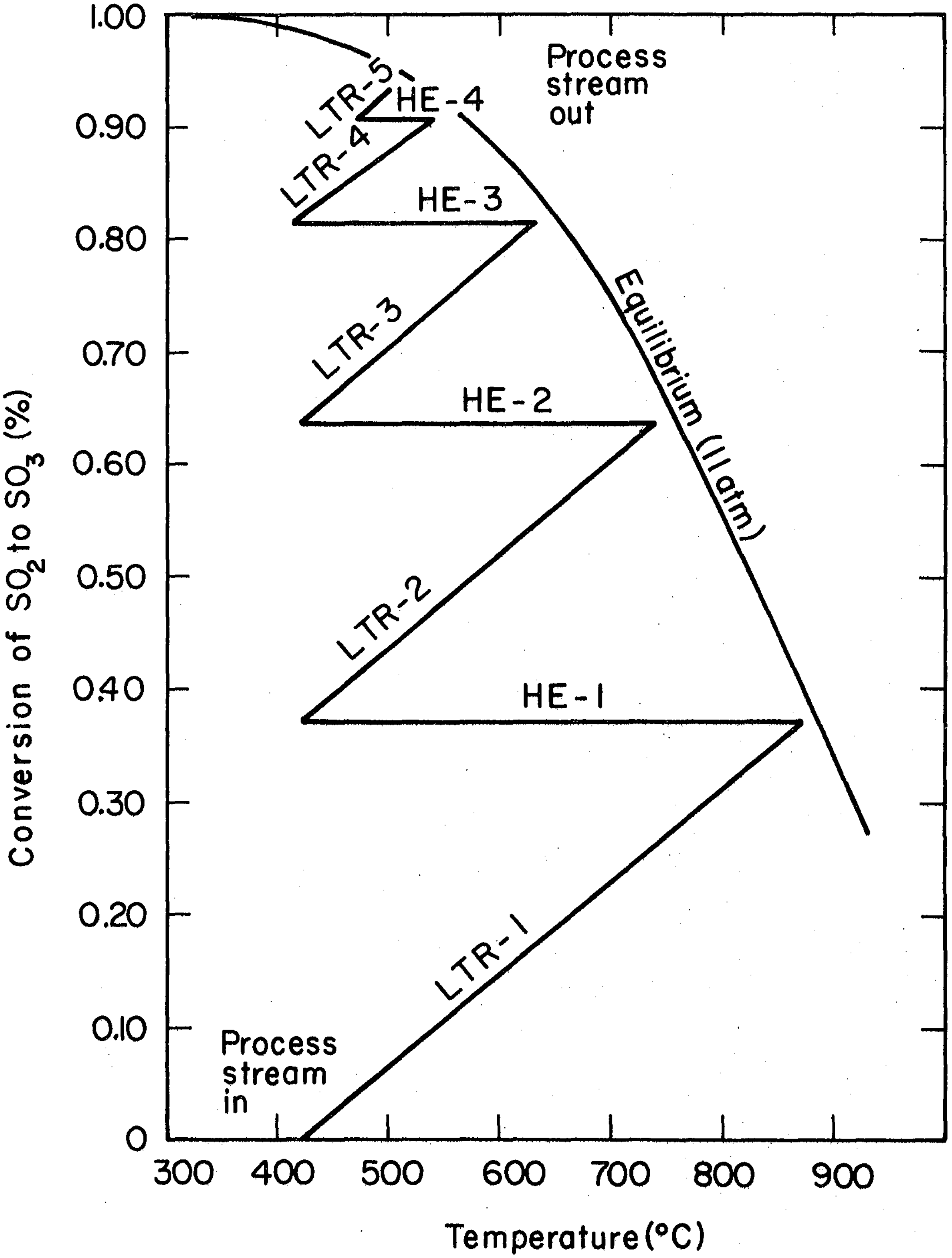

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Fig. 3.4. Conversion and temperature changes in the low temperature reactor system.

420°C. The fourth reactor exit stream, which is the inlet to the fifth reactor, is cooled to 474°C, a temperature selected so that the effluent temperature of Reactor 5 would be 500°C.

3. Electricity Generating System (Steam Turbines): A General Electric system designed for high back pressure [33] has been modified to meet the requirements of this system. The configuration is shown in Figure 3.5; stream conditions are given in Table 3.3. Stream conditions are essentially those of the G. E. design. Flows were determined from those of the G. E. design by ratio of the electric power produced in this application to that of the G. E. design.

Some of the boiler feedwater preheat necessary at night is provided by condensing SO_3 in the BFW heater (Figure 3.1). The rest is provided by steam extraction from the high and intermediate pressure turbines (Figure 3.5).

Design of the steam turbine system for the power plant is dependent on the rate at which the storage system is to be discharged and the strategy that is adopted for keeping the turbine system in standby condition when the rate of power generation is low. The amount of energy stored in the base case studied here is about 808 MW_t-hr after 8 hours of daytime operation. This is enough to operate the daytime steam turbine system at its rated capacity of 30.9 MW_e for only about 8 hours. Since operation of a steam turbine at a rate of about 50% of design capacity results in a substantial drop in efficiency, the choice of discharge program will affect the equivalent amount of electric storage materially.

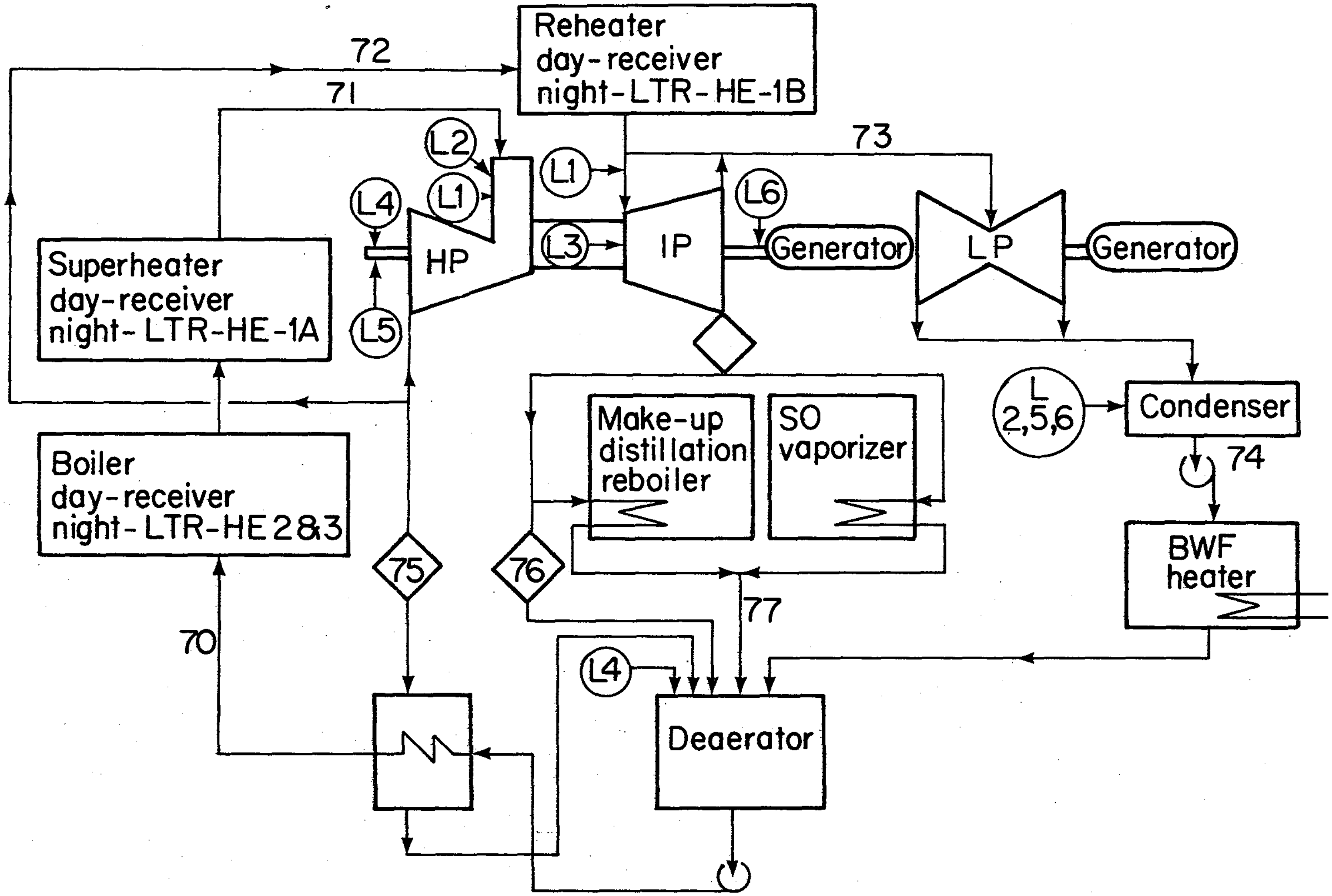

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Fig. 3.5. Steam power cycle.

Table 3.3. Flows and stream conditions in steam power cycle.

	Flow Rate, 10^3 lb/hr					
		Nighttime				
Stream No.	Daytime	Large Turbine	Small Turbine	Temp., °F	Pressure, psia	Enthalpy Btu/lb
70	335	5.9	108.8	455	494	457
71	335	5.9	108.8	1000	1800	1480
72	297	5.2	96.5	1000	459	1521
73	83	4.6	85.6	736	158	1394
74	84	4.6	86.0	141	3	109
75	32	0.6	10.5	679	510	1344
76	11	0.6	11.9	736	158	1394
77	206	0	0	363	153	335
Seal Leaks						
L1	0.39	0.01	0.13			
L2	0.1	0.00	0.04			
L3	3.38	0.06	1.10			
L4	1.30	0.02	0.42			
L5	0.47	0.01	0.15			
L6	0.52	0.01	0.17			
Power Generation (MW_e)						
	30.9	0	15.1			

Another factor of importance is the benefit to be derived by keeping the turbine system hot and turning when it is at standby. If the turbines are not kept hot, a start-up period of about 90 min will be required at the beginning of daytime operation. A flow of steam of about 3.5% of design rate was assumed to be required to keep a turbine in hot standby condition.

The strategy that was chosen here was to design a dual daytime steam turbine system, each having about the same electrical capacity. One would consist of a conventional set of high-, intermediate-, and low-pressure turbines and would operate with about one-third of the total steam flow during the day. The other would consist only of the high- and intermediate-pressure turbines. The steam discharged from this set, about two-thirds of the daytime total, is required for the vaporizer and reboiler in the storage system. This design results in a ratio of solar heat inputs to the power plant and storage receivers of 1.05.

During nighttime operation the conventional turbine system would be operated at its rated capacity for the entire night by steam generated from the storage system. The other turbine system would be kept on hot stand-by. This design strategy would result in the maximum generating efficiency for the base case. However, a different splitting of capacities might be chosen if it were preferable to discharge the storage system at a higher rate for part of the discharge period.

4. Heat Economizers (Vaporizer, HE-2, HE-3). These units make as much use of process heat as possible. They preheat boiler feedwater, preheat reaction feed, and vaporize SO_2 by exchanging heat with the SO_3 stream coming out of LTR 5 at 500°C. The heat exchangers have been

arranged so that the temperatures that the SO_3 stream first encounters in each economizer are always decreasing.

IV. STORAGE VESSELS

One problem associated with large-scale energy storage of any type is the enormous mass of storage medium that is required. Chemical storage presents several potential advantages over other systems, but perhaps the most important is the potential for less mass that must be stored [4].

In the sulfur oxide system a nighttime discharge of 15.1 MW_e lasting 16 hours (790 MW_t-hours storage) requires storage of 1704×10^3 kg of SO_2 and 636×10^3 kg of O_2. (This O_2 also contains 18% SO_2 and 2% SO_3) It requires daytime storage of 2370×10^3 kg of SO_3.

Sulfur dioxide and SO_3 are storable as liquids at ambient temperature. The storage volume for the amount of reactants indicated above is 1290 m^3 (SO_3 density at 38°C is 1.843 g/cm^3; thermal expansion of the liquid is neglected). Liquid SO_2 has a density of 1.356 g/cm^3, giving an SO_2 storage volume of 1260 m^3.

It has been suggested that joint storage of SO_2 and SO_3, using the same storage vessels for both, be utilized [5]. The basis for this suggestion is the fact that SO_2 and SO_3 need not be stored simultaneously; the same storage volume may be used for both. A joint storage system would be modular, as shown in Figure 4.1. One tank would be in the process of filling as another was being emptied. One disadvantage to this system would be the necessity of a complex manifold to distribute and collect the SO_x streams. Another apparent disadvantage is that of contamination. Neither stream, however, is expected to be chemically pure. Contamination by liquid adhering to storage tank walls will not be significant when compared to that caused by incomplete separation in the distillation column.

Oxygen must be stored as a gas. The pressure of oxygen storage should be optimized, playing the capital cost of high storage volume against the energy cost of compressing oxygen to a high pressure, plus the energy cost of reheating the oxygen when it expands to system pressure.

In this design the pumping of gases has been totally avoided. All pumping is done on liquids, with great savings in energy consumption. The pressure used for oxygen storage, therefore, will be the daytime operating pressure of 40 atmospheres.

At 40 atmospheres and 60°C, the storage volume for 636 x 10^3 kg of O_2 is 11,280 m^3. This is the volume of accessible oxygen that must be provided. A holdover volume of 11/40 times the total volume must also be provided if no pumping is to be done. Finally, additional storage volume is required because of the SO_2 and SO_3 content. Thus a total gas storage volume of 14,420 m^3 is required, and provision must be made for removing SO_2 liquid that may condense during storage.

A possible alternative to steel pressure vessels for storing oxygen is cavern storage. A large underground cavity is excavated and lined with steel to prevent leakage. The cavity is constructed at a depth of approximately 300 m. The depth is chosen so that the surrounding rock takes up all of the pressure in the system. The lining serves only to prevent contact between the gas and the rock.

It is difficult to evaluate the economy of this method of storage in this application. Cost estimates of between 5 and 25 dollars per cubic yard have been reported [30]; others range up to 300 dollars per cubic yard [22]. This last cost is still less than the cost of above-ground steel pressures vessels for the oxygen storage; thus it seems that cavern storage is a definite possibility in this case. More accurate estimates should be obtained in any continued investigation of this system.

Cavern storage becomes economical only for large volumes, and thus will not be economical for storage of the liquid SO_2 and SO_3. The volumes involved in storing these liquids are relatively small. Above-ground tank storage seems indicated for storage of these reactants.

Table 4.1 summarizes the information presented in this chapter.

Table 4.1 Reactant Storage

Reactant	Mass Stored	Volume Stored	Pressure	Method of Storage
SO_3	2370×10^3 kg	1,290 m^3	11 atm	mild steel vessel
SO_2	1704×10^3 kg	1,260 m^3	11 atm	mild steel vessel
O_2	636×10^3 kg	14,400 m^3	40 atm	underground cavern, steel lined

V. CATALYST EVALUATION

In this storage process, SO_3 dissociates at temperatures in excess of 700°C, and SO_2 and O_2 recombine at temperatures between about 400°C and 700°C. In both cases catalysis is required. Hill [14] has studied part of the extensive literature on the latter reaction, which is practiced industrially in the manufacture of sulfuric acid. Vanadium pentoxide is used below 600°C, platinum above. The kinetics of the reaction over both catalysts has been investigated. Hill used the results reported to size his heat-release reactors. The following literature references are cited in this thesis [7,11-13,15,16,18,28,32].

The dissociation of SO_3 is not practiced commercially. However, on thermodynamic grounds one would predict that a catalyst for the recombination reaction would also catalyze the dissociation. The only questionable aspect of this assumption would arise if the catalyst's physical characteristics were adversely affected by the higher temperature. V_2O_5, for instance, becomes appreciably volatile as the temperature approaches 700°C. Because platinum is expensive, a cheaper alternative would be preferred if it were sufficiently reactive. Iron oxide is a promising candidate because it was used in the now-obsolete Mannheim process. Westinghouse [25] studied the reaction over specular hematite and observed relative low reaction rates. Using pelleted Harshaw catalyst Fe-030IT, a finely divided Fe_2O_3 supported on alumina, Hill observed a significant reactivity at temperatures above 700°C. Hill's work was exploratory in nature and would need to be extended to obtain design data for a reactor.

VI. MATERIALS OF CONSTRUCTION

Hill [14] searched the literature for promising materials of construction for the reactor tubes within the solar receiver. Useful information was found in Refs. 1-3, 6, 21, 22, 29, 30. He found, as did Boeing [5], that Haynes 188 appears to be the most promising candidate for containing a stream of SO_3, SO_2, and O_2 at a pressure of 40 atm and a temperature of 880°C on one side and atmospheric air at a similar temperature on the other. The properties cited by Hill are listed below.

Haynes 188, a "superalloy" made by Union Carbide, contains 38% Co, 22% Cr, 22% Ni, and 3% Fe. In addition to having high-temperature tensile strength and oxygen resistance in common with several other alloys, Haynes 188 is expected to be resistant to attack by sulfur compounds to an extent that gives it a significant advantage over its competitors. It should be emphasized, however, that the project reported here did not involve any experimental work with Haynes 188.

VII. SYSTEM ENERGY ACCOUNTING, EFFICIENCY, AND COSTS

Information derived from the heat and material balances presented in earlier chapters is summarized here to display the important energy flows into, within, and out of the process. The efficiencies of storage and power production are derived from these energy flows. In addition, storage equipment costs are estimated and compared with the costs of other components of the solar power plant.

The calculations presented in this chapter are for the Base Case described in Chapter III. Many of the operating parameters used in this case were chosen rather arbitrarily. In Chapter VIII several of these parameters are varied individually in order to determine the changes in system efficiency and system costs that result.

A. Energy Accounting

An overall plant energy balance is given in Table 7.1. This energy balance is for the base case outlined in Chapters II and III for the process configuration of Figs. 2.1 and 3.1. The storage process is integrated with the power plant in this flowsheet: extraction steam from one of the power plant turbines is used to heat the reboiler and to vaporize SO_3, and low-temperature heat from the storage process is used to preheat boiler feed water during the daytime. The storage system generates steam to run the turbines at night. The relative sizes of the power plant and the storage process are set so that the make-up reboiler and SO_3 vaporizer completely consume all steam discharging from one of the intermediate-pressure turbines.

From Table 7.1 it is seen that the major energy dissipations to the environment are from the distillation column condenser and the

Table 7.1. Total Plant Energy Balance. Base Case.

	MW (e or t)	MW-hr (e or t)
I. Inputs (8 hours Daytime)		
Power Plant Receiver	117.8 (t)	
Storage Receiver	112.2	
	230.0 (t)	1840.0 (t)
II. Outputs		
A. Daytime (8 hours)		
Generator Terminals	30.9 (e)	
Parasitic Power		
BFW Pump	(0.4)	
SO_3 Pump	(0.5)	
Cooling System Power	(0.4)	
Net Power	29.6 (e)	236.8 (e)
Waste Heat		
Trimmer	6.52 (t)	
Dist. Condenser	57.03	
Turbine Steam Leaks	0.40	
LP Turbine Condenser	24.43	
Misc. Heat Losses	5.3	42.5
Total Waste Heat	93.68 (t)	749.5 (t)
B. Nighttime (16 hours)		
Generator Turbine (small turbine)	15.11 (e)	
Gas Turbine	.81	
Parasitic Power		
BFW Pump	(0.1)	
SO_2 Pump	(0.2)	
Cool. Syst. Power	(0.1)	
Net Power Prod.	15.5 (e)	248.3 (e)
Waste Heat		
Trimmer	8.36 (t)	
Small Turbine Condenser	24.74	
Large Turbine Bleed	2.10	
Net Night Out	35.20 (t)	563.2 (t)
Misc. Heat Losses	2.66 (t)	42.5 (t)
Total Output		1840.0 (e and t)

power plant condenser during daytime operation and from the trimmer and the power plant condenser during the night. Of these, only the loss from the distillation column can be appreciably affected by process modifications: that step in the process can be eliminated as described in Chapter VIII at the cost of the additional liquid storage required and the larger throughput during discharge of storage.

As noted above, the power plant and the storage process interchange heat at various temperature levels in order to improve the overall thermal efficiency. The heat balance for this storage system is given in Table 7.2. It is seen that there is a large requirement of steam heat to vaporize the SO_3 but that the boiler water preheat supplied by the storage system is small.

B. Efficiency Calculations

Three measures of process efficiency are used in this report to evaluate various aspects of the energy efficiency of the Base Case. These same efficiency indices are used in Chapter VIII to measure the response of the system to variations in several important design parameters. These indices, defined below, represent the overall system efficiency, the efficiency of the daytime power plant, and the efficiency of thermal energy storage. In addition, the ratio of the solar thermal inputs to the daytime power plant and the storage system necessary to minimize energy loss from the total system is an item of interest. The three efficiency indices are E_{OA}, the overall efficiency; E_{PP}, the daytime power plant efficiency; and E_{TS}, the efficiency of thermal storage. The following expressions were used to calculate numerical values for the efficiency indices:

Table 7.2. Storage system energy balance. Base Case.

Inputs	MW-hr
Daytime	
Solar Receiver	897.6 (t)
SO_3 Vaporizer	421.2 (t)
Makeup Reboiler	90.1 (t)
Liq. SO_3 Pump	4.0 (e)
Total Input	1412.9
Outputs	
Daytime	
Boiler Feed Preheat	12.5 (t)
Distillation Column	456.2 (t)
Trimmer	52.2 (t)
Daytime Total	520.9
Nighttime	
Boiler Feed Preheat	29.3 (t)
Trimmer	133.7 (t)
LT Reactors (QAAN)	645.4 (t)
Gas Turbine Work (isentropic expansion)	14.4 (e)
Nighttime Total	822.8
Total Output	1343.7

$$E_{OA} = \frac{P_{Day}\cdot\theta_{Day} + P_{Sto}\cdot\theta_{sto}}{(Q_{PR} + Q_{SR})\,\theta_{Day}}$$

where

P_{Day} = Net power produced by daytime power plant (MW_e)

P_{Sto} = Net power produced from storage (MW_e)

θ_{Day} = Duration of daytime operation (hr)

θ_{Sto} = Duration of storage discharge operation (hr)

θ_{PR} = Rate of thermal input to power plant receiver (MW_t)

θ_{SR} = Rate of thermal input to storage receiver (MW_t)

In this simplified expression the thermal inputs and power outputs are assumed constant for the time periods of operation. If these rates are not constant, appropriate integrals would be used.

Low- and intermediate-temperature heat is exchanged between the power plant and the storage system. In discussing the energy efficiencies of the two separately one must therefore arbitrarily "credit" and "debit" the two operations for the heat that is supplied by the one to the other. The power plant efficiency then becomes

$$E_{PP} = \frac{P_{Day}\cdot\theta_{Day}}{(Q_{PP} + Q_{BFW} - Q_{VAP} - Q_{REB})\,\theta_{Day}}$$

where

Q_{BFW} = Rate of heat transfer to boiler feed water (MW_t)

Q_{VAP} = Rate of heat transfer to SO_3 vaporizer (MW_t)

Q_{REB} = Rate of heat transfer to distillation column reboiler, (MW_t)

The thermal storage efficiency is defined as the ratio of usable heat delivered by the storage system to the heat input to the storage system

$$E_{TS} = \frac{\sum Q_{Sto} \cdot \theta_{Sto}}{(Q_{SR} + Q_{VAP} + Q_{REB} - Q_{BFW})\ \theta_{Day}}$$

where

$\sum Q_{Sto}$ = Sum of rates of heat transfer to power plant system from storage discharge (MW_t).

The overall efficiency, E_{OA}, is simply the second-law efficiency for the total operation, the net total electric energy produced divided by the total thermal energy absorbed by the solar receiver tubes. The definition of E_{OA} is uncomplicated; however, because it combines the daytime power production with the production from storage, its use does not reveal where losses in efficiency occur. The other efficiencies, E_{PP} and E_{TS}, have therefore been defined in a way intended to show the behavior of the separate parts of the integrated operation.

The allocation of energy between the daytime power plant and the storage system is of necessity arbitrary, since the two are integrated to achieve near maximum combined performance. Energy is transferred from the power plant to the storage system by the steam used to vaporize SO_3 and to heat the reboiler. That heat is subtracted from the heat input to the daytime power plant in defining E_{PP} and is added to the heat input to the storage system in defining E_{TS}. Conversely, the storage system provides boiler feed water preheat for the power plant both during the day and during the night. Hence the Q_{BFW} term is added to the heat input to the power plant in defining E_{PP} and subtracted from the heat input in defining E_{TS}. This method of energy allocation tends to make the values of Epp appear high because the electricity generated by the steam sent to the storage system "costs" the power plant only the enthalpy that is converted into electrical work and not the heat that would normally be discharged to the environment in the power plant condenser.

The thermal storage efficiency, E_{TS}, represents the fraction of the heat input to the storage system that is released when the storage system is discharged. The steam generated when the storage system is discharged is used in part to generate power and in part to keep some of the daytime turbines on hot standby. The arbitrary distribution between these uses makes it difficult to define a useful index of nighttime power efficiency.

Values of these efficiencies may be calculated from data presented in Tables 7.1 and 7.2.

$$E_{OA} = \frac{(29.6)8 + (15.5)16}{(230)8} = 0.26$$

$$E_{PP} = \frac{(29.6)8}{(117.8)8 + (12.5 - 421 - 90)} = 0.53$$

$$E_{TS} = \frac{645 + 29 + 134}{(112.2)8 - (12.5 - 421 - 90)} = 0.58^*$$

---

*No credit taken for gas turbine work at night and no debit included for the SO_3 pump during the day. These are small quantities.

The value of E_{TS} is telltale. Only 58% of the net thermal input to the storage system is actually stored as heat of reaction. The rest is dissipated as unuseable low-temperature heat transferred to the environment. From Table 7.2 it is apparent that most of this loss occurs in the condenser of the distillation column. This relatively low storage efficiency is the principal cause of the low overall efficiency (E_{OA} = 0.26%). If the daytime power plant were operated by itself, its efficiency would be about 40%.

C. System Costs

Estimates are made here of the cost of installed, functioning equipment; such costs include the cost of connecting process piping, control systems, electrical connections, etc. No plant site auxiliaries such as roads, fences, rail lines, etc. are included. All costs are adjusted to June 1978 by indices published in Chemical Engineering.

Some fabricated equipment costs were determined from the weight of material used and a price stated in $/kg. The price for fabricated thick-wall pressure vessels made of carbon steel is $3.20 per kg [7] and 4.25 times this when made of 316 stainless steel [9], or $13.50 per kg. In these cases, the cost of installation has been taken to be 140% of the fabricated cost [Peters and Timmerhaus, 34]. That is, the cost of in-place equipment is 2.4 times the fabricated equipment cost.

1. The Tower, Receiver, and Mirror Field

The cost of these items is probably the greatest source of uncertainty in the entire design. Nothing even remotely resembling the equipment used in this design has ever been built on this scale.

The cost of these items is not important, however, in choosing between alternative solar storage system designs; almost all proposed designs may be assumed to have the same tower costs per unit of heat absorbed by the storage system. Estimated costs are reported here for the purpose of placing the storage system in perspective.

The Boeing Company [5] has estimated the cost of a heliostat field, tower, and receiver having a 230-MW net thermal output to be about \$40.5 million in mid 1976. In mid 1978, the cost would be

$$40.5 \left(\frac{217.9}{192.1}\right) = \$46 \text{ million}$$

This figure is probably low because the heliostat cost was taken to be \$60 per m^2, a cost well below that presently obtainable.

2. Turbines

The installed cost of a General Electric 100 MW_e high back-pressure turbine has been estimated to be between \$6 and 6.5 million dollars. This estimate is based upon the recent experience of G. E. in the construction of similar turbines. The cost quoted includes support equipment such as boiler feed pumps, control equipment, etc. For the base case, the turbine system consists of two turbines, each of about 16 MW_e capacity. In the absence of definitive information about scaling turbine costs, we have taken turbine costs to vary as the 0.6 power of rated capacity. Such an approach gives a total turbine cost of \$4 million (2 turbines).

3. Distillation Column

The column has been sized with 16 ideal trays and a reflux ratio of 2.1. Limiting vapor flow rates were estimated to be 0.63 m/sec using equations presented by Treybal [26]; the design was based on 85% of the limiting velocity. Application of the general rules for design of bubble cap tray columns presented in the same work resulted in the following column dimensions:

Distillation Column

Number of trays: 16 Theoretical, 23 actual
Tray spacing: 0.46 m
Downcomer area: 1.8 m^2
Tray area: 13.1 m^2
Tower diameter: 4.4 m
Tower height: 10.6 m
Shell thickness: 0.01 m

Fabricated cost (ss): $0.46 million

Installed cost (including piping, instrumentation, etc): $0.61 million

Cost estimates were made by the method of Pikulik and Diaz [19]. This tower cost does not include the reboiler or distillate condenser. These will be included with the other heat exchangers in the next section.

4. Heat Exchangers

Detailed calculations involving the estimation of individual heat transfer coefficients, mean temperature driving forces, and pressure drops were carried out in sizing each exchanger. Costs were estimated from Popper [37] according to a general cost equation of the following form.

$$\text{Cost} = \begin{pmatrix}\text{Base}\\ \text{Cost}\end{pmatrix}\begin{bmatrix}\text{Material} & + & \text{Installation}\\ \text{Factor} & & \text{Factor}\end{bmatrix}\begin{pmatrix}\text{Pressure}\\ \text{Factor}\end{pmatrix}\begin{pmatrix}\text{Cost}\\ \text{Index}\end{pmatrix}$$

The base cost pertains to equipment made from carbon steel and is determined from Popper's data according to the heat exchange area needed. The exchanger material required in this process is stainless steel, for which the material factor is 4.5. The installation factor was taken to be 1.3. Table 7.3 summarizes the sizes and costs of all heat exchangers. These costs represent the cost of equipment in place including interunit piping, electrical connections, and control systems. More detailed information about the heat exchanger designs is available in Hill [14].

5. Storage

The calculations giving the volumes of the SO_2/SO_3 and the oxygen storage are described in Chapter IV. The SO_2 and SO_3 are stored as liquids jointly in a number of spherical tanks. The thickness of each tank is determined by the diameter of the tank and by the 10-atmosphere pressure differential across the tank wall. The storage vessel costs were based on the basic \$3.20-per-kg price for equipment fabricated from carbon steel plus about 140% for installation.

The total installation and material cost of 23 spherical (mild steel) vessels 4.94 m in diameter and 1.33 cm thick is \$0.86 million. The total volume of these vessels is 1452 m^3, which represents storage of 2.4×10^6 kg of SO_3.

A precise cost estimate for the oxygen storage is difficult. Cavern storage cost estimates range from \$6.5/m^3 to \$390/m^3 [22]. These rates correspond to a storage price ranging from \$0.1 to \$5.8 million for a cavern volume of 14,900 m^3. The extremes in the price range correspond to extremes in the construction; the low price is for very large reservoirs constructed not too far underground. The high price is associated with small, deep caverns. A cavern cost of

Table 7.3. Heat Exchanger Sizes and Costs.

Unit	Heat Duty (MW_t)	Heat-Transfer Area (m^2)	Installed Cost ($K)	
HE-1	110.8	2,642	1,753	
SO_3 Vaporizer	52.6	619	438	
Preheater	44.9	743	507	
Reboiler	45.2	1,131	812	
Make-Up Reboiler	11.3	285	250	
Dist. Condenser	57.0	1,633	813	
				Charge Mode $5,483 K
CFW Heater	1.56	235	170	
Trimmer (Air Cooled)	6.5	767	740	
HE-2	10.8	4,284	2,142	
HE-3	24	425	340	
SO_2 Vaporizer	8.8	129	135	
LTS BFW Heater	1.8	159	145	
LTS Trimmer (Air Cooled)	8.4	825	453	
LTR HE1-A	10.1	356	241	
LTR HE1-B	7.1	206	176	
LTR HE-2	12.3	143	137	
LTR HE-3	8.4	130	132	
LTR HE-4	2.4	116	118	Discharge Mode
			$9,502K	$4,019K

\$200/m^3 will be used in these calculations because the cavern used for oxygen is at neither extreme. It is assumed that the excavated cavern will be lined with mild steel sheets (about 1/4-in. thick) supported by the rock wall and concrete poured between the wall and the lining. A rate of \$200/m^3 corresponds to a cavern cost of \$3.0 million. Further experience of the industry with the excavation of caverns for fluid storage may eventually yield better estimates.

6. Reactors and Catalysts

The low-temperature reactors represent a relatively small investment when compared with other major process equipment. They have a total volume of 29.2 m^3 divided between five vanadium beds and three platinum beds. If the total pressure drop across all eight beds is limited to one atmosphere, pressure-drop calculations using the Ergun correlation [18] reveal that a minimum cross sectional area of 8.3 m^2 is required.

Typical sulfur dioxide oxidizing reactors have one or two shells with trays in them that support the catalyst. Partially reacted gas is withdrawn between stages, cooled in heat exchangers, and returned to the reactor. A possible configuration for the low-temperature reactors in this system utilizes two shells: one shell containing LTR 5 (a reactor volume of 18.2 m^3), and the other shell containing all of the other reactor beds. For estimation of the cost of these reactors, the following assumptions were made: for shell 1 (LTR's 1 through 4), the shell thickness is 3.33 cm; the partitions between beds are steel sheets 1.0 cm thick; and spaces of 25 cm on each side of each partition are empty of catalyst and are needed for gas distribution. For shell 2, the shell thickness is 2.6 cm. Hence the total volume in shell 1 is 23.7 m^3, and the total volume in shell 2 is 18.2 m^3. The cost of shell 1 is $205,000, and the cost of shell 2 is $117,000, based upon the weight of metal used. Installed cost is 2.4 times the fabricated cost and thus is $772,000.

Vanadium pentoxide catalyst costs vary depending upon the quantity purchased, the manufacturer, support used, etc. The total mass of supported V_2O_5 required for the low-temperature reactors is 15,400 kg. Vendor-supplied cost data indicate that this much catalyst would cost approximately $38 K, not including installation.

Price data for platinum catalysts were more difficult to obtain than for the vanadium. For the purposes of this estimate, the catalyst cost was assumed to be the cost of the platinum metal plus 10% for catalyst processing.

The platinized asbestos catalyst, which has a platinum concentration of 7% by weight, contains a total of 11.32 kg (364.0 troy oz) of platinum. The market price of platinum is currently $320 per troy ounce. The total cost of the platinum catalyst is calculated to be $128K.

A credit for platinum recovery may be claimed for this catalyst. Ninety per cent of the platinum will be recovered. If the cost of platinum inflates at the same rate as other costs, this platinum will not decrease in value. The full value of the reclamation credit may be claimed; this credit is $115 K. The net cost of the platinum catalyst is therefore $13 K.

The cost of the high-temperature reactor tubes is assumed to be included in the $42.3 M spent for the receiver and mirror field. This cost is also assumed to include the cost of the Fe_2O_3 catalyst used, and the cost of applying it to the inner surface of the collector/reactor tubes. While the cost of this operation is difficult to estimate, it is felt that the added cost will have little effect on the cost of the receiver.

7. Reactants

The most economical form in which to ship the system reactants to the project site is as liquid SO_3. Shipping the SO_3 eliminates the need of transporting large volumes of high-pressure oxygen. A very large mass of SO_3 is required: 2.4×10^6 kg of SO_3 is stored in one day.

Cost data for large quantities of liquid SO_3 were not readily available. The assumption was made that such a large volume of SO_3 could be obtained at about the same cost per kg as for SO_2. This assumption is supported by the observation that, even if such large-scale manufacture of SO_3 does not currently occur, a conventional sulfuric acid plant could be made over with relatively minor changes into an SO_3 plant. Furthermore, if this form of energy storage is seen as economical, construction of a grassroots SO_3 plant to supply SO_3 for a number of solar power plants may be feasible.

Chemical Marketing Reporter for June 1978 reports that the average cost for liquid SO_2, when purchased by the tank, is \$148/ton. This corresponds to a total reactant cost, assuming the same cost for SO_3, of \$364 K.

8. Dry Cooling Tower

Design of the dry cooling tower is beyond the scope of this report. The cost of this piece of equipment was estimated very roughly for a

"Heller" dry cooling system using $40^{o}F$ ITD. The updated costs come to \$30,600 per MW of heat load. This corresponds to a cost of \$747 K for a tower for the 31 MW_e power plant (24.4 MW_t) by itself, or \$2,690,000 for the tower for the combined power and storage systems (63.5 MW_t for the trimmer and the condenser of the distillation tower, or approximately 87.9 MW_t total).

D. Summary of Costs

1. Entire Power Plant-Storage System

Costs for all equipment by major category are summarized in Table 7.4. The cost of the storage process equipment is seen to be about 24% of the total plant cost. Heat exchangers are responsible for most of the storage equipment costs owing to the large areas required. The cost of the oxygen and sulfur-oxide storage vessels must be viewed with respect to the amount stored; in this base case, the oxygen and sulfur dioxide would supply about 8.3 hours of power at the 31 MW_e nominal load.

2. Incremental Cost of Storage

It is of interest to estimate the amount by which the total plant cost is increased owing to the presence of the storage system. In making this estimate, it is necessary to account for the increased cost of heliostats, tower, receiver, and cooling tower system needed for the storage system heat requirements.

For purposes of this estimate, the incremental costs of heliostats, tower, and receiver are taken to be proportional to the thermal input. A stand-alone 31 MW_e solar power plant operating at 40% efficiency (dry cooling conditions) would need 77.5 MW_t input. Thus, by using

Table 7.4. Plant Cost Summary

Heliostats, Tower, and Receiver		$46.0 M
Turbine Generators		4.0
Dry Cooling Tower		2.7
		52.7
Chemical Storage System (244 MW_e-hr)		
Heat Exchangers	$9.5 M	
Distillation Column	0.6	
Low Temperature Reactors and Catalyst	0.8	
Reactants	0.4	
Storage Vessels		
O_2 (steel-lined caverns)	3.0	
SO_x (mild steel tanks)	0.9	
Total Storage Equipment	$15.2 M	$15.2 M
TOTAL Power plant with storage system		$67.9 M

the \$46 million cost for a 230 MW_t heliostat-tower-receiver system, the incremental cost of this equipment is

$$46\left(1 - \frac{77.5}{230}\right) = \$30.6 \text{ million}$$

The dry cooling system incremental cost is also taken in direct proportion to the cooling heat load. Calculations accounting for changes in steam cycle flows upon displacement of the storage system gave an incremental cost of \$1.8 million. There is an additional cost associated with the steam turbine because it has been split into 15 MW_e and 16 MW_e turbines, resulting in an increase of perhaps 20% in cost over a single 31 MW_e turbine.

The incremental cost of storage is thus the sum of the following four items.

Storage system equipment	\$15.2 M
Heliostat-tower-receiver	30.6
Dry cooling system	1.8
Turbine split	7
Total Incremental Cost	\$48.3 million

3. Cost of Power

An estimate of the cost of electric power per kW-hr produced by the solar plant and the sulfur-oxide storage system may be obtained by deciding on a capitalization rate and an on-stream factor. The capitalization rate for the non-storage equipment is taken at 18%, 3% higher than the 15% used by Skinrood, et al. [35]. The higher rate acknowledges increased maintenance costs attributable to the presence of SO_x and O_2 in the receiver tubes. An even higher rate is taken for the storage equipment to account for maintenance costs due to corrosion. Peters and Timmerhaus [34] cite maintenance costs for high corrosion conditions of about 10%/year; we thus take the storage equipment capitalization rate to be 25% per year. The number of full capacity operating days is assumed to be 256 per year.

The cost of power is thus calculated to be

$$\text{cost} = \frac{[46.0 + 4.0 + 2.7](0.18) + [15.2](0.25)}{256[8\{30.9 - 0.4 - 0.5 - 0.4\} + 16\{15.1 + 0.8 - 0.1 - 0.2 - 0.1\}]}$$

$$= \$1.07 \times 10^{-4}/\text{W-hr}$$

$$= 107 \text{ mils/kW hr}$$

Similarly, the incremental cost of power produced from stored heat is

$$\text{cost} = \frac{[48.3 - 15.2](0.18) + [15.2](0.25)}{256[16\{15.1 + 0.8 - 0.1 - 0.2 - 0.1\}]}$$

$$= \$1.53 \times 10^{-4}/\text{W-hr}$$

$$= 153 \text{ mils/kW-hr}$$

CHAPTER VIII. SENSITIVITY ANALYSIS

In the base case presented in Chapters II and III the energy and material balances for the chemical energy storage system were calculated for a specific set of operational parameters. This chapter discusses the response of the system to variations in the most important of these parameters. Their number is too great to permit investigating the effects of varying two or more of them simultaneously. However, the response of the system to the individual parameters may be used to try to select a more nearly optimum set than was chosen for the base case.

A. Parameters Varied

The parameters selected for this study were:

1) The maximum tube-wall temperature in the solar reactor--the value of 880°C, chosen for the base case, may prove to be the highest practicable temperature, but it is instructive to be aware of the rewards and penalties associated with higher and lower values.

2) The temperature rise through the solar reactor--this is also the temperature difference, ΔT_{5-6}, at the hot end of the heat interchanger, HE-1. Reducing ΔT_{5-6} from the 140°C used in the base case not only increases the size needed for HE-1 but also influences the heat balance within the reactor.

3) The pressure in the solar reactor--pressures both above and below the 40 bar chosen for the base case were studied.

4) The temperature level of heat discharge to the environment, T_{min}--the value of 60°C used in the base case as the lowest temperature that could be reached by the system is a conservative estimate suitable for a hot desert location. Lower temperatures would be possible at many times of the year in most sites.

Two other process modifications were also studied--elimination of the distillation column for separating SO_2 and SO_3 during daytime operation and dissipating low-level heat to the environment instead of using it to heat boiler feedwater. The former step saves the energy input to the reboiler, but the SO_2 produced is diluted with a substantial quantity of SO_3. The latter step results in some reduction in overall efficiency, but makes sizing of the power plant and the storage systems relatively independent of each other.

B. Restatement of Efficiency Indices

The three efficiencies defined in Chapter VII are used here as measures of the response of the system to variations of the parameters mentioned above. These efficiencies are:

Overall (2nd-law) Plant Efficiency

$$E_{OA} = \frac{P_{DAY} \cdot \theta_{DAY} + P_{STO} \cdot \theta_{STO}}{(Q_{PR} + Q_{SR})\,\theta_{DAY}}$$

Daytime Power Plant Efficiency

$$E_{PP} = \frac{P_{DAY} \cdot \theta_{DAY}}{(Q_{PP} + Q_{BFW} - Q_{VAP} - Q_{REB}) \cdot \theta_{DAY}}$$

Thermal Storage Efficiency

$$E_{TS} = \frac{\sum Q_{STO} \cdot \theta_{STO}}{(Q_{SR} + Q_{VAP} + Q_{REB} - Q_{BFW}) \cdot \theta_{DAY}}$$

C. Effect of Tube-wall Temperature

Figure 8.1 shows the response of the system indices to variations in the maximum allowable tube-wall temperature. For reasons that are discussed below, the ratio Q_{PP}/Q_{SR} was set at 1.05 for this and the following parameter studies. The surprising result, shown in Fig. 8.1, is that E_{OA} is nearly independent of the value of $T_{w\ max}$, increasing only about 1.5 percentage points for an increase of 100^o. The slightly greater increase in Epp is illusory. With the higher value of $T_{w\ max}$ there is a greater conversion of SO_3 in the storage reactor. As a result, the quantity of SO_3 fed decreases, since the total thermal input to the reactor is kept constant. A larger fraction of this thermal input is absorbed by the chemical reaction and a smaller fraction is converted to sensible heat of the reactor effluent. The reduced sensible heat flow means that more steam must be taken from the power plant for the vaporizer and reboiler, which increases the value of Epp. E_{TS} increases with $T_{w\ max}$ because of the increased conversion of thermal input to chemical energy.

D. Effect of Temperature Rise in the Reactor, ΔT_{5-6}

Figure 8.2 shows the response of the system to the temperature rise in the reactor, with $T_{w\ max}$ kept constant. Increasing ΔT_{5-6} thus implies a decrease in the feed temperature at the inlet to the reactor and an increased ΔT throughout the heat interchanger HE-1. The larger heat-transfer driving force reduces the area required for HE-1 correspondingly. Increasing ΔT_{5-6} also means that a larger fraction of the heat absorbed by the gas stream is used to increase the sensible heat of the stream, and a smaller fraction is converted to chemical

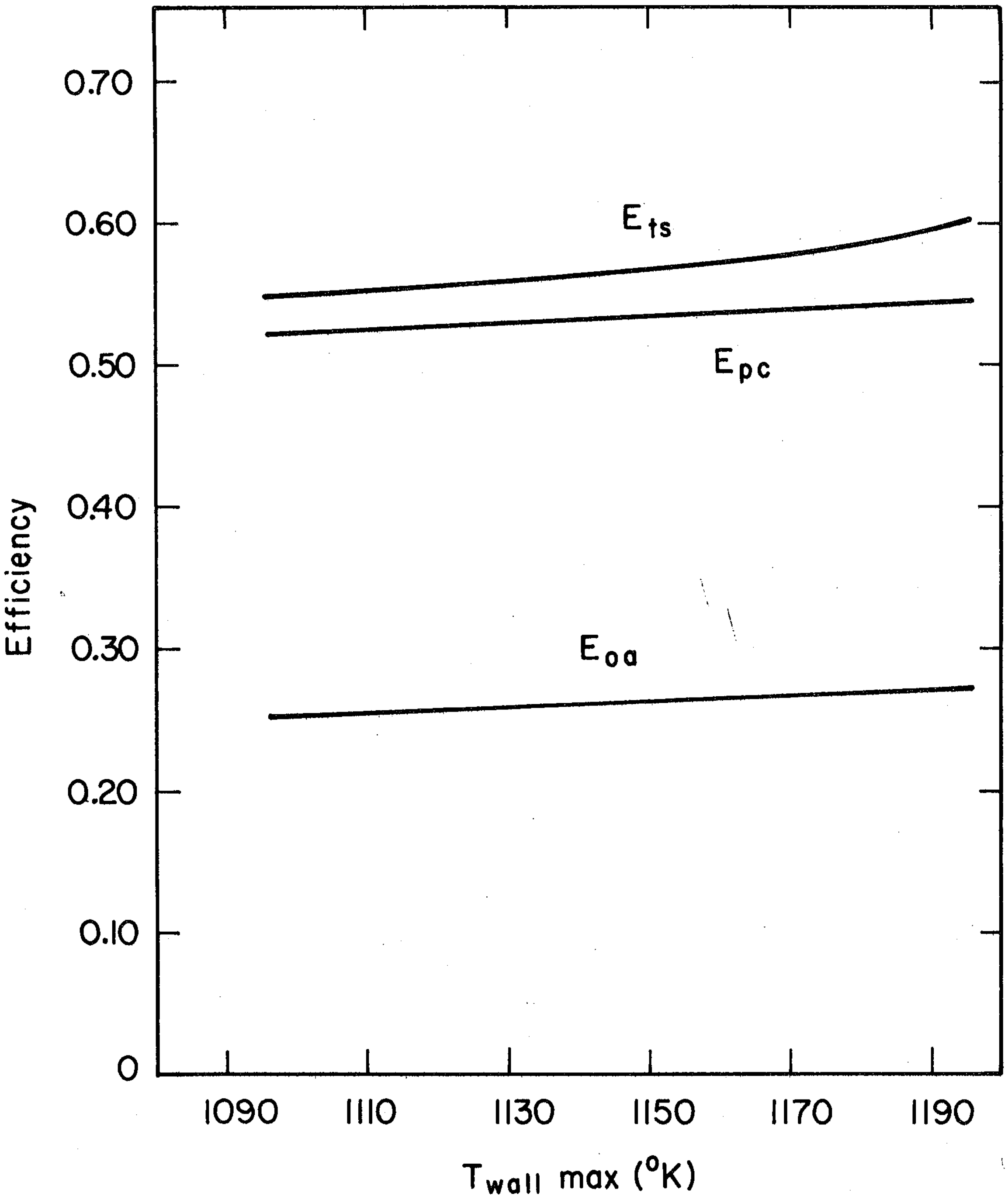

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Fig. 8.1. Efficiencies vs. maximum reactor wall temperature.

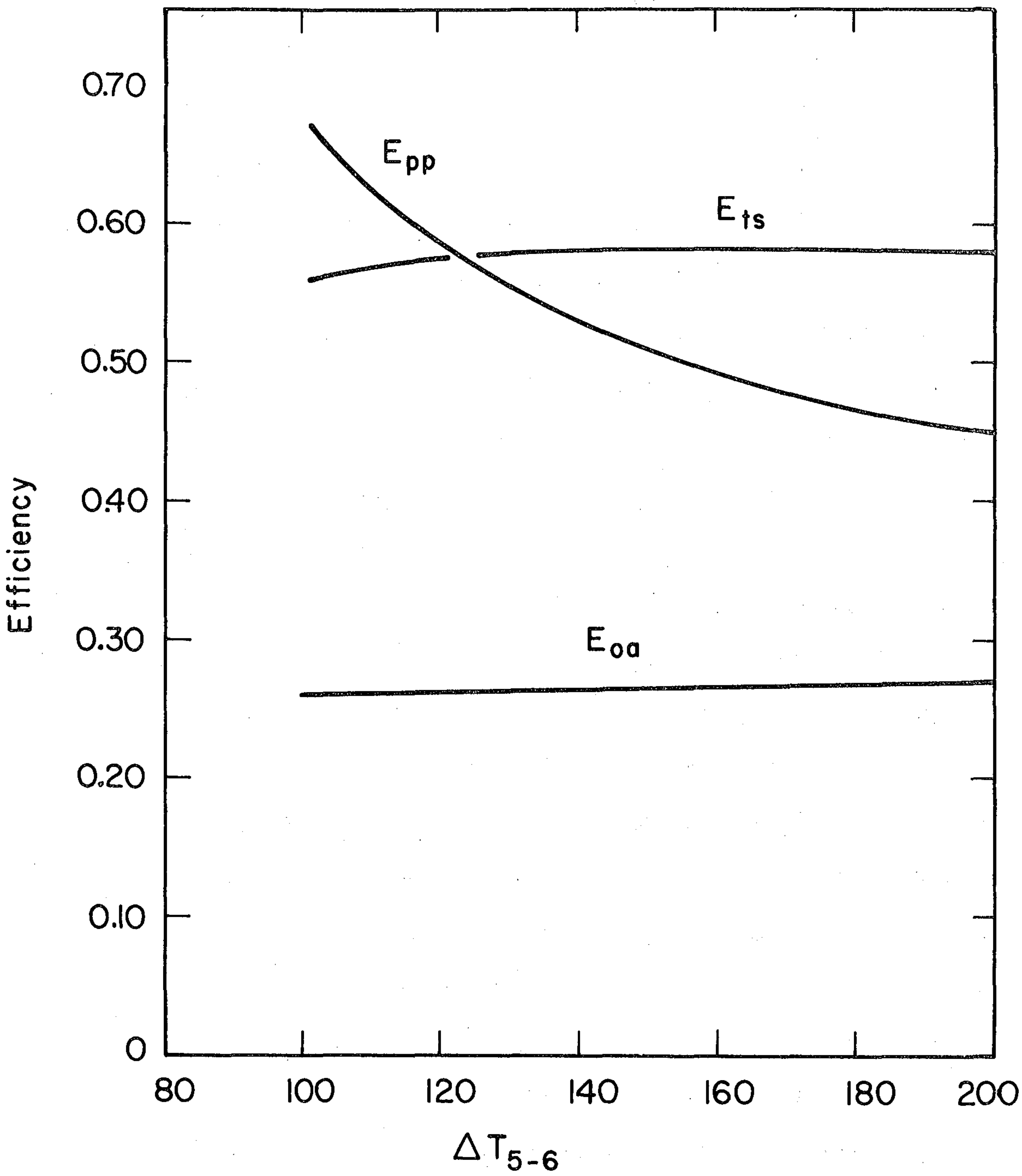

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Fig. 8.2. Efficiencies vs. temperature increase across reactor.

energy. As a result, the flow of SO_3 per unit of heat absorbed in the reactor must increase. However, the fractional conversion of SO_3 stays nearly constant. Because less heat is interchanged in HE-1 with increasing ΔT_{5-6}, relatively more heat is available from the reactor effluent for the vaporizer and reboiler. In effect, the heat duty for those operations has been partially shifted from the power-plant receiver tubes to the storage-reactor receiver tubes. The value of Epp drops because of this shift, but E_{OA} and E_{TS} are nearly unaffected. This means that ΔT_{5-6} may be chosen so as to minimize the total costs of the heat exchangers without paying an appreciable penalty in overall efficiency.

E. Effect of Changing Pressure, P, in the Solar Receiver-Reactor

Figure 8.3 shows the effect of pressure on the system indices. Higher pressure reduces the fractional conversion of SO_3 to SO_2 and O_2 because of the mass-action effect. However, this effect is overshadowed by the increase in temperature in the SO_3 vaporizer and in the reboiler, and by the increased range of temperature in which condensation of SO_3 and SO_2 occurs as the reactor effluent is cooled. At low pressure the low temperature of condensation means that only a small fraction of the heat of condensation will be absorbed by the boiler feed water. However, at low P a larger fraction of the heat for the reboiler must be supplied by steam from the power plant. Thus, Epp shows the gain that results from higher steam usage by the storage system. There are slight drops in E_{OA} and E_{TS} at the lowest pressure, but the effects are so small as to be of negligible importance. An effect that is not shown by these indices is that on the required volume for gas storage. Because the gas-storage vessels are considered

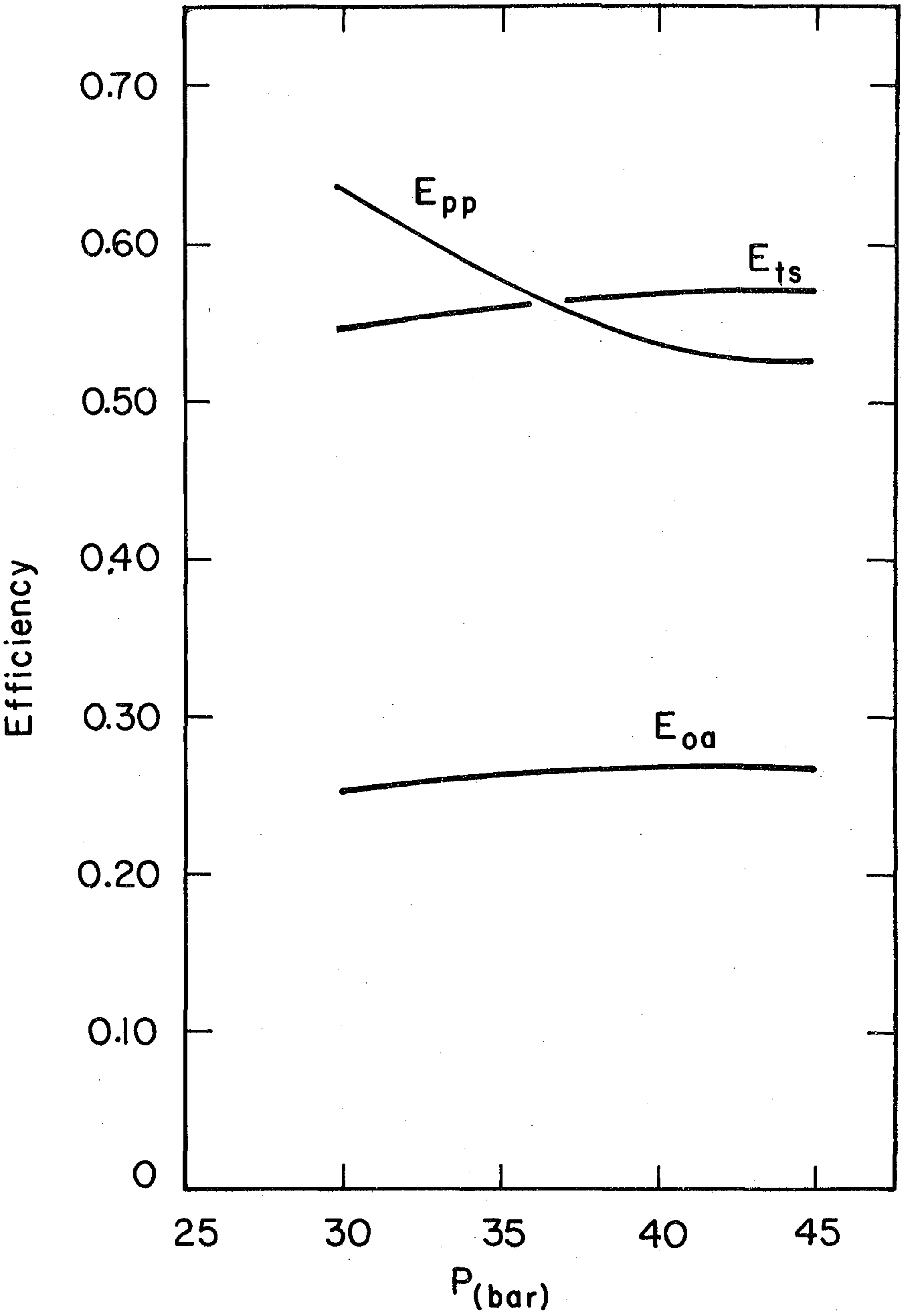

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Fig. 8.3. Efficiencies vs. pressure (HTS).

"empty" when the pressure of the stored gas has dropped to that of the discharge system, reducing the operating pressure of the charge will increase both the volume and the cost of those vessels.

F. Effect of Minimum System Temperature, T_{min}

As was mentioned previously, the minimum system temperature for the base case, 60°C, was chosen to simulate the effect of using dry cooling in a desert environment. The minimum temperature at which heat can be transferred to the environment sets the pressure for the condensers for the steam turbines, the temperature of the boiler feedwater, the temperature and pressure in the condenser of the distillation column, and the temperature in the reboiler of the distillation column. It is clear from basic thermodynamic principles that reducing T_{min} will improve the efficiency of the power plant operations. Figure 8.4 shows this as well as other effects.

As T_{min} is reduced from the base case value, the temperature of the boiler feed water is reduced and a given flow of BFW absorbs a larger fraction of the heat of condensation of the SO_2 and SO_3 in the reactor effluent. The result is an improvement in the overall heat economy, as indicated by the rise in E_{OA}. E_{PP} is reduced at lower values of T_{min}, but this again is the reflection of the fact that receiving BFW preheat reduces the efficiency index for the power plant. The slight maximum in the value of E_{TS} has a similar effect, and one can say that that index is effectively independent of T_{min}.

G. Effect of Eliminating the Distillation Column

The reboiler of the distillation column requires a substantial heat input in the form of intermediate-pressure steam from the power

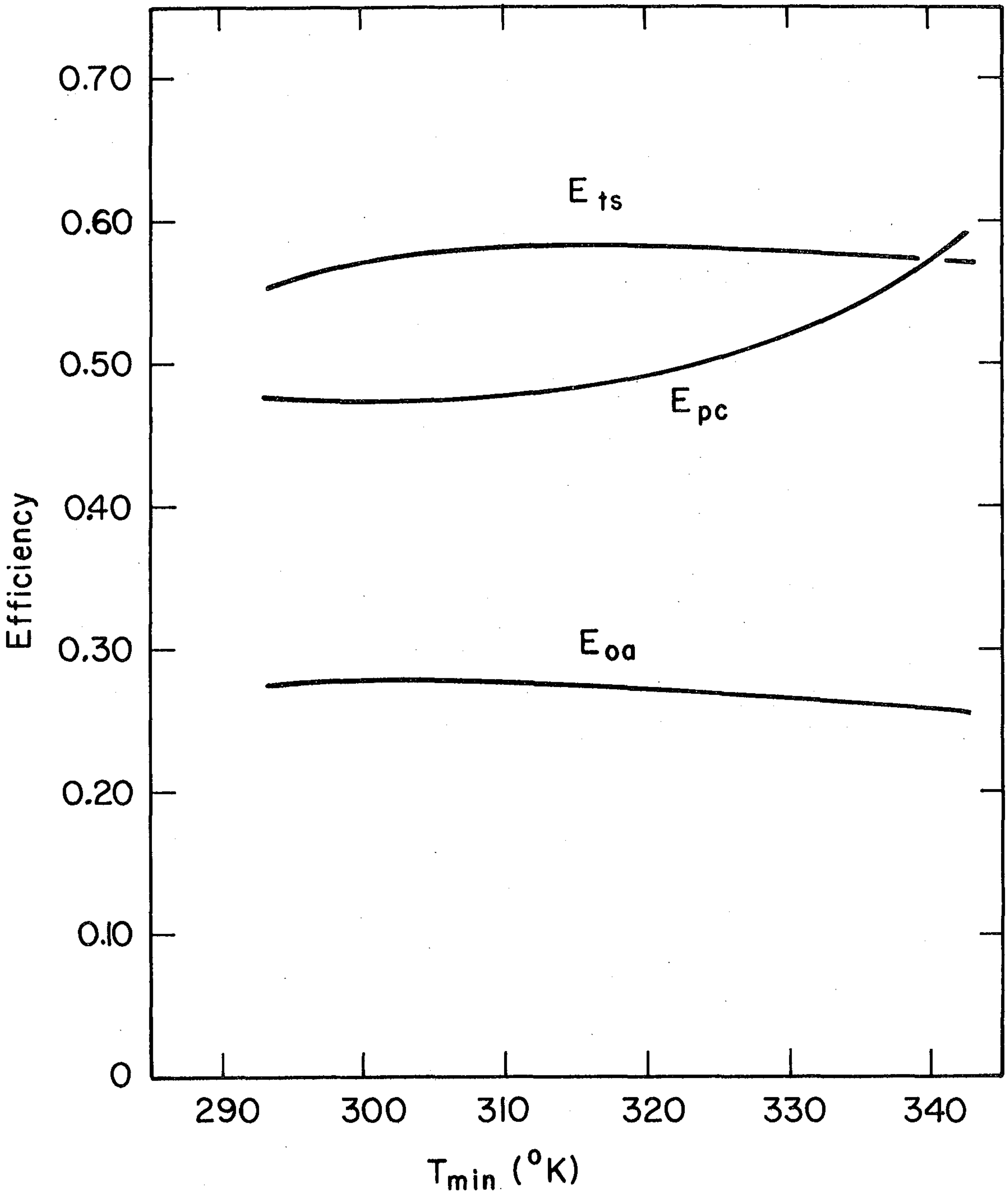

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Fig. 8.4. Efficiencies vs. minimum system temperature.

plant. Elimination of the distillation column would eliminate that heat load and would also eliminate the cost of the column. On the other hand, elimination of the column would require storage of most of the SO_2 in the form of a solution in SO_3, roughly tripling the liquid storage volume required for a given quantity of energy storage. In addition, the sizes of the flow lines, heat exchangers, and reactors would have to be increased to accommodate the flow of the inert component, and the amount of low level heat dissipated to the environment in the nighttime trimmer would be increased. These effects are compared by considering the effect of eliminating the distillation column while keeping other system parameters the same as in the base case. The results are shown in Tables 8.1, 8.2, and 8.3.

Table 8.1 shows the changes in the system indices, power, and reactor feed rates that result from eliminating the distillation column. There is a small gain in overall efficiency and an increase in P_{Day} at the expense of P_{Sto}. The increase in feed rate to the high-temperature reactor is small, but the increased feed to the LT reactor is substantial and would be mirrored by the increased requirement for liquid storage and the sizes of the LT heat exchangers.

The reasons why the change in E_{OA} is so small even though E_{pp} and E_{TS} change substantially are found from an examination of the energy balances shown in Tables 8.2 and 8.3. These can be compared to those in Tables 7.1 and 7.2 for the base case. For the base case (with distillation) intermediate-pressure steam supplies 511.3 MW_t - hr to the SO_3 vaporizer and make-up reboiler. This is reduced to 249.2 MW-hr by eliminating the distillation column, and the net power plant

Table 8.1. Effect of eliminating distillation column and BFW preheat.

	Base Case		
	w Dist.	w/o Dist.	w/o BFW Preheat
Efficiencies			
E_{OA}	0.263	0.276	0.257
E_{PP}	0.534	0.408	0.542
E_{TS}	0.579	0.818	0.574
Power and Flow Rates			
P_{Day} (MW_e)	30.9	39.4	
P_{Sto} (MW_e)	15.1	12.2	
LT react. feed rate (Stream 27) (kmol/s)	2.69	2.78	
HT react. feed rate (Stream 5) (kmol/s)	0.76	1.65	

Table 8.2 Total Plant Energy Balance. Base Case Without Distillation.

	MW (e or t)	MW-hr (e or t)
I. Inputs (8 Hours Daytime)		
Power Plant Receiver	117.8 (t)	1840 (t)
Storage Receiver	112.2	
Total Inputs	230.0 (t)	1840 (t)
II. Outputs		
A. Daytime (8 Hours)		
Generator Terminals	39.4 (e)	
Parasitic Power		
BFW Pump	(0.4)	
SO_3 Pump	(0.5)	
Cooling System Power	(0.4)	
Net Power	38.1 (e)	304.8 (e)
Waste Heat		
Trimmer	22.2 (t)	
Turbine Steam Leaks	0.4	
LP Turbine Condenser	53.1	
Misc. Heat Losses	3.4	
Total Waste Heat	79.1 (t)	632.9 (t)
B. Nighttime (16 Hours)		
Generator Terminals	12.4 (e)	
Gas Turbine	.8	
Parasitic Power		
BFW Pump	(.1)	
SO_2 Pump	(.6)	
Cooling System Power	(.2)	
Net Power	12.3 (e)	196.8 (e)
Waste Heat		
Trimmer	19.3 (t)	
Small Turbine Condenser	20.3	
Large Turbine Bleed	2.9	
Misc. Heat Losses	1.6	
Total Waste Heat	44.1 (t)	705.5 (t)
Total Outputs		1840

Table 8.3 Storage System Energy Balance. Base Case Without Distillation.

	MW-hr
Inputs	
Daytime	
Solar Receiver	897.6 (t)
SO_3 Vaporizer	249.2 (t)
Liquid SO_3 Pump	4.0 (e)
Total Inputs	1152.4
Outputs	
Daytime	
Boiler Feed Preheat	46.9 (t)
Trimmer	177.9 (t)
Misc.	7.4 (t)
Daytime Total	232.2
Nighttime	
Boiler Feed Preheat	39.4 (t)
Trimmer	308.2 (t)
LTR Reactors (QAAN)	551.4 (t)
Gas Turbine Work (isentropic expansion)	13.9 (e)
Misc.	7.4 (t)
Nighttime Total	920.2
Total Outputs	1152.4

output increases from 29.6 MW_e to 38.1 MW_e as a result. However, in the latter case the load to the daytime trimmer increases from 52.1 MW_t-hr to 177.9, and the dissipation in the nighttime trimmer increases from 133.7 to 308.2 MW_t-hr. The added daytime trimmer load results from shifting the heat of condensation of the SO_2 - SO_3 mixture from the reboiler. The added nighttime trimmer load is the result of the large increase in SO_3 flow around the nighttime system.

It appears likely that the optimum process configuration would feature a distillation column without a make-up reboiler. This would utilize the heat of condensation of the SO_2 - SO_3 mixture, which is otherwise wasted, to concentrate the SO_2 significantly, but not to the 99% purity that was specified for the base case. Nighttime efficiency, liquid storage volume, and heat exchanger areas would thereby be improved without diverting steam from the daytime power plant. An improvement of 0.01 in E_{0A} might thereby be achieved, together with an increase of nighttime power output of between 1 and 2 MW_e.

It appears unlikely that changing the process flowsheet to the configuration of limited distillation would have a significant effect on the response of the system to the changes in process parameters discussed above.

H. Effect of Eliminating Boiler Feed Water Preheat

In the base case low-level heat is utilized to the extent considered practicable to preheat boiler feed water for the daytime power plant. This energy saving maximizes E_{0A}, but it is of interest to determine just how important the saving is in order to gain perspective. To this end the result of eliminating all BFW preheat during the day from the system operating under base-case conditions was determined. The impact on the efficiency indices is also shown in Table 8.1. The effect is small--a slight decrease in E_{OA} and E_{TS}, and a slight increase in E_{PP}. The effects are so small because the temperature level of the heat being discarded is so low. It is thus clear that the value of this low-level heat should not be overemphasized in conceptualizing modifications for the design of this type of storage system.

I. Effect of Varying Q_{PR}/Q_{SR} on System Performance

Because of the heat interchange between the daytime power plant and the storage system, there is an optimum ratio of thermal inputs to the two that minimizes dissipation of heat to the environment. However, this ratio is not necessarily the most desirable from the standpoint of nighttime generating capacity relative to daytime capacity. It is therefore of interest to determine the effect of varying the ratio Q_{PR}/Q_{SR} on the efficiency indices. This variation is shown in Fig. 8.5 for values of the ratio between 1.0 and 2.25. The overall system efficiency increases as the value of the ratio increases. However, as was shown in the previous section, this increase is not due primarily to the more optimal use of low-level heat. Rather, it is the result of the fact that the daytime power plant is inherently more efficient at producing power than is the storage system. (If there were no storage system associated with it, the steam cycle used for the power plant would have an efficiency of about 0.40). Thus, if the ratio of Q_{PR}/Q_{SR} is increased the primary increase in E_{OA} is simply due to weighted averaging. The drop in E_{PP} as the ratio increases is

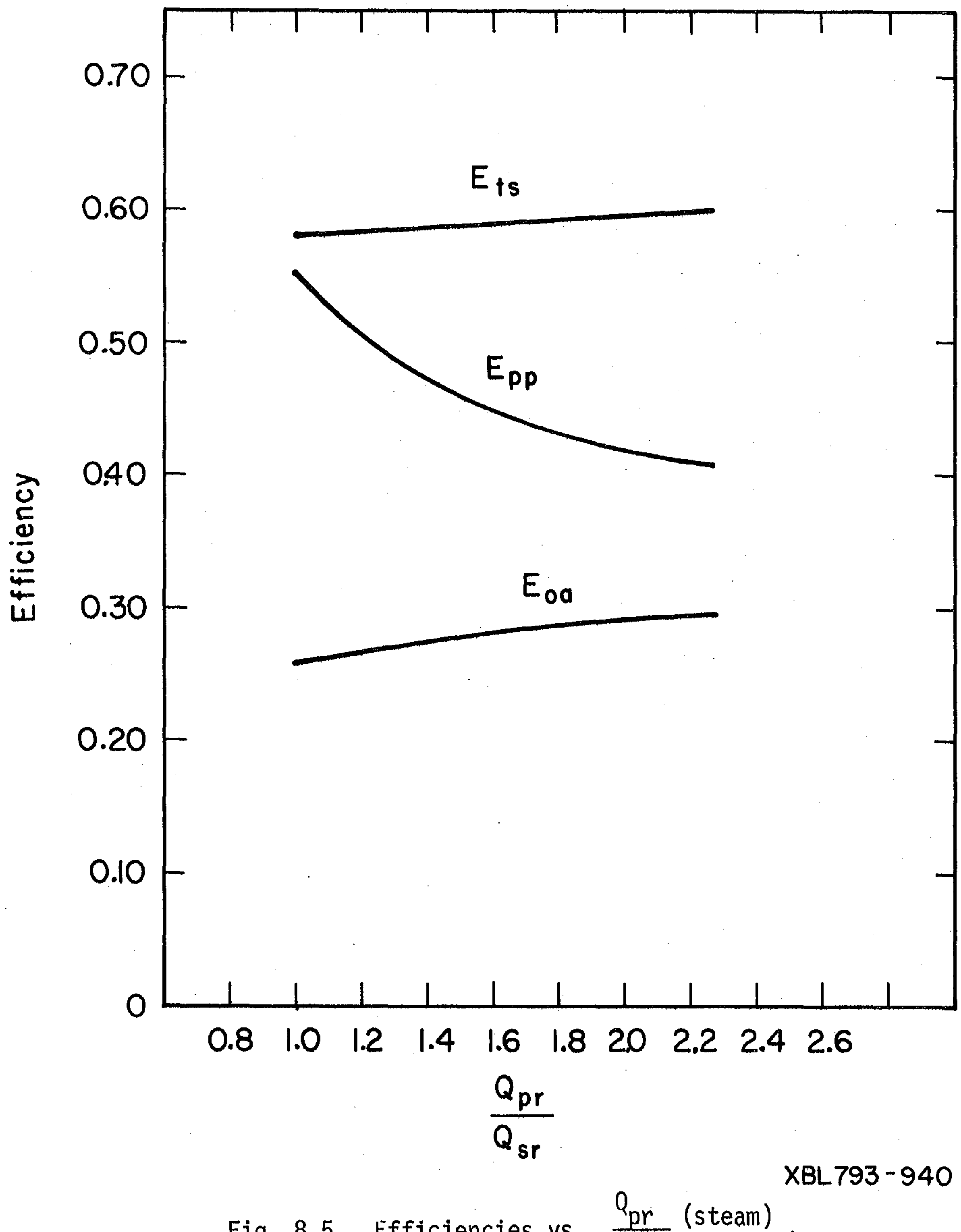

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Fig. 8.5. Efficiencies vs. $\frac{Q_{pr}\ \text{(steam)}}{Q_{sr}\ \text{(storage)}}$.

primarily the result of having a smaller fraction of the total steam produced being sent to the storage system, and is thus an artifact of the method of energy accounting. The increase in E_{TS} is real, since the storage system is being credited with the increased usage of low-level heat that the larger ratio makes possible. However, the conclusion that one draws from this study is that the ratio of thermal inputs to the two systems should be set by the desired ratio of P_{Day}/P_{Sto}, since there is a negligible penalty associated with varying the relative sizes of the two systems within the ranges studied.

J. Duration of Storage

The base case presented in Chapters II and III is sized to provide 16 hours of storage-generated power at a rate about half that of the daytime power plant. As was noted above, the design of the storage system could readily be modified to allow discharge at a more rapid rate. However, there appears to be a significant advantage to keeping the high-pressure steam turbines hot at all times to avoid the delay of cold start-up. Any modification of the proposed design should probably make provision for generating sufficient high-pressure steam at all times to keep those turbines on hot stand-by when they are not being used for power generation.

Modification of the system to allow for more than 16 hours of operation from storage also appears to be straight-forward. There is only a slight sensitivity of the system to variations in Q_{PR}/Q_{SR}. It thus appears that there would be little efficiency penalty in making Q_{SR} large enough to allow some accumulation of stored SO_2 and O_2 above nighttime usage for periods of a week or longer. The cost of the storage tanks themselves would be the primary additional cost involved in providing the capability of generating power from the storage system for periods of several days at a time.

It would appear unlikely, on the other hand, to be economical to provide overnight storage for a solar power plant by a second type of energy-storage system while having a chemical system for longer-term storage. The high capital investment required to install a chemical-energy storage system would make it desirable to use it for all of the energy-storage requirements of the installation. Although a sensible-heat or latent-heat storage system might prove advantageous as buffer (less than 1-hour) storage for the daytime power plant, longer-term storage should be provided by a single energy storage system.

K. Accuracy of Calculational Methods

The calculations presented in this report are based on a number of assumptions regarding physical properties, reaction kinetics, and heat and mass transfer behavior. In some cases the error in these assumptions can be estimated with reasonable accuracy whereas in others experimental data are needed to improve the certainty. In the following discussion a number of these assumptions will be examined.

1. Physical Properties

The three system components, O_2, SO_2 and SO_3, were assumed to follow ideal gas behavior in the vapor phase. This assumption is quite accurate except at temperatures near the dew point. The uncertainty introduced is that the predicted pressure drops will be somewhat high, and thus conservative.

Ideal heat capacities were assumed, with no allowance being made for the effect of pressure. This assumption for SO_3 gives a value that is about 40% too low at the boiling point at 40 bar. The error becomes negligible after the temperature of the SO_3 vapor has risen about 200°. The effect of the error is to underestimate by a few percent the duty of heat exchanger HE-1. The error is less than the uncertainty in the heat-transfer coefficients.

The distillation column design is based on the assumption that SO_2 and SO_3 form ideal solutions. This assumption is based on general chemical principles and should be tested experimentally if it seems economically desirable to have a distillation column. If there is significant interaction between the two molecules then the number of theoretical stages required may be greater than the number calculated. However, it seems likely that the uncertainty in the predicted tray efficiency is greater than that in the equilibrium behavior.

2. Transport Properties

Heat- and mass-transfer coefficients were estimated from the standard correlations. The accuracy of such correlations is typically ±50%. Since the projected cost of the heat exchangers is a major fraction of the cost of the storage system, more accurate cost data for the storage system should be obtained before it is developed further. The very large sizes of the gas-gas heat exchangers makes an accurate estimation of their cost particularly difficult.

The behavior of the storage solar receiver-reactor is based on the assumption that the reactor tubes can be coated on the inside surface with a suitably reactive catalyst. If the reactivity of the catalyst is sufficiently high, then heat transfer and mass transfer will control the reaction rate rather than reaction kinetics. The small amount of experimental kinetic data obtained in this work makes this assumption plausible.

It was also assumed that the reactor tubes were heated by a single, uniform radiative source. The reactor design has a maximum permissible wall temperature as one constraint. It would thus be necessary to model the radiative flux in an actual receiver more accurately than was done here to be sure that the temperature limitation was not exceeded.

The calculations indicate that there will be a substantial influence of mass-transfer resistance on the conversion of SO_3 that occurs in the reactor tubes. Since the correlation used here is based on smooth-walled, straight tubes, one would want to obtain experimental data for a catalyst-coated tube of the desired geometry to validate the computational model.

3. Cost Data

The cost data used to estimate the capital requirements and operating expenses were obtained from the references cited in Chapter VII. It should be recognized, however, that much of the equipment proposed for this system is larger and/or made of material that is more exotic than is typical of plant in the chemical industry. In some cases experimental work will be required just to demonstrate that the proposed design is technically feasible. For these reasons the cost estimates have an accuracy that can be no more than ±50%.

CHAPTER IX. CONCLUSIONS AND RECOMMENDATIONS

The sensitivity analysis has shown the chemical-energy storage system to be remarkably insensitive to the parameters that were chosen for study. Additional parameters that might have more effect do not come readily to mind. It thus appears that the following conclusions can be drawn:

1) There is no particular incentive to increasing the allowable tube-wall temperature much above 800°C, although operation at 850°C would be slightly advantageous.
2) Heat interchange between the solar reactor feed and the reactor effluent does not have a significant effect on the system efficiency. The entire heat-exchange operation (interchanger, vaporizer, reboiler, BFW preheater, and trimmer) should thus be designed to minimize costs.
3) The pressure of operation does not have a large effect on system efficiency, but should be of the order of 40 bar to minimize costs of gas-storage vessels.
4) The ratio of solar thermal inputs to the daytime power plant and the storage reactor should be set to give the desired ratio of daytime power and power from storage.
5) The reflux ratio and the number of plates in the distillation column should be adjusted to eliminate the need for the make-up reboiler and to minimize the steam requirement in the SO_3 vaporizer.
6) A chemical energy storage system should be designed to provide all of the energy storage required for a solar power plant, not just the long-term storage.

The cost analysis of the process configuration developed in this study shows that the heat exchangers represent a major fraction of the total cost of the storage system. Furthermore, the heat-exchange networks used during charging of the storage system and during discharge are independent and somewhat redundant. Further development of this process should aim at reducing the cost of the system through reducing the size and/or number of heat exchangers employed. A possible method of accomplishing this would be to eliminate the heat interchanger HE-1 and to use the hot reactor effluent to generate steam during the day in the same set of boilers that is used in generating power from storage. Such a process configuration would have the added advantage of avoiding the costly piping necessary to carry high-pressure water and steam to the top of the solar receiver and back. In addition, modification of the process in this manner would facilitate switching the system from charge mode to discharge mode, making its use for short-term storage practical.

Finally, it must be emphasized that the components of the system studied here, SO_3, SO_2, and O_2, pose severe problems of corrosion and toxicity under many of the process conditions that have been proposed. These problems may or may not have solutions that are technically and economically feasible. In the light of these and other matters discussed in this report this chemical process would have to offer a clear advantage over alternative methods of energy storage before further development were undertaken.

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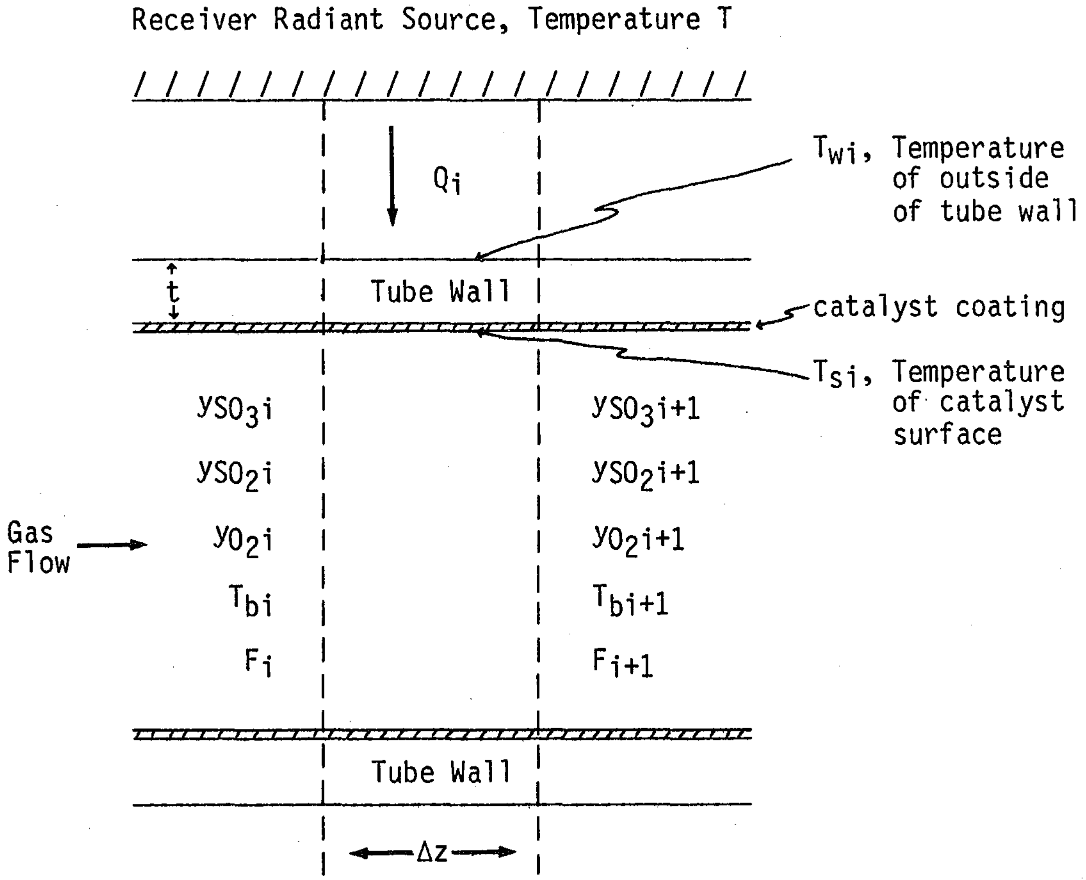
APPENDIX A. EQUATIONS FOR THE HIGH-TEMPERATURE REACTOR MODEL

Notation

Equations are written for an incremental reactor length. The diagram below displays some of the notation.



Other Notation:

$\overset{o}{y}_{SO_3}$, $\overset{o}{y}_{SO_2}$, $\overset{o}{y}_{O_2}$ - mole fractions in feed gas

F_0 - molar flow rate of feed per tube

P - pressure

d_o, d_i - outside and inside tube diameter

L - number of increments

Assumptions

1. Chemical reaction reaches equilibrium on catalyst surface. Rate of chemical conversion is limited by the rate of diffusion of SO_2 from catalyst surface to bulk gas.
2. Gas is in plug flow; there are no radial gradients outside of boundary layer.
3. Uniform source temperature throughout receiver.
4. Heat capacity of gas mixture on mass basis is independent of gas concentration.
5. Ideal gas laws apply.

Equations

Radiant heat flux from receiver source

$$Q_i = \sigma(T^4 - T_{wi}^4) \tag{1}$$

Heat flux balance at exterior surface of tube wall

$$Q_i = \frac{k_w}{t} (T_{wi} - T_{si}) \tag{2}$$

Heat flux balance at catalyst surface

$$Q_i = h(T_{si} - T_{bi}) + (\Delta H_R)k_g P \left[\left(y_{SO_2}\right)_s - y_{SO_2} \right]_i \tag{3}$$

Chemical equilibrium at the surface

$$Kp(T_s) = \frac{\left(p_{SO_2}\right)_s \left(p_{O_2}\right)_s^{1/2}}{\left(p_{SO_3}\right)_s}$$

By stoichiometry,

$$Kp(T_s) = \frac{\left(y^o_{SO_2} + y^o_{SO_3}x\right)}{y^o_{SO_3}\,(1-x)} \left[\frac{P\left(y^o_{SO_3}x + 2y^o_{O_2}\right)}{2 + y^o_{SO_3}x} \right]^{1/2}$$

$$K_p = 10^{(4.765-5022/T_s)} \tag{4a}$$

where

$x \equiv$ fraction of SO_3 in feed stream that is converted at conditions of catalyst surface.

and

$$\left(y^o_{SO_2}\right)_s = \frac{y^o_{SO_2} + y^o_{SO_3}x}{y^o_{SO_3}\ (1+x/2)} \tag{5}$$

Heat balance on gas

$$(F_oC_{po}) \left[T_{bi+1} - T_{bi}\right] = h(\pi d_i \Delta z) \left[T_{si} - T_{bi}\right] \tag{6}$$

Material balance on SO_3 in gas

$$F_i\ y_{SO_3i} - N_i a = \underbrace{(F_i + \frac{N_i a}{2})}_{F_{i+1}}\ y_{SO_3i+1} \tag{7a}$$

where

$$N_i a = kgP(\pi d_i \Delta z) \left[\left(y_{SO_2}\right)_s - y_{SO_2}\right]_i$$

Material balance on SO_2 in gas

$$F_i\ y_{SO_2i} + N_i a = F_{i+1}\ y_{SO_2i+1} \tag{7b}$$

Oxygen concentration by difference

$$y_{O_2i+1} = 1 - \left[y_{SO_3} + y_{SO_2}\right]_{i+1} \tag{7c}$$

Molar flow rate (from addition of Eqs. (7a) and (7b)

$$F_{i+1} = F_i \left[\frac{y_{SO_3i} + 2}{y_{SO_3i+1} + 2}\right] \tag{8}$$

Total heat flux per tube

$$Q = (\pi d_o L \Delta z) \sum_{i=1}^{L} Q_i \tag{9}$$

Solution Sequence

The method of iterative solution is as follows:

1. Radiant source temperature T assumed (uniform for all increments).
2. For each increment, Equations (1) - (5) are solved iteratively for Q_i, T_{wi}, T_{si}, x, and $(y_{SO_2})_{si}$ by adjusting trial values of T_{wi} until satisfaction of the heat balances is achieved. Δz was taken = 0.2m.
3. Equations (6) - (8) yield T_{bi+1}, F_{i+1}, and mole fractions at the (i+1)st increment.
4. When all increments have been calculated, the total heat flux per tube calculated by Eq. (9) is compared with the specified flux and adjustment made in the source temperature T if mismatch exists. Iteration from Step (1) is made until convergence is achieved.

Parameter values used in the calculations are given in Table A.1.

Table A.1. Parameter values for the High-Temperature Reactor Model.

	Parameter	Value (or representative average value)	Relationship	Reference
k_w	tube thermal conductivitiy	35 J/s·m·K	-----	[18, Table 23.5]
kg	convective mass transfer coefficient	(1.14×10^{-6} mol/s·m^2·N·m^{-2})	$Sh = 0.023Re^{0.81}Sc^{0.33}$	Nusselt correlation
h	convective heat transfer coefficient	(350 J/s·m^2·K)	$Nu = 0.023Re^{0.81}Pr^{0.33}$	Nusselt correlation
C_{Po}	Gas molar heat capacity	(75 J/mol·K)		[11]
ΔH_R	Heat of reaction	(86.6 kJ/mol)	$98.3 - 1.09 \times 10^{-2}T + 7.07 \times 10^{-6}T^2 + \frac{628}{T-577}$	[11]
σ	Radiant heat flux constant	5.67×10^{-8} J/m^2·s·K^4		
SO_2	diffusivity	0.018 cm^2/s		[18, Eq. 3-29]
Gas	viscosity	4×10^{-5} kg/m·s		[18, Eq. 3-129]
Gas	thermal conductivity	0.043 J/s·m·K		[18, Eq. 3-102]

Critical constants		SO_3	SO_2	O_2
T_c	°C	218.3	157.2	-118.8
P_c	atm	83.6	77.7	49.7
ρ_c	g/cm^3	0.63	0.52	0.43

---

*Actual calculations in HTR-routine uses MKhr units (m, kg, hr, Cal, C°, atm) rather than SI units as given in this table.

APPENDIX B. LOW-TEMPERATURE REACTOR COMPUTER MODEL

The temperature and concentration profiles in the low temperature reactor are calculated from incremental heat and material balances.

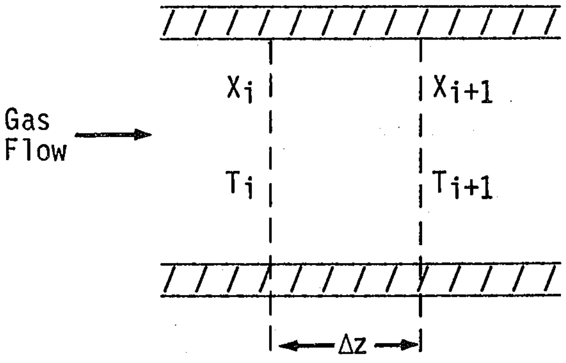


Fig. B-1. Diagram of spatial increment in LTR.

X = bulk conversion

T = bulk temperature

Δz = length increment

Heat Balance:

$$(\Delta H_r)(X_{i+1} - X_i) = C_p(T_{i+1} - T_i) \tag{B-1}$$

Material Balance:

$$X_{i+1} - X_i = 1/F \;\; r \cdot \rho_c \, A \cdot \Delta z \tag{B-2}$$

Reaction rates over both V_2O_5 and platinum catalysts are reported in the literature as overall rates (g-moles converted per sec per kg catalyst). Diffusion resistance and thermal resistance were therefore assumed to be incorporated into these effective reaction rates.

The kinetic expressions used are:

V_2O_5 Catalyst (Mars + Maessen [17])

$$r = Ae^{-E/RT} \frac{K\, P_{SO_2}/P_{SO_3}}{[1 + (K\, P_{SO_2}/P_{SO_3})^{1/2}]^2} \qquad \text{(B-3)}$$

$$K = 2.3 \times 10^{-8} \exp(27200/RT);\; R = 1.98 \text{ cal/mole}^{o}\text{K} \qquad \text{(B-4)}$$

	Temperature Range, ^{o}C	
	420-454	454-600
E, cal/mole	70,000	36,000
A	1.56×10^{17}	9.38×10^{6}

Herce et al. [13] give evidence that this relation is valid at pressures up to 10 atmospheres.

Platinum Catalyst (Lewis and Ries [14], Uyehara and Watson [20]).

$$r = \frac{kTe^{(-E/RT)}}{(1 + K_{O_2}P_{O_2} + K_{SO_3}P_{SO_3})^2} \left[P_{SO_2}P_{O_2}^{1/2} - \frac{P_{SO_2}}{K} \right]$$

$$\ln K_{SO_3} = 21400/RT - 23/R$$

$$\ln K_{SO_2} = 20360/RT - 23/R$$

$$\ln K = 22980/RT - 19.5/R$$

$$E = 3690 \text{ cal/mole}$$

$$k = 0.57 \text{ gmole/(sec)(kg cat.)}(^{o}\text{K})$$

Partial pressures in the above rate expressions were represented in terms of conversion x through the stoichiometry of the reaction and the ideal gas law.

The low temperature reactor calculations were carried in two separate parts. First, the temperature and conversion in each of the five adiabatic reactors were determined. This portion was carried out by the LTS (low-temperature side) routine and the LTR (low-temperature reactor) routine as part of the overall material and energy balance program for the entire system. The flow chart for the LTR routine is given in Appendix C. It has been assumed that reaction reaches 99% of equilibrium in each reactor and that reactor effluents are cooled back to 420°C before entering the next reactor.

Second, the size (length) of each reactor was determined by a separate program LTRS (low temperature reactor sizing) which was run after all process balances were completed.

The calculational procedure used to model the low-temperature reactor was quite simple. The reaction-rate equation for the catalyst and temperature of the increment was selected. The rate of reaction per unit volume was calculated, and the length of the increment adjusted to make the temperature rise in the increment equal to a predetermined amount. The new bulk temperature and composition for the reaction mixture was calculated, and the procedure was repeated. When the temperature reached 454°C, the V_2O_5 reaction rate constants changed. When the temperature reached 600°C, the platinum bed started. When the program calculated that equilibrium had been passed, it went back one increment and cut the incremental temperature rise in half. Calculations proceeded in this manner until the incremental temperature rise had been decreased to 0.5°C. This occurred when the gas was within 1.0°C of equilibrium.

The program then moved on to the next reactor, using the outlet composition of the previous reactor and an input-specified temperature as a starting point.

All of the variables and constants used in the LTR program are in MKS units.

APPENDIX C. FLOW CHARTS AND PROGRAM LISTINGS

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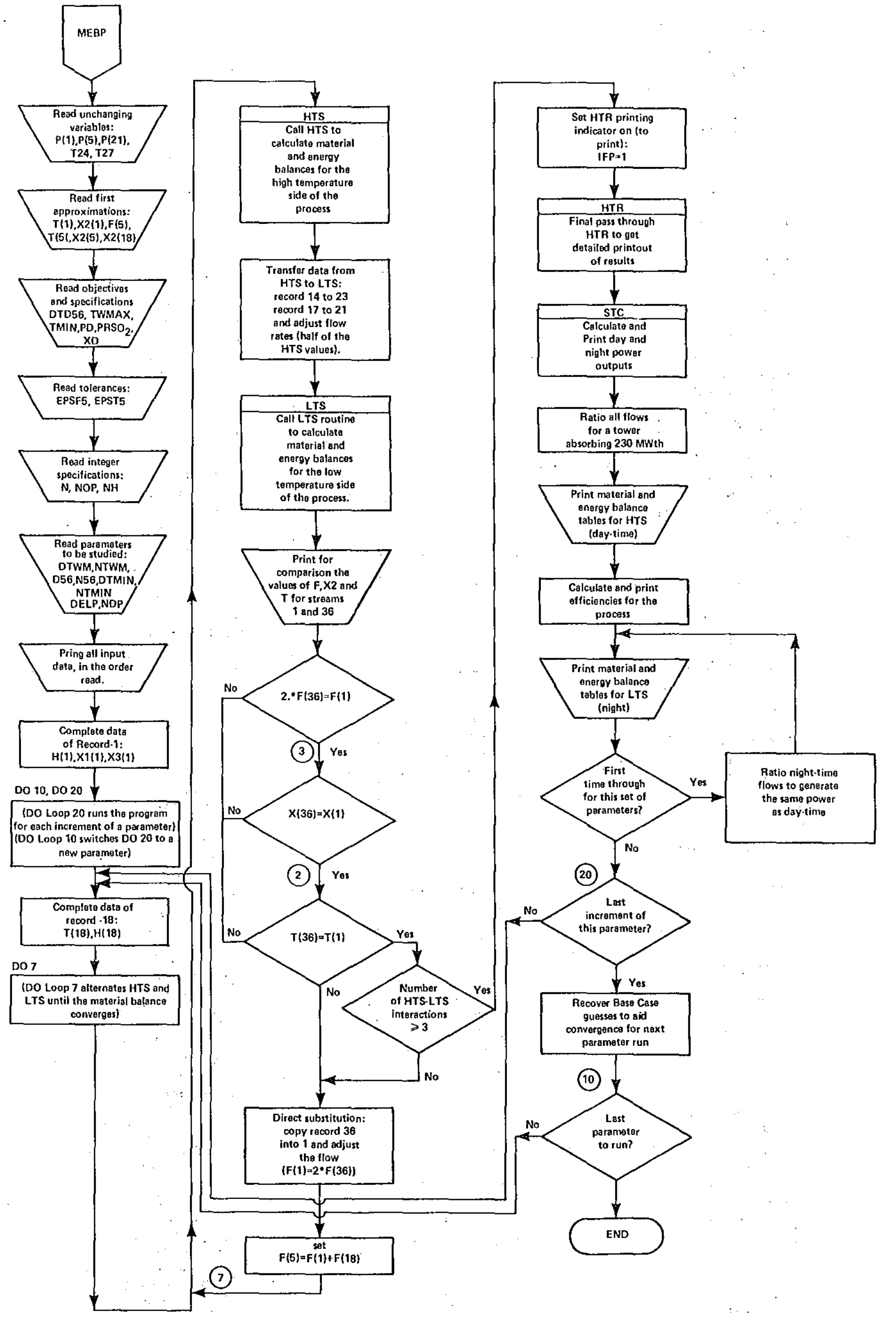
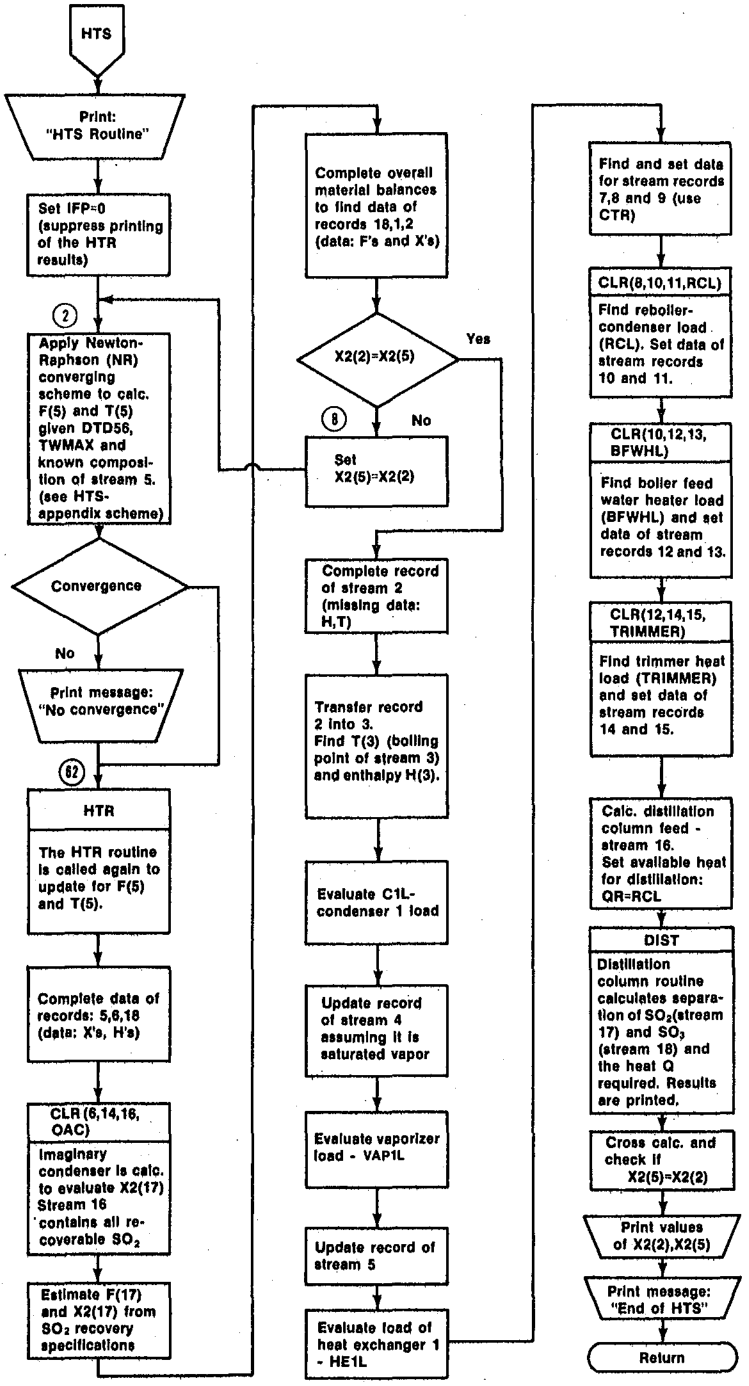
Contents (Continued)

MEBP – Material and Energy Balances Program



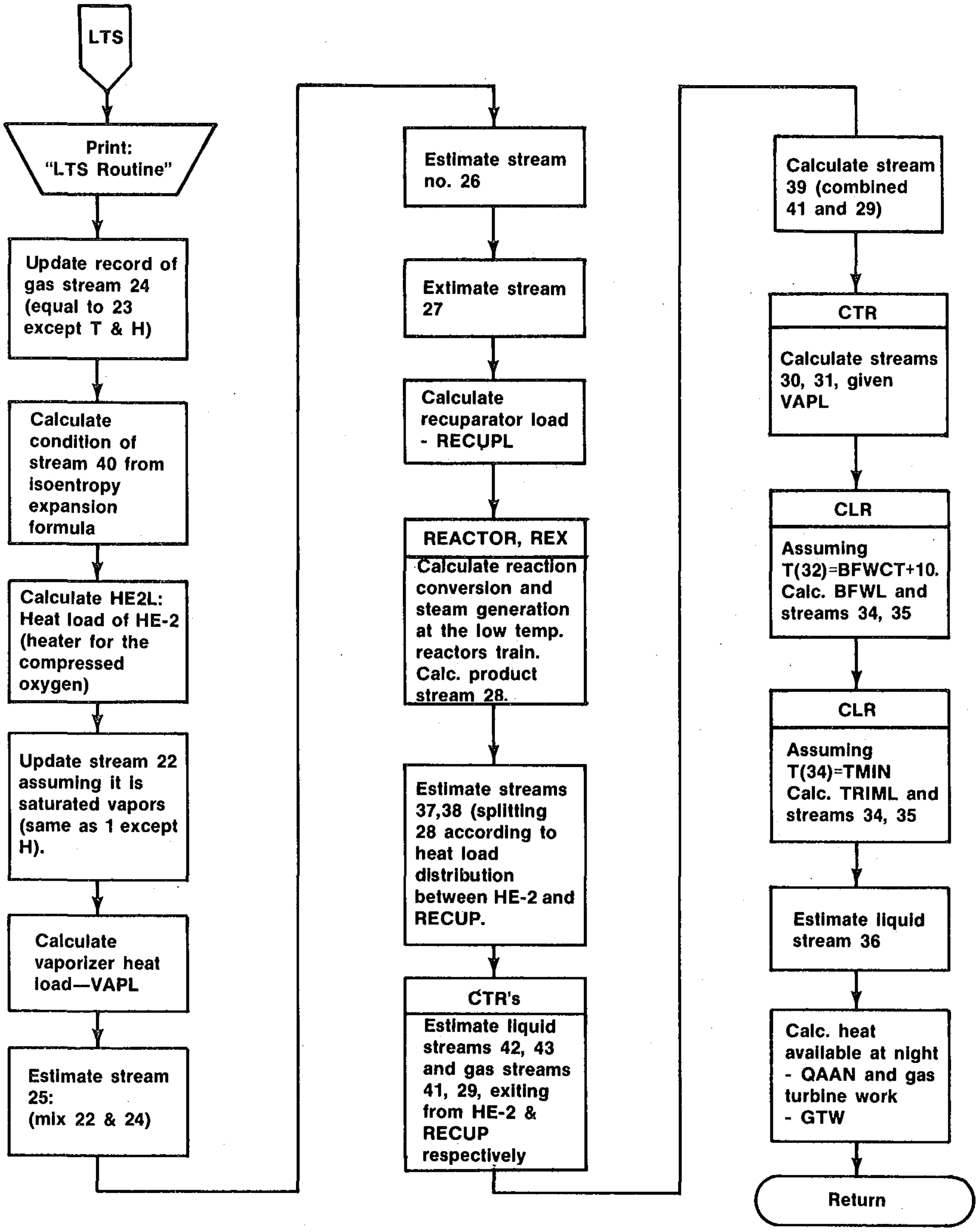
XBL 793-956

HTS — High Temperature Side Routine



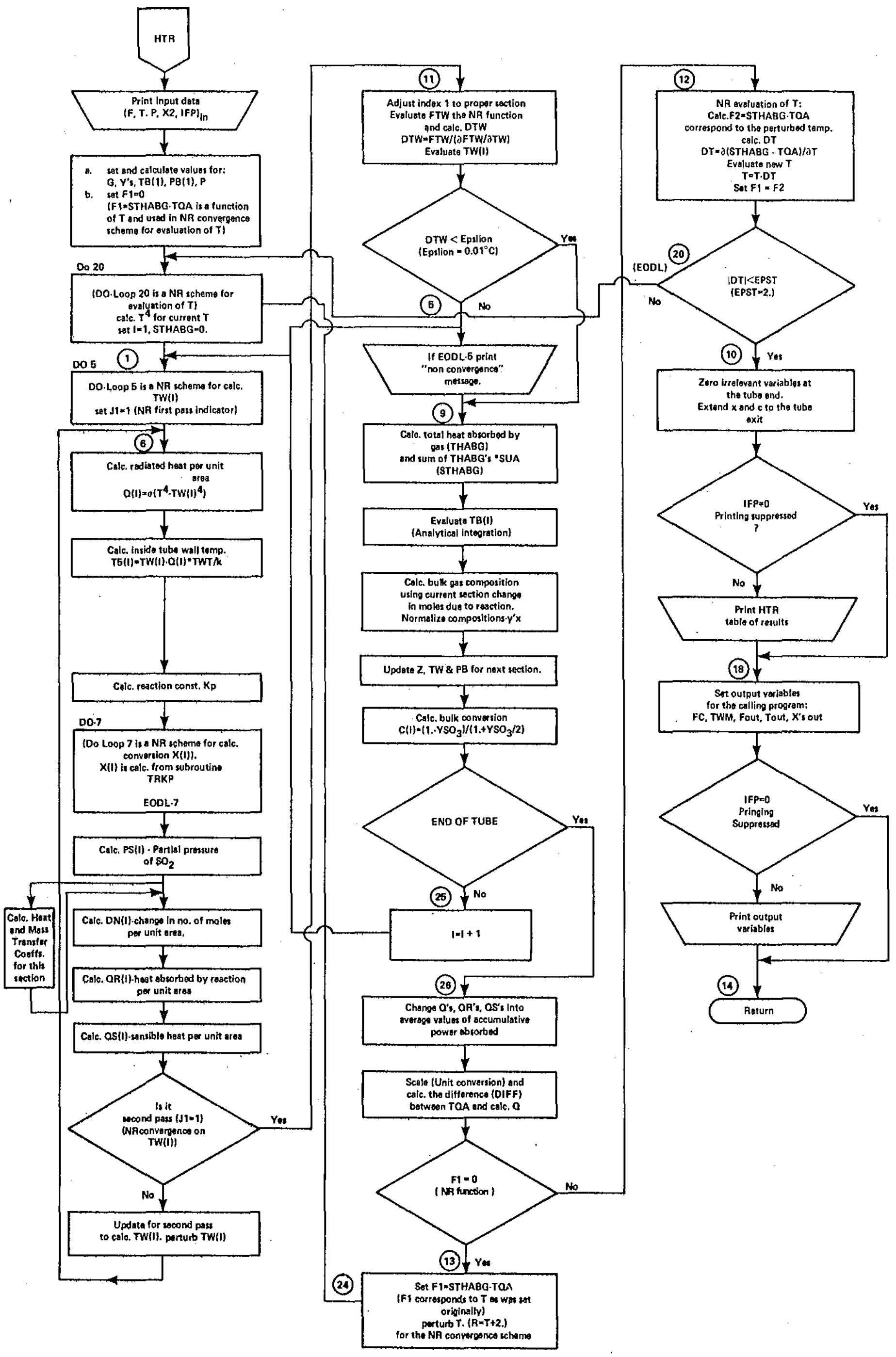
XBL 785-865

LTS — Low Temperature Side Material and Energy Balances Routine



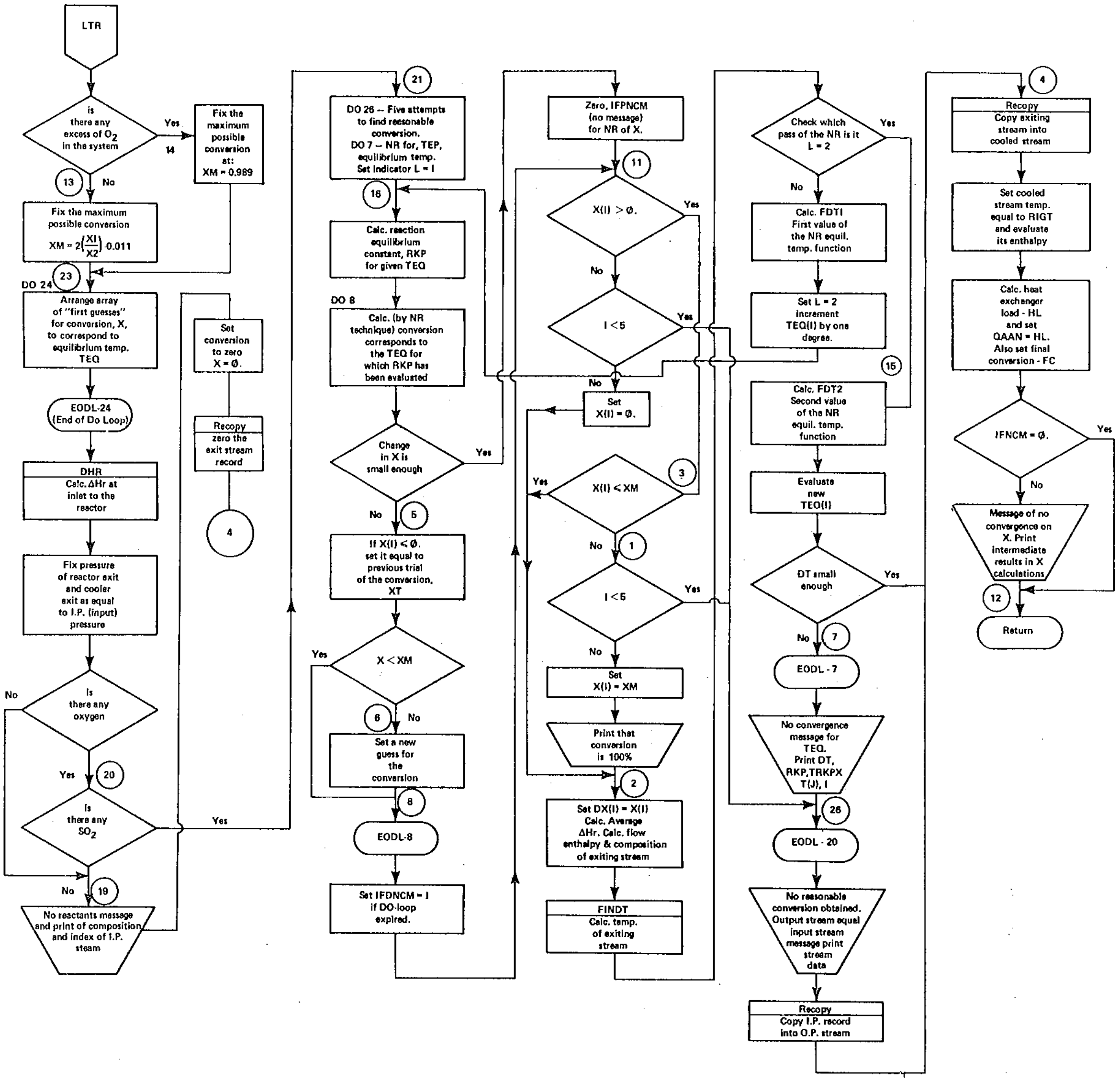
XBL 785-864

HTR – High Temperature Reactor Routine



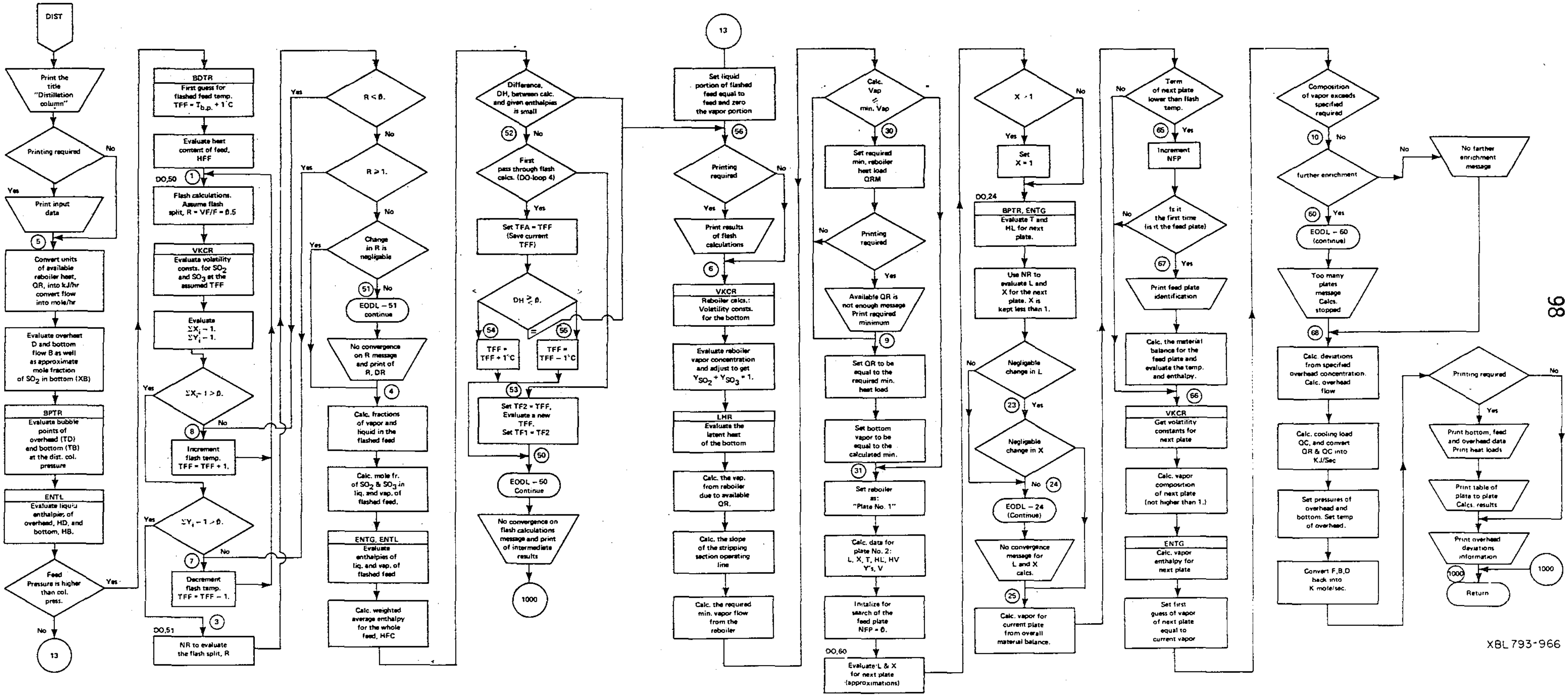
XBL793-967

LTR – Low Temperature Routine



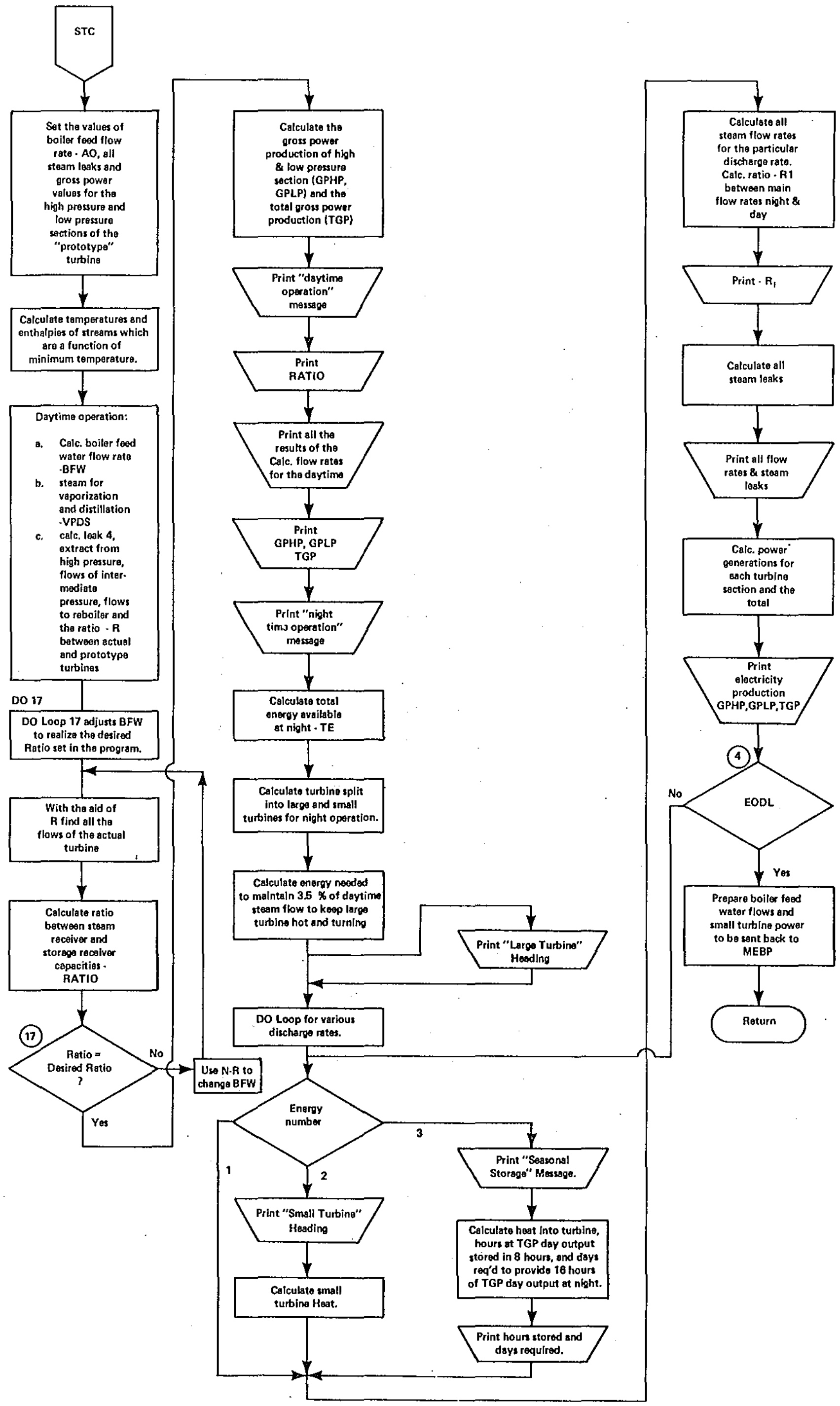
XBL 793-957

Distillation Column Routine Flow Chart



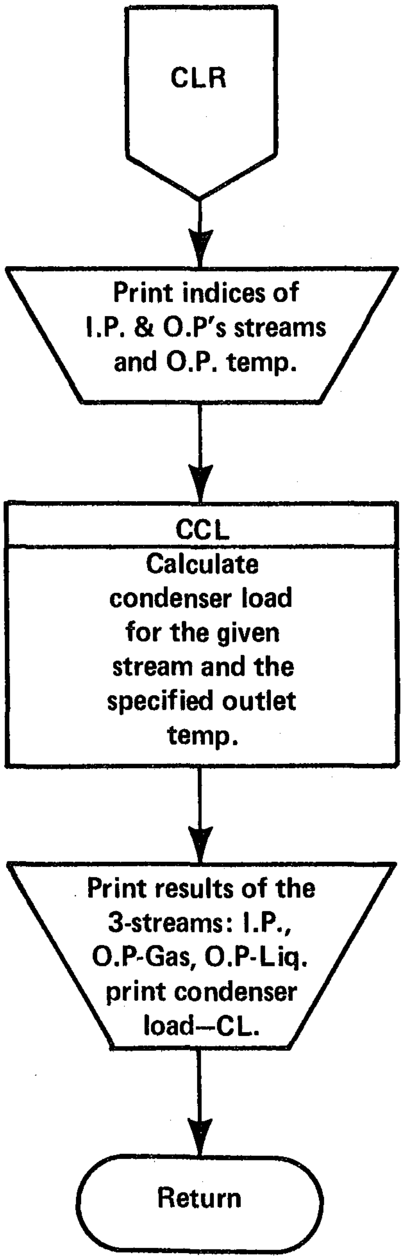
XBL 793-966

STC -- Steam Turbine Calculations Routine



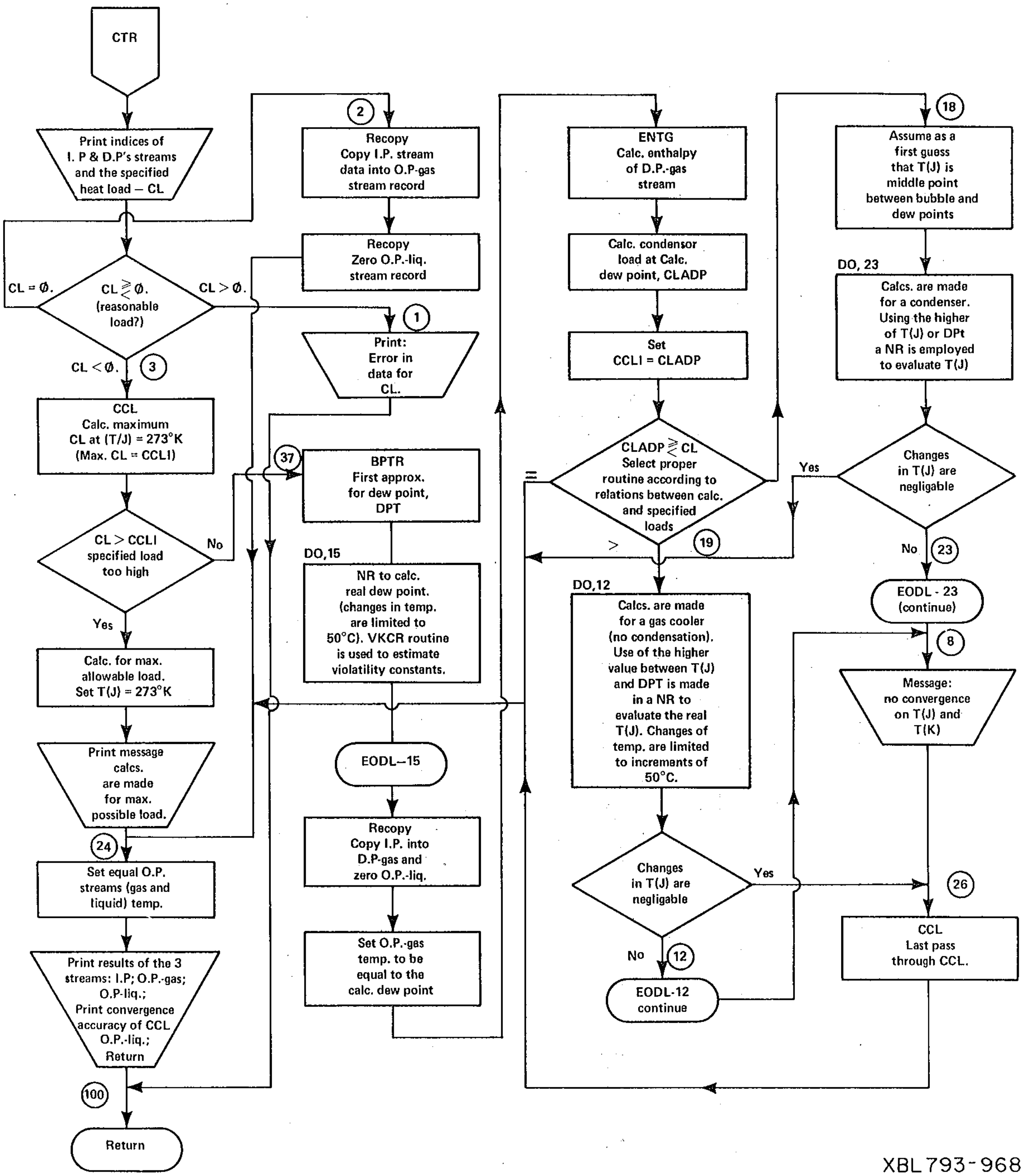
XBL 793-965

CLR — Condenser
Lead Routine



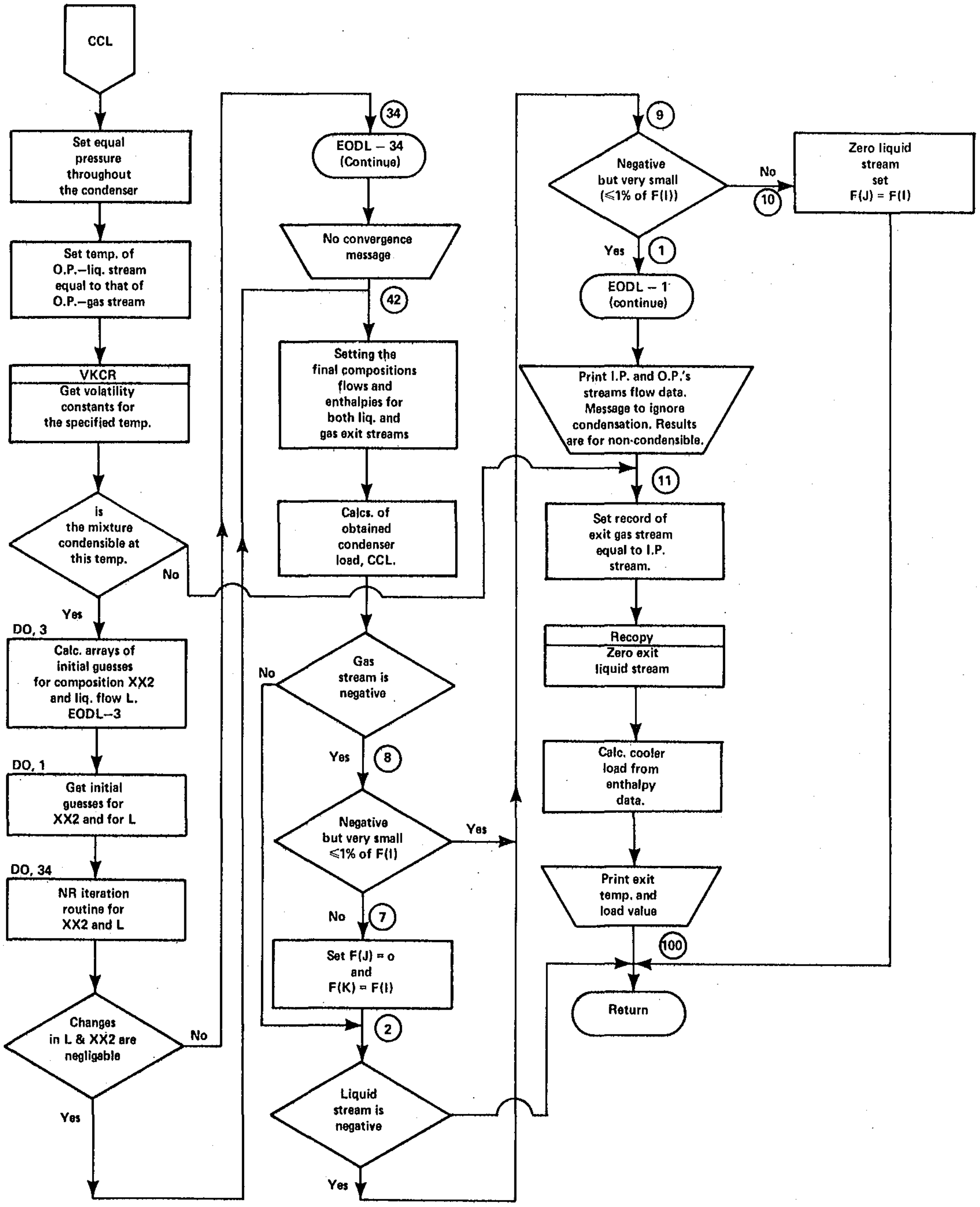
XBL 793-950

CTR – Cordenser Temperature Routine



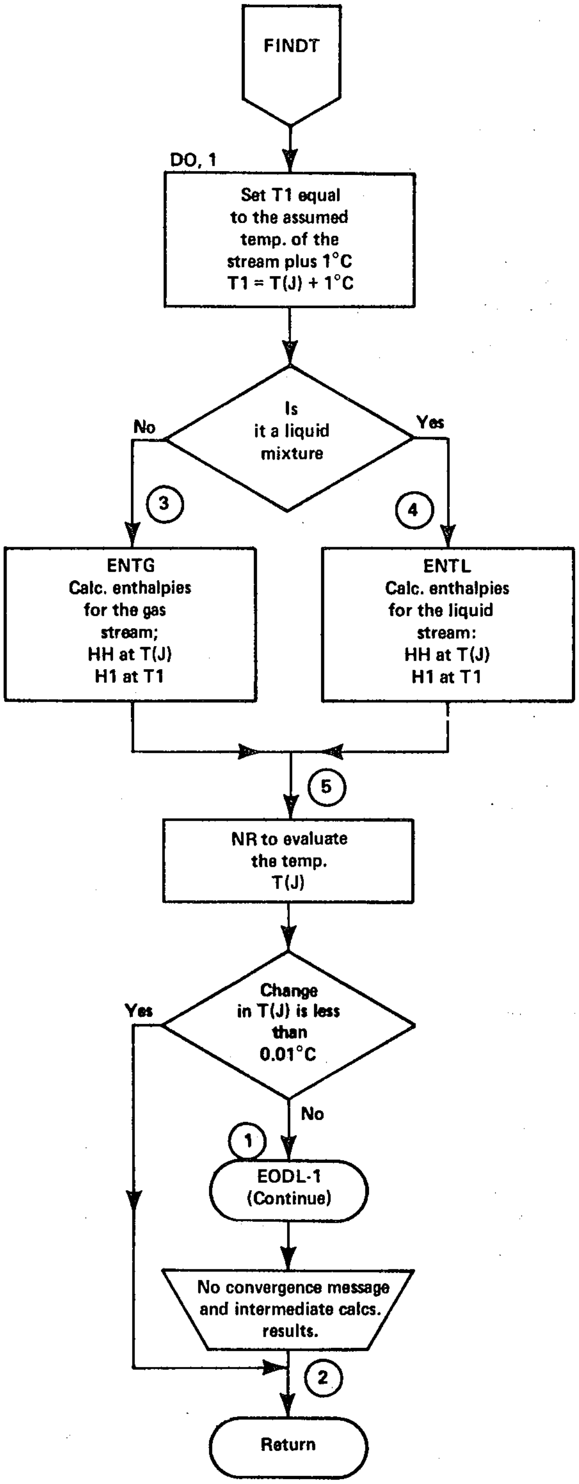
XBL 793-968

CCL – Calculation of Condenser Load



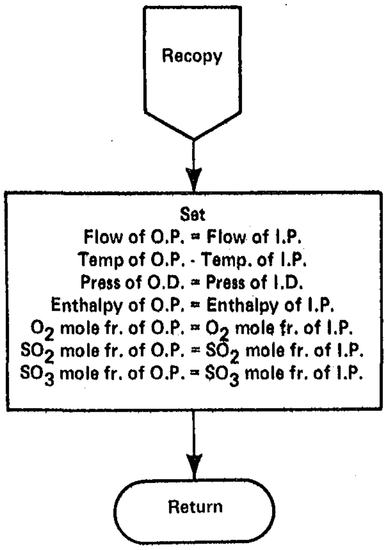
XBL 793-953

FINDT – Find Temperature
of Stream Routine



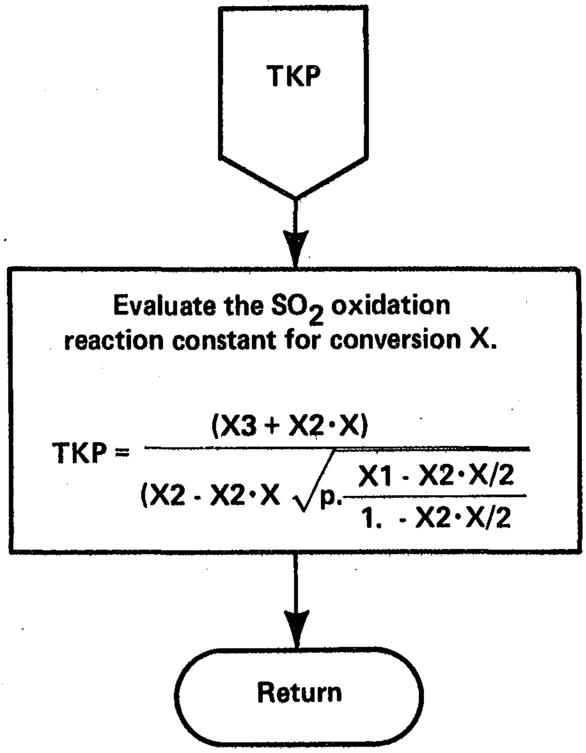
XBL 793-955

Recopy -recopy
one record into
another



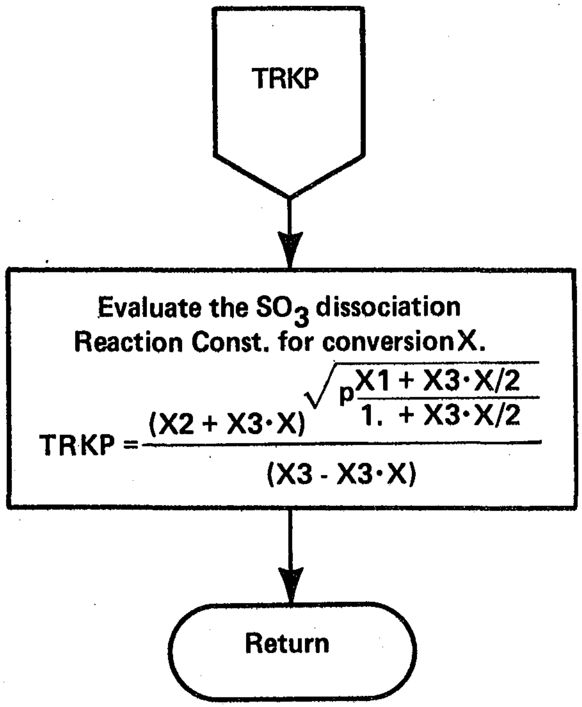
XBL 793-954

TKP - SO_2 SO_3 Equilibrium
Constant Function



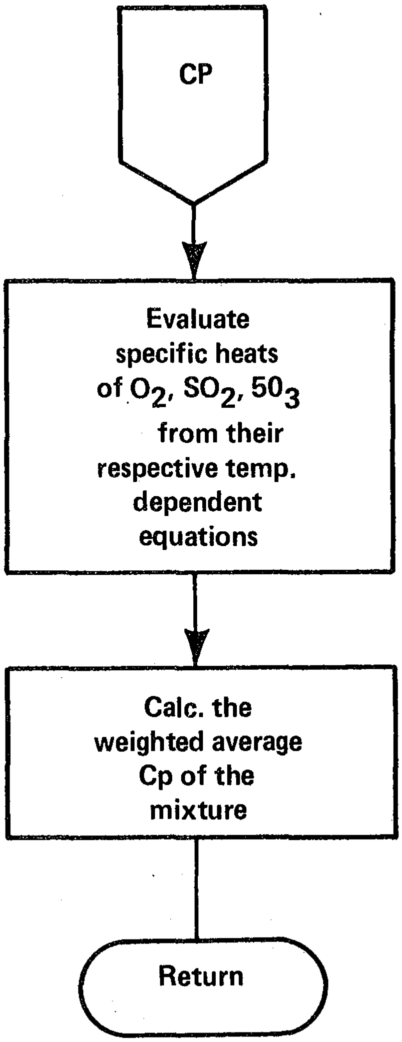
XBL 793-964

TRKP — SO_3 SO_2 Equilibrium
Constant Function



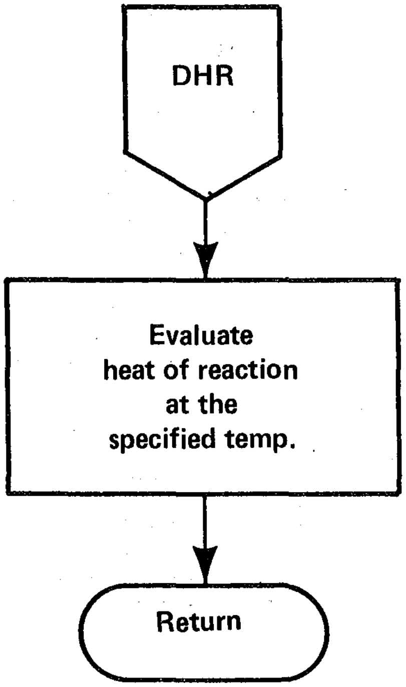
XBL 793-963

CP — Specific Heat Function



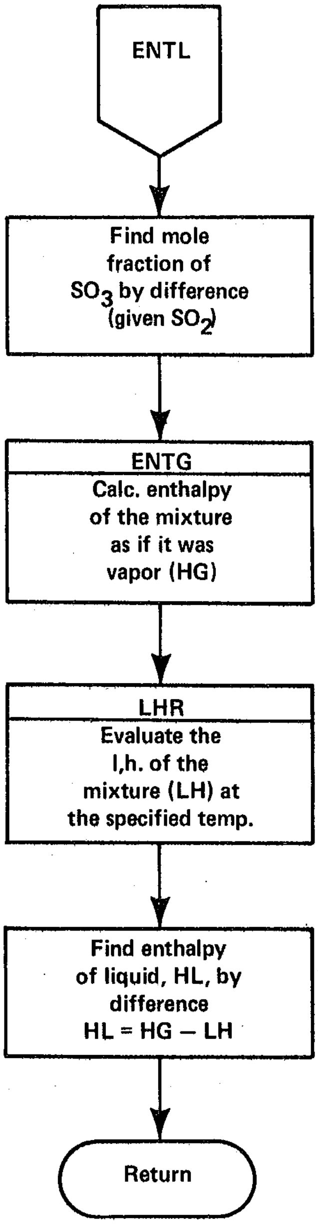
XBL793-962

DHR — Delta Heat of Reaction



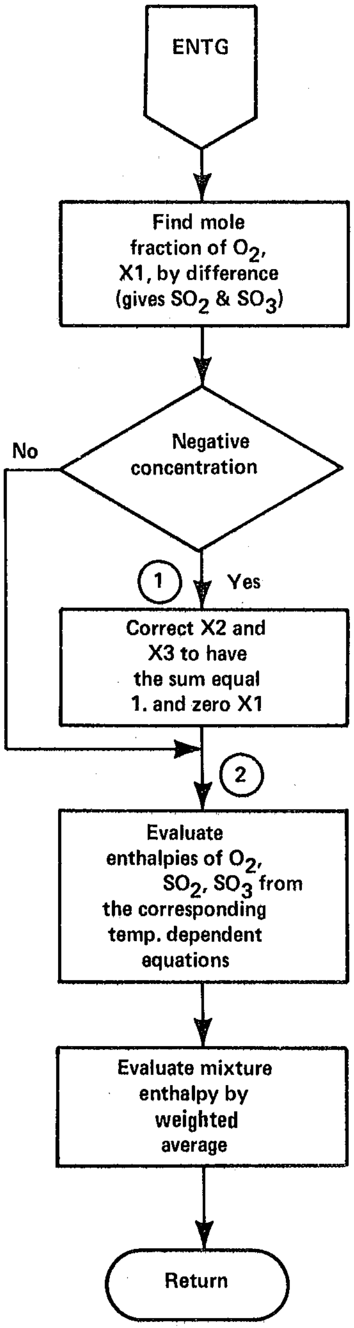
XBL 793-961

ENTL — Enthalpy of Liquid Mixture Routine



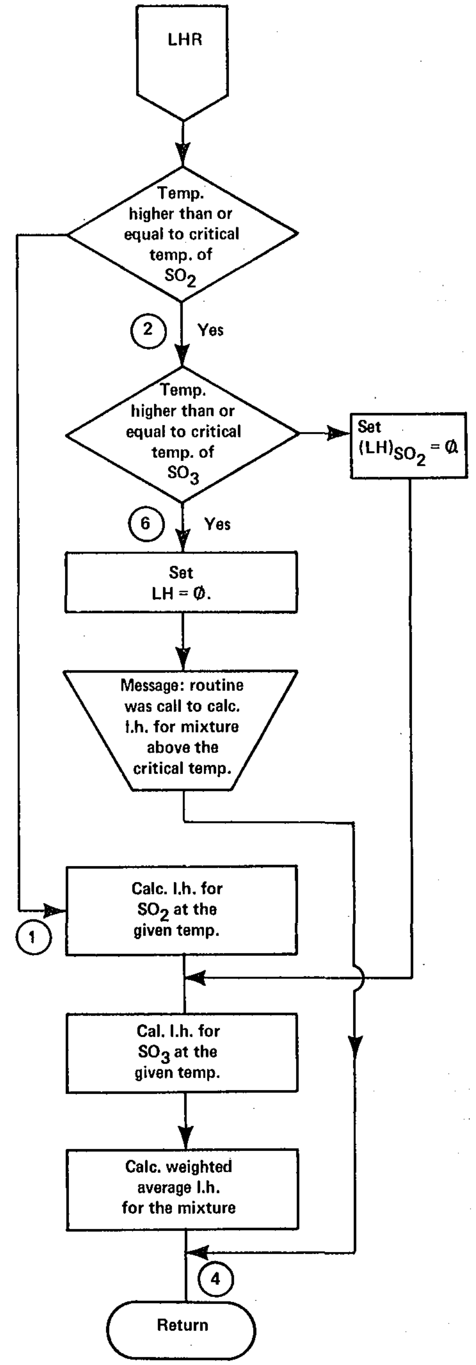
XBL 793-960

ENTG — Enthalpy of Gas Mixture Routine



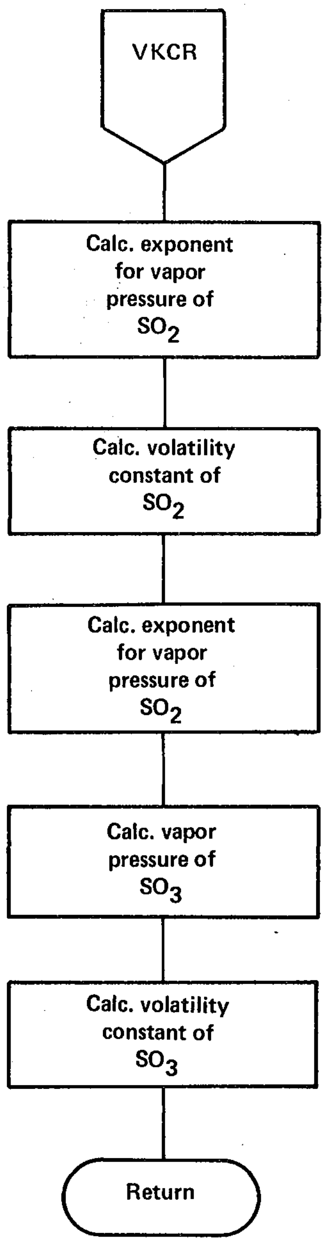
XBL 793-958

LHR — Latent Heat
of Reaction Routine



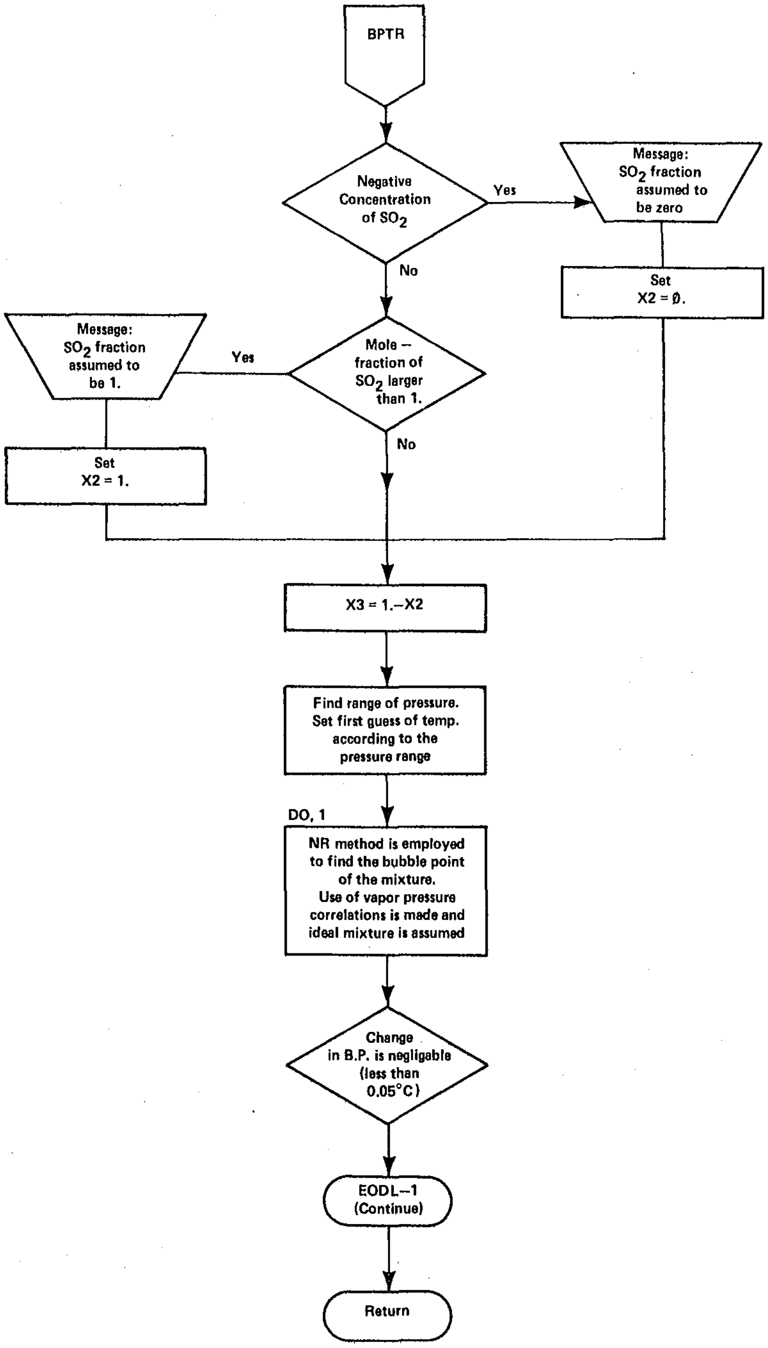
XBL 793-959

VKCR — Volatility K
Constant Routine



XBL 793-952

BPTR — Bubble Point
Temperature Routine



XBL 793-951

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      PROGRAM MEBP(INPUT,OUTPUT,PUNCH)                                  MEBP  10
************************************************************************MEBP  20
*                                                                      *MEBP  30
*     UPDATED 2/28/78                                                  *MEBP  40
*     MEBP - MATERIAL AND ENERGY BALANCES PROGRAM FOR CES              *MEBP  50
*                                                                      *MEBP  60
************************************************************************MEBP  70
*PROGRAM CALCULATES MATERIAL AND ENERGY BALANCES FOR THE CHEMICAL HEAT *MEBP  80
*STORAGE SYSTEM BASED ON 02,S02,S03. THE PROCESS IS DESIGNED TO SUPPLY *MEBP  90
*THE NECESSARY HEAT FOR A STEAM POWER PLANT DURING NIGHT TIME. DIRECT  *MEBP 100
*STEAM GENERATION PLANT IS INTEGRATED WITH THE STORAGE SYSTEM TO PROVIDEMEBP 110
*MAXIMUM HEAT EFFICIENCY FOR THE COMBINED PROCESS (SEE DAYAN ET AL ,   *MEBP 120
*PROCEEDING OF THE 12TH IECEC,P.1181,WASHINGTON DC 1977).              *MEBP 130
*THE PROGRAM STARTS WITH READING BASIC DATA (SPECIFICATIONS,TOLERANCES,*MEBP 140
*TOTAL HEAT AVAILABILITY,ETC.) AND FIRST GUESSES FOR KEY STREAMS (THESE*MEBP 150
*ARE LATER UPDATED). THE PROGRAM USES TWO MAIN SUBROUTINES-HTS AND LTS *MEBP 160
*TO CALCULATE THE BALANCES FOR THE  DAY AND NIGHT-TIME OPERATIONS RESPE-MEBP 170
*CTIVELY. DIRECT SUBSTITUTION IS USED FOR THE CYCLIC PROCESS UNTIL     *MEBP 180
*CONVERGENCE ON FLOW, TEMP. AND COMPOSITION IS REACHED. THEN STC ROUTINEMEBP 190
*IS CALLED TO CALCULATE STEAM POWER PLANT GENERATION DATA. OUTPUT IS   *MEBP 200
*SCALED AND PRINTED ACCORDING TO TQA-TOTAL HEAT AVAILABLE AT THE RECEIV-MEBP 210
*ER FOR THE STORAGE PROCESS.                                           *MEBP 220
*                                                                      *MEBP 230
*THE FOLLOWING SUBROUTINES ARE BEING USED=                             *MEBP 240
*BPTR(P,X2,T)  - BOILING POINT TEMP.T OF LIQ. MIX. OF S02-S03 AT P,X2  *MEBP 250
*CCL(TJ)-COMMON(TO CTR+CLR)FUNCTION TO CALC. CONDENSER LOAD AT EXIT T-TJMEBP 260
*CLR(NI,NG,NL,CL)-CONDENSER LOAD CL, FOR INCOMING GAS STREAM NI AND    *MEBP 270
*     OUTGOING GAS STREAM NG AND LIQ. STREAM NL.                       *MEBP 280
*CP(T,X1,X2,X3)-HEAT CAPACITY OF GAS MIX.(X1,X2,X3) AT TEMP. T         *MEBP 290
*CTR(NI,NG,NL,CL)-CONDENSER EXIT STREAMS(NG,NL)TEMP. FOR GIVEN LOAD-CL *MEBP 300
*DHR(T)-HEAT OF REACTION AS FUNCTION OF TEMP. T                        *MEBP 310
*DIST(F,TF,PF,HF,XF,QR,XD,P,PRS02,N,D,TM,PD,HLM,YM,B,TB,PB,HB,XB)-PLATE*MEBP 320
*     TO PLATE CALC. OF DISTILLATION TOWER FOR BINARY MIX. S02-S03     *MEBP 330
*ENTR1(T,X2,HL)-ENTHALPY CALCS. FOR S02-S03 LIQ.MIX AT TEMP-T,COMPOS-X2*MEBP 340
*ENTR2(T,X2,X3,HG)-ENTHALPY CALCS. FOR 02-S02-S03 GAS MIX.AT T,X2,X3   *MEBP 350
*FINDT(NS,NF)-FIND TEMP. OF STREAM NF. NS=STREAM STATE=1-LIQ. 2-GAS    *MEBP 360
*HTR(FI,TI,PI,X2I,FO,TO,PO,X10,X20,X30,FC,TWM,IFP)-HIGH TEMP. RECEIVER-*MEBP 370
*     REACTOR. I-INPUT STREAM, O-OUTPUT STREAM,FINAL CONV.,TW-MAX,PRINT*MEBP 380
*HTS - MATERIAL AND ENERGY BALANCES FOR THE HIGH TEMP. SIDE            *MEBP 390
*LHR(T,X2,LH)-LATENT HEAT OF S02-S03 MIX. AT TEMP.-T,COMPOSITION-X2    *MEBP 400
*LTR(X,Q,N-IN,N-OUT,N-COLD) LOW TEMP. REACTOR ROUTINE. (N=STREAM NO.)  *MEBP 410
*LTS - MATERIAL AND ENERGY BALANCES FOR THE LOW TEMP. SIDE             *MEBP 420
*RECOPY(IIN,IOUT)-COPY RECORD NO.-IIN INTO RECORD NO.-IOUT             *MEBP 430
*STC(QAAN, R )-STEAM TURBINE CALC. DETERMINES STEAM POWER PLANT SIZE   *MEBP 440
*     AND OPERATION RATES DURING DAY AND NIGHT (VARIOUSE DISCHARGE RATESMEBP 450
*TRKP(X,P)-CALC. TRIAL VALUE FOR REACTION EQUILIBRIUM CONSTANT-KP      *MEBP 460
*VKCR(P,T,K2,K3)-VOLATILITY CONSTANTS K2,K3 FOR S02,S03 AT P AND T     *MEBP 470
*                                                                      *MEBP 480
*NOMENCLATURE= (SEE PROCESS SCHEMES FOR DETAILS)                       *MEBP 490
*COMMON BLOCKS NAMES=                                                  *MEBP 500
*     LAHTV     LOW AND HIGH TEMP. VARIABLES                           *MEBP 510
*     HTHEL     HIGH TEMP. HEAT-EXCHANGERS LOADS                       *MEBP 520
*     HTV       HIGH TEMP. VARIABLES                                   *MEBP 530
*     LTV       LOW  TEMP. VARIABLES                                   *MEBP 540
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*     LTHEL     LOW TEMP. HEAT-EXCHANGERS LOADS                          *MEBP 550
*     NWORK     NIGHT WORK                                               *MEBP 560
*     STREAM    STREAM RECORDS NAME (F,P,T,H,X1,X2,X3)                   *MEBP 570
*                                                                        *MEBP 580
*VARIABLES=                                                              *MEBP 590
*     ATQA      ADJUSTED TQA (ATQA=TQA*R)                                *MEBP 600
*     BDT56     BASE CASE DELTA T BETWEEN 5 AND 6 (K)                    *MEBP 610
*     BFWCT     BOILER FEED WATER CONDENSER TEMP. (K)                    *MEBP 620
*     BFWHL     BOILER FEED WATER HEAT LOAD - HTS - (KJ/S)               *MEBP 630
*     BFWL      BOILER FEED WATER HEAT LOAD - LTS - (KJ/S)               *MEBP 640
*     BFWN1     BOILER FEED WATER HEAT LOAD AT NIGHT-TIME NORMAL OUTPUT.*MEBP 650
*     BFWN2     BFW HEAT LOAD AT NIGHT, SEASONAL STORAGE (100 MW).       *MEBP 660
*     BP        BASE CASE HIGH PRESSURE (BAR)                            *MEBP 670
*     BTMAX     BASE CASE TUBE WALL MAX TEMP (K)                         *MEBP 680
*     BTMIN     BASE CASE MIN ACHIEVABLE TEMP (K)                        *MEBP 690
*     C         TOTAL CONVERSION FOR THE LTR SYSTEM                      *MEBP 700
*     C1L       CONDENSER-1 LOAD (HTS) - (KJ/S)                          *MEBP 710
*     DELP      INCREMENT FOR STUDIED PARAMETER P                        *MEBP 720
*     DTA       ARRAY FOR DTD56$S TO BE STUDIED                          *MEBP 730
*     DTD56     DT DESIRED BETWEEN T(6) AND T(5) ,(K)                    *MEBP 740
*     DTMIN     INCREMENT FOR STUDIED PARAMETER TMIN                     *MEBP 750
*     DTWM      INCREMENT FOR STUDIED PARAMETER TWMAX                    *MEBP 760
*     D56       INCREMENT FOR STUDIED PARAMETER DTD56                    *MEBP 770
*     DT56      FIRST LOOP DELTA T 5-6                                   *MEBP 780
*     DYPR      DAYTIME POWER OUTPUT (MW-E)                              *MEBP 790
*     EDAN      ENERGY DISSIPATED AT NIGHT (MW)                          *MEBP 800
*     EOPAN     ENERGY OUTPUT AT NIGHT (MW)                              *MEBP 810
*     EPSF5     LIMITS FOR CONVERTION ON F(5)                            *MEBP 820
*     EPST5     LIMITS FOR CONVERTION ON T(5)                            *MEBP 830
*     E1        OVERALL EFFICIENCY OF PROCESS                            *MEBP 840
*     E2        EFFICIENY OF STEAM CYCLE                                 *MEBP 850
*     E3        THERMAL EFFICIENCY OF STORAGE                            *MEBP 860
*     F         FLOW(KMOL/SEC)                                           *MEBP 870
*     FC        FINAL CONVERSION IN REACTOR-RECEIVER (HTR)               *MEBP 880
*     F5        FLOW OF STREAM 5 (KMOL/S)                                *MEBP 890
*     GTW       GAS TURBINE WORK (NWORK) - (KJ/S)                        *MEBP 900
*     H         ENTHALPY,(KJ/KMOL)                                       *MEBP 910
*     HE1L      HEAT EXCHR. 1 LOAD (HTHEL) - (KJ/S)                      *MEBP 920
*     HE2L      HEAT EXCHR. 2 LOAD (LTHEL) - (KJ/S)                      *MEBP 930
*     IFP       INDICATOR FOR PRINTING (HTR)  (0-NO,1-YES)               *MEBP 940
*     I         DO-LOOP INDEX FOR TWMAX STUDY AND STREAM CLEAR           *MEBP 950
*     J         RECORD INDEX (1-45)                                      *MEBP 960
*     K         DO-LOOP INDEX FOR TMIN  STUDY                            *MEBP 970
*     L         DO-LOOP INDEX FOR DTD56 STUDY                            *MEBP 980
*     M         DO-LOOP INDEX FOR CONVERGENCE ON STREAMS                 *MEBP 990
*     N         NO.OF STREAMS                                            *MEBP1000
*     NDP       NO. OF VALUES FOR STUDIED PARAMETER P                    *MEBP1010
*     NH        NO. OF RECORDS IN HTS                                    *MEBP1020
*     NOP       NO. OF PLATES, DIST. COL. (MAX. ALLOWED)                 *MEBP1030
*     NOPL      NUMBER OF PARAMETER LOOPS                                *MEBP1040
*     NOSP      NUMBER OF STUDIED PARAMETERS                             *MEBP1050
*     NTMIN     NO. OF VALUES FOR STUDIED PARAMETER TMIN                 *MEBP1060
*     NTWMN     NO. OF VALUES FOR STUDIED PARAMETER TWMAX                *MEBP1070
*     N56       NO. OF VALUES FOR STUDIED PARAMETER DTD56                *MEBP1080
*     P         PRESSURE(BAR)                                            *MEBP1090
*     PD        PRESS. OF THE DIST. COL.                                 *MEBP1100
*     PHA       ARRAY FOR HIGH PRESSURE SIDE PARAMETER P                 *MEBP1110
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*      PRSO2    PERCENT RECOVERY OF SO2 IN THE DIST. COL.                 *MEBP1120
*      P1       PRESSURE FOR STREAM 1                                     *MEBP1130
*      P5       PRESSURE FOR STREAM 5                                     *MEBP1140
*      P21      PRESSURE FOR STREAM 21                                    *MEBP1150
*      Q        ARRAY FOR HEAT AVAILABLE AT REACTORS HEAT-EXCHANGERS      *MEBP1160
*      QAAN     Q AVAILABLE AT NIGHT (NWORK) - (KJ/S)                     *MEBP1170
*      QR       TOTAL Q REQUIRED IN REBOILER (KJ/S)                       *MEBP1180
*      QRFS     Q FOR REBOILER COMINR FROM STEAM (HTHEL) - (KJ/S)         *MEBP1190
*      R        100./(GROSS STEAM TURBINE POWER PRODUCTION)               *MEBP1200
*      RATIO    STEAM GENERATION-STORAGE RATIO (FROM STC)                 *MEBP1210
*      RCL      REBOILER-CONDENSER LOAD (HTHEL) - (KJ/S)                  *MEBP1220
*      RECUPL   RECUPERATOR LOAD (LTHEL) - (KJ/S)                         *MEBP1230
*      STOP     SMALL TURBINE OUTPUT (FROM STC) (MW)                      *MEBP1240
*      SUM      SUM OF BOILER FEED AND TRIMMER HEAT DUTIES                *MEBP1250
*      T        TEMP.(K)                                                  *MEBP1260
*      TGPD     TOTAL GENERATED POWER DURING THE DAY (MW-E)               *MEBP1270
*      TMA      ARRAY FOR TMIN$S  TO BE STUDIED                           *MEBP1280
*      TM1      FIRST LOOP TMIN                                           *MEBP1290
*      TMIN     MIN. ACHIVABLE T ANYWHERE IN THE SYSTEM                   *MEBP1300
*      TQA      TOTAL Q AVAILABLE AT THE RECEIVER (HTR) - (MJ/S=MW)       *MEBP1310
*      TRIML    TRIMMER LOAD (LTS) - (KJ/S)                               *MEBP1320
*      TRIMMER  TRIMMER LOAD (HTS) - (KJ/S)                               *MEBP1330
*      TW       MAX. TEMP. AT TUBE WALLS AS CALC. BY HTR - (K)            *MEBP1340
*      TWA      ARRAY FOR TWMAX$S TO BE STUDIED                           *MEBP1350
*      TWMA     FIRST LOOP TWMAX                                          *MEBP1360
*      TWMAX    MAX. PERMISSABLE WALL TEMP. AT THE ABSORBER               *MEBP1370
*      T1       TEMPERATURE STREAM 1 (K)                                  *MEBP1380
*      T24      SPECIFIED T(24) FOR LTS - (K)                             *MEBP1390
*      T27      SPECIFIED REACTOR IGNITION TEMP. FOR LTS - (K)            *MEBP1400
*      VAPL     VAPORIZER LOAD (LTS) - (KJ/S)                             *MEBP1410
*      VAP1L    VAPORIZER LOAD (HTS) - (KJ/S)                             *MEBP1420
*      X        ARRAY FOR CONVERSIONS AT THE LTR$S                        *MEBP1430
*      XD       SPECIFIED X2 AT THE DIST. COL. CONDENSER                  *MEBP1440
*      X1       OXYGEN CONTENT (MOLE FRACTION)                            *MEBP1450
*      X2       SO2 CONTENT (MOLE FR.)                                    *MEBP1460
*      X3       SO3 CONTENT (MOLE FR.)                                    *MEBP1470
*      X21      MOLE FRAC. SO2 IN STREAM 1  (FIRST APPROX.)               *MEBP1480
*      X25      MOLE FRAC. SO2 IN STREAM 5  (FIRST APPROX.)               *MEBP1490
*      X218     MOLE FRAC. SO2 IN STREAM 18 (FIRST APPROX.)               *MEBP1500
*                                                                         *MEBP1510
**************************************************************************MEBP1520
*                                                                         *MEBP1530
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)           MEBP1540
      COMMON/LTV/N,T24,T27,Q(5),X(5),C                                     MEBP1550
      COMMON/HTV/DTD56,EPST5,TWMAX,      PD,PRSO2,XD,EPSF5,NH,NOP          MEBP1560
      COMMON /LAHTV/BFWCT,TMIN                                             MEBP1570
      COMMON/HTHEL/C1L,VAP1L,HE1L,RCL,BFWHL,TRIMMER,QRFS                   MEBP1580
      COMMON/LTHEL/RECUPL,VAPL,BFWL,TRIML,HE2L                             MEBP1590
      COMMON/NWORK/QAAN,GTW                                                MEBP1600
      DIMENSION TWA(10),DTA(10),TMA(10),PHA(10)                            MEBP1610
*KEEP RECORD 45 ZERO FOR VARIOUS PROGRAM USES.                            *MEBP1620
      DATA F(45),P(45),T(45),H(45),X1(45),X2(45),X3(45)/7*0./              MEBP1630
*ALL CALC. BASED ON A BOEING TYPE RECEIVER ABSORBING 230. MW-TH.          *MEBP1640
      DATA TQA/230./                                                       MEBP1650
*PARAMETERS FOR THE BASE CASE                                             *MEBP1660
      DATA BTMIN,BTMAX,BDT56,BP/333.,1153.,140.,40./                       MEBP1670
*                                                                         *MEBP1680
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*SET ALL VARIABLES IN STREAM EQUAL TO ZERO                             *MEBP1690
      DO 8 I=1,60                                                       MEBP1700
    8 CALL RECOPY(45,I)                                                 MEBP1710
*                                                                      *MEBP1720
*READ UNCHANGING VARIABLES                                             *MEBP1730
      READ 45,P1,P5,P21,T24,T27                                         MEBP1740
*READ FIRST APROXIMATIONS TO BE UPDATED BY THE PROGRAM                 *MEBP1750
      READ 45,T1,X21,F5,X25,X218                                        MEBP1760
*     READ OBJECTIVE DATA AND SPECIFICATIONS                           *MEBP1770
      READ 45,DT56,TWMA,TMI,PRSO2,XD                                    MEBP1780
*READ TOLERANCES AND INCREMENTS DELTASS.                               *MEBP1790
      READ 45,EPSF5,EPST5                                               MEBP1800
*READ INTEGER SPECIFICATIONS=N,NOP,NH                                  *MEBP1810
      READ 48,N,NOP,NH                                                  MEBP1820
*READ PARAMETERS TO BE STUDIED=                                        *MEBP1830
      READ 56,DTWM,NTWM,D56,N56,DTMIN,NTMIN                             MEBP1840
      READ 56,DELP,NDP                                                  MEBP1850
      READ 48,NOPL                                                      MEBP1860
*WRITE ALL INPUTS FOR THE RECORD                                       *MEBP1870
      PRINT 16                                                          MEBP1880
      PRINT46,P1,P5,P21,T24,T27                                         MEBP1890
      PRINT 17,T1,X21,F5,X25,X218                                       MEBP1900
      PRINT18,DT56,TWMA,TMI,PRSO2,XD                                    MEBP1910
      PRINT 19,EPSF5,EPST5                                              MEBP1920
      PRINT 49,N,NOP,NH                                                 MEBP1930
      PRINT57,DTWM,NTWM,D56,N56,DTMIN,NTMIN                             MEBP1940
      PRINT 58,DELP,NDP                                                 MEBP1950
*PRELIMINARY CALCULATIONS, DATA PREPARATION AND FIRST ESTIMATES        *MEBP1960
*COMPLETE DATA OF F(1)                                                 *MEBP1970
      P(1)=P1                                                           MEBP1980
      T(1)=T1                                                           MEBP1990
      X2(1)=X21                                                         MEBP2000
      CALL ENTR1(T(1),X2(1),H(1))                                       MEBP2010
      X1(1)=0.0                                                         MEBP2020
      X3(1)=1.-X2(1)                                                    MEBP2030
*DO LOOPS FOR STUDIED PARAMETERS                                       *MEBP2040
      TMA(1)=TMI                                                        MEBP2050
      DO 14 K=2,10                                                      MEBP2060
   14 TMA(K)=TMA(K-1)+DTMIN                                             MEBP2070
      DO 32 K=1,10                                                      MEBP2080
      TWA(K)=BTMAX                                                      MEBP2090
      DTA(K)=BDT56                                                      MEBP2100
   32 PHA(K)=BP                                                         MEBP2110
      NOSP=NTMIN                                                        MEBP2120
      DO 10 I=1,NOPL                                                    MEBP2130
      DO 20 K=1,NOSP                                                    MEBP2140
      TWMAX=TWA(K)                                                      MEBP2150
      DTD56=DTA(K)                                                      MEBP2160
      P(5)=PHA(K)                                                       MEBP2170
      TMIN=TMA(K)                                                       MEBP2180
      T(1)=T1                                                           MEBP2190
      X2(1)=X21                                                         MEBP2200
      F(5)=F5                                                           MEBP2210
      X2(5)=X25                                                         MEBP2220
      X2(18)=X218                                                       MEBP2230
*PD ESTIMATED FROM KNOWN F(TMIN)                                       *MEBP2240
      PD=4.64E-4*EXP(.0303*TMIN)                                        MEBP2250
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*COMPLETE DATA OF F(18)                                                *MEBP2260
*T(18) UPDATED FROM KNOWN F(TMIN)                                      *MEBP2270
      T(18)=TMIN+50.+(TMIN-273.)/100.                                   MEBP2280
      P(18)=PD                                                          MEBP2290
      CALL BPTR(P(18),X2(18),T(18))                                     MEBP2300
      CALL ENTR1(T(18),X2(18),H(18))                                    MEBP2310
      BFWCT=TMIN                                                        MEBP2320
      PRINT 44,TWMAX,TMIN,DTD56,P(5)                                    MEBP2330
      DO 7 M=1,6                                                        MEBP2340
      CALL HTS                                                          MEBP2350
      CALL RECOPY(14,23)                                                MEBP2360
      CALL RECOPY(17,21)                                                MEBP2370
      F(23)=F(23)/2.                                                    MEBP2380
      F(21)=F(21)/2.                                                    MEBP2390
      P(21)=P21                                                         MEBP2400
      IF(F(21))31,31,29                                                 MEBP2410
*                                                                      *MEBP2420
   29 CALL LTS                                                          MEBP2430
      PRINT 52,F(36),F(1),X2(36),X2(1),T(36),T(1)                       MEBP2440
      IF(ABS(2.*F(36)-F(1))-0.015)3,3,4                                 MEBP2450
    3 IF(ABS(X2(1)-X2(36))-0.008)2,2,4                                  MEBP2460
    2 IF(ABS(T(1)-T(36))-1.0)1,1,4                                      MEBP2470
    1 IF(M-2.)4,4,21                                                    MEBP2480
    4 CALL RECOPY(36,1)                                                 MEBP2490
      P(1)=P1                                                           MEBP2500
      F(1)=2.*F(1)                                                      MEBP2510
      IF(F(21))31,31,12                                                 MEBP2520
   31 PRINT 30,TMIN                                                     MEBP2530
      GO TO 10                                                          MEBP2540
   12 F(5)=F(1)+F(18)                                                   MEBP2550
      P(5)=PHA(K)                                                       MEBP2560
    7 CONTINUE                                                          MEBP2570
      PRINT 22                                                          MEBP2580
*FINAL PASS THROUGH HTR                                                *MEBP2590
   21 IFP=1                                                             MEBP2600
      PRINT 44,TWMAX,TMIN,DTD56,P(5)                                    MEBP2610
      CALL HTR(F(5),T(5),P(5),X2(5),F(6),T(6),P(6),X1(6),X2(6),X3(6),FC,MEBP2620
     1TW,IFP)                                                           MEBP2630
      L=0                                                               MEBP2640
*CALL STEAM TURBINE CALC. ROUTINE                                      *MEBP2650
      PRINT 9                                                           MEBP2660
      SUM=BFWHL+TRIMMER                                                 MEBP2670
      CALL STC(QAAN,R,T(10),T(30),R4,RATIO,STOP,BFWN1,BFWN2,TGPD)       MEBP2680
*ADJUST FOR AN INTEGRATED POWER PLANT WITH A RECEIVER ABSORBING 230 MW  MEBP2690
      DO 11 J=1,18                                                      MEBP2700
   11 F(J)=F(J)*R                                                       MEBP2710
      C1L=C1L*R                                                         MEBP2720
      VAP1L=VAP1L*R                                                     MEBP2730
      HE1L=HE1L*R                                                       MEBP2740
      RCL=RCL*R                                                         MEBP2750
      TRIMMER=SUM*R-BFWHL                                               MEBP2760
      QRFS=QRFS*R                                                       MEBP2770
   34 DO 36 J=21,60                                                     MEBP2780
   36 F(J)=F(J)*R                                                       MEBP2790
      DO 15 J=1,5                                                       MEBP2800
   15 Q(J)=Q(J)*R                                                       MEBP2810
      RECUPL=RECUPL*R                                                   MEBP2820
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      VAPL=VAPL*R                                                       MEBP2830
      BFWL=BFWN1                                                        MEBP2840
      HE2L=HE2L*R                                                       MEBP2850
      GTW=GTW*R                                                         MEBP2860
      ATQA=TQA*R                                                        MEBP2870
      QAAN=QAAN*R                                                       MEBP2880
      CALL CTR(30,32,33,BFWL)                                           MEBP2890
      CALL CLR(32,34,35,TRIML)                                          MEBP2900
      IF(L.GT.0) GO TO 35                                               MEBP2910
*FINAL CALL FOR DIST. ROUTINE AND PRINTING ITS RESULTS.                *MEBP2920
      PRINT 9                                                           MEBP2930
      QR=RCL                                                            MEBP2940
      CALL DIST(F(16),T(16),P(16),H(16),X2(16),QR, XD,PD,PRSO2,NOP,F(17)MEBP2950
     1,T(17),P(17),H(17),X2(17),F(18),T(18),P(18),H(18),X2(18),IFP)     MEBP2960
*                                                                      *MEBP2970
*PRINTOUT MATERIAL AND ENERGY BALANCES - HTS                           *MEBP2980
      PRINT 44,TWMAX,TMIN,DTD56,P(5)                                    MEBP2990
      PRINT 40                                                          MEBP3000
      PRINT 41                                                          MEBP3010
      PRINT 42                                                          MEBP3020
      PRINT 54,(J,X1(J),X2(J),X3(J),T(J),P(J),F(J),H(J),J=1,NH)         MEBP3030
      PRINT 47,C1L,VAP1L,HE1L,RCL,BFWHL,TRIMMER,QRFS                    MEBP3040
*CALCULATE SEVERAL EFFICIENCIES WHICH DESCRIBE THE SYSTEM.             *MEBP3050
      EOPAN=STOP*.97+GTW*.9/2./1000.                                    MEBP3060
      DYPR=.958*TGPD                                                    MEBP3070
      E1=(DYPR+EOPAN*2.)/((RATIO+1.)*ATQA)                              MEBP3080
      E2=DYPR/(RATIO*ATQA-VAP1L/1000.+BFWHL/1000.-QRFS/1000.)           MEBP3090
      EDAN=QAAN+BFWL+TRIML                                              MEBP3100
      E3=2.*EDAN/(ATQA*1000.+VAP1L-BFWHL+QRFS)                          MEBP3110
      PRINT 37,E1,E2,E3                                                 MEBP3120
   37 FORMAT(/3X,*SUMMARY OF EFFICIENCIES AT THE CHOSEN PARAMETERS*,//3XMEBP3130
     1,4HE1= ,F6.4, /3X,4HE2= ,F6.4,/3X,4HE3= ,F6.4)                    MEBP3140
*PRINT RESULTS. LTS                                                     MEBP3150
   35 PRINT53                                                           MEBP3160
      PRINT 41                                                          MEBP3170
      PRINT 42                                                          MEBP3180
      PRINT 54,(J,X1(J),X2(J),X3(J),T(J),P(J),F(J),H(J),J=21,N)         MEBP3190
      PRINT50,RECUPL,VAPL,BFWL,TRIML,HE2L                               MEBP3200
      PRINT 43,QAAN,GTW                                                 MEBP3210
      PRINT 55,ATQA                                                     MEBP3220
      PRINT 5                                                           MEBP3230
      PRINT 42                                                          MEBP3240
      PRINT 54,(J,X1(J),X2(J),X3(J),T(J),P(J),F(J),H(J),J=50,60)        MEBP3250
      PRINT 13,(J,Q(J), J=1,5),(X(J),J=1,5),C                           MEBP3260
*REPEAT LTS PRINTOUT FOR 100MW OUTPUT IF L IS GREATER THAN 0.          *MEBP3270
      IF(L.GT.0) GO TO 33                                               MEBP3280
      R=R4                                                              MEBP3290
      BFWN1=BFWN2                                                       MEBP3300
      L=1                                                               MEBP3310
      GO TO 34                                                          MEBP3320
   33 PRINT 6                                                           MEBP3330
   20 CONTINUE                                                          MEBP3340
*RECOVER BASE CASE GUESSES TO AID CONVERGENCE FOR OTHER PARAMETERS     *MEBP3350
      IF(I-2)23,24,25                                                   MEBP3360
   23 TWA(1)=TWMA                                                       MEBP3370
      TMA(1)=BTMIN                                                      MEBP3380
      DO 26 K=2,10                                                      MEBP3390
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   TWA(K)=BTMIN                                                      MEBP3400
26 TWA(K)=TWA(K-1)+DTWM                                              MEBP3410
   NOSP=NTWM                                                         MEBP3420
   GO TO 10                                                          MEBP3430
24 DTA(1)=DT56                                                       MEBP3440
   TWA(1)=BTMAX                                                      MEBP3450
   DO 27 K=2,10                                                      MEBP3460
   TWA(K)=BTMAX                                                      MEBP3470
27 DTA(K)=DTA(K-1)+D56                                               MEBP3480
   NOSP=N56                                                          MEBP3490
   GO TO 10                                                          MEBP3500
25 IF(I.EQ.4)GO TO 10                                                MEBP3510
   PHA(1)=P5                                                         MEBP3520
   DTA(1)=BDT56                                                      MEBP3530
   DO 28 K=2,10                                                      MEBP3540
   DTA(K)=BDT56                                                      MEBP3550
28 PHA(K)=PHA(K-1)-DELP                                              MEBP3560
   NOSP=NDP                                                          MEBP3570
10 CONTINUE                                                          MEBP3580
 5 FORMAT(1H1,3X,*RESULTS OF THE LOW TEMP. REACTORS SYSTEM*)         MEBP3590
 6 FORMAT(3X,*END OF MEBP.*)                                         MEBP3600
 9 FORMAT(1H1)                                                       MEBP3610
13 FORMAT(3X,5(1HQ,I2,E10.4),/3X,5(1HX,F12.3),/3X,*LTR CONVERSION. C=MEBP3620
  1*,F5.3)                                                           MEBP3630
16 FORMAT(/15X,*MEBP PROGRAM*,/3X,*INPUT DATA*)                      MEBP3640
17 FORMAT(/3X,*FIRST APPROX=T(1),X2(1),F(5),     X2(5),X2(18)*,7F10.3MEBP3650
  1)                                                                 MEBP3660
18 FORMAT(/3X,*SPECIFICATION= DT56,TWMAX,TMIN,PRSO2,XD,*/3X,5F10.3)  MEBP3670
19 FORMAT(/3X,*TOLERANCES= EPSF5,EPST5= *2F10.4)                     MEBP3680
22 FORMAT(3X,*MATERIAL BALANCE DIDNT CONVERGE.*)                     MEBP3690
30 FORMAT(3X,*F(36)=F(1)=0. NO CONDENSATION AT TMIN=*,F5.1,* GO TO NEMEBP3700
  1XT TMAX*)                                                         MEBP3710
400FORMAT(/3X,*TABLE-1,MATERIAL AND ENERGY DATA FOR THE DAYTIME HIGH MEBP3720
  1TEMPERATURE SIDE*,/3X,*STORAGE SYSTEM*)                           MEBP3730
410FORMAT(/4X,*STREAM COMPOSITION  (MOL PR.)  TEMP.  PRESSURE  FLOW  MEBP3740
  1 ENTHALPY*)                                                       MEBP3750
420FORMAT(7X,3HNO.,4X,2HO2,5X,3HSO2,5X,3HSO3,5X,3H(K),4X,*(BAR) (KMOLMEBP3760
  1/S)(KJ/KMOL)*)                                                    MEBP3770
43 FORMAT(/3X,*ENERGY PRODUCED AT NIGHT= QAAN=*,E11.4,3X,4HGTW=,E11.4MEBP3780
  1,4H(KW))                                                          MEBP3790
44 FORMAT(1H1,2X,*PARAMETERS STUDIED= TWMAX=*,F6.1,2X,5HTMIN=,F5.1,2XMEBP3800
  1,6HDTD56=,F5.1,2X,5HPHTS=,F4.1)                                   MEBP3810
45 FORMAT(10X,F10.3)                                                 MEBP3820
46 FORMAT(/3X,*NON-CHANGING DATA=P(1),P(5),P(21),T24,T27*,5F10.3)    MEBP3830
47 FORMAT(/3X,*HEAT EXCHANGER LOAD (KW)=*,/3X,4HC1L=,F10.3,3X,6HVAP1LMEBP3840
  1=,F10.3,3X,5HHE1L=,F10.3,3X,4HRCL=,F10.3,/3X,6HBFWHL=,F9.3,3X,8HTRMEBP3850
  2IMMER=,F10.3,3X,5HQRFS=,F10.3)                                    MEBP3860
48 FORMAT(10X,3I10)                                                  MEBP3870
49 FORMAT(/3X,*GENERAL= N=*,I3,3X,4HNOP=,I3,3X,3HNH=,I2)             MEBP3880
50 FORMAT(/3X,*HEAT EXCHANGERS LOAD (KW)=*,3X,6HRECUP=,F10.3,3X,4HVAPMEBP3890
  1=,F10.3,/3X,4HBFW=,F10.3,3X,5HTRIM=,F10.3,3X,4HHE2=,F10.3)        MEBP3900
52 FORMAT(/3X,*CALC. ARE REPEATED IF ANY OF THE FOLLOWING CONDS. IS NMEBP3910
  1OT SATISFIED=*/3X,                                               *MEBP3920
  2IF(ABS(2.-F(36)-F(1))-0.015) F(36)=*,E11.5,3X,5HF(1)=,E11.5,/3X,*MEBP3930
  3IF(ABS(X2(1)-X2(36))-0.008)  X(36)=*,E11.5,3X,5HX(1)=,E11.5,/3X,*MEBP3940
  4IF(ABS(T(1)-T(36))-1.0)      T(36)=*,E11.5,3X,5HT(1)=,E11.5)     MEBP3950
53 FORMAT(1H1,3X,*TABLE-2,MATERIAL AND ENERGY BALANCES FOR THE NIGHT MEBP3960
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 1TIME OPERATION OF*,/4X,*THE LOW TEMPERATURE SIDE*)                    MEBP3970
54 FORMAT(/2X,I6,3F8.2,2F8.2,F8.2,F9.1)                                 MEBP3980
55 FORMAT(/3X,*RECEIVER LOAD TQA=*,F6.1,*(MW-THRM)*)                    MEBP3990
56 FORMAT(10X,3(F10.3,I10))                                             MEBP4000
57 FORMAT(3X,*INCREMENTS OF STUDIED PARAMS. TWMAX,DTD56,TMIN=*,3(F5.1MEBP4010
 1,I3,2X))                                                              MEBP4020
58 FORMAT(3X,*INCREMENTS OF STUDIED PARAMS. DELP, NDP=*,7X,F5.1,I3)  MEBP4030
   END                                                                  MEBP4040
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      SUBROUTINE HTS                                                    HTS
************************************************************************HTS
*     UPDATED 2/28/78                                                  *HTS
*     HTS -HIGH TEMP SIDE MATERIAL AND ENERGY BALANCES                 *HTS
*                                                                      *HTS
************************************************************************HTS
*ROUTINE IS CALLED BY MEBP TO CALC. MATERIAL AND ENERGY BALANCES FOR   *HTS
*THE HIGH TEMP. SIDE (DAY-TIME OR CHARGING MODE) OF THE PROCESS.       *HTS
*NO PARAMETERS ARE SPECIFIED IN THE CALL (COMMUNICATION BY COMMON BLOCK)HTS
*THE FOLLOWING SUBROUTINES ARE BEING USED=                             *HTS
*BPTR(P,X2,T)  - BOILING POINT TEMP.T OF LIQ. MIX. OF SO2-SO3 AT P,X2  *HTS
*CLR(NI,NG,NL,CL)-CONDENSER LOAD CL, FOR INCOMING GAS STREAM NI AND    *HTS
*     OUTGOING GAS STREAM NG AND LIQ. STREAM NL.                       *HTS
*CTR(NI,NG,NL,CL)-CONDENSER EXIT STREAMS(NG,NL)TEMP. FOR GIVEN LOAD-CL *HTS
*DIST(F,TF,PF,HF,XF,QR,XD,P,PRSO2,N,D,TM,PD,HLM,YM,B,TB,PB,HB,XB)-PLATE*HTS
*     TO PLATE CALC. OF DISTILLATION TOWER FOR BINARY MIX. SO2-SO3     *HTS
*ENTR1(T,X2,HL)-ENTHALPY CALCS. FOR SO2-SO3 LIQ.MIX AT TEMP-T,COMPOS-X2*HTS
*ENTR2(T,X2,X3,HG)-ENTHALPY CALCS. FOR O2-SO2-SO3 GAS MIX.AT T,X2,X3   *HTS
*FINDT(NS,NF)-FIND TEMP. OF STREAM NF. NS=STREAM STATE=1-LIQ. 2-GAS    *HTS
*HTR(FI,TI,PI,X2I,FO,TO,PO,X1O,X2O,X3O,FC,TWM,IFP)-HIGH TEMP. RECEIVER-*HTS
*     REACTOR. I-INPUT STREAM, O-OUTPUT STREAM,FINAL CONV.,TW-MAX,PRINT*HTS
*RECOPY(IIN,IOUT)-COPY RECORD NO.-IIN INTO RECORD NO.-IOUT             *HTS
*NOMENCLATURE= (SEE PROCESS SCHEMES FOR DETAILS)                       *HTS
*COMMON BLOCKS NAMES=                                                  *HTS
*     LAHTV     LOW AND HIGH TEMP. VARIABLES                           *HTS
*     HTHEL     HIGH TEMP. HEAT-EXCHANGERS LOADS                       *HTS
*     HTV       HIGH TEMP. VARIABLES                                   *HTS
*     STREAM    STREAM RECORDS NAME (F,P,T,H,X1,X2,X3)                 *HTS
*VARIABLES=                                                            *HTS
*     A         TERM IN THE J-MATRIX (NEWTON-RAPHSON METHOD)           *HTS
*     ABSDX2    ABS. VALUE OF DIFF. BETWEEN X2(5) AND X2(2)            *HTS
*     B         TERM IN THE J-MATRIX (NEWTON-RAPHSON METHOD)           *HTS
*     BFWCT     BOILER FEED WATER CONDENSER TEMP. (K)                  *HTS
*     BFWHL     BOILER FEED WATER HEAT LOAD - HTS - (KJ/S)             *HTS
*     C         TERM IN THE J-MATRIX (NEWTON-RAPHSON METHOD)           *HTS
*     C1L       CONDENSER-1 LOAD (HTS) - (KJ/S)                        *HTS
*     D         TERM IN THE J-MATRIX (NEWTON-RAPHSON METHOD)           *HTS
*     DET       DETERMINANT OF THE J-MATRIX (NR)                       *HTS
*     DF5       CORRECTION FOR F(5) (NR)                               *HTS
*     DTD56     DT DESIRED BETWEEN T(6) AND T(5) ,(K)                  *HTS
*     DT5       CORRECTION FOR T(5) (NR)                               *HTS
*     EPSF5     LIMITS FOR CONVERTION ON F(5)                          *HTS
*     EPST5     LIMITS FOR CONVERTION ON T(5)                          *HTS
*     F         FLOW(KMOL/SEC)                                         *HTS
*     FC        FINAL CONVERSION IN REACTOR-RECEIVER (HTR)             *HTS
*     FF        FLOW VERIABLE IN THE F-VECTOR (NR)                     *HTS
*     FT        TEMP VERIABLE IN THE F-VECTOR (NR)                     *HTS
*     F5        PERTUBED F(5) (F5=F(5)+0.5)                            *HTS
*     H         ENTHALPY,(KJ/KMOL)                                     *HTS
*     HE1L      HEAT EXCHR. 1 LOAD (HTHEL) - (KJ/S)                    *HTS
*     I         RUNNING INDEX IN DO LOOP (NR)                          *HTS
*     IFP       INDICATOR FOR PRINTING (HTR)  (0-NO,1-YES)             *HTS
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*     L         INDICATOR FOR REPEATTED CALCS. OF FIRST 6 STREAMS      *HTS  530
*     NH        NO. OF RECORDS IN HTS                                  *HTS  540
*     NOP       NO. OF PLATES, DIST. COL. (MAX. ALLOWED)               *HTS  550
*     OAC       OVER-ALL CONDENSER (IMAGINARY COND. FOR MAT.BAL.CALC.) *HTS  560
*     P         PRESSURE(BAR)                                          *HTS  570
*     PD        PRESS. OF THE DIST. COL.                               *HTS  580
*     PRSO2     PERCENT RECOVERY OF SO2 IN THE DIST. COL.              *HTS  590
*     QR        Q AVAILABLE (OR REQUIRED) FOR DIST. REBOILER           *HTS  600
*     QRFS      Q FOR REBOILER COMINR FROM STEAM (HTHEL) - (KJ/S)      *HTS  610
*     RCL       REBOILER-CONDENSER LOAD (HTHEL) - (KJ/S)               *HTS  620
*     T         TEMP.(K)                                               *HTS  630
*     TMIN      MIN. ACHIVABLE T ANYWHERE IN THE SYSTEM                *HTS  640
*     TRIMMER   TRIMMER LOAD (HTS) - (KJ/S)                            *HTS  650
*     TW        MAX. WALL TEMP. AS CALC. BY HTR                        *HTS  660
*     TWF       TW AS CALC. BY HTR FOR F5 AS INPUT (NR)                *HTS  670
*     TWMAX     MAX. PERMISSABLE WALL TEMP. AT THE ABSORBER            *HTS  680
*     TWT       TW AS CALC. BY HTR FOR T5 AS INPUT (NR)                *HTS  690
*     T5        PERTUBED T(5) (T6=T(6)+2.) (NR)                        *HTS  700
*     T6F       T(6) AS CALC. BY HTR FOR F5 AS INPUT (NR)              *HTS  710
*     T6T       T(6) AS CALC. BY HTR FOR T5 AS INPUT (NR)              *HTS  720
*     VAP1L     VAPORIZER LOAD (HTS) - (KJ/S)                          *HTS  730
*     XD        SPECIFIED X2 AT THE DIST. COL. CONDENSER               *HTS  740
*     X1        OXYGEN CONTENT (MOLE FRACTION)                         *HTS  750
*     X2        SO2 CONTENT (MOLE FR.)                                 *HTS  760
*     X3        SO3 CONTENT (MOLE FR.)                                 *HTS  770
***********************************************************************HTS  780
*                                                                      *HTS  790
      COMMON/HTV/DTD56,EPST5,TWMAX,      PD,PRSO2,XD,EPSF5,NH,NOP       HTS  800
      COMMON /LAHTV/BFWCT,TMIN                                          HTS  810
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)        HTS  820
      COMMON/HTHEL/C1L,VAP1L,HE1L,RCL,BFWHL,TRIMMER,QRFS                HTS  830
      DATA L/0/                                                         HTS  840
*                                                                      *HTS  850
      PRINT 1                                                           HTS  860
*NEWTON-RAPHSON TECH. IS USED IN SEARCH FOR F(5) AND T(5).             *HTS  870
*SUPPRESS TABLE PRINTING BY HTR ROUTINE AND THE DIST. ROUTINE .        *HTS  880
      IFP=0                                                             HTS  890
*                                                                      *HTS  900
    2 DO 60 I=1,10                                                      HTS  910
      F5=F(5)+0.5                                                       HTS  920
      T5=T(5)+2.                                                        HTS  930
      CALL HTR(F(5),T(5),P(5),X2(5),F(6),T(6),P(6),X1(6),X2(6),X3(6),FC,HTS  940
     1TW,IFP)                                                           HTS  950
      CALL HTR(F5,  T(5),P(5),X2(5),F(6),T6F, P(6),X1(6),X2(6),X3(6),FC,HTS  960
     1TWF,IFP)                                                          HTS  970
      CALL HTR(F(5),T5,  P(5),X2(5),F(6),T6T, P(6),X1(6),X2(6),X3(6),FC,HTS  980
     1TWT,IFP)                                                          HTS  990
      FF=TW-TWMAX                                                       HTS 1000
      FT=T(6)-T(5)-DTD56                                                HTS 1010
      A=(TWF-TW)/0.5                                                    HTS 1020
      B=(TWT-TW)/2.                                                     HTS 1030
      C=(T6F-T(6))/0.5                                                  HTS 1040
      D=(T6T-T(6))/2.-1.                                                HTS 1050
      DET=A*D-B*C                                                       HTS 1060
      DF5=(FF*D-FT*B)/DET                                               HTS 1070
      DT5=(FT*A-FF*C)/DET                                               HTS 1080
      F(5)=F(5)-DF5                                                     HTS 1090
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      T(5)=T(5)-DT5                                                     HTS 1100
      PRINT 63,DF5,DT5                                                  HTS 1110
      IF(ABS(DF5)-EPSF5)61,61,60                                        HTS 1120
   61 IF(ABS(DT5)-EPST5)62,62,60                                        HTS 1130
   60 CONTINUE                                                          HTS 1140
*IF LOOP COMPLEETED NO CONVERGENCE ACHIEVED. PRINT MESSAGE.            *HTS 1150
      PRINT 64                                                          HTS 1160
*UPDATE FOR FINAL F(5) AND T(5)                                        *HTS 1170
   62 CALL HTR(F(5),T(5),P(5),X2(5),F(6),T(6),P(6),X1(6),X2(6),X3(6),FC,HTS 1180
     1TW,IFP)                                                           HTS 1190
      X3(5)=1.-X2(5)                                                    HTS 1200
      X3(18)=1.-X2(18)                                                  HTS 1210
      CALL ENTR2(T(6),X2(6),X3(6),H(6))                                 HTS 1220
*OVER ALL MAT. BAL. TO CORRECT FOR X2(5). NOTE THAT T(16)=T(14)=TMIN   *HTS 1230
*ARE NOT THE FINAL RESULTS FOR THESE STREAMS.                          *HTS 1240
      T(14)=TMIN                                                        HTS 1250
      CALL CLR(6,14,16,QAC)                                             HTS 1260
      F(17)=F(16)*X2(16)*PRSO2/XD                                       HTS 1270
      X2(17)=XD                                                         HTS 1280
      F(18)=F(16)-F(17)                                                 HTS 1290
      X2(18)=(F(16)*X2(16)-F(17)*X2(17))/F(18)                          HTS 1300
      F(1)=F(5)-F(18)                                                   HTS 1310
      F(2)=F(5)                                                         HTS 1320
      P(2)=P(5)                                                         HTS 1330
      X1(2)=0.                                                          HTS 1340
      X2(2)=(F(1)*X2(1)+F(18)*X2(18))/F(2)                              HTS 1350
      X3(2)=1.0-X2(2)                                                   HTS 1360
      IF(L.EQ.1)GO TO 7                                                 HTS 1370
      ABSDX2=ABS(X2(2)-X2(5))                                           HTS 1380
      IF(ABSDX2-0.1*X2(2))7,7,8                                         HTS 1390
    8 X2(5)=X2(2)                                                       HTS 1400
      L=1                                                               HTS 1410
      GO TO 2                                                           HTS 1420
    7 H(2)=(F(1)*H(1)+F(18)*H(18))/F(2)                                 HTS 1430
*FIND T(2). FIRST GUESS FOR T(2) IS (T(1)+T(18))/2                     *HTS 1440
      T(2)=(T(1)+T(18))/2.                                              HTS 1450
      CALL FINDT(1,2)                                                   HTS 1460
*PASSING THIS POINT IT IS ASSUMED THAT F(2) IS KNOWN.UPDATE FOR F(3)   *HTS 1470
      CALL RECOPY(2,3)                                                  HTS 1480
*COND-1 HEATS SO3 STREAM TO ITS BOILING PT. T(3)=T(4).FIND IT          *HTS 1490
      CALL BPTR(P(3),X2(3),T(3))                                        HTS 1500
*ENTHALPY CHANGE BETWEEN H(2) AND H(3) EQUAL TO COND-1 HEAT LOAD (C1L) *HTS 1510
      CALL ENTR1(T(3),X2(3),H(3))                                       HTS 1520
      C1L=(H(3)-H(2))*F(3)                                              HTS 1530
*UPDATE FOR F(4)                                                       *HTS 1540
      CALLRECOPY(3,4)                                                   HTS 1550
*VAPORIZER(VAP-1)LOAD IS CALC. FROM LATENT HEAT OR ENTHALPY CHANGE AT T4HTS 1560
      CALL ENTR2(T(4),X2(4),X3(4),H(4))                                 HTS 1570
      VAP1L=(H(4)-H(3))*F(4)                                            HTS 1580
*UPDATE FOR F(5) (ALL IS KNOWN BUT THERE MAY BE SOME SMALL  DIFFERENCES*HTS 1590
      F(5)=F(4)                                                         HTS 1600
      P(5)=P(4)                                                         HTS 1610
      X1(5)=X1(4)                                                       HTS 1620
      X2(5)=X2(4)                                                       HTS 1630
      X3(5)=X3(4)                                                       HTS 1640
*HEAT LOAD AND TEMPS. OF HE-1 ARE FOUND WITH THE AID OF THE HIGH TEMP. *HTS 1650
*REACTOR (HTR) ROUTINE RESULTS.                                        *HTS 1660
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      CALL ENTR2(T(5),X2(5),X3(5),H(5))
      HE1L=(H(5)-H(4))*F(5)
*      CALC.                          CONDITIONS (T,H) OF F7.       F(6)    *
*X1(6),X2(6),X3(6),P(6) WILL BE GIVEN BY HTR                            *
*UPDATE FOR STREAM F7. FIND T7 BY EQUATING HE1L TO H7-H6.FIRST GUESS    *
*FOR T7 IS T(4)+DTD56                                                   *
      CALL RECOPY(6,7)
      H(7)=H(6)-HE1L/F(7)
      T(7)=T(4)+DTD56
      CALL FINDT(2,7)
*CONTINUE HERE IF T7 CONVERGED OR ASSUME TO CONVERGED.                  *
*ENTERING CONDENSATION ZONE. START WITH COND-1. KNOWING C1L,CALC. T(8) *
      CALL CTR(7,8,9,C1L)
*KNOWING CONDITIONS OF F8 REBOILLER CALCS. ARE MADE.ASSUME T10=T18+10C *
      T(10)=T(18)+10.
       CALLCLR(8,10,11,RCL)
*KNOWING CONDITIONS OF F10, BFW HEATE IS CALC. ASS.T12=T(STEAM COND)+10*
      T(12)=BFWCT+10.
      CALL CLR(10,12,13,BFWHL)
*TRIMMER CALCULATIONS                                                   *
      CALL CLR(12,14,15,TRIMMER)
      P(16)=P(15)
*CALC.DISTILLATION FEED CONDITIONS,I.E. F16=F9+F11+F13+F15             *
      F(16)=F(9)+F(11)+F(13)+F(15)
      X1(16)=0.
      X2(16)=(F(9)*X2(9)+F(11)*X2(11)+F(13)*X2(13)+F(15)*X2(15))/F(16)
      X3(16)=1.-X2(16)
      H(16)=(F(9)*H(9)+F(11)*H(11)+F(13)*H(13)+F(15)*H(15))/F(16)
*FIRST GUESS OF T16 WAS SET=TMIN   .NEWTON RAPHSON TECH. IS USED.       *
      CALL FINDT(1,16)
*FIND DISTILLATION  COL  PRESSURE (CORESPONDING TO TMIN AT THE DIST.    *
*CONDENSER.)FIRST ASSUME PD AS READ AT THE DATA INPUT.                  *
      DO 14 I=1,10
      IF(PD)18,18,19
   18 PD=1.
      GO TO 20
   19 IF(PD-50.)20,20,21
   21 PD=50.
   20 CALL BPTR(PD,XD,TD1)
      CALL BPTR(PD+0.1,XD,TD2)
       FOP=TD1-TMIN
      DFDP=10.*(TD2-TD1)
      PD=PD-FOP/DFDP
      IF(ABS(FOP/DFDP).LE.0.1)GO TO 16
   14 CONTINUE
      PRINT 15,PD,TD1
   15 FORMAT(3X,*NO CONV. ON PD. PD=*,F6.3,3X,*TEMP. AT COND. IS=*,F5.1)
*CALL THE DISTILLATION ROUTINE                                          *
   16 QR=RCL
      CALL DIST(F(16),T(16),P(16),H(16),X2(16),QR, XD,PD,PRSO2,NOP,F(17)
     1,T(17),P(17),H(17),X2(17),F(18),T(18),P(18),H(18),X2(18),IFP)
*IF EXCESS HEAT IS AVAILABLE AT RCL PUSH IT DOWN TO BFW.                *
      QRFS=QR-RCL
      IF(QRFS)3,4,4
    3 BFWHL=BFWHL-QRFS
      QRFS=0.
*ADJUST FOR MISSING VARIABLES                                           *
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```
    4 X1(17)=0.                                                         HTS 2240
      X1(18)=0.                                                         HTS 2250
      X3(17)=1.-X2(17)                                                  HTS 2260
      X3(18)=1.-X2(18)                                                  HTS 2270
*PASSING THIS PT. IT IS ASSUMED THAT ALL THE PROGRAM IS COMPLETED.     *HTS 2280
*CHECK X2(2),AGAIN,TO SEE IF EQUAL TO X2(5). PRINT BOTH X2(2),X2(5)    *HTS 2290
      F(1)=F(2)-F(18)                                                   HTS 2300
      X2(2)=(F(1)*X2(1)+F(18)*X2(18))/F(2)                              HTS 2310
      X3(2)=1.0-X2(2)                                                   HTS 2320
      PRINT 38,X2(2),X2(5)                                              HTS 2330
*IF THERE IS NO MATCH IN X2(2) AND X2(5) IT SOULD BE RECTIFIED AT 2ND PSHTS 2340
      PRINT 39                                                          HTS 2350
    1 FORMAT(/3X,*HTS ROUTINE*)                                         HTS 2360
   38 FORMAT(/3X,*OVERALL MAT. BAL. RESULTS IN X2(2) OF=*,F6.4,3X,      HTS 2370
     1*COMPARE TO ASSUMED= *,F6.4,*HTS ROUTINE*)                        HTS 2380
   39 FORMAT(/3X,*END OF HTS  RTN.*)                                    HTS 2390
   63 FORMAT(/3X,*CONVERGENCE ON F(5) AND T(5)= DF5=*,E11.4,3X,4HDT5=,E1HTS 2400
     11.4,*HTS ROUTINE*)                                                HTS 2410
   64 FORMAT(/3X,*NO CONVERGENCE ON F(5) AND T(5) AT HTS ROUTINE.*)     HTS 2420
      RETURN                                                            HTS 2430
      END                                                               HTS 2440
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```
      SUBROUTINE LTS                                                    LTS
***********************************************************************LTS
*     UPDATED 2/28/78                                                  *LTS
*     LTS - LOW TEMP. SIDE, MATERIAL AND ENERGY BALANCES.              *LTS
*                                                                      *LTS
***********************************************************************LTS
*ROUTINE IS CALLED BY MEBP. COMUNICATION IS DONE THROUGH COMMON BLOCKS.*LTS
* ROUTINE CALC. MATERIAL AND ENERGY BALANCES FOR THE LOW TEMP. SIDE.   *LTS
* SCHEME INCLUDES GAS TURBINE FOR THE EX7A5S905 6F 62 '6U33ET TEMP. -  *LTS
*T24 IS SPECIFIED).                                                    *LTS
*REACTOR INLET TEMP. T27=IGNITION TEMP. IS SPECIFIED.                  *LTS
*REACTOR ROUTINE CALCS. QAAN - Q TO STEAM AT NIGHT AND THE FINAL CONVER-LTS
*SION - FC. REX CALCS. THE CONDITIONS OF STREAM 28.                    *LTS
*                                                                      *LTS
*THE FOLLOWING SUBROUTINES ARE BEING USED=                             *LTS
*CLR(NI,NG,NL,CL)-CONDENSER LOAD CL, FOR INCOMING GAS STREAM NI AND    *LTS
*     OUTGOING GAS STREAM NG AND LIQ. STREAM NL.                       *LTS
*CTR(NI,NG,NL,CL)-CONDENSER EXIT STREAMS(NG,NL)TEMP. FOR GIVEN LOAD-CL *LTS
*DHR(T)-HEAT OF REACTION AS FUNCTION OF TEMP. T                        *LTS
*ENTR2(T,X2,X3,HG)-ENTHALPY CALCS. FOR O2-SO2-SO3 GAS MIX.AT T,X2,X3   *LTS
*FINDT(NS,NF)-FIND TEMP. OF STREAM NF. NS=STREAM STATE=1-LIQ. 2-GAS    *LTS
*LTR(X,Q,N-IN,N-OUT,N-COLD) LOW TEMP. REACTOR ROUTINE. (N=STREAM NO.)  *LTS
*RECOPY(IIN,IOUT)-COPY RECORD NO.-IIN INTO RECORD NO.-IOUT             *LTS
*                                                                      *LTS
*NOMENCLATURE= (SEE PROCESS SCHEMES FOR DETAILS)                       *LTS
*COMMON BLOCKS NAMES=                                                  *LTS
*     LAHTV     LOW AND HIGH TEMP. VARIABLES                           *LTS
*     LTV       LOW  TEMP. VARIABLES                                   *LTS
*     LTHEL     LOW TEMP. HEAT-EXCHANGERS LOADS                        *LTS
*     NWORK     NIGHT WORK                                             *LTS
*     STREAM    STREAM RECORDS NAME (F,P,T,H,X1,X2,X3)                 *LTS
*VARIABLES=                                                            *LTS
*     BFWCT     BOILER FEED WATER CONDENSER TEMP. (K)                  *LTS
*     BFWL      BOILER FEED WATER HEAT LOAD - LTS - (KJ/S)             *LTS
*     C         TOTAL CONVERSION FOR THE LTR SYSTEM                    *LTS
*     CMBC      COMBINED CONDENSER HE2+RECUP                           *LTS
*     DHRA      DHR AT AVERAGE TEMP. OF REACTOR OPERATION              *LTS
*     DT        TEMP. DEVIATION OF STREAM J-2 FROM 693K                *LTS
*     F         FLOW(KMOL/SEC)                                         *LTS
*     GTW       GAS TURBINE WORK (NWORK) - (KJ/S)                      *LTS
*     H         ENTHALPY,(KJ/KMOL)                                     *LTS
*     HE2L      HEAT EXCHR. 2 LOAD (LTHEL) - (KJ/S)                    *LTS
*     I         INDEX IN VARIOUS DO LOOPS                              *LTS
*     J         DEFINED AS (50+2*I) IN LTR$S DO LOOP                   *LTS
*     N         NO.OF STREAMS                                          *LTS
*     P         PRESSURE(BAR)                                          *LTS
*     Q         ARRAY FOR HEAT AVAILABLE AT REACTORS HEAT-EXCHANGERS   *LTS
*     QAAN      Q AVAILABLE AT NIGHT (NWORK) - (KJ/S)                  *LTS
*     QRES      Q FOR REBOILER COMING FROM STEAM (HTHEL) - (KJ/S)      *LTS
*     RECUPL    RECUPERATOR LOAD (LTHEL) - (KJ/S)                      *LTS
*     T         TEMP.(K)                                               *LTS
*     TMIN      MIN. ACHIVEABLE T ANYWHERE IN THE SYSTEM               *LTS
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*     TRIML    TRIMMER LOAD (LTS) - (KJ/S)                             *LTS  530
*     T24      SPECIFIED T(24) FOR LTS - (K)                           *LTS  540
*     T27      SPECIFIED REACTOR IGNITION TEMP. FOR LTS - (K)          *LTS  550
*     VAPL     VAPORIZER LOAD (LTS) - (KJ/S)                           *LTS  560
*     X        ARRAY FOR CONVERSIONS AT THE LTR$S                      *LTS  570
*     X1       OXYGEN CONTENT (MOLE FRACTION)                          *LTS  580
*     X2       SO2 CONTENT (MOLE FR.)                                  *LTS  590
*     X3       SO3 CONTENT (MOLE FR.)                                  *LTS  600
************************************************************************LTS  610
*                                                                      *LTS  620
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)        LTS  630
      COMMON/LTV/N,T24,T27,Q(5),X(5),C                                  LTS  640
      COMMON /LAHTV/BFWCT,TMIN                                          LTS  650
      COMMON/LTHEL/RECUPL,VAPL,BFWL,TRIML,HE2L                          LTS  660
      COMMON/NWORK/QAAN,GTW                                             LTS  670
*                                                                      *LTS  680
      PRINT 6                                                           LTS  690
* STREAM 24 = STREAN 23 EXCEPT FOR T AND H                             *LTS  700
      CALL RECOPY(23,24)                                                LTS  710
      T(24)=T24                                                         LTS  720
      CALL ENTR2(T(24),X2(24),X3(24),H(24))                             LTS  730
*CALC. FROM TURBINE EXPANSION FORMULA THE CONDITIONS FOR STREAM - 40.  *LTS  740
      CALL RECOPY(24,40)                                                LTS  750
      P(40)=P(21)                                                       LTS  760
      T(40)=T(24)*(P(24)/P(40))**(0.4/1.4)                              LTS  770
      CALL ENTR2(T(40),X2(40),X3(40),H(40))                             LTS  780
*CALC. HEAT LOADS OF HE2         FOR THE ASSUMED T(24) AND T(40)       *LTS  790
      HE2L=F(24)*(H(24)-H(23))                                          LTS  800
*CALC. STREAM 22.(EQ. TO 21 EXCEPT FOR H).                             *LTS  810
      CALL RECOPY(21,22)                                                LTS  820
      CALL ENTR2(T(22),X2(22),X3(22),H(22))                             LTS  830
      VAPL=(H(22)-H(21))*F(22)                                          LTS  840
*CALC. STREAM 25. FIRST GUESS FOR T(25) IS T(22)                       *LTS  850
      F(25)=F(22)+F(34)                                                 LTS  860
      P(25)=P(22)                                                       LTS  870
      X1(25)=(X1(22)*F(22)+X1(34)*F(34))/F(25)                          LTS  880
      X2(25)=(X2(22)*F(22)+X2(34)*F(34))/F(25)                          LTS  890
      X3(25)=1.-X1(25)-X2(25)                                           LTS  900
      H(25)=(H(22)*F(22)+H(34)*F(34))/F(25)                             LTS  910
      T(25)=T(22)                                                       LTS  920
      CALL FINDT(2,25)                                                  LTS  930
*CALC. STREAM 26. FIRST GUESS FOR T(26) IS(T(25)+T(40))/2.             *LTS  940
      T(26)=(T(25)+T(40))/2.                                            LTS  950
      F(26)=F(25)+F(40)                                                 LTS  960
      P(26)=P(25)                                                       LTS  970
      X1(26)=(X1(25)*F(25)+X1(40)*F(40))/F(26)                          LTS  980
      X2(26)=(X2(25)*F(25)+X2(40)*F(40))/F(26)                          LTS  990
      X3(26)=1.-X1(26)-X2(26)                                           LTS 1000
      H(26)=(H(25)*F(25)+H(40)*F(40))/F(26)                             LTS 1010
      CALL FINDT(2,26)                                                  LTS 1020
*CALC. STREAM 27. (EQUAL TO STREAM 26 EXCEPT FOR T).                   *LTS 1030
      CALL RECOPY(26,27)                                                LTS 1040
      T(27)=T27                                                         LTS 1050
      CALL ENTR2(T(27),X2(27),X3(27),H(27))                             LTS 1060
      RECUPL=F(27)*(H(27)-H(26))                                        LTS 1070
*INITIATE(ZERO) REACTORS RECORDS AND H.E.S LOADS (Q).                  *LTS 1080
      DO 7 I=51,60                                                      LTS 1090
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    7 CALL RECOPY(45,I)                                                 LTS 1100
      DO 8 I=1,5                                                        LTS 1110
    8 Q(I)=0.                                                           LTS 1120
*CALL LTR TO CALC. ALL LOW TEMP. REACTORS                              *LTS 1130
      CALL RECOPY(27,50)                                                LTS 1140
      DO 1 I=1,5                                                        LTS 1150
      J=50+2*I                                                          LTS 1160
      CALL LTR(X(I),Q(I),J-2,J-1,J)                                     LTS 1170
      IF(T(J-1)-773.)2,10,3                                             LTS 1180
    2 DT=(773.-T(J-1))*(T(J-3)-693.)/(T(J-3)-T(J-1))                    LTS 1190
      T(J-2)=693.+DT                                                    LTS 1200
      CALL ENTR2(T(J-2),X2(J-2),X3(J-2),H(J-2))                         LTS 1210
      Q(I-1)=F(J-2)*(H(J-3)-H(J-2))                                     LTS 1220
      CALL LTR(X(I),Q(I),J-2,J-1,J)                                     LTS 1230
   10 Q(I)=0.                                                           LTS 1240
      CALL RECOPY(45,J)                                                 LTS 1250
      CALL RECOPY(J-1,60)                                               LTS 1260
      GO TO 4                                                           LTS 1270
    3 IF(I.LT.5)GO TO 1                                                 LTS 1280
      T(60)=773.                                                        LTS 1290
      CALL ENTR2(773.,X2(60),X3(60),H(60))                              LTS 1300
      Q(I)=F(60)*(H(59)-H(60))                                          LTS 1310
    1 CONTINUE                                                          LTS 1320
*GET STREAM 28 AND QAAN FROM REACTOR ROUTINE.                          *LTS 1330
    4 QAAN=0.                                                           LTS 1340
      DO 11 I=1,5                                                       LTS 1350
   11 QAAN=QAAN+Q(I)                                                    LTS 1360
*FINAL CONVERSION CALCULATIONS                                         *LTS 1370
       C=(X2(50)-X2(60))/X2(50)/(1.-X2(60)/2.)                          LTS 1380
*UPDATE REACTOR SYSTEM OUTPUT STREAM NO.28                             *LTS 1390
      CALL RECOPY(60,28)                                                LTS 1400
*CALC. STREAMS 37 AND 38. F WILL BE LATER UPDATED.                     *LTS 1410
      CALL RECOPY(28,37)                                                LTS 1420
      CALL RECOPY(28,38)                                                LTS 1430
      CMBC=HE2L+RECUPL                                                  LTS 1440
      CALL CTR(28,29,43,CMBC)                                           LTS 1450
      F(37)=F(28)*HE2L/CMBC                                             LTS 1460
      F(38)=F(28)-F(37)                                                 LTS 1470
*RECALC. HE2 AS A CONDENSER STANDING BY ITSELF.                        *LTS 1480
      CALL CTR(37,41,42,HE2L)                                           LTS 1490
*CALC, STREAMS 29 AND 43.                                              *LTS 1500
      CALL CTR(38,29,43,RECUPL)                                         LTS 1510
*CALC. STREAM 39. FIRST GUESS FOR T(39) IS (T(29)+T(41))/2.            *LTS 1520
      F(39)=F(41)+F(29)                                                 LTS 1530
      P(39)=P(29)                                                       LTS 1540
      X1(39)=(X1(29)*F(29)+X1(41)*F(41))/F(39)                          LTS 1550
      X2(39)=(X2(29)*F(29)+X2(41)*F(41))/F(39)                          LTS 1560
      X3(39)=1.-X1(39)-X2(39)                                           LTS 1570
      H(39)=(H(29)*F(29)+H(41)*F(41))/F(39)                             LTS 1580
      T(39)=(T(29)+T(41))/2.                                            LTS 1590
      CALL FINDT(2,39)                                                  LTS 1600
*CALC. STREAMS 30 AND 31.                                              *LTS 1610
      CALL CTR(39,30,31,VAPL)                                           LTS 1620
*CALC. STREAMS 32 AND 33                                               *LTS 1630
      T(32)=BFWCT+10.                                                   LTS 1640
      CALL CLR(30,32,33,BFWL)                                           LTS 1650
*CALC. STREAMS 34,35.                                                  *LTS 1660
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      T(34)=TMIN                                                        LTS 1670
      CALL CLR(32,34,35,TRIAL)                                          LTS 1680
*CALC. STREAM 36. FIRST GUESS FOR T(36) IS (T(31)+T(33))/2.            *LTS 1690
      P(36)=P(35)                                                       LTS 1700
      F(36)=F(31)+F(33)+F(35)+F(42)+F(43)                               LTS 1710
      X1(36)=0.                                                         LTS 1720
      X2(36)=(F(31)*X2(31)+F(33)*X2(33)+F(35)*X2(35)+F(42)*X2(42)+F(43)*LTS 1730
     1X2(43))/F(36)                                                     LTS 1740
      X3(36)=1.-X2(36)                                                  LTS 1750
      H(36)=(F(31)*H(31)+F(33)*H(33)+F(35)*H(35)+F(42)*H(42)+F(43)*H(43)LTS 1760
     1)/F(36)                                                           LTS 1770
      T(36)=(T(31)+T(33))/2.                                            LTS 1780
      CALL FINDT(1,36)                                                  LTS 1790
*CALC. GAS TURBINE WORK.                                               *LTS 1800
      GTW=(H(24)-H(40))*F(24)                                           LTS 1810
      PRINT 5                                                           LTS 1820
    5 FORMAT(/3X,*END OF LTS  RTN.*)                                    LTS 1830
    6 FORMAT(/3X,*LTS ROUTINE*)                                         LTS 1840
      RETURN                                                            LTS 1850
      END                                                               LTS 1860
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      SUBROUTINE HTR(F5,T5,P5,X25,F6,T6,P6,X16,X26,X36,FC,TWM,IFP)       HTR
************************************************************************HTR
*                                                                       *HTR
*                 HTR - CENTRAL RECEIVER (HEATER-REACTOR) ROUTINE       *HTR
*                                                                       *HTR
************************************************************************HTR
*HIGH TEMP. RECEIVER-REACTOR ROUTINE IS CALLED BY *HTR(F5,T5,P5,X25,F6,*HTR
*T6,P6,X16,X26,X36,FC,TWM,IFP) FROM HTS. (5-FOR IP STREAM,6-FOR OUTPUT *HTR
*STREAM,FC-FINAL CONVERSION, TWM-MAX.WALL TEMP.,IFP-INDICATOR FOR PRINT)HTR
*THE DESIGN IS BASED ON THE BOEING RECEIVER FOR HELIUM (*CLOSED CYCLE   *HTR
*HIGH TEMP. CENTRAL RECEIVER CONCEPT FOR SOLAR ELECTRIC POWER* EPRI -   *HTR
*SY 32 INTERIM REPORT,FEB.1976.PREPARED BY BOEING ENG.+CONSTRUCTION CO.*HTR
*PROG.MANAGER J.R.GINTZ)                                                *HTR
*THE BASIC DESIGN INCLUDES 5600 TUBES 19. METER LONG MADE OF HAYNES 188*HTR
*THE PROGRAM ASSUMES ONE SINGLE SOURCE TEMP. SEEN BY ALL TUBES AND IDE-*HTR
*NTICAL TEMP.-CONVERSION PROFILE IN ALL TUBES. TUBES ARE ASSUMED TO BE *HTR
*COATED BY FE2O3 CATALYST FOR THE DISSOCIATION REACTION OF SO3. MASS TR*HTR
*ANSFER COEFF. KG AND HEAT TRANSFER COEFF. H ARE ASSUMED FUNCTIONS OF T,HTR
*MASS VELOCITY, AND PRESSURE.  CP, DHR (DELTA HEAT OF REACTION),        *HTR
*AND KP ARE CONSIDERED TO BE FUNCTION OF TEMP.(KP(T) IS TAKEN FROM G.   *HTR
*NICKLESS *INORGANIC SULPHUR CHEMISTRY* ELSEVIER,1968 P.546  CP(T) AND *HTR
*DHR(T) ARE EXTERNAL FUNCTION)                                          *HTR
*IT IS ASSUMED THAT THE RECEIVER ABSORBED 230 MWT. T-SOURCE AND THE     *HTR
*TEMP. PROFILE IN AND OUTSIDE THE TUBE AS WELL AS THE CONVERSION OF SO3*HTR
*ARE DETERMINED BY NEWTON-RAPHSON ITERATION TECHNIQUE TO PROVIDE FOR    *HTR
*THE ABOVE MENTIONED 230MWT ABSORBED.(SEE PROGRAM FLOWSHEET FOR DETAILS)HTR
*                                                                       *HTR
*EXTERNAL SUBROUTINES USED=CP,DHR,TRKP                                  *HTR
*                                                                       *HTR
*NOMENCLATURE=                                                          *HTR
*                                                                       *HTR
*     A          PARTIAL VALUE OF EXPONENT USED IN DERIVING TB          *HTR
*     C          CALCULATED BULK CONVERSION                             *HTR
*     D          NO.OF MOLES DIFFUSED TO REACTION ZONE                  *HTR
*     DEN        DENOMINATOR FOR MOLE FRC CALCSC                        *HTR
*     DF         DIFF. BETWEEN F2 AND F1 - PARTIAL VALUE IN EQUATING HEAT*HTR
*     DIFF       DIFFERENCE BETWEEN HEAT DELIVERED AND CALC. HEAT ABSORPD*HTR
*     DN         D                                                      *HTR
*     DT         INCREMENT IN SEARCH FOR SOURCE TEMP. T                 *HTR
*     DTW        DELTA TW (NR CONVERGING ON TW)                         *HTR
*     DX         DELTA X  (NR CONVERGING ON X)                          *HTR
*     DZ         DELTA Z                                                *HTR
*     EXPA       EXPONENT OF A                                          *HTR
*     FC         FINAL CONVERSION                                       *HTR
*     FTW        FUNCTION FOR TW (DIFF.IN HEAT GIVEN AND HEAT ABSORBED) *HTR
*     F1         FUNCTION IN NR SCHEME TO CONVERGE ON TQA               *HTR
*     F2         FUNCTION IN NR SCHEME TO CONVERGE ON TQA               *HTR
*     F5         STREAM INPUT (KMOL/S)                                  *HTR
*     F6         STREAM OUTPUT(KMOL/S)                                  *HTR
*     G          MASS FLOW PER UNIT CROSS-SEC.OF TUBE.                  *HTR
*     H          HEAT TR. COEFF.                                        *HTR
*     I          RUNING INDEX POINTING AT A PARTICULAR SECTION IN TUBE  *HTR
*     IFP        INDICATOR FOR PRINTING (1-PRINT,0-DONT)                *HTR
*     J          RUNING INDEX IN DO LOOPS 7,27                          *HTR
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*      J1        INDEX USED IN NR SCHEME TO INDICATE FIRST OR SECOND CALC*HTR  550
*      K         TUBE METAL CONDUCTIVITY                                 *HTR  560
*      KG        MASS TR. COEFF.                                         *HTR  570
*      L         LENGTH OF TUBE (METER)                                  *HTR  580
*      LON       NO. OF ITERATION IN DO LOOP 5                           *HTR  590
*      M         RUNING INDEX IN DO LOOP  20                             *HTR  600
*      MU        VISCOSITY OF THE STREAM (CP)                             HTR  610
*      N         RUNING INDEX IN DO LOOP -5                              *HTR  620
*      NO        NOS+1 INDEX USED TO PREPARE OUTPUT STREAM (LAST SECTION)*HTR  630
*      NOS       NO. OF SECTIONS IN TUBE                                 *HTR  640
*      NOT       NUMBER OF TUBES IN THE REACTOR                           HTR  650
*      P         TOTAL PRESSURE IN RECEIVER TUBES                        *HTR  660
*      PAI       3.14                                                    *HTR  670
*      PB        GAS BULK PRESSURE ARRAY                                 *HTR  680
*      PS        PARTIAL PRESSURE OF SO2 CONVERTED                       *HTR  690
*      P5        INPUT STREAM PRESSURE                                   *HTR  700
*      P6        OUTPUT STREAM PRESSURE                                  *HTR  710
*      Q         HEAT DELIVERED FROM RADIATING SOURCE                    *HTR  720
*      QR        HEAT ABSORBED BY REACTION                               *HTR  730
*      QS        SENSIBLE HEAT ABSORBED BY GAS                           *HTR  740
*      REF       REYNOLDS NUMBER FACTOR (DIMENSIONLESS)                   HTR  750
*      RFY       CONST. USED IN CALCS. OF Y$S (RATIO FOR Y).             *HTR  760
*      RKP       REACTION KP AS FUNCTION OF TS.                          *HTR  770
*      SIGMA     STEFAN BOLTZMANN CONST.                                 *HTR  780
*      STHABG    SUM OF TOTAL HEAT ABSORBED BY GAS                       *HTR  790
*      SUA       SURFACE UNIT AREA (PAI*TID*DZ) CONST. USED IN CALC. Q$S *HTR  800
*      T         SOURCE TEMP. (RADIATING SOURCE)                         *HTR  810
*      TB        BULK GAS TEMP.                                          *HTR  820
*      THABG     TOTAL HEAT ABSORBED BY GAS                              *HTR  830
*      TID       TUBE INSIDE DIAMETER (METER)                            *HTR  840
*      TQA       TOTAL Q AVAILABLE (MWT)-HEAT ABSORBED BY CENTRAL RECEIVERHTR  850
*      TRKPX     KP OF REACTION FOR A PARTICULAR VALUE OF X.             *HTR  860
*      TS        SURFACE TEMP. (INSIDE TUBE WALL TEMP.)                  *HTR  870
*      TW        EXTERNAL TUBE WALL TEMP.                                *HTR  880
*      TWM       MAX. TUBE WALL TEMP.                                    *HTR  890
*      TWT       TUBE WALL THICKNESS                                     *HTR  900
*      T4                                                                *HTR  910
*      T5        TEMP. OF INPUT  STREAM                                  *HTR  920
*      T6        TEMP. OF OUTPUT STREAM                                  *HTR  930
*      W         TOTAL MASS FLOW (MOLE/SEC)                              *HTR  940
*      X         CONVERSION                                              *HTR  950
*      X1        TEMPORARY VALUE OF X IN NR SCHEME TO FIND IT.           *HTR  960
*      X16       MOLE FR. O2  IN F6                                      *HTR  970
*      X25       MOLE FR. SO2 IN F5                                      *HTR  980
*      X26       MOLE FR. SO2 IN F6                                      *HTR  990
*      X36       MOLE FR. SO3 IN F6                                      *HTR 1000
*      YO2       MOLE FR. O2  IN BULK                                    *HTR 1010
*      YSO2      MOLE FR. SO2 IN BULK                                    *HTR 1020
*      YSO3      MOLE FR. SO3 IN BULK                                    *HTR 1030
*      Z         LENGTH OF TUBE AT SECTION BEING CALC.                   *HTR 1040
*************************************************************************HTR 1050
*                                                                        *HTR 1060
       DIMENSION TW(100),TS(100),TB(100),X(100),YSO3(100),YSO2(100)       HTR 1070
       DIMENSION YO2(100),PB(100),PS(100),Q(100),QR(100),QS(100),Z(100)   HTR 1080
       DIMENSION C(100),F(11)                                             HTR 1090
       REAL K,KG,L,TRKP,MU                                                HTR 1100
*                                                                        *HTR 1110
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*PHYSICAL DATA AND CONSTANTS.                                          *HTR 1120
      DATA K,     L,NOS,TID,TWT,X(1),TW(1),TQA,LON/30.,           19.,95,HTR 1130
     10.037,0.008,0.1,885.,230.,100/                                    HTR 1140
      DATA NOT/5600/                                                    HTR 1150
*CONSTANTS AND INITIAL CONDITIONS.                                     *HTR 1160
      DATA SIGMA,PAI,YO2(1)/ 4.88E-08,3.141592,0./                      HTR 1170
*CONSTANTS AND CONVERSION FACTORS                                      *HTR 1180
      DZ=L/NOS                                                          HTR 1190
      W=F5*3600.                                                        HTR 1200
      G=W/NOT/PAI/TID**2*4.                                             HTR 1210
      RFY=4.*DZ/G/TID                                                   HTR 1220
      P=P5                                                              HTR 1230
      YSO2(1)=X25                                                       HTR 1240
      SUA=PAI*TID*DZ                                                    HTR 1250
      TB(1)=T5                                                          HTR 1260
      PB(1)=P*YSO2(1)                                                   HTR 1270
      YSO3(1)=1.0-YSO2(1)                                               HTR 1280
      T=1200.                                                           HTR 1290
      F1=0.                                                             HTR 1300
      DO 20 M=1,20                                                      HTR 1310
   24 T4=T**4                                                           HTR 1320
      I=1                                                               HTR 1330
      STHABG=0.                                                         HTR 1340
    1 DO 5 N=1,LON                                                      HTR 1350
      J1=1                                                              HTR 1360
*CALCULATE RADIATED HEAT PER UNIT AREA Q                               *HTR 1370
    6 Q(I)=SIGMA*(T4-TW(I)**4)                                          HTR 1380
*CALCULATE INSIDE TUBE WALL TEMPERATURE TS                             *HTR 1390
      TS(I)=TW(I)-Q(I)*TWT/K                                            HTR 1400
*USE FIRST ESTIMATE OF X(I) FROM KNOWN APPROXIMATE FUNCTION OF TS(I).   HTR 1410
      IF(TS(I).GT.1120..OR.TS(I).LT.880.) GO TO 79                      HTR 1420
      IF(I.NE.1) GO TO 79                                               HTR 1430
      X(I)=6.83E-23*TS(I)**7.152                                        HTR 1440
*CALCULATE HEAT ABSORBED BY REACTION PER UNIT AREA QR=DHR*KG*(PS-PB)   *HTR 1450
*FIND PS FROM X VS TS DEPENDENCY. X IS FOUND BY TRIAL AND ERROR.       *HTR 1460
*REACTION CONSTANT=RKP                                                 *HTR 1470
   79 RKP=10.0**(4.765-5022./TS(I))                                     HTR 1480
      DO 7 J=1,10                                                       HTR 1490
      X1=X(I)                                                           HTR 1500
      TRKPX=TRKP(X1,P,YO2(1),YSO2(1),YSO3(1))                           HTR 1510
      X1=X(I)+0.005                                                     HTR 1520
      DX=.005*(TRKPX-RKP)/(TRKP(X1,P,YO2(1),YSO2(1),YSO3(1))-TRKPX)     HTR 1530
      X(I)=X(I)-DX                                                      HTR 1540
      IF(X(I).GT.1.) X(I)=.999                                          HTR 1550
      IF(ABS(DX)-0.001)8,8,7                                            HTR 1560
    7 CONTINUE                                                          HTR 1570
* EQUILIBRIUM CONVERSION FOR THIS SECTION IS FOUND                     *HTR 1580
*CALCULATE PS OF SO2                                                   *HTR 1590
    8 PS(I)=2.*P*(YSO2(1)+YSO3(1)*X(I))/(2.+YSO3(1)*X(I))               HTR 1600
*CALCULATE HEAT AND MASS TRANSFER COEFFICIENTS FOR THIS SECTION.        HTR 1610
      MU=2.46E-3+3.2E-5*TB(I)                                           HTR 1620
      REF=(.822*G/MU)**.81                                              HTR 1630
      H=REF*MU*.782                                                     HTR 1640
      KG=1.50E-6*REF*TB(I)**.81/P5                                      HTR 1650
*CALCULATE DN PER UNIT AREA. DN=KG*(PS-PB)                             *HTR 1660
      D =KG*(PS(I)-PB(I))                                               HTR 1670
*CALCULATE QR                                                          *HTR 1680
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```
      QR(I)=DHR(TS(I))*D                                                 HTR 1690
*CALCULATE SENSIBLE HEAT PER UNIT AREA QS=H*(TS-TB)                     *HTR 1700
      QS(I)=H*(TS(I)-TB(I))                                              HTR 1710
      X(I+1)=X(I)                                                        HTR 1720
      IF(J1.GE.2) GO TO 11                                               HTR 1730
      J1=2                                                               HTR 1740
      I=I+1                                                              HTR 1750
      DN=D                                                               HTR 1760
      TW(I)=TW(I-1)+1.                                                   HTR 1770
      TB(I)=TB(I-1)                                                      HTR 1780
      PB(I)=PB(I-1)                                                      HTR 1790
      YO2(I)=YO2(I-1)                                                    HTR 1800
      YSO2(I)=YSO2(I-1)                                                  HTR 1810
      YSO3(I)=YSO3(I-1)                                                  HTR 1820
      GO TO 6                                                            HTR 1830
   11 I=I-1                                                              HTR 1840
      FTW=Q(I)-QR(I)-QS(I)                                               HTR 1850
      DTW=FTW/(Q(I+1)-QR(I+1)-QS(I+1)-FTW)                               HTR 1860
      TW(I)=TW(I)-DTW                                                    HTR 1870
      IF(ABS(DTW)-0.01)9,9,5                                             HTR 1880
    5 CONTINUE                                                           HTR 1890
*IF LOOP COMPLETTEL NO CONVERGENCE ON TW IN LON STEPS.                  *HTR 1900
      PRINT 2,I,T,TW(I),TS(I)                                            HTR 1910
      PRINT 3,Q(I),QR(I),QS(I)                                           HTR 1920
      PRINT 4                                                            HTR 1930
    2 FORMAT(/*  DIDNT CONVERGE ON TW. I=*,I4,2X,*T,TW,TS=*,3(F6.1,2X),*HTR 1940
     1RESPECTIVELY.*)                                                    HTR 1950
    3 FORMAT(/2X,*Q,QR,QS,THABG=*,4(E11.4,2X),*RESPECTIVELY*)            HTR 1960
    4 FORMAT(/2X,*HOWEVER ASSUMED TW IS OK PROGRAM CONTINUE*)            HTR 1970
*CALCULATE TOTAL HEAT ABSORBED BY GAS - THABG .                         *HTR 1980
    9 THABG=QR(I)+QS(I)                                                  HTR 1990
*ACCUMULATE HEAT ABSORBED BY GAS - STHABG                               *HTR 2000
      STHABG=STHABG+THABG*SUA                                            HTR 2010
* EVALUATE TB-H*(TS-TB)*PAI*TID*DZ=G*PAI*TID**2/4*CP*DTB                *HTR 2020
* AFTER INTEGRATION THE ABOVE EQ. RESULTSS IN THE FOLLOWING             *HTR 2030
      A=4.*H*DZ/(G*TID)                                                  HTR 2040
      EXPA=EXP(-A/CP(TB(I),YO2(I),YSO2(I),YSO3(I)))                      HTR 2050
      TB(I+1)=TS(I)-(TS(I)-TB(I))*EXPA                                   HTR 2060
*CALCULATE GAS BULK COMPOSITION                                         *HTR 2070
      DEN=1.+DN*RFY/2.                                                   HTR 2080
      YSO3(I+1)=(YSO3(I)-DN*RFY)/DEN                                     HTR 2090
      YSO2(I+1)=(YSO2(I)+DN*RFY)/DEN                                     HTR 2100
      YO2(I+1)=1.-YSO2(I+1)-YSO3(I+1)                                    HTR 2110
*UPDATE Z,TW,PB                                                         *HTR 2120
      Z(I)=I*DZ                                                          HTR 2130
      PB(I+1)=YSO2(I+1)*P                                                HTR 2140
* CALCULATE BULK CONVERSION - C                                         *HTR 2150
      C(I)=(1.-YSO3(I)/YSO3(1))/(1.+YSO3(I)/2.)                          HTR 2160
*UPDATE FOR NEXT SECTION AFTER CHECKING FOR COMPLETION. IF DONE-PRINT   *HTR 2170
      IF(NOS-I)26,26,25                                                  HTR 2180
   25 I=I+1                                                              HTR 2190
      GO TO 1                                                            HTR 2200
*ALL CALCULATIONS ARE COMPLETED. PRINT RESULTS.                         *HTR 2210
*CHANGE Q INTO ACCUMULATIVE POWER ABSORBED                              *HTR 2220
   26 Q(1)=Q(1)*SUA                                                      HTR 2230
      QR(1)=QR(1)*SUA                                                    HTR 2240
      QS(1)=QS(1)*SUA                                                    HTR 2250
```

```
      DO 27 J=2,NOS                                                     HTR 2260
      Q(J)=Q(J)*SUA+Q(J-1)                                              HTR 2270
      QR(J)=QR(J)*SUA+QR(J-1)                                           HTR 2280
      QS(J)=QS(J)*SUA+QS(J-1)                                           HTR 2290
   27 CONTINUE                                                          HTR 2300
      STHABG=NOT*1.163E-6*STHABG                                        HTR 2310
      DIFF=NOT*1.163E-6*Q(NOS)-STHABG                                   HTR 2320
*CHECK FOR DIFFERANCE BETWEEN AVAILABLE Q (TQA) AND CALC. Q.           *HTR 2330
*CHANGE SOURCE TEMP (T) ACCORDINGLY.                                   *HTR 2340
      IF(F1)12,13,12                                                    HTR 2350
   13 F1=STHABG-TQA                                                     HTR 2360
      T=T+2.                                                            HTR 2370
      GO TO 24                                                          HTR 2380
   12 F2=STHABG-TQA                                                     HTR 2390
      DF=(F2-F1)/2.                                                     HTR 2400
      DT=F2/DF                                                          HTR 2410
      IF(F1*F2.LT.0. .AND. DF.LT.0.) DT=-DT                             HTR 2420
      T=T-DT                                                            HTR 2430
      F1=F2                                                             HTR 2440
      IF(ABS(F2)-1.01)10,10,20                                          HTR 2450
   20 CONTINUE                                                          HTR 2460
      PRINT 80                                                          HTR 2470
   80 FORMAT(/3X,*NO CONVERGENCE ON TQA*)                               HTR 2480
*ZERO IRRELEVANT VARIABLES AT THE TUBE END                             *HTR 2490
   10 PS(I+1)=0.                                                        HTR 2500
      TS(I+1)=0.                                                        HTR 2510
      TW(I+1)=0.                                                        HTR 2520
      Z(I+1)=Z(I)                                                       HTR 2530
      Q(I+1)=0.                                                         HTR 2540
      QR(I+1)=0.                                                        HTR 2550
      QS(I+1)=0.                                                        HTR 2560
      X(I+1)=X(I)                                                       HTR 2570
      C(I+1)=C(I)                                                       HTR 2580
      NO=NOS+1                                                          HTR 2590
*SUPPRESS TABLE PRINTING IF IFP=0.                                     *HTR 2600
      IF(IFP.EQ.0) GO TO 18                                             HTR 2610
      PRINT 30                                                          HTR 2620
   30 FORMAT(/10X,*HIGH TEMP REACTOR DESIGN-COMPUTATION RESULTS*/)      HTR 2630
      PRINT 31                                                          HTR 2640
   31  FORMAT(/8X,3HNOS,8X,1HL,9X,2HTW,9X,2HTS,9X,2HTB,8X,1HQ,9X,2HQR,  HTR 2650
     1 9X,2HQS,12X,1HC,8X,5HY-SO3,6X,5HY-SO2,7X,4HY-O2/)                HTR 2660
     0PRINT 32,(J,Z(J),TW(J),TS(J),TB(J),Q(J) ,QR(J),QS(J),C(J),YSO3(J),HTR 2670
     1YSO2(J),YO2(J),J=1,NO)                                            HTR 2680
      PRINT 33,STHABG,T,DIFF                                            HTR 2690
   32 FORMAT(/I11,F11.2,3F11.1,3E11.4,4F11.3)                           HTR 2700
   330FORMAT(/10X,*THERMAL POWER ABSORBED BY GAS-*,E11.4,*MW-THERMAL)   HTR 2710
     1   SOURCE TEMP.=*,F5.1,3H(K),2X,5HDIFF=,E10.4,2HMW)               HTR 2720
      PRINT 15,(Z(J),X(J),J=1,NO)                                       HTR 2730
   15 FORMAT(/3X,F5.2,F11.4)                                            HTR 2740
*SET OUTPUT VARIABLES FOR CALLING PROGRAM                              *HTR 2750
   18 P6=P                                                              HTR 2760
      FC=C(NOS)                                                         HTR 2770
      F6=F5*(1.+(1.-X25)*FC/2.)                                         HTR 2780
      T6=TB(NO)                                                         HTR 2790
      X16=YO2(NOS)                                                      HTR 2800
      X26=YSO2(NOS)                                                     HTR 2810
        X36=YSO3(NOS)                                                   HTR 2820
```

```
      TWM=TW(NOS)                                                       HTR 2830
      IF(IFP.EQ.0)GO TO 14                                              HTR 2840
      PRINT 22,F6,T6,P6,X16,X26,X36,FC,TWM                              HTR 2850
   22 FORMAT(/3X,*HTR RETURNS WITH=        F(6)       T(6)        P(6)  HTR 2860
     1   X1(6)       X2(6)       X3(6)        FC      TWM*,/20X,8F11.3) HTR 2870
   14 RETURN                                                            HTR 2880
      END                                                               HTR 2890
```

```
      SUBROUTINE LTR(FC,QAAN,IN,J,K)
************************************************************************
*     JUNE 1,1978                                                      *
*     LTR - LOW TEMP. REACTOR                                          *
*                                                                      *
************************************************************************
*CALCULATIONS ARE FOR ADIABATIC OXIDATION OF SO2 TO SO3 IN A REACTOR   *
*WICH REACHES EQUILIBRIUM CONVERSION.I.E. RESULTS OF FC AND TEQ ARE    *
*GIVEN FOR DATA FULFILING THE REACTION CONSTANT,KP,EQUATION (REF.  -   *
*NICLESS).                                                             *
************************************************************************
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)
      DIMENSION X(5),DX(5),TEQ(5),HR(5),HL(5)
      DATA EPSDT,DDX/1.01,0.001/
      DATA RIGT/693./
      JI1=IN
      IF(X1(IN)-X2(IN)/2.)13,13,14
   13 XM=2.*X1(IN)/X2(IN)-0.011
      GO TO 23
   14 XM=0.989
   23 DO 24 I=1,5
      FACTOR=0.15*I
      X(I)=FACTOR*XM
   24 TEQ(I)=1000.-100.*I
      DHR420=DHR(T(IN))
      I=1
      P(J)=P(IN)
      P(K)=P(IN)
      IF(X1(JI1))19,19,20
   20 IF(X2(JI1))19,19,21
   19 PRINT 22,X1(JI1),X2(JI1),X3(JI1),JI1
   22 FORMAT(3X,*NO MORE REACTANTS. X1=*,F5.3,3X,3HX2=,F5.3,3X,3HX3=,F5.
     13,3X,2HJ=,I2,*LTR*)
      X(I)=0.
      CALL RECOPY(JI1,J)
      GO TO 4
   21 CONTINUE
      DO 26 I=1,5
      DO 7 N=1,20
      L=1
   16 RKP=10.**(5022./TEQ(I)-4.765)
      DO 8 M=1,10
      XT=X(I)
      TRKPX=TKP(XT,P(J),X1(JI1),X2(JI1),X3(JI1))
      XT=X(I)+.01
      TRKPY=TKP(XT,P(J),X1(JI1),X2(JI1),X3(JI1))
      DEN=TRKPY-TRKPX
      IF(DEN.EQ.0.) GO TO 26
      DXT=0.01*(TRKPX-RKP)/DEN
      X(I)=X(I)-DXT
      IF(ABS(DXT)-DDX)9,9,5
    9 IFPNCM=0
```

```
      GO TO 11
    5 IF(X(I).LE.0.) X(I)=0.1*XT
      IF(X(I)-XM)8.6,6
    6 X(I)=(XT-0.01+XM)/2.
    8 CONTINUE
*NO CONVERGENCE MASSEGE                                                *
      IFPNCM=1
   11 IF(X(I).GT.0.) GO TO 3
      IF(I.LT.5) GO TO 26
      X(I)=0.
      GO TO 2
    3 IF(X(I)-XM)2,2,1
    1 IF(I.LT.5)GO TO 26
      X(I)=XM
      PRINT 10
   10 FORMAT(3X,*100 P.C. CONVERSION IN LTR*)
    2 DX(I)=X(I)
      HR(I)=(DHR420+DHR(TEQ(I)))/2.
      D=1.-X2(IN)*X(I)/2.
      F(J)=F(IN)*D
      X1(J)=(X1(IN)-X2(IN)*X(I)/2.)/D
      X2(J)=X2(IN)*(1.-X(I))/D
      X3(J)=1.-X1(J)-X2(J)
      H(J)=(4.2*DX(I)*X2(JI1)*HR(I)+H(JI1))*F(JI1)/F(J)
      T(J)=TEQ(I)
      CALL FINDT(2,J)
      IF(L.EQ.2) GO TO 15
      FDT1=T(J)-TEQ(I)
      L=2
      TEQ(I)=TEQ(I)+1.
      GO TO 16
   15 FDT2=T(J)-TEQ(I)
         DT=FDT2/(FDT2-FDT1)
      TEQ(I)=TEQ(I)-DT
      IF(ABS(DT)-EPSDT)4,4,7
    7 CONTINUE
      PRINT 28,TEQ(I),DT,RKP,TRKPX,T(J),I
   28 FORMAT(3X,*DIDNT CONVERGE ON TEQ. TEQ=*,F6.1,3X,3HDT=,F6.1,3X,4HRK
     1P=,E12.4,3X,4HTRK=,E12.4,3X,*T(J)=*,F6.1,*LTR  I=*,I2)
   26 CONTINUE
      PRINT 29,J,F(J),P(J),T(J),H(J),X1(J),X2(J),X3(J)
   29 FORMAT(3X,*STREAM I=*,I2,7E12.4,*COPY IN INTO J*)
      CALL RECOPY(IN,J)
    4 CALL RECOPY(J,K)
      T(K)=RIGT
      CALL ENTR2(T(K),X2(K),X3(K),H(K))
      HL(I)=F(J)*(H(J)-H(K))
      QAAN=HL(I)
      FC=X(I)
      IF(IFPNCM.EQ.0) GO TO 12
      PRINT 17,X(I), DXT,TEQ(I),T(J),IN
   17 FORMAT(/3X,*NO CONVERGENCE ON X=*,E10.4,3X,*DXT=*,E10.4,3X,*TEQ=*,
     1E10.4,*T(J)=*,F6.1,3X,*INPUT STREAM TO LTR IS *,I2)
      PRINT 30,I,N,TEQ(I),RKP.X(I),TRKPX,TRKPY,DEN,DXT
   30 FORMAT(3X,*I   N   TEQ   RKP   X   TRKPX   TRKPY   DEN   DXT*,/3X,2I5,7E10
     1.4)
   12 RETURN
      END
```

```
      SUBROUTINE DIST(F,TF,PF,HF,XF,QR,XD,P,PRSO2,N,D,TM,  PD,HLM,  YM, DIST  10
     1 B,TB,PB,HB,XB,IFP)                                               DIST  20
***********************************************************************DIST  30
*                                                                     *DIST  40
*     UPDATED 8/15/78                                                 *DIST  50
*              DISTILLATION  COLUMN  ROUTINE                          *DIST  60
*                                                                     *DIST  70
***********************************************************************DIST  80
*                                                                     *DIST  90
*INPUTS TO THE PROGRAM ARE=                                           *DIST 100
*     FEED= FLOW-F, SO2 MOLE FRAC.-XF, ENTHALPY-HF, PRESSURE-PF, TEMP-TFDIST 110
*     TOP= SO2 MOLE FRAC.-XD, PECENT RECOVERY OF SO2-PRSO2            *DIST 120
*     BOTTOM= REBOILER DUTY-QR                                        *DIST 130
*     GENERAL= TOTAL PRESSURE-P, MAX.NO.OF PLATES PERMITTED-N         *DIST 140
*                                                                     *DIST 150
*OUTPUT= THE PROGRAM CALC. OVERALL MATERIAL AND ENERGY BALANCES FOR A  *DIST 160
*         BINARY DISTILLATION COLUMN SEPARATING SO2 FROM SO3          *DIST 170
*                                                                     *DIST 180
* INPUT DATA= FEED= F,TF,PF,HF,XF. BOTTOM= QR. TOP= XD. GENERAL=P,PRSO2*DIST 190
*,N                                                                   *DIST 200
*FOREACH PLATE=L=LIQUID,V=VAPOR,X=SO2 MOLE FRAC.IN LIQ,Y=SO2 MOLE FRAC.*DIST 210
*IN VAP.,T=PLATE TEMP.,HL=LIQ.ENTHALPY,HV=VAP.ENTHALPY.               *DIST 220
*ALL UNITS CONSIDERED TO BE IN METRIC,I.E. F-MOLE/HR,T-K,P-BAR,H-KJ/KMOLDIST 230
*Q-MW(CONVERTED INTO KJ/HR IN THE TEXT)           )                   *DIST 240
*ROUTINE ACCEPT FLOWS IN KMOLE/SEC AND RETURNS THEM IN THE SAME UNITS  *DIST 250
*BUT CALC. ARE MADE IN KMOLE/HR. NECESSARY CONVERTIONS ARE MADE BEFORE *DIST 260
*AND AFTER THE CALCS.                                                 *DIST 270
*                                                                     *DIST 280
*     NOMENCLATURE=                                                   *DIST 290
*     A          JACOBIAN MATRIX COMPONENT IN NR FOR X AND L          *DIST 300
*     A11        INVERSED JACOBIAN COMPONENT IN NR FOR X AND L        *DIST 310
*     A12        INVERSED JACOBIAN COMPONENT IN NR FOR X AND L        *DIST 320
*     A21        INVERSED JACOBIAN COMPONENT IN NR FOR X AND L        *DIST 330
*     A22        INVERSED JACOBIAN COMPONENT IN NR FOR X AND L        *DIST 340
*     B          BOTTOM LIQUID OUTPUT FLOW (KMOL/HR)                  *DIST 350
*     C          JACOBIAN MATRIX COMPONENT IN NR FOR X AND L          *DIST 360
*     D          DISTILLATE FLOW (KMOL/SEC) -OUTPUT                   *DIST 370
*     DENFR2     DENOMINATOR FOR FR2 -NR FLASH CALCS.                 *DIST 380
*     DENFR3     DENOMINATOR FOR FR3 -NR FLASH CALCS.                 *DIST 390
*     DET        DETERMINANT OF JACOBIAN MATRIX IN NR FOR X AND L     *DIST 400
*     DFR        DIFF. IN NR FLASH CALCS.                             *DIST 410
*     DH         DIFF. BETWEEN GIVEN AND CALC. FEED ENTHALPIES (ARRAY) *DIST 420
*     DHDX       DERIVATIVE OF H W.R.T. X - NR CALCS. FOR X AND L     *DIST 430
*     DHF        TOLERANCE VALUE FOR DH -ACCEPTABLE CALC. H OF FLASH  *DIST 440
*     DL         INCREMENT OF L IN NR FOR X AND L                     *DIST 450
*     DR         INCREMENT OF R IN NR FLASH CALCS.                    *DIST 460
*     DSOY       DIFF. BETWEEN 1. AND SUM OF Y$S AT B FOR ADJUSTMENT CALC*DIST 470
*     DV         DEVIATION OF V AT TOP FROM OVERALL MATERIAL BAL. CALCS. *DIST 480
*     DX         DELTA X FOR CALC. DH/DX                              *DIST 490
*     DXJ        INCREMENT OF X IN NR FOR X AND L                     *DIST 500
*     DY         DIFF. BETWEEN CALC. COMPOSITION AND GIVEN COMP. AT D *DIST 510
*     E          JACOBIAN MATRIX COMPONENT IN NR FOR X AND L          *DIST 520
*     EDR        MAX. TOLERANCE FOR DR IN NR FLASH CALCS.             *DIST 530
*     F          FEED FLOW (KMOLE/SEC)                                *DIST 540
```

```
*     FL       LIQUID IN FLASHED FEED                                  *DIST 550
*     FR       NR FUNCTION IN FLASH CALC.                              *DIST 560
*     FR2      PARTIAL NR FUNCTION IN FLASH CALCS.                     *DIST 570
*     FR3      PARTIAL NR FUNCTION IN FLASH CALCS.                     *DIST 580
*     FV       VAPOR IN FLASHED FEED                                   *DIST 590
*     F1       NR FUNCTION IN L AND X CALCS.                           *DIST 600
*     F2       NR FUNCTION IN L AND X CALCS.                           *DIST 610
*     G        JACOBIAN MATRIX COMPONENT IN NR FOR X AND L             *DIST 620
*     HB       ENTHALPY OF BOTTOM STREAM (KJ/KMOL) - OUTPUT            *DIST 630
*     HD       ENTHALPY OF TOP    STREAM (KJ/KMOL)                     *DIST 640
*     HF       FEED ENTHALPY (KJ/KMOL) - GIVEN                         *DIST 650
*     HFC      CALCULATED FEED ENTHALPY                                *DIST 660
*     HFF      HEAT IN FEED (HF*F(KJ/HR))                              *DIST 670
*     HFL      ENTHALPY OF LIQUID PORTION IN FLASHED FEED              *DIST 680
*     HFV      ENTHALPY OF VAPOR  PORTION IN FLASHED FEED              *DIST 690
*     HL       LIQUID ENTHALPY ARRAY FOR COL. LIQ. STREAMS             *DIST 700
*     HLM      DISTILLATE (CONDENSATE) ENTHALPY(KJ/KMOL) - OUTPUT      *DIST 710
*     HM1P     ENTHALPY CORRESPONDS TO XM1P (NR)                       *DIST 720
*     HP1P     ENTHALPY CORRESPONDS TO XP1P (NR)                       *DIST 730
*     HV       VAPOR ENTHALPY ARRAY FOR COL. VAPOR STREAMS             *DIST 740
*     I        INDEX OF DO LOOP USING NR TO FIND L AND X2              *DIST 750
*     IFP      INDICATOR FOR PRINTING                                  *DIST 760
*     J        DO LOOP 50 INDEX -FLASH CALC.+DO LOOP 60 INDEX-PLATES   *DIST 770
*     JR       DO LOOP 51 INDEX - NR IN FLASH CALC.                    *DIST 780
*     KB2      VOLATILITY CONST. FOR SO2 IN B                          *DIST 790
*     KB3      VOLATILITY CONST. FOR SO3 IN B                          *DIST 800
*     KSO2     VOLATILITY CONST. FOR SO2 - FLASH AND PLATE TO PLAT CALC*DIST 810
*     KSO3     VOLATILITY CONST. FOR SO3 - FLASH AND PLATE TO PLAT CALC*DIST 820
*     L        LIQUID FLOW ARRAY FOR COL. PLATES (KMOL/HR)             *DIST 830
*     LHB      LATENT HEAT OF B                                        *DIST 840
*     M        J+1                                                     *DIST 850
*     N        NO. OF PLATES                                           *DIST 860
*     NFP      FEED PLATE NO. - INDICATOR IN SEARCH FOR FEED PLATE     *DIST 870
*     P        DISTILATION COLUMN PRESSURE (BAR) -PRESCRIBED           *DIST 880
*     PB       BOTTOM STREAM PRESSURE (BAR) -OUTPUT                    *DIST 890
*     PD       DISTILLATE STREAM PRESSURE (BAR) -OUTPUT                *DIST 900
*     PF       FEED PRESSURE (IP) (BAR) - BEFORE FLASH                 *DIST 910
*     PRSO2    PERCENT RECOVERY OF SO2                                 *DIST 920
*     QC       CONDENSER HEAT LOAD (KJ/SEC)                            *DIST 930
*     QR       REBOILER HEAT LOAD (KJ/SEC)                             *DIST 940
*     QRM      MIN. REQUIRED REBOILER DUTY                             *DIST 950
*     R        THE RATIO FV/F IN FLASH CALCS.                          *DIST 960
*     RS       (L/V)MIN FOR STRIPPING SECTION                          *DIST 970
*     SL       INTERMEDIATE VALUE OF LIQUID FLOW AT FEED PLATE         *DIST 980
*     SV       INTERMEDIATE VALUE OF VAPOR FLOW AT FEED PLATE          *DIST 990
*     SXFM1    SUM OF X$S MINUS 1                                      *DIST1000
*     SYFM1    SUM OF Y$S MINUS 1                                      *DIST1010
*     T        TEMP. ARRAY FOR PLATES STREAMS(K)                       *DIST1020
*     TB       TEMP. OF BOTTOM STREAM(K) - OUTPUT                      *DIST1030
*     TD       TEMP. OF TOP  D STREAM(K) - OUTPUT                      *DIST1040
*     TF       FEED TEMP. (K) -GIVEN AS IP                             *DIST1050
*     TFF      FLASH TEMP. OF FEED(K)                                  *DIST1060
*     TF1      VALUE OF TEMP. OF FLASH (INTERMEDIATE RESULT NR METHOD) *DIST1070
*     TF2      VALUE OF TEMP. OF FLASH (INTERMEDIATE RESULT NR METHOD) *DIST1080
*     TM       DISTILLATE TEMP. (K) - OUTPUT                           *DIST1090
*     TM1P     TEMP. CORRESPONDS TO XM1P (NR X,L)                      *DIST1100
*     TP1P     TEMP. CORRESPONDS TO XP1P (NR X,L)                      *DIST1110
```

```
*      V          VAPOR FLOW ARRAY FOR COL. PLATES (KMOL/HR)              *DIST1120
*      VB         VAPOR FLOW FROM REBOILER                                *DIST1130
*      VMIN       REQUIRED MIN. VAPOR FLOW FROM REBOILER                  *DIST1140
*      X          LIQUID SO2  COMPOSITION ARRAY FOR COL. PLATES (MOL.FR.) *DIST1150
*      XB         COMPOSITION (SO2 MOL.FR.) OF BOTTOM STREAM              *DIST1160
*      XD         COMPOSITION (SO2 MOL.FR.) OF TOP    STREAM -PRESCRIBED. *DIST1170
*      XF         SO2 COMPOSITION IN FEED - GIVEN IP. (MOL.FR.)           *DIST1180
*      XF2        MOLE FR. OF SO2 IN LIQUID PORTION OF FLASHED FEED       *DIST1190
*      XF3        MOLE FR. OF SO3 IN LIQUID PORTION OF FLASHED FEED       *DIST1200
*      XM1P       X(M)-0.01 PERTUBED VALUE IN NR FOR X AND L              *DIST1210
*      XP1P       X(M)+0.01 PERTUBED VALUE IN NR FOR X AND L              *DIST1220
*      Y          VAPOR COMPOSITION (SO2 MOL.FR.) ARRAY FOR COL. PLATES   *DIST1230
*      YB2        VAPOR COMPOSITION (SO2 MOL.FR.) IN B                    *DIST1240
*      YB3        VAPOR COMPOSITION (SO3 MOL.FR.) IN B                    *DIST1250
*      YM         DISTILLATE COMPOSITION (SO2 MOL.FR.) -OUTPUT            *DIST1260
*      Y2         MOLE FR. OF SO2 IN VAPOR PORTION OF FLASHED FEED        *DIST1270
*      Y3         MOLE FR. OF SO3 IN VAPOR PORTION OF FLASHED FEED        *DIST1280
*************************************************************************DIST1290
*                                                                         *DIST1300
      DIMENSION DH(21)                                                     DIST1310
      REAL L( 50),V( 50),X( 50),Y( 50),T( 50),HL( 50),HV( 50)              DIST1320
      REAL KB2,KB3,KSO2,KSO3,LHB                                           DIST1330
      DATA EDR, DHF/0.001,100./                                            DIST1340
*PRINT INPUT FOR RECORDING AND CHECKING                                   *DIST1350
      PRINT 69                                                             DIST1360
   69 FORMAT(/4X,*DISTILLATION COLUMN*)                                    DIST1370
      IF(IFP.EQ.0)GO TO 5                                                  DIST1380
      PRINT 82,F,TF,PF,HF,XF,QR,XD,P,PRSO2,N                               DIST1390
   820FORMAT(1X,* INPUT DATA*/1X,*STREAM     *,4X,1HF,9X,1HT,9X,1HP,9X,1HDIST1400
     1H,9X,1HC,9X,1HQ/,* FEED      *,5F10.3/,* BOTTOM    *,50X,F10.3/,* DIDIST1410
     2STILATE*,40X,F10.3/,2X,2HP=,F5.2,3X,6HPRSO2=,F5.3,3X,2HN=,I3/)      DIST1420
      PRINT 14                                                             DIST1430
   14 FORMAT(/3X,*RESULTS OF THE DISTILLATION COLUMN*)                     DIST1440
*FIRST,                         CONVERT Q TO KJ/HR                        *DIST1450
    5 QR=QR*3.6E3                                                          DIST1460
*CONVERT FLOW INTO MOLE/HR                                                *DIST1470
      F=F*3600.                                                            DIST1480
*SECOND,CALCULATE OVERALL MATERIAL AND ENERGY BALANCES ON ALL 3-STREAMS*DIST1490
      D=F*XF*PRSO2/XD                                                      DIST1500
      B=F-D                                                                DIST1510
      XB=(F*XF-D*XD)/B                                                     DIST1520
*CALC.T$S AND H$S OF B AND D                                              *DIST1530
      CALL BPTR(P,XD,TD)                                                   DIST1540
      CALL BPTR(P,XB,TB)                                                   DIST1550
      CALL ENTR1(TD,XD,HD)                                                 DIST1560
      CALL ENTR1(TB,XB,HB)                                                 DIST1570
*FLASH CALCS. FOR THE FEED STREAM (TFF= FLASH FEED TEMP)                  *DIST1580
*IF PF SMALLER OR EQ. TO THE DIST. COL. PRESSURE THERE IS NO FLASH        *DIST1590
*SEPARATION AND FEED IS ASSUMED TO BE AT COL. PRESS. AND AT LIQ. STATE *DIST1600
      IF(PF-P.LE.0.) GO TO 13                                              DIST1610
*FIRST GUESSES OF TFF-ASSUME TFF=T(BP)+1.                                 *DIST1620
      CALL BPTR(P,XF,TFF)                                                  DIST1630
      TFF=TFF+1.                                                           DIST1640
      HFF=HF*F                                                             DIST1650
*FLASH CALC. ARE ACCORDING TO C.D.HOLLAND - FUND.AND MODELING OF SEPARATDIST1660
*PROCESSES 1975,PP. 59-67                                                 *DIST1670
    1 DO 50 J=1,20                                                         DIST1680
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      R=0.5                                                             DIST1690
*FIND KSO2 AND KSO3 BY THE VOLATILITY K CONST. ROUTINE - VKCR          *DIST1700
      CALL VKCR(P,TFF,KSO2,KSO3)                                        DIST1710
*CHECK IF B.P.'TFF'D.P. NOTE THAT IF TFF IS NOT WITHIN THESE BOUNDARIES*DIST1720
*CORRECTION IS MADE AND LOOP STARTS FROM FRESH                         *DIST1730
      SXFM1=KSO2*XF+KSO3*(1.-XF)-1.                                     DIST1740
      SYFM1=XF/KSO2+(1.-XF)/KSO3-1.                                     DIST1750
      IF(SXFM1.GT.0.0) GO TO 2                                          DIST1760
    8 TFF=TFF+1.                                                        DIST1770
      GO TO 1                                                           DIST1780
    2 IF(SYFM1.GT.0.0) GO TO 3                                          DIST1790
    7 TFF=TFF-1.                                                        DIST1800
      GO TO 1                                                           DIST1810
*SEARCH FOR R=FV/F START HERE USING NEWTON RAPHSON METHOD.             *DIST1820
    3 DO 51 JR=1,10                                                     DIST1830
      DENFR2=1.-R*(1.-KSO2)                                             DIST1840
      DENFR3=1.-R*(1.-KSO3)                                             DIST1850
      FR2=XF/DENFR2                                                     DIST1860
      FR3=(1.-XF)/DENFR3                                                DIST1870
      FR=FR2+FR3-1.                                                     DIST1880
      DFR=FR2*(1.-KSO2)/DENFR2+FR3*(1.-KSO3)/DENFR3                     DIST1890
      DR=FR/DFR                                                         DIST1900
      R=R-DR                                                            DIST1910
      IF(R.LE.0.) GO TO 8                                               DIST1920
      IF(R-1.0.GE.0.0) GO TO 7                                          DIST1930
      IF(ABS(DR)-EDR)4,4,51                                             DIST1940
   51 CONTINUE                                                          DIST1950
      PRINT 76,R,DR                                                     DIST1960
   76 FORMAT(3X,*NO CONVERGENCE ON R=FV/F DIST. COL. R,DR=*,2E10.4)     DIST1970
*ASSUME CONVERTION ON R. CALC. AND CHECK ENERGY BAL. FOR THE FLASH CALC.DIST1980
    4 FV=R*F                                                            DIST1990
      FL=F-FV                                                           DIST2000
      XF2=XF/(R*(KSO2-1.)+1.)                                           DIST2010
      XF3=1.-XF2                                                        DIST2020
*CALC. Y2 AND Y3                                                       *DIST2030
      Y2=KSO2*XF2                                                       DIST2040
      Y3=1.-Y2                                                          DIST2050
      CALL ENTR1(TFF,XF2,HFL)                                           DIST2060
      CALL ENTR2(TFF,Y2,Y3,HFV)                                         DIST2070
      HFC=HFL*FL+HFV*FV                                                 DIST2080
      DH(J)=HFC-HFF                                                     DIST2090
      IF(ABS(DH(J))-DHF)56,56,52                                        DIST2100
   52 IF(J.GT.1) GO TO 53                                               DIST2110
      TF1=TFF                                                           DIST2120
      IF(DH(J))54,56,55                                                 DIST2130
   54 TFF=TFF+1.                                                        DIST2140
      GO TO 50                                                          DIST2150
   55 TFF=TFF-1.                                                        DIST2160
      GO TO 50                                                          DIST2170
   53 TF2=TFF                                                           DIST2180
      TFF=(TF2*DH(J-1)-TF1*DH(J))/(DH(J-1)-DH(J))                       DIST2190
      TF1=TF2                                                           DIST2200
   50 CONTINUE                                                          DIST2210
      PRINT 500                                                         DIST2220
      PRINT 510,TFF,HF,HFC,FL,FV,XF2,XF3,Y2,Y3                          DIST2230
  500 FORMAT(/3X,*FLASH CALCS. DIDNT CONVERGE IN 100 STEPS*)            DIST2240
  5100FORMAT(/3X,4HTFF=,F5.1,2Y,3HHF=,E11.4,2X,4HHFC=,E11.4,2X,3HFL=,2X,DIST2250
```

```
     1E11.4,2X,3HFV=,E11.4,2X,4HXF2=,F5.3,2X,4HXF3=,F5.3,2X,3HY2=,F5.3,2
     2X,3HY3=,F5.3)
      GO TO 1000
*CONTINUE HERE IF NO FLASH CALC. ARE NEEDED.                           *
   13 TFF=TF
      FL=F
      XF2=XF
      XF3=1.-XF
      HFL=HF
      FV=0.
      Y2=0.
      Y3=0.
      HFV=0.
   56 IF(IFP.EQ.0)GO TO 6
      PRINT 12,TFF,FL,XF2,FV,Y2
   12 FORMAT(/3X,*FLASH RESULTS= TFF=*,F7.2,3X,3HFL=,E11.4,3X,4HFX2=,
     1F6.4,3X,3HFV=,E11.4,3X,4HFY2=,F6.4)
*REBOILER CALCS. FIRST,FIND BOILER VAPOR COMPOSITION                  *
    6 CALL VKCR(P,TB,KB2,KB3)
      YB2=KB2*XB
      YB3=KB3*(1.-XB)
*ADJUST TO GET YB2+YB3=1.                                              *
      DSOY=1.-YB2-YB3
      YB2=YB2+0.01*DSOY
      YB3=YB3+0.99*DSOY
*CALL LATENT HEAT ROUTINE - LHR. 2-FOR SO2,3 FOR SO3                   *
      CALL LHR(TB,XB,LHB)
      VB=QR/LHB
*CHECK IF REBOILER HEAT IS SUFFICIENT. IF NOT CALC. FOR MIN QR.        *
*RS=(L/V)MIN FOR THE STRIPPIG SECTION. THIS SLOP IS THE SLOP OF THE LINE
*    CONNECTING (XB,XB) AND (XF2,Y2). (V)MIN IS THEN FOUND AND COMPARED*
*WITH VB. IF VB'(V)MIN, QR IS NOT ENOUGH. (QR)MIN=(V)MIN*LHB.          *
      RS=(Y2-XB)/(XF2-XB)
      VMIN=B/(RS-1.)
      IF(VB-VMIN)30,31,9
   30 QRM=VMIN*LHB/3.6E6
      IF(IFP.EQ.0)GO TO 9
      PRINT 32,QRM
   32 FORMAT(/3X,*HEAT INPUT TO REBOILER IS NOT ENOUGH.  QR-MIN SHOULD
     1BE OVER*,2X,E11.4,2X,2HMW/3X,*DIST. COL. IS CALCUL. FOR QR-MIN*)
    9 QR=VMIN*LHB
      VB=VMIN
*MAKE REBOILER TO BE PLATE NO. 1                                       *
   31 L(1)=B
      V(1)=VB
      T(1)=TB
      Y(1)=YB2
      X(1)=XB
      HL(1)=HB
      HV(1)=HL(1)+LHB
*CALC. DATA FOR PLATE NO.2                                             *
      L(2)=VB+B
      X(2)=(B*XB+VB*YB2)/L(2)
      CALL BPTR(P,X(2),T(2))
      CALL VKCR(P,T(2),KSO2,KSO3)
      Y(2)=KSO2*X(2)
      Y3=1.-Y(2)
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      CALL ENTR1(T(2),X(2),HL(2))                                       DIST2830
      CALL ENTR2(T(2),Y(2),Y3,HV(2))                                    DIST2840
*PLATE TO PLATE CALCS. ASSUME V(J)=V(J-1),CALC.L(J+1),X(J+1),T(J+1).   *DIST2850
      V(2)=V(1)                                                         DIST2860
*INITIALIZE FOR FEED PLATE SEARCH                                      *DIST2870
      NFP=0                                                             DIST2880
*                                                                      *DIST2890
      DO 60 J=2,N                                                       DIST2900
      M=J+1                                                             DIST2910
*FIND L(J+1) FROM OVERALL MATERIAL BALANCE                             *DIST2920
      L(J+1)=L(J)+V(J)-V(J-1)                                           DIST2930
*FIND X(J+1) FROM SO2 BALANCE                                          *DIST2940
      X(J+1)=(L(J)*X(J)+V(J)*Y(J)-V(J-1)*Y(J-1))/L(J+1)                 DIST2950
      IF(X(J+1).GT.1.0)X(J+1)=1.0                                       DIST2960
*FIND BUBBLE PT. OF PLATE (J+1)                                        *DIST2970
      DO 24 I=1,30                                                      DIST2980
      CALL BPTR (P,X(J+1),T(J+1))                                       DIST2990
      CALL ENTR1(T(J+1),X(J+1),HL(J+1))                                 DIST3000
*NEWTON RAPHSON METOD IS USED TO CALC. L(J+1) AND X(J+1) .             *DIST3010
      XP1P=X(J+1)+0.01                                                  DIST3020
      XM1P=X(J+1)-0.01                                                  DIST3030
      IF(XP1P-1.)20,20,21                                               DIST3040
   21 XP1P=1.                                                           DIST3050
      DX=1.-XM1P                                                        DIST3060
      GO TO 22                                                          DIST3070
   20 DX=0.02                                                           DIST3080
   22 CALL BPTR(P,XP1P,TP1P)                                            DIST3090
      CALL BPTR(P,XM1P,TM1P)                                            DIST3100
      CALL ENTR1(TP1P,XP1P,HP1P)                                        DIST3110
      CALL ENTR1(TM1P,XM1P,HM1P)                                        DIST3120
      DHDX=(HP1P-HM1P)/DX                                               DIST3130
      A=X(J+1)-Y(J)                                                     DIST3140
      E=L(J+1)                                                          DIST3150
      C=HL(J+1)-HV(J)                                                   DIST3160
      G=E*DHDX                                                          DIST3170
      DET=A*G-E*C                                                       DIST3180
      A11=G/DET                                                         DIST3190
      A12=-E/DET                                                        DIST3200
      A21=-C/DET                                                        DIST3210
      A22=A/DET                                                         DIST3220
      F1=A*E+(Y(J-1)-Y(J))*V(J-1)+(Y(J)-X(J))*L(J)                      DIST3230
      F2=E*C+V(J-1)*(HV(J-1)-HV(J))+L(J)*(HV(J)-HL(J))                  DIST3240
      DL=A11*F1+A12*F2                                                  DIST3250
      DXJ=A21*F1+A22*F2                                                 DIST3260
      L(J+1)=L(J+1)-DL                                                  DIST3270
      X(J+1)=X(J+1)-DXJ                                                 DIST3280
      IF(X(J+1).GT.1.0)X(J+1)=1.0                                       DIST3290
      IF(ABS(DL)-10.000)23,23,24                                        DIST3300
   23 IF(ABS(DXJ)-0.005)25,25,24                                        DIST3310
   24 CONTINUE                                                          DIST3320
      PRINT 19,M                                                        DIST3330
   19 FORMAT(3X,*DIDNT CONVERGED ON X AND L AT PLATE NO.*,I3)           DIST3340
   25 V(J)=L(J+1)+V(J-1)-L(J)                                           DIST3350
*FEED PLATE CHECK AND CALCULATIONS                                     *DIST3360
      IF(T(J+1)-TFF)65,66,66                                            DIST3370
   65 NFP=NFP+1                                                         DIST3380
      IF(NFP-1)67,67,66                                                 DIST3390
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   67 PRINT 16,J,M                                                      DIST3400
   16 FORMAT(/3X,*FEED ENTERS BETWEEN PLATES=*,I3,* AND *,I2)           DIST3410
      SL=L(J+1)                                                         DIST3420
      SV=V(J)                                                           DIST3430
      L(J+1)=L(J+1)-FL                                                  DIST3440
      V(J)=V(J)+FV                                                      DIST3450
      X(J+1)=(SL*X(J+1)-FL*XF2)/L(J+1)                                  DIST3460
      IF(X(J+1).GT.1.0)X(J+1)=1.0                                       DIST3470
      Y(J)=(SV*Y(J)+FV*Y2)/V(J)                                         DIST3480
      IF(Y(J).GT.1.0)Y(J)=1.0                                           DIST3490
      CALL BPTR(P,X(J+1),T(J+1))                                        DIST3500
      CALL ENTR1(T(J+1),X(J+1),HL(J+1))                                 DIST3510
   66 CALL VKCR(P,T(J+1),KSO2,KSO3)                                     DIST3520
      Y(J+1)=KSO2*X(J+1)                                                DIST3530
      IF(Y(J+1).GT.1.0)Y(J+1)=1.0                                       DIST3540
      Y3=1.-Y(J+1)                                                      DIST3550
      CALL ENTR2(T(J+1),Y(J+1),Y3,HV(J+1))                              DIST3560
*FIRST GUESS FOR V(J+1) - NEXT J.                                      *DIST3570
      V(J+1)=V(J)                                                       DIST3580
*CHECK FOR TOP PLATE                                                   *DIST3590
      IF(Y(J)-XD)10,68,68                                               DIST3600
   10 IF(X(J+1)-X(J)-0.001)11,11,60                                     DIST3610
   60 CONTINUE                                                          DIST3620
* IF DO LOOP COMPLETED THERE ARE TOO MANY STAGES                       *DIST3630
      PRINT 73,M                                                        DIST3640
   73 FORMAT(/3X,*TOO MANY STAGES.CALCULATIONS STOPPED AT M=*,I3)       DIST3650
      GO TO 68                                                          DIST3660
   11 PRINT 17                                                          DIST3670
   17 FORMAT(/3X,*NO MORE ENRICHMENT. CALC. STOPPED AT THIS POINT.*)    DIST3680
*FNAL PLATE CALCULATIONS                                               *DIST3690
*CHECK AND CALC. MISMATCH AT THE TOP                                   *DIST3700
   68 DY=Y(J)-XD                                                        DIST3710
      DV=V(J)-(L(J+1)+D)                                                DIST3720
*CALC. COOLING LOAD QC.                                                *DIST3730
      QC=QR+F*HF-D*HD-B*HB                                              DIST3740
      QR=QR/3.6E3                                                       DIST3750
      QC=QC/3.6E3                                                       DIST3760
      M=M-1                                                             DIST3770
      PD=P                                                              DIST3780
      PB=P                                                              DIST3790
      TM=T(M)                                                           DIST3800
      HLM=HL(M)                                                         DIST3810
      YM=Y(M)                                                           DIST3820
      F=F/3600.                                                         DIST3830
      B=B/3600.                                                         DIST3840
      D=D/3600.                                                         DIST3850
      IF(IFP.EQ.0)GO TO 1000                                            DIST3860
      PRINT 71,B,XB,TB,QR,F,XF,TF,D,XD,TD,QC                            DIST3870
   710FORMAT(3X,*OUTPUT=                                              *,/DIST3880
     13X,*REBOILER= B=*,E11.4,3X,3HXB=,F5.3,3X,3HTB=,F5.1,3X,3HQR=,E11.4DIST3890
     2,/*   FEED=      F=*,E11.4,3X,3HXF=,F5.3,3X,3HTF=,F5.1,/3X,*CONDENSDIST3900
     3ER=D=*,           E11.4,3X,3HXD=,F5.3,3X,3HTD=,F5.1,3X,3HQC=,E11.4)DIST3910
      PRINT 72                                                          DIST3920
      PRINT74,(J,T(J),L(J),X(J),HL(J),V(J),Y(J),HV(J),J=1,M)            DIST3930
   720FORMAT(3X,*PLATES CONDITIONS                                    */DIST3940
     1*    J      T            L            X           HL            V DIST3950
     2    Y          HV*)                                               DIST3960
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  740FORMAT(/3X,I2,3X,F5.1,3X,E11.4,3X,F5.3,3X,E11.4,3X,E11.4,3X,F5.3,3DIST3970
    1X,E11.4)                                                           DIST3980
     PRINT 75,M,DY,DV                                                   DIST3990
  750FORMAT(3X,*NO.OF PLATES M=*,I2,3X,*DEVIATION FROM XD=*,F6.4,3X,*DEDIST4000
    1VIATION FROM V=*,E11.4/)                                           DIST4010
1000 RETURN                                                             DIST4020
     END                                                                DIST4030
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      SUBROUTINE STC(QAAN,R2,T10,T30,R4,RATIO,ATGP2,BFWA1,BFWA2,TGPD)    STC
*********************************************************************STC
*                                                                   *STC
*     UPDATED 4/15/78                                               *STC
*        STEAM TURBINE CALC.                                        *STC
*                                                                   *STC
*********************************************************************STC
*CALCULATIONS ARE MADE FOR ACONVENTIONAL CROSS-COMPOUND TYPE TURBINE *STC
*WITH HIGH BACK-PRESSURE. REF= GE DOCUMENTATION ON THE BLACK-HILLS PROJ*STC
*THE BLACK-HILLS DESIGN (250MW,1800PSI,1000F/1000F) IS TAKEN AS THE  *STC
*BASE DESIGN. ACCORDING TO BFWHL THE NEW DESIGN IS DERIVED BY DIRECT *STC
*PROPORTION TO THE BASE DESIGN. IT ALSO PROVIDE FOR ABSORBING THE LOW- *STC
*TEMP. HEAT AVAILABLE FROM THE STORAGE (BFWHL) AND TO PROVIDE THE NECE-*STC
*SSARY EXTRACTIONS OF STEAM FOR REBOILER (QRES) AND VAPORIZER (VAP1L) *STC
*AT THE HTS-STORAGE.                                                *STC
*AFTER THE NEW DESIGN IS ESTABLISHED THE DAY TIME GENERATION IS DETERM-*STC
*IND AND BECOMES THE*TURBINE RATING*                                *STC
*THE NIGHT OPERATION IS DETERMINED ACCORDING TO QAAN BY DIRECT PROPORTN*STC
*TO THE DAY TIME OPERATION.  THE TURBINE IS SPLIT INTO TWO SEPARATE TUR*STC
*-BINES,A SMALL ONE TO RUN AT FULL LOAD DURING 16 HRS AND A LARGE ONE, *STC
*WHICH RUNS AT 3.5 PERCENT OF DAYTIME FLOW TO KEEP IT HOT AND TURNING *STC
*BUT PRODUCING NO ELECTRICITY. THIS INCREASES EFFICIENCY BY AVOIDING  *STC
*FLOWS FAR BELOW DESIGN.  IN ADDITION TO REGULAR DISCHARGE,.A SEASONAL *STC
*STORAGE CASE IS STUDIED WHERE DISCHARGE IS AT THE REGULAR DAYTIME RATE*STC
*OF POWER OUTPUT                                                    *STC
*NOTE-STREAM NUMBERS (EXCEPT THOSE IN CALL) ARE FOR THE STEAM CYCLE AND*STC
*SHOULD NOT BE CONFUSED WITH PROCESS STREAMS.                       *STC
*NOTE-DATA ARE GIVEN AND CALCULATIONS ARE MADE IN BRITISH UNITS. ALL  *STC
*PARAMETERS SPECIFIED BY CALLING ROUTINE OR BY COMMON BLOCKS ARE     *STC
*CONVERTED TO BRITISH UNITS (FLOW-(LB/HR),ENTHALPIES-(BTU/LB),HEAT LOAD*STC
*-(BTU/HR),PRESSURE-(PSI),TEMP-(F),ETC.)                            *STC
*NOMENCLATURE=                                                      *STC
*     A          TOTAL WATER FLOW INTO BOILER -NEW DESIGN           *STC
*     AD         TOTAL WATER FLOW INTO BOILER -DAY TIME             *STC
*     AN         TOTAL WATER FLOW INTO BOILER -NIGH TIME            *STC
*     AO         BLACK-HILLS (BH) TOTAL WATER FLOW TO BOILER        *STC
*     ATGP       ARRAY FOR TOTAL GENERATED POWER                    *STC
*     ATGP2      TGP OF SMALL TURBINE (16 HOUR OPERATION)           *STC
*     B          BH LOW PRESSURE EXTRACTION AT 86.7PSI              *STC
*     BFW        BOILER FEED WATER FLOW                             *STC
*     BFWA       ARRAY FOR BOILER FEED WATER AT NIGHT               *STC
*     BFWA1      TOTAL BFW FLOW FOR NORMAL 16 HR OUTPUT             *STC
*     BFWA2      BFW FOR SEASONAL STORAGE,(100 MW OUTPUT AT NIGHT   *STC
*     BFWF       BOILER FEED WATER FLOW FACTOR                      *STC
*     BFWHL      BOILER FEED WATER HEAT LOAD (IN COMMON HTHEL)      *STC
*     C          BH LOW PRESSURE EXTRACTION AT 28.5PSI              *STC
*     C1L        CONDENSER 1 HEAT LOAD (IN COMMON HTHEL)            *STC
*     D          BH LOW PRESSURE EXTRACTION AT 14.3PSI              *STC
*     EC         HEAT RATE (BTU/HR) FOR STEAM THROUGH LP TURBINE    *STC
*     FACTOR     FACTOR FOR CONVERTING FLOW INTO ENTHALPY IN KJ/S.  *STC
*     FH         STEAM EXTRACT FROM HIGH PRESSURE TURBINE           *STC
*     FHF        STEAM EXTRACT FROM HIGH PRESSURE TURBINE FACTOR    *STC
*     FI         STEAM EXTRACT FROM ITER.PRESSURE TURBINE           *STC
*     FIF        STEAM EXTRACT FROM ITER.PRESSURE TURBINE FACTOR    *STC
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*      FIF1     STEAM EXTRACT FROM ITER.PRESSURE TURBINE FACTOR IN EQ-1 *STC  550
*      FIF2     STEAM EXTRACT FROM ITER.PRESSURE TURBINE FACTOR IN EQ-2 *STC  560
*      FIP      STEAM FLOW THROUGH ITER.PRESSURE TURBINE                *STC  570
*      FIPF     STEAM FLOW THROUGH ITER.PRESSURE TURBINE FACTOR         *STC  580
*      FIPV     STEAM FLOW THROUGH ITER.PRESSURE TURBINE VALVE          *STC  590
*      FLP      FLOW THROUGH LP TURBINE                                 *STC  600
*      FLPF     FLOW THROUGH LP TURBINE FACTOR                          *STC  610
*      GPHP     GROSS PRODUCTION (MWE)OF HIGH PRESSURE TURBINE (NEW)    *STC  620
*      GPHPO    GROSS PRODUCTION(MWE) OF HIGH PRESSURE TURBINE (BH)     *STC  630
*      GPLP     GROSS PRODUCTION OF LOW PRESSURE TURBINE (NEW DESIGN)   *STC  640
*      GPLPO    GROSS PRODUCTION OF LOW PRESSURE TURBINE (BH)           *STC  650
*      H        ENTHALPY OF ORIGINAL BH SL6 (AT 162.4PSI)               *STC  660
*      HB       ENTHALPY OF B                                           *STC  670
*      HC       ENTHALPY OF C                                           *STC  680
*      HD       ENTHALPY OF D                                           *STC  690
*      HE1L     HEAT EXCHANGER 1 LOAD (IN COMMON HTHEL)                 *STC  700
*      H1-H16   ENTHALPIES AT VARIOUS LOCATIONS (SEE SCHEME)            *STC  710
*      I        DO-LOOP INDEX FOR DISCHARGE RATE                        *STC  720
*      L        INDEX TO RATIO POWER TO 100MW                           *STC  730
*      OEC      BH OVERALL HEAT (BTU/HR) CARRIED BY LP TURBINE STEAM.   *STC  740
*      OFL      BH LOW PRESSURE STEAM FLOW INTO CONDENSER               *STC  750
*      P12      PRESSURE STREAM 12 IN STEAM CYCLE (PSIA)                *STC  760
*      Q        HEAT ABSORBED BY STEAM (DAY-RECEIVER,NIGHT-REACTORS)    *STC  770
*      QAN      QAAN SCALED BY R2                                       *STC  780
*      QAAN     Q AVAILABLE AT NIGHT -CALL STR PARAMETER                *STC  790
*      QBIGAN   Q IN LARGE TURBINE AT NIGHT (KJ/S)                      *STC  800
*      QSMLAN   Q IN SMALL TURBINE AT NIGHT (KJ/S)                      *STC  810
*      QFST     Q FROM STORAGE TOWER                                    *STC  820
*      QRFS     Q REBOILER FROM STEAM (IN COMMON HTHEL)                 *STC  830
*      R        RATIO OF NEW DESIGN A TO BH DESIGN AO (R=A/AO)          *STC  840
*      RATIO    RATIO OF HEAT ABSORBED IN STEAM RECEIVER TO STORAGE (TQA)STC  850
*      RCL      REBOILER-CONDENSER LOAD (IN COMMON HTHEL)               *STC  860
*      RHTR     REHEATER FLOW                                           *STC  870
*      RHTRF    REHEATER FLOW FACTOR                                    *STC  880
*      R1       RATIO OF FLOW AT NIGHT TO FLOW AT DAY (R1=AN/AD)        *STC  890
*      R2       RATIO FOR POWER AT 100MW                                *STC  900
*      R4       RATIO FOR NIGHT-TIME POWER OF 100MW                     *STC  910
*      SL10-SL60 STEAM LEAKS BH-DESIGN  (SEE SCHEME)                    *STC  920
*      SL1-SL6   STEAM LEAKS NEW DESIGN (SEE SCHEME)                    *STC  930
*      SPLIT    SPLIT BETWEEN LARGE AND SMALL TURBINES                  *STC  940
*      TE       TOTAL ENERGY (BTU) AVAILABLE AT NIGHT                   *STC  950
*      TGP      TOTAL GROSS ELECTRIC PRODUCTION (MWE) NEW DESIGN        *STC  960
*      TGPD     TOTAL GENERATED POWER DURING THE DAY                    *STC  970
*      TIME     PERIOD OF TIME QAAN CAN SUPPLY 100.MW-E                  STC  980
*      TMIN     MIN T ACHIEVABLE IN THE SYSTEM (K)                      *STC  990
*      TPNF     THREE AND A HALF PERCENT OF NOMINAL FLOW (O. GENERATION)*STC 1000
*      TQA      TOTAL Q AVAILABLE-STORAGE RECEIVER CAPACITY(MWT)        *STC 1010
*      TRIMMER  TRIMMER HEAT LOAD (IN COMMON HTHEL)                     *STC 1020
*      T10      TEMP STREAM 10 IN STORAGE CYCLE (K)                     *STC 1030
*      T12      TEMP STREAM 12 IN STEAM CYCLE (F)                       *STC 1040
*      T15      TEMP STREAM 15 IN STEAM CYCLE (F)                       *STC 1050
*      T30      TEMP. STREAM 30 IN STORAGE CYCLE (K)                    *STC 1060
*      VAP1L    VAPRZ-1 HEAT LOAD (IN COMMON HTHEL)                     *STC 1070
*      VPDS     STEAM FLOW TO VAPORIZER AND DIST.COL. AT HTS-STORAGE    *STC 1080
****************************************************************************STC 1090
       DIMENSION ATGP(3),BFWA(3)                                         STC 1100
       DIMENSION RATIA(15),BFA(15)                                       STC 1110
```

```
      COMMON/HTHEL/C1L,VAP1L,HE1L,RCL,BFWHL      ,TRIMMER,QRFS
      COMMON/LAHTV/BFWCT,TMIN
*BASIC TQA=230.MW HOWEVER, DIRECT STEAM TOWER IS SCALED FOR 2339MW-E
      DATA TQA/230./
      DATA H1,H2,   H4,H5,H6,H7,H8,H9,H10/1480.1,1344.4,      1521.6,139
     14.3,334.9,332.1,341.,350.2,436.7/
      DATA OFL,B,C,D,HB,HC,HD,H/1729723.,115729.,70436.,107501.,1333.3,
     11233.,1180.8,1398.8/
*BASIC DATA OF THE BLACK HILL TURBINE(1800PSIA, 1000F/1000F)
      DATA AO,SL10,SL20,SL30,SL40,SL50,SL60,GPHPO,GPLPO/2373398.,2791.,
     1811.,23984.,9226.,3323.,3667.,167.4,164.5/
*STEAM CYCLE T AND H CALCULATED USING HTS SPECIFICATIONS
      T15=1.8*(T10-10.)-460.
      H15=1.011*T15-34.21
      T12=1.8*TMIN-460.
      H13=.9975*T12-31.78
      P12=.0490*EXP(.0291*(T12))
      H12=1038.+49.*ALOG(P12)
      H14=H13+1.4
      PRINT 13,TMIN,H12,P12
   13 FORMAT(2X,*TMIN(K)= *,F4.0,5X,*H12(BTU/LB)= *,F5.0,5X,*P12(PSIA)=
     1*,F6.3)
*   DAY  OPERATION
      L=0
      QFST=TQA
      FACTOR=3600./1.0551/(H15-H14)
      BFW=BFWHL*FACTOR
       VPDS=(VAP1L+QRFS)*3.6E6/1055.1/(H5-H6)
      SL4F=SL40/AO
      FHF=(H10-H8)/(H2-H9)
      FIF1=(H7-SL4F*H2-FHF*H9)/H5
      DO 17 K=1,15
    7 FIF2=(BFW*H15+VPDS*H6)/H5
      A=(BFW+VPDS-FIF2)/(1.-SL4F-FHF-FIF1)
      FH=FHF*A
      FI=FIF1*A-FIF2
      R=A/AO
      AD=A
      SL1=SL10*R
      SL2=SL20*R
      SL3=SL30*R
      SL4=SL40*R
      SL5=SL50*R
      SL6=SL60*R
      RHTR=A-SL1-SL2-SL4-SL5-FH-SL3
      FIPV=RHTR+SL1
      FIP=FIPV+SL3
      FLP=FIP-SL6-FI-VPDS
*HEAT ABS. BY STEAM.
      Q=(A*(H1-H10)+RHTR*(H4-H2))*1055.1/3.6E9
      RATIO=Q/QFST
      IF(L.GT.0)GO TO 5
      RATIA(K)=RATIO
      IF(K.GT.1) GO TO 22
      BFA(K)=BFW
      BFW=BFW+40000.
      BFA(K+1)=BFW
```

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      GO TO 17                                                          STC 1690
   22 DCH=(RATIA(K)-RATIA(K-1))/(BFA(K)-BFA(K-1))                       STC 1700
      DBFW=(RATIA(K)-1.05)/DCH                                          STC 1710
      BFA(K+1)=BFA(K)-DBFW                                              STC 1720
      BFW=BFA(K+1)                                                      STC 1730
      IF(DBFW.LT.1000.)GO TO 5                                          STC 1740
   17 CONTINUE                                                          STC 1750
      PRINT 24, DBFW                                                    STC 1760
   24 FORMAT(/3X,*NO CONVERGENCE ON BFW, LAST DELTA BFW= *,F10.3)       STC 1770
   5  OEC=OFL*(H-H12)+B*(H-HB)+C*(H-HC)+D*(H-HD)                        STC 1780
      EC=FLP*(H5-H12)                                                   STC 1790
      GPHP=GPHPO*R                                                      STC 1800
      GPLP=GPLPO*EC/OEC                                                 STC 1810
      TGP=GPHP+GPLP                                                     STC 1820
      L=L+1                                                             STC 1830
      IF(L.GT.1)GO TO 23                                                STC 1840
      R2=1./(1.+RATIO)                                                  STC 1850
      BFW=BFW*R2                                                        STC 1860
      VPDS=VPDS*R2                                                      STC 1870
      QFST=QFST*R2                                                      STC 1880
      QAN=QAAN*R2                                                       STC 1890
      GO TO 7                                                           STC 1900
   23 BFW=BFW/FACTOR                                                    STC 1910
      TGPD=TGP                                                          STC 1920
      BFWHL=BFW                                                         STC 1930
      PRINT 2                                                           STC 1940
    2 FORMAT(/3X,* DAY-TIME OPERATION.*)                                STC 1950
      PRINT 1,A,SL1,SL2,SL3,SL4,SL5,FH,RHTR,FIPV,FIP,SL6,FI,VPDS,FLP,BFWSTC 1960
    1 FORMAT(                                                           STC 1970
     1/3X,*WATER TO BOILER   *,F10.1,                                   STC 1980
     2/3X,*SEAL LEAK - 1     *,F10.1,                                   STC 1990
     3/3X,*SEAL LEAK - 2     *,F10.1,                                   STC 2000
     4/3X,*SEAL LEAK - 3     *,F10.1,                                   STC 2010
     5/3X,*SEAL LEAK - 4     *,F10.1,                                   STC 2020
     6/3X,*SEAL LEAK - 5     *,F10.1,                                   STC 2030
     7/3X,*HP - EXTRACTION   *,F10.1,                                   STC 2040
     8/3X,*REHEATER FLOW     *,F10.1,                                   STC 2050
     9/3X,*IP-FLOW AT VALVE  *,F10.1,                                   STC 2060
     A/3X,*IP TOTAL FLOW     *,F10.1,                                   STC 2070
     B/3X,*SEAL LEAK - 6     *,F10.1,                                   STC 2080
     C/3X,*IP EXTRACTION     *,F10.1,                                   STC 2090
     D/3X,*VAP.+DIST. STEAM  *,F10.1,                                   STC 2100
     E/3X,*LP TOTAL FLOW     *,F10.1,                                   STC 2110
     F/3X,*TOTAL CONDENSATE  *,F10.1)                                   STC 2120
      PRINT 9,RATIO                                                     STC 2130
    9 FORMAT(/3X,*DIRECT STEAM GEN. TO STORAGE RATIO=*,F6.4)            STC 2140
      PRINT14,GPHP,GPLP,TGP                                             STC 2150
   14 FORMAT(                                                           STC 2160
     1/3X,*POWER GENERATED AT HP TURBINE=*,F6.2,                        STC 2170
     2/3X,*POWER GENERATED AT LP TURBINE=*,F6.2,                        STC 2180
     3/3X,*TOTAL POWER GENERATED       =*,F6.2)                         STC 2190
*NIIGHT OPERATION                                                      *STC 2200
      PRINT 3                                                           STC 2210
    3 FORMAT(/3X,*NIGHT-TIME OPERATION*)                                STC 2220
      RHTRF=1.-(SL10+SL20+SL30+SL40+SL50)/AO-FHF                        STC 2230
      FIPF=RHTRF+(SL10+SL30)/AO                                         STC 2240
      T15=1.8*(T30-10.)-460.                                            STC 2250
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      H15=1.011*T15-34.21                                               STC 2260
      FIF=((H7-H15)-SL40/AO*(H2-H15)-FHF*(H9-H15))/(H5-H15)             STC 2270
      FLPF=FIPF-SL60/AO-FIF                                             STC 2280
      BFWF=FLPF+(SL20+SL50+SL60)/AO                                     STC 2290
*TOTAL ENERGY AT NIGHT = QAAN*16(HRS)                                  *STC 2300
      TE=QAN*3600.*16./1.0551                                           STC 2310
*ASSUME 3.5 P.C.FLOW IS OBTAINED BY SUPPLYING  5 P.C. OF HEAT.         *STC 2320
      Q=QFST*RATIO*1000.                                                STC 2330
*TURBINE IS SPLIT INTO SMALL AND LARGE TURBINES                        *STC 2340
      SPLIT=.26*(RATIO-1.)+.5                                           STC 2350
      QBIGAN=(Q-QAN)*3600./1.0551/0.965*0.050*SPLIT                     STC 2360
      QSMLAN=TE-QBIGAN*16.                                              STC 2370
      TPNF=QBIGAN/(RHTRF*(H4-H2)+(H1-H10))                              STC 2380
      A=TPNF                                                            STC 2390
      Q=QBIGAN                                                          STC 2400
      PRINT 6                                                           STC 2410
    6 FORMAT(/3X,*LARGE TURBINE AT 3.5P.C. OF DAY-TIME FLOW*)           STC 2420
      DO 4 I=1,3                                                        STC 2430
      IF(I-2)8,19,20                                                    STC 2440
   19 PRINT 10                                                          STC 2450
   10 FORMAT(/3X,*POWER RATE AT SMALL TURBINE DURING 16 HRS AT NIGHT.*) STC 2460
      Q=QSMLAN/16.                                                      STC 2470
      GO TO 11                                                          STC 2480
   20 PRINT 21                                                          STC 2490
   21 FORMAT(/3X,*100 MW-E TURBINE AT SEASONAL STORAGE OP. CONDITIONS*) STC 2500
      Q=TGPD*Q/TGP                                                      STC 2510
      TIME=TE/Q                                                         STC 2520
      R4=16./TIME                                                       STC 2530
      PRINT 15,TIME,R4                                                  STC 2540
   15 FORMAT(/3X,*DISCHARGE AT FULL LOAD*,F6.3,*HRS. NEEDS*,F6.3,* DAYS STC 2550
     1OF STORAGE TO*,/3X,*RUN 16 HRS AT FULL LOAD*)                     STC 2560
   11 A=Q/(RHTRF*(H4-H2)+(H1-H10))                                      STC 2570
    8 AN=A                                                              STC 2580
*ALL FLOWS RATIOD TO FLOW INTO BOILER                                  *STC 2590
      RHTR=RHTRF*A                                                      STC 2600
      FIP=FIPF*A                                                        STC 2610
      FLP=FLPF*A                                                        STC 2620
      BFW=BFWF*A                                                        STC 2630
      FI=FIF*A                                                          STC 2640
      FH=FHF*A                                                          STC 2650
      VPDS=0.                                                           STC 2660
      R=A/AO                                                            STC 2670
      R1=AN/AO                                                          STC 2680
      PRINT 12,R,R1                                                     STC 2690
   12 FORMAT(/3X,2HR=,E10.4,3X,3HR1=,E10.4)                             STC 2700
      SL1=SL10*R                                                        STC 2710
      SL2=SL20*R                                                        STC 2720
      SL3=SL30*R                                                        STC 2730
      SL4=SL40*R                                                        STC 2740
      SL5=SL50*R                                                        STC 2750
      SL6=SL60*R                                                        STC 2760
      FIPV=RHTR+SL1                                                     STC 2770
      PRINT 1,A,SL1,SL2,SL3,SL4,SL5,FH,RHTR,FIPV,FIP,SL6,FI,VPDS,FLP,BFWSTC 2780
      EC=FLP*(H5-H12)                                                   STC 2790
      GPHP=GPHPO*R                                                      STC 2800
      GPLP=GPLPO*EC/OEC                                                 STC 2810
      TGP=GPHP+GPLP                                                     STC 2820
```

```
      PRINT14,GPHP,GPLP,TGP                                           STC 2830
      ATGP(I)=TGP                                                     STC 2840
      BFWA(I)=BFW                                                     STC 2850
    4 CONTINUE                                                        STC 2860
*ONLY THE SMALL TURBINE POWER IS SENT BACK TO MEBP                   *STC 2870
      ATGP2=ATGP(2)                                                   STC 2880
      BFWA1=BFWA(1)+BFWA(2)                                           STC 2890
      BFWA2=BFWA(3)                                                   STC 2900
      FACTOR=3600./1.0551/(H15-H14)                                   STC 2910
      BFWA1=BFWA1/FACTOR                                              STC 2920
      BFWA2=BFWA2/FACTOR                                              STC 2930
      RETURN                                                          STC 2940
      END                                                             STC 2950
```

```
      SUBROUTINE CLR(I,J,K,CL)                                           CLR
***********************************************************************CLR
*                                                                      *CLR
*     UPDATED 4/15/78                                                  *CLR
*                       CLR - CONDENSER LOAD ROUTINE                   *CLR
*                                                                      *CLR
***********************************************************************CLR
*ROUTINE IS USED TO CALC. CONDENSER LOAD FOR GIVEN INPUT GAS STREAM AND*CLR
*GIVEN OUTPUT TEMP. IT ALSO SET THE RECORD FOR BOTH LIQUID AND GAS     *CLR
*LEAVING STREAMS.                                                      *CLR
*     ROUTINE IS CALLED BY *CALL CCR(NI,NG,NL,CL)*  * WHERE NI IS NO.  *CLR
*     OF INPUT STREAM, NG IS NO. OF GAS EXITING STREAM,NL IS LIQUID OUT*CLR
*     - PUT STREAM, CL-CONDENSER LOAD .                                *CLR
*     ROUTINE HAS ACCESS TO THE MAIN PROGRAM ARRAYS=F,P,T,H,X1,X2,X3   *CLR
*ROUTINE USES CCL FUNCTION TO DETERMINE THE LOAD                       *CLR
*   ROUTINE ASSUMES CONDENSATION AT CONSTANT PRESSURE AND SET =        *CLR
*   P(NL)=P(NG)=P(NI).                                                 *CLR
*     ROUTINE ASSUMES THAT BOTH T(NI) AND T(NG) ARE GIVEN.             *CLR
*                                                                      *CLR
*NOMENCLATURE=                                                         *CLR
*     CL        CONDENSER LOAD (KJ/S)                                  *CLR
*     F         FLOW(KMOL/SEC)                                         *CLR
*     H         ENTHALPY,(KJ/KMOL)                                     *CLR
*     I         INPUT GAS STREAM INDEX                                 *CLR
*     J         OUTPUT GAS STREAM INDEX                                *CLR
*     K         OUTPUT LIQ. STREAM INDEX                               *CLR
*     NG        OUTPUT GAS STREAM INDEX  (USED FOR PRINTIG ONLY)       *CLR
*     NI        INPUT GAS STREAM INDEX  O(USED FOR PRINTIG ONLY)       *CLR
*     NL        OUTPUT LIQ. STREAM INDEX (USED FOR PRINTIG ONLY)       *CLR
*     P         PRESSURE(BAR)                                          *CLR
*     T         TEMP.(K)                                               *CLR
*     TJ        EXIT TEMP. AS SPECIFIED TO CCL                         *CLR
*     X1        OXYGEN CONTENT (MOLE FRACTION)                         *CLR
*     X2        SO2 CONTENT (MOLE FR.)                                 *CLR
*     X3        SO3 CONTENT (MOLE FR.)                                 *CLR
***********************************************************************CLR
*                                                                      *CLR
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)         CLR
*                                                                      *CLR
      PRINT 50,I,J,K,T(J)                                                CLR
   50 FORMAT(/3X,*CLR ROUTINE*,/3X,*INPUTS= NI=*,I2,3X,3HNG=I2,3X,3HNL=,CLR
     1I2,3X,                7HT(OUT)=,F7.2)                              CLR
* CONDENSER LOAD CALCS.                                                *CLR
      TJ=T(J)                                                            CLR
      CL=CCL(I,J,K,TJ)                                                   CLR
*              END OF ROUTINE.RETURN AFTER SUCCESSFUL CALCULATIONS     *CLR
      T(K)=T(J)                                                          CLR
      PRINT 44                                                           CLR
      PRINT 55,I,F(I),X1(I),X2(I),X3(I),T(I),H(I)                        CLR
      PRINT 55,J,F(J),X1(J),X2(J),X3(J),T(J),H(J)                        CLR
      PRINT 55,K,F(K),X1(K),X2(K),X3(K),T(K),H(K)                        CLR
      PRINT 5,CL                                                         CLR
```

```
44 FORMAT(/3X,*RESULTS OF CLR     ROUTINE*/,5X,2HSN,10X,1HF,8X,2HX1,   CLR  530
  18X,2HX2,8X,2HX3,9X,1HT,9X,1HH)                                      CLR  540
55 FORMAT(/6X,I2,5X,6F10.4)                                            CLR  550
 5 FORMAT(/3X,*CONDENSER LOAD= CL=*,E11.4)                             CLR  560
   RETURN                                                              CLR  570
   END                                                                 CLR  580
```

```
      SUBROUTINE CTR(I,J,K,CL)                                          CTR
***********************************************************************CTR
*                                                                      *CTR
*     UPDATED 4/15/78                                                  *CTR
*     CTR - CONDENSER TEMP. ROUTIE.                                    *CTR
*                                                                      *CTR
***********************************************************************CTR
*ROUTINE IS CALLED BY *CTR(NI,NG,NL,CL)*                               *CTR
*ROUTINE CALCS. EXIT TEMP. FOR A CONDENSER WHOSE LOAD IS GIVEN.        *CTR
*IN ADDITION THE ROUTINE CALCS. AND UPDATE THE STREAM FILE (EXIT STREAM*CTR
*     ROUTINE IS CALLED BY *CALL CCR(NI,NG,NL,CL)*  * WHERE NI IS NO.  *CTR
*     OF INPUT STREAM, NG IS NO. OF GAS EXITING STREAM,NL IS LIQUID OUT*CTR
*     - PUT STREAM, CL-CONDENSER LOAD .                                *CTR
*   ROUTINE ASSUMES CONDENSATION AT CONSTANT PRESSURE AND SET =        *CTR
*   P(NL)=P(NG)=P(NI).                                                 *CTR
*     ROUTINE ASSUMES THAT BOTH T(NI) AND T(NG) ARE GIVEN. HOWEVER,    *CTR
*T(NG) IS CONSIDERED AS FIRST APPROXIMATION ONLY AND IS UPDATED.       *CTR
*     ROUTINE HAS ACCESS TO THE MAIN PROGRAM ARRAYS=F,P,T,H,X1,X2,X3   *CTR
*ROUTINE USES THE FOLLOWING SUBROUTINES= VKCR,BPTR,CCL,RECOPY,ENTR2    *CTR
*                                                                      *CTR
*NOMENCLATURE=                                                         *CTR
*     BPT        BUBBLE POINT TEMP.                                    *CTR
*     CCL1       MAX. CL FOR T(J)=273. ALSO USED IN NR TO FIND T       *CTR
*     CCL2       USED IN NR (=F*DH) TO FIND T                          *CTR
*     CL         CONDENSER LOAD (KJ/S)                                 *CTR
*     CLADP      CONDENSER LOAD AT DEW POINT                           *CTR
*     DP         DEW POINT (=DPT) IN CALL FOR VKCR                     *CTR
*     DPF1       NR FUNCTION VALUE (FOR DPT) IN DO LOOP 15             *CTR
*     DPF2       NR FUNCTION VALUE (FOR DPT-1) IN DO LOOP 15           *CTR
*     DPT        DEW POINT TEMP.                                       *CTR
*     DT         INCREMENT FOR DPT AS CALC. BY NR (DO LOOP 15)         *CTR
*     EPST       TOLERANCE FOR ACCEPTABLE DT                           *CTR
*     F          FLOW (KMOL/HR)                                        *CTR
*     H          ENTHALPY (KJ/KMOL)                                    *CTR
*     I          INPUT GAS STREAM INDEX                                *CTR
*     J          OUTPUT GAS STREAM INDEX                               *CTR
*     K          OUTPUT LIQ. STREAM INDEX                              *CTR
*     K2         VOLATILITY CONST. FOR SO2                             *CTR
*     K3         VOLATILITY CONST. FOR SO3                             *CTR
*     M          NO.OF ITERATIONS IN DPT DO LOOP AND T DO LOOPS        *CTR
*     N          DO LOOP INDEX IN DPT CALCS.(15) AND IN T CALCS.(12,23)*CTR
*     NG         OUJPUT GAS SOREAM INDEX (USED IN PRINTING ONLY)       *CTR
*     NI         INPUT GAS STREAM INDEX    (USED FOR PRINTIG ONLY)     *CTR
*     NL         OUTPUT LIQ. STREAM INDEX (USED FOR PRINTIG ONLY)      *CTR
*     P          PRESSURE (BAR)                                        *CTR
*     TJ         GAS EXIT TEMP.                                        *CTR
*     X1         MOLE FRACTION O2                                      *CTR
*     X2         MOLE FRACTION SO2                                     *CTR
*     X3         MOLE FRACTION SO3                                     *CTR
***********************************************************************CTR
      DIMENSION TJ(10)                                                  CTR
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)        CTR
```

```
      REAL K2,K3
      DATA EPST,M/1.,10/
      PRINT 50,I,J,K,CL
   50 FORMAT(/3X,*CTR ROUTINE*,/3X,*INPUTS= NI=*,I2,3X,3HNG=I2,3X,3HNL=,
     1I2,3X,3HCL=,E11.4,)
*CHECK WHETHER CL IS NOT  NEGATIVE . IF NEG. PRINT ERROR MASSEGE, IF  0*
*SET STREAM NG EQ. TO NI ANDSTREAMNL EQ. ZERO.                         *
      IF(CL)1,2,3
* 1- ERROR. CL CANT BE NEGATIVE                                        *
    1 PRINT 4,I,CL
    4OFORMAT(/3X,*ERROR IN CONDENSER LOAD DATA. CL IS NEGATIVE. NI=*,
     1I2,3X,3HCL=,E11.4)
      GO TO 100
    2 CALL RECOPY(I,J)
      CALL RECOPY(45,K)
      GO TO 24
*CALC. CL MAX. AT T(J)=273.
    3 CCL1=CCL(I,J,K,273.)
*CHECK IF SPECIFIED LOAD IS NOT TOO HIGH.                              *
      IF(CCL1.GT.CL)GO TO 37
*MAX. LOAD CALCS.                                                      *
      T(J)=273.
      PRINT 38
   38 FORMAT(/3X,*CONDENSER CANT ACCOMODATE SUCH LOAD DEMAND WITH THE SP
     1ECIFIED FLOW.*,/3X,*RESULTS ARE GIVEN FOR MAX. POSSIBLE LOAD-CCL*)
      GO TO 24
*FIND BUBBLE POINT. (IT IS NOT A TRUE BP. IT IS USED ONLY AS A FIRST   *
*APPROXIMATION FOR THE DEW POINT.)                                     *
   37 CALL BPTR(P(I),X2(I),BPT)
*FIND DPT-DEW POINT TEMP. (FIRST APPROX. FOR DPT IS BPT.)              *
      DPT=BPT
      DO 15 N=1,M
      DP=DPT
      CALL VKCR(P(I),DP,K2,K3)
      DPF1=X2(I)/K2+X3(I)/K3-1.
      DP=DP-1.
      CALL VKCR(P(I),DP,K2,K3)
      DPF2=X2(I)/K2+X3(I)/K3-1.
      DT=DPF1/(DPF1-DPF2)
      IF(ABS(DT)-50.)6,6,7
    7 DT=50.0*DT/ABS(DT)
    6 DPT=DPT-DT
      IF(ABS(DT)-EPST)16,16,15
   15 CONTINUE
*GET CLADP - CL AT DEW POINT.                                          *
   16 CALL RECOPY(I,J)
      CALL RECOPY(45,K)
      T(J)=DPT
      CALL ENTR2(DPT,X2(J),X3(J),H(J))
      CLADP=F(I)*(H(I)-H(J))
      CCL1=CLADP
*SELECT CONDENSER OR COOLER ROUTINE
      IF(CLADP-CL)18,24,19
*                                                                      *
*                                                                      *
* EXIT TEMP. CALC. FOR COOLER.                                         *
   19 CALL RECOPY(I,J)
```

```
      CALL RECOPY(45,K)                                                 CTR 1100
      T(J)=DPT                                                          CTR 1110
      DO 12 N=1,M                                                       CTR 1120
      IF(T(J)-DPT)25,28,28                                              CTR 1130
   25 T(J)=DPT                                                          CTR 1140
   28 TJ(N)=T(J)                                                        CTR 1150
      CALL ENTR2(TJ(N),X2(J),X3(J),H(J))                                CTR 1160
      CCL1=F(I)*(H(I)-H(J))                                             CTR 1170
      TJ(N)=TJ(N)-1.                                                    CTR 1180
      CALL ENTR2(TJ(N),X2(J),X3(J),H(J))                                CTR 1190
      CCL2=F(I)*(H(I)-H(J))                                             CTR 1200
      DT=(CL-CCL1)/(CCL1-CCL2)                                          CTR 1210
      IF(ABS(DT)-50.)32,32,33                                           CTR 1220
   33 DT=50.0*DT/ABS(DT)                                                CTR 1230
   32 T(J)=T(J)+DT                                                      CTR 1240
      IF(ABS(DT)-EPST)26,26,12                                          CTR 1250
   12 CONTINUE                                                          CTR 1260
      GO TO 8                                                           CTR 1270
*   -EXIT TEMPS. CALCULATIONS. (CONDENSER).                            *CTR 1280
*FIRST GUESS= T(J)=(DPT+BPT)/2.                                         CTR 1290
   18 T(J)=(DPT+BPT)/2.                                                 CTR 1300
   21 DO 23 N=1,M                                                       CTR 1310
      IF(T(J)-DPT)10,10,11                                              CTR 1320
   11 T(J)=DPT                                                          CTR 1330
   10 TJ(N)=T(J)                                                        CTR 1340
      CCL1=CCL(I,J,K,TJ(N))                                             CTR 1350
      TJ(N)=TJ(N)-1.                                                    CTR 1360
      CCL2=CCL(I,J,K,TJ(N))                                             CTR 1370
      DT=(CL-CCL1)/(CCL1-CCL2)                                          CTR 1380
      IF(ABS(DT)-50.)34,34,35                                           CTR 1390
   35 DT=50.0*DT/ABS(DT)                                                CTR 1400
   34 T(J)=T(J)+DT                                                      CTR 1410
      IF(ABS(DT)-EPST)26,26,23                                          CTR 1420
   23 CONTINUE                                                          CTR 1430
*NO CONVERGENCE ON T.                                                  *CTR 1440
    8 PRINT 27                                                          CTR 1450
   27 FORMAT(/3X,*NO CONVERGENCE ON T(J) AND T(K) AT CTR*)              CTR 1460
*                                                                      *CTR 1470
*LAST PASS THROUGH CCL                                                 *CTR 1480
   26 CCL1=CCL(I,J,K,T(J))                                              CTR 1490
* 24- IS THE END OF ROUTINE.RETURN AFTER SUCCESSFUL CALCULATIONS       *CTR 1500
   24 T(K)=T(J)                                                         CTR 1510
      PRINT 44                                                          CTR 1520
      PRINT 55,I,F(I),X1(I),X2(I),X3(I),T(I),H(I)                       CTR 1530
      PRINT 55,J,F(J),X1(J),X2(J),X3(J),T(J),H(J)                       CTR 1540
      PRINT 55,K,F(K),X1(K),X2(K),X3(K),T(K),H(K)                       CTR 1550
   44 FORMAT(/3X,*RESULTS OF CTR    ROUTINE*/,5X,2HSN,10X,1HF,8X,2HX1,  CTR 1560
     18X,2HX2,8X,2HX3,9X,1HT,9X,1HH)                                    CTR 1570
   55 FORMAT(/6X,I2,5X,6E10.4)                                          CTR 1580
      PRINT 9,CL,CCL1                                                   CTR 1590
    9 FORMAT(/3X,*CONVERGENCE ACCURACY= CL=*,E11.4,3X,*COMPARE TO CCL=*,CTR 1600
     1E11.4)                                                            CTR 1610
  100 RETURN                                                            CTR 1620
      END                                                               CTR 1630
```

```
      FUNCTION CCL(I,J,K,TJ)                                            CCL    10
*********************************************************************** CCL    20
*                                                                      *CCL    30
*     UPDATED - 5/17/78                                                *CCL    30
*     CCL - COMPUTATIONS OF CONDENSER LOAD FUNCTION                    *CCL    50
*                                                                      *CCL    60
************************************************************************CCL    70
*CCL IS A FUNCTION CALLED BY BOTH CLR AND CTR TO DETERMINE CONDENSER   *CCL    80
*LOAD. FUNCTION IS CALLED BY *CCL(TJ)* WHERE TJ IS THE OUTPUT TEMP.    *CCL    90
*FUNCTION HAS ACCESS TO ALL STREAM RECORDS. NR SCHEME IS USED TO FIND  *CCL   100
*LIQUID FLOW AND COMPOSITION OF THE EXIT STREAM. FIRST GUESSES ARRAYS  *CCL   110
*ARE BASED ON INPUT.                                                   *CCL   120
*FUNCTION USES THE FOLLOWING ROUTINES= VKCR,ENTR1,ENTR2,RECOPY         *CCL   130
*     NOMENCLATURE=                                                    *CCL   140
*     AL         ARRAY FOR POSSIBLE FIRST GUESSES OF L                 *CCL   141
*     AX         ARRAY FOR POSSIBLE FIRST GUESSES OF X2                *CCL   142
*     A11        NR JACOBIAN MATRIX VARIABLE                           *CCL   150
*     A12        NR JACOBIAN MATRIX VARIABLE                           *CCL   160
*     A21        NR JACOBIAN MATRIX VARIABLE                           *CCL   170
*     A22        NR JACOBIAN MATRIX VARIABLE                           *CCL   180
*     CCL        CALCULATED CONDENSER LOAD  (FUNCTION)                 *CCL   190
*     CL         CONDENSER LOAD (KJ/SEC)                               *CCL   200
*     D          DETERMINANT OF THE NR JACOBIAN MATRIX                 *CCL   210
*     DL         INCREMENT FOR L IN NR SCHEME                          *CCL   220
*     DX2        INCREMENT FOR XX2 IN NR SCHEME                        *CCL   230
*     EPSL       TOLERANCE FOR ACCEPTABLE DL                           *CCL   240
*     EPSX2      TOLERANCE FOR ACCEPTABLE DX2                          *CCL   250
*     F          FLOW     (KMOL/SEC)                                   *CCL   260
*     F1         FUNCTION IN NR FOR XX2 AND L                          *CCL   270
*     F2         FUNCTION IN NR FOR XX2 AND L                          *CCL   280
*     H          ENTHALPY (KJ/KMOL)                                    *CCL   290
*     I          INPUT GAS STREAM INDEX                                *CCL   300
*     I1         INDEX FOR DO LOOP PREPARING INITIAL GUESSES           *CCL   310
*     J          OUTPUT GAS    STREAM INDEX                            *CCL   320
*     K          OUTPUT LIQUID STREAM INDEX                            *CCL   330
*     K2         VOLATILITY CONST. FOR SO2                             *CCL   340
*     K3         VOLATILITY CONST. FOR SO3                             *CCL   350
*     L          LIQUID FLOW -ARRAY IN NR SCHEME                       *CCL   360
*     M          NO. OF ITERATIONS -NR SCHEME                          *CCL   370
*     N          INDEX IN DO LOOP 34 -NR SCHEME                        *CCL   380
*     NP1        N+1 IN DO LOOP 34                                     *CCL   390
*     P          PRESSURE (BAR)                                        *CCL   400
*     T          TEMP.    (K)                                          *CCL   410
*     TFC        TEST FOR CONDENSATION FUNCTION                        *CCL   420
*     TJ         GAS EXIT TEMP.                                        *CCL   430
*     TK         LIQUID EXIT TEMP.                                     *CCL   440
*     XX2        X2 IN L -ARRAY IN NR SCHEME                           *CCL   450
*     X1         MOL. FR. O2                                           *CCL   460
*     X2         MOL. FR. SO2                                          *CCL   470
*     X3         MOL. FR. SO3                                          *CCL   480
************************************************************************CCL   220
*                                                                      *CCL  *230
```

```
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)        CCL  240
      DIMENSION AX(5),AL(5)                                             CCL  250
      REAL K2,K3                                                        CCL  260
      REAL L( 20),XX2( 20)                                              CCL  270
      DATA M/20/                                                        CCL  280
      DATA EPSX2,EPSL/0.005,100.0/                                      CCL  290
*    * SET EQUAL PRESSURE THROUGHOUT THE CONDENSER.                     CCL  300
      P(J)=P(I)                                                         CCL  310
      P(K)=P(I)                                                         CCL  320
      TK=TJ                                                             CCL  330
      CALLVKCR(P(K),TK,  K2,K3)                                         CCL  340
*CHECK IF MIXTURE IS CONDENSIBLE AT THIS TEMP. TFC=TEST FOR CONDENSATIONCCL  350
      TFC=X2(I)/K2+X3(I)/K3                                             CCL  360
      IF(TFC.LE.1.00) GO TO 11                                          CCL  370
* CALC, INITIAL GUESSES FOR XX2(N=1),L(N=1)                            *CCL  380
      DO 3 I1=1,5                                                       CCL  390
      AX(I1)=0.1*I1                                                     CCL  400
    3 AL(I1)=0.15*I1*F(I)                                               CCL  410
      DO 1 I1=1,5                                                       CCL  420
      XX2(1)=AX(I1)                                                     CCL  430
      L(1)=AL(I1)                                                       CCL  440
*ENTERING NEWTON RAPHSON ITERATION ROUTINE FOR XX2 AND L               *CCL  450
    4 DO 34 N=1,M                                                       CCL  460
      NP1=N+1                                                           CCL  470
      F1=(F(I)-L(N))*(1.-K3-XX2(N)*(K2-K3))-F(I)*X1(I)                  CCL  480
      F2=(F(I)-L(N))*K2*XX2(N)+L(N)*XX2(N)-F(I)*X2(I)                   CCL  490
      A11=XX2(N)*(K2-K3)+K3-1.                                          CCL  500
      A12=(F(I)-L(N))*(K3-K2)                                           CCL  510
      A21=XX2(N)*(1.-K2)                                                CCL  520
      A22=(F(I)-L(N))*K2+L(N)                                           CCL  530
      D=A11*A22-A12*A21                                                 CCL  540
      DL=(A12*F2-A22*F1)/D                                              CCL  550
      DX2=(A21*F1-A11*F2)/D                                             CCL  560
      L(N+1)=L(N)+DL                                                    CCL  570
      XX2(N+1)=XX2(N)+DX2                                               CCL  580
      IF(ABS(DX2)-EPSX2)41,41,34                                        CCL  590
   41 IF(ABS(DL)-EPSL)42,42,34                                          CCL  600
   34 CONTINUE                                                          CCL  610
      PRINT 43,M                                                        CCL  620
   43 FORMAT(/3X,*COMMON ROUTINE DIDN$T CONVERGED AFTER M=*,I2,*ITERATIOCCL  630
     1NS*)                                                              CCL  640
   42 X2(K)=XX2(NP1)                                                    CCL  650
      X3(K)=1.-X2(K)                                                    CCL  660
      X1(K)=0.                                                          CCL  670
      X2(J)=K2*X2(K)                                                    CCL  680
      X3(J)=K3*X3(K)                                                    CCL  690
      X1(J)=1.-X2(J)-X3(J)                                              CCL  700
      F(K)=L(NP1)                                                       CCL  710
      F(J)=F(I)-F(K)                                                    CCL  720
* CALC. CONDENSER LOAD FOR THE PARTICULAR T(J) GIVEN TO THE COMMON ROUTNCCL  730
      CALL ENTR1(TK,  X2(K),H(K))                                       CCL  740
      CALL ENTR2(TJ,  X2(J),X3(J),H(J))                                 CCL  750
      CCL=F(I)*H(I)-F(J)*H(J)-F(K)*H(K)                                 CCL  760
*CHECK IF ANY IMPOSSIBLE NEGATIVE FLOWS EXIST.                         *CCL  770
      IF(F(J))8,2,2                                                     CCL  780
    8 IF(F(J)+0.01*F(I))1,7,7                                           CCL  790
    7 F(J)=0.                                                           CCL  800
```

```
      F(K)=F(I)                                                         CCL  810
    2 IF(F(K))9,100,100                                                 CCL  820
    9 IF(F(K)+0.01*F(I))1,10,10                                         CCL  830
   10 F(K)=0.                                                           CCL  840
      F(J)=F(I)                                                         CCL  850
      GO TO 100                                                         CCL  860
*TRY DIFF. INITIAL CONDITIONS. IF DOESNT HELP STOP PROG.               *CCL  870
    1 CONTINUE                                                          CCL  880
      PRINT 6,F(I),F(J),F(K)                                            CCL  890
    6 FORMAT(/3X,*FLOWS I,J,K, ARE=*,3(3X,F11.4))                       CCL  900
      PRINT 5                                                           CCL  910
    5 FORMAT(3X,*IGNORE CONDENSER. SET F(J)=F(I) AS IF NON-COND.*)      CCL  920
*CALCS. FOR NON-CONDENSIBLE FEED.                                      *CCL  930
   11 X1(J)=X1(I)                                                       CCL  940
      X2(J)=X2(I)                                                       CCL  950
      X3(J)=X3(I)                                                       CCL  960
      F(J)=F(I)                                                         CCL  970
      CALL ENTR2(TJ,X2(J),X3(J),H(J))                                   CCL  980
      CALL RECOPY'45,K)                                                 CCL  990
      CL=(H(I)-H(J))*F(I)                                               CCL 1000
      CCL=CL                                                            CCL 1010
      PRINT 12,T(J),CL                                                  CCL 1300
   12 FORMAT(/3X,*CCL WAS CALLED TO CALC. FOR NONCONDENSIBLE MIXTURE. LOCCL 1310
     1AD CALC. ON BASIS OF GAS ENTHALPY CHANGE ONLY. T(J)=*,F7.2,3X,3HCLCCL 1320
     2=,E11.4)                                                          CCL 1330
  100 RETURN                                                            CCL 1020
 1000 CONTINUE                                                          CCL 1030
      END                                                               CCL 1040
```

```
      SUBROUTINE FINDT(NS,J)                                            FINT  10
************************************************************************FINT  20
*                                                                      *FINT  30
*     UPDATED 4/15/78                                                  *FINT  40
*     FINDT - ROUTINE TO FIND T IF H IS GIVEN.                         *FINT  50
*                                                                      *FINT  60
************************************************************************FINT  70
*ROUTINE IS CALLED BY *FINDT(NS,NF) WHERE NS IS STATE INDICATOR (1 FOR *FINT  80
*LIQ. 2 FOR GAS) AND NF IS THE STREAM RECORD NO. IT HAS ACCESS TO ALL  *FINT  90
*STREAM RECORDS. ROUTINE USES VALUE FOUND IN T(J) AS FIRST GUESS IN A  *FINT 100
*NR SCHEME TO FIND THE EXACT VALUE OF THIS TEMP.                       *FINT 110
*ROUTINE USES THE FOLLOWING SUBROUTINES= ENTR1,ENTR2                   *FINT 120
*     NOMENCLATURE=                                                    *FINT 130
*     DT       INCREMENT OF T(J) CALC.BY NR SCHEME                     *FINT 140
*     F        FLOW(KMOL/SEC)                                          *FINT 150
*     H        ENTHALPY,(KJ/KMOL)                                      *FINT 160
*     HH       ENTHALPY CORRESPOND TO T(J)                             *FINT 170
*     H1       ENTHALPY CORRESPOND TO T1                               *FINT 180
*     I        INDEX IN DO LOOP 1                                      *FINT 190
*     J        NO. OF STREAM RECORD FOR WHICH T IS CALC.               *FINT 200
*     NS       STATUS OF STREAM= LIQUID (1) OR GAS (2)                 *FINT 220
*     P        PRESSURE(BAR)                                           *FINT 230
*     T        TEMP.(K)                                                *FINT 240
*     T1       T(J)+1                                                  *FINT 250
*     X1       OXYGEN CONTENT (MOLE FRACTION)                          *FINT 260
*     X2       SO2 CONTENT (MOLE FR.)                                  *FINT 270
*     X3       SO3 CONTENT (MOLE FR.)                                  *FINT 280
*                                                                      *FINT 290
**************************** )******************************************FINT 300
*                                                                      *FINT 310
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)        FINT 320
      DO 1 I=1,30                                                       FINT 330
      T1=T(J)+1.                                                        FINT 340
      IF(NS-1)4,4,3                                                     FINT 350
    3 CALL ENTR2(T(J),X2(J),X3(J),HH)                                   FINT 360
      CALL ENTR2(T1,  X2(J),X3(J),H1)                                   FINT 370
      GO TO 5                                                           FINT 380
    4 CALL ENTR1(T(J),X2(J),HH)                                         FINT 390
      CALL ENTR1(T1,  X2(J),H1)                                         FINT 400
    5 DT=(HH-H(J))/(H1-HH)                                              FINT 410
      T(J)=T(J)-DT                                                      FINT 420
      IF(ABS(DT)-0.01)2,2,1                                             FINT 430
    1 CONTINUE                                                          FINT 440
* NO CONVERGENCE ON T= PRINT MESSAGE.                                  *FINT 450
      PRINT 6,T(J),HH,H1,H(J),J                                         FINT 460
    6 FORMAT(/3X,*NO CONV. ON T= T(J)=*,F6.2,3X,3HHH=,E10.4,3X,3HH1=,E10FINT 470
     1.4,3X,5HH(J)=,E10.4,3X,2HJ=,I2,*IN FINDT*)                        FINT 480
    2 RETURN                                                            FINT 490
      END                                                               FINT 500
```

```
      SUBROUTINE RECOPY(I,J)                                            COPY  10
************************************************************************COPY  20
*                                                                      *COPY  30
*     UPDATED 4/15/78                                                  *COPY  40
*     RECOPY - RECORD COPYER.                                          *COPY  50
*                                                                      *COPY  60
************************************************************************COPY  70
*ROUTINE CALLED BY CALL RECOPY(IIN,IOUT) WHERE IIN=RECORD TO COPY FROM *COPY  80
*AND IOUT=RECORD TO UPDATE.                                            *COPY  90
*                                                                      *COPY 100
*VARIABLES=                                                            *COPY 110
*     F        FLOW(KMOL/SEC)                                          *COPY 120
*     H        ENTHALPY,(KJ/KMOL)                                      *COPY 130
*     I        INPUT STREAM INDICATOR                                  *COPY 140
*     J        OUTPUT STREAM INDICATOR                                 *COPY 170
*     P        PRESSURE(BAR)                                           *COPY 180
*     T        TEMP.(K)                                                *COPY 190
*     X1       OXYGEN CONTENT (MOLE FRACTION)                          *COPY 200
*     X2       SO2 CONTENT (MOLE FR.)                                  *COPY 210
*     X3       SO3 CONTENT (MOLE FR.)                                  *COPY 220
************************************************************************COPY 230
*                                                                      *COPY 240
*                                                                      *COPY 250
      COMMON/STREAM/F(60),P(60),T(60),H(60),X1(60),X2(60),X3(60)        COPY 260
      F(J)=F(I)                                                         COPY 270
      T(J)=T(I)                                                         COPY 280
      P(J)=P(I)                                                         COPY 290
      H(J)=H(I)                                                         COPY 300
      X1(J)=X1(I)                                                       COPY 310
      X2(J)=X2(I)                                                       COPY 320
      X3(J)=X3(I)                                                       COPY 330
      RETURN                                                            COPY 340
      END                                                               COPY 350
```

```
      FUNCTION TRKP(X,P,X1,X2,X3)                                       TRKP  10
************************************************************************TRKP  20
*                                                                      *TRKP  30
*     UPDATED 4/15/78                                                  *TRKP  40
*        TRKP - KP CONSTANT ROUTINE                                    *TRKP  50
*                                                                      *TRKP  60
************************************************************************TRKP  70
*ROUTINE IS CALLED BY HTR                                              *TRKP  80
*ROUTINE CALCS. KP FOR GIVEN X AND P.                                  *TRKP  90
*     NOMENCLATURE=                                                    *TRKP 100
*     C        CONVERTED FRACTION X*X3                                 *TRKP 105
*     P        TOTAL PRESSURE                                          *TRKP 110
*     TRKP     FUNCTION-TEMP. DEPENDED REACTION KP CONSTANT            *TRKP 120
*     X1        O2 MOL. FR.                                           -*TRKP 130
*     X2       SO2 MOL. FR.                                           -*TRKP 131
*     X3       SO3 MOL. FR.                                           -*TRKP 132
************************************************************************TRKP 140
*                                                                      *TRKP 150
      C=X*X3                                                            TRKP 160
      TRKP=(X2+C)/(X3-C)*SQRT(P*(2.*X1+C)/(2.+C))                       TRKP 170
      RETURN                                                            TRKP 180
      END                                                               TRKP 190
```

```
      FUNCTION TKP(X,P,X1,X2,X3)                                        TKP   10
************************************************************************TKP   20
*                                                                      *TKP   30
*        TRKTKP  -  CONSTANT ROUTINE                                   *TKP   40
*                                                                      *TKP   50
************************************************************************TKP   60
*ROUTINE IS CALLED BY LTR                                              *TKP   70
*ROUTINE CALCS. KP FOR GIVEN X AND P.  OXIDATION REACTION.             *TKP   80
*     NOMENCLATURE=                                                    *TKP   90
*     C         CONVERTED FRACTION X*X3                                *TKP  100
*     P         TOTAL PRESSURE                                         *TKP  110
*     TKP       FUNCTION-TEMP. DEPENDED 95133965 27 365STANT           *TKP  120
*     X1         O2 MOL. FR.                                           *TKP  130
*     X2        SO2 MOL. FR.                                           *TKP  140
*     X3        SO3 MOL. FR.                                           *TKP  150
************************************************************************TKP  160
*                                                                      *TKP  170
      C=X*X2                                                            TKP  180
      TKP=(X3+C)/(X2-C)/SQRT(P*(2.*X1-C)/(2.-C))                        TKP  190
      RETURN                                                            TKP  200
      END                                                               TKP  210
```

```
      FUNCTION CP(T,Y1,Y2,Y3)                                           CP      10
************************************************************************CP      20
*                                                                      *CP      30
*     UPDATED 4/15/78                                                  *CP      40
* CP - SPACIFIC HEAT ROUTINE                                           *CP      50
*                                                                      *CP      60
************************************************************************CP      70
*ROUTINE CALCS. CP AT ANY GIVEN T AND COMPOSITION.                     *CP      80
*CP AS FUNCTION OF TEMP. IS TAKEN ACCORDING TO EKLUND.                 *CP      90
*(FOR EXACT REFERENCE SEE ENTG ROUTINE)                                *CP     100
*     NOMENCLATURE=                                                    *CP     110
*     CP        FUNCTIO-OVERALL SPECIFIC HEAT                          *CP     120
*     CP1       SPECIFIC HEAT OF O2                                    *CP     130
*     CP2       SPECIFIC HEAT OF SO2                                   *CP     140
*     CP3       SPECIFIC HEAT OF SO3                                   *CP     150
*     T         SYSTEM TEMP.                                           *CP     160
*     Y1        MOL. FR. OF O2                                         *CP     170
*     Y2        MOL. FR. OF SO2                                        *CP     180
*     Y3        MOL. FR. OF SO3                                        *CP     190
************************************************************************CP     200
      CP1=7.16+0.001*T-4.0E4/T**2                                       CP     210
      CP2=10.38+2.54E-3*T-1.42E5/T**2                                   CP     220
      CP3=13.7+6.42E-3*T-3.12E5/T**2                                    CP     230
      CP=CP1*Y1+CP2*Y2+CP3*Y3                                           CP     240
      RETURN                                                            CP     250
      END                                                               CP     260
```

```
      FUNCTION DHR(T)                                                   DHR   10
************************************************************************DHR   20
*                                                                      *DHR   30
*     UPDATED 4/15/78                                                  *DHR   40
*     DHR - HEAT OF REACTION ROUTINE                                   *DHR   50
*                                                                      *DHR   60
************************************************************************DHR   70
*ROUTINE CALCS. HEAT OF REACTION AT ANY T ACCORDING TO S               *DHR   80
*     DHR(T)=DHR(298K)+(H-PROD.-H-REAC.) AT T                          *DHR   90
*     GIVEN= DHR(298K)=23523. CAL/MOLE     (REF. EKLUND).              *DHR  100
*                                                                      *DHR  110
*NOMENCLATURE=                                                         *DHR  120
*     DHR       FUNCTION-DELTA HEAT OF REACTION                        *DHR  130
*     T         REACTION TEMP.                                         *DHR  140
************************************************************************DHR  150
      DHR=23523.-2.6*T+1.69E-3*T**2+1.5E5/T-577.5                       DHR  160
      RETURN                                                            DHR  170
      END                                                               DHR  180
```

```
      SUBROUTINE ENTR1(T,X2,HL)                                         ENTL  10
************************************************************************ENTL  20
*                                                                      *ENTL  30
*     UPDATED 4/15/78                                                  *ENTL  40
*         ENTR1 - ENTHALPY OF LIQUID MIXTURE ROUTINE                   *ENTL  50
*                                                                      *ENTL  60
************************************************************************ENTL  70
*     ROUTINE IS CALLED BY *CALL ENTR1(T,X2,HL)* WHERE T IS TEMP.(K),  *ENTL  80
*     X2-SO2 MOLE FR. (BOTH T AND X2 ARE SPECIFIED BY THE CALLING PROG)*ENTL  90
*     HL-LIQUID MIXTURE ENTHALPY(KJ/KMOLE) TO BE CALCULATED.           *ENTL 100
*     IT IS ASSUMED THAT LIQ. MIXTURES CONTAIN ONLY SO2+SO3 AND BEHAVE *ENTL 110
*     AS AN IDEAL MIXTURE.                                             *ENTL 120
*     ROUTINE CALL ENTR2 TO OBTAIN H(GAS MIXTURE) AND THEN IT CALL LHR *ENTL 130
*     TO OBTAIN HEAT OF VAPORIZATION AT THE SAME TEMP.                 *ENTL 140
*     H(LIQUIDE MIXTURE)=H(GAS)-LH(MIXTURE)                            *ENTL 150
*     NOMENCLATURE=                                                    *ENTL 160
*     HG       ENTHALPY OF GAS AT T AND COMPOSITION X2,X3              *ENTL 170
*     HL       ENTHALPY OF LIQ AT T AND COMPOSITION X2,X3              *ENTL 180
*     LH       LATENT HEAT OF STREAM AT T AND X2,X3 COMPOSITION        *ENTL 190
*     T        TEMP. OF STREAM                                         *ENTL 200
*     X2       MOLE FR. SO2                                            *ENTL 210
*     X3       MOLE FR. SO3                                            *ENTL 220
************************************************************************ENTL 230
      REAL LH                                                           ENTL 240
      X3=1.-X2                                                          ENTL 250
      CALL ENTR2(T,X2,X3,HG)                                            ENTL 260
      CALL LHR(T,X2,LH)                                                 ENTL 270
      HL=HG-LH                                                          ENTL 280
      RETURN                                                            ENTL 290
      END                                                               ENTL 300
```

```
      SUBROUTINE ENTR2(T,X2,X3,H)
************************************************************************
*                                                                      *
*     UPDATED 4/15/78                                                  *
*         ENTR2 - ENTHALPY ROUTINE FOR GAS MIXTURES                    *
*                                                                      *
************************************************************************
*     ROUTINE IS CALLED BY *CALL ENTR2(T,X2,X3,H)* WHERE T IS TEMP.(K),*
*     X2-SO2 MOLE FR., X3-SO3 MOLE FR., H-ENTHALPY TO BE CALC. BY THE  *
*     ROUTINE (KJ/KMOLE).                                              *
*     ROUTINE CALCULATES ENTHALPIES FOR O2-X1,SO2-X2,SO3-X3 GAS MIXTURES
*     (X2 AND X3 ARE GIVEN, X1 MAKES THE BALANCE).                     *
*     ENTHALPIES ARE CALC. FROM TEMP. DEPENDENT SPECIFIC HEATS AS GIVEN*
*     BY K.K.KELLEY, HIGH TEMP. HEAT-CONTENT,HEAT-CAPACITY,AND ENTROPY *
*     DATA FOR INORGANIC COMPOUNDS. BUREAU OF MINES, BULL. 476 (1949)  *
*     AND AS INTEGRATED BY R.B.EKLUND,THE RATE OF OXIDATION OF SO2 WITH*
*     COMERCIAL VANADIUM CATALYST. PH.D DISSERTATION, THE ROYAL INST.  *
*     OF TECH. STOCKHOLM (1956).                                       *
*     MIXTURES ASSUME TO BE IDEAL,I.E. H=X1*H1+X2*H2+X3*H3             *
*     H IS CALC. IN (KJOULS/KMOLE). BASIS IS HO(298.16K)               *
*NOMENCLATURE=                                                         *
*     H         OVERALL ENTHALPY OF THE GAS STREAM                     *
*     H1        ENTHALPY OF O2  AT T                                   *
*     H2        ENTHALPY OF SO2 AT T                                   *
*     H3        ENTHALPY OF SO3 AT T                                   *
*     T         TEMP. OF STREAM                                        *
*     X1        MOLE FRACTION OF O2  IN STREAM                         *
*     X2        MOLE FRACTION OF SO2 IN STREAM                         *
*     X3        MOLE FRACTION OF SO3 IN STREAM                         *
************************************************************************
*     CALC. OXYGEN CONTENT X1 AND ADJUST IF ZERO                       *
      X1=1.-X2-X3
      IF(X1)1,2,2
    1 X2=X2+X2*X1
      X3=1.-X2
      X1=0.
*     CALCULATE INDIVIDUAL ENTHALPIES AND WEIGHTED MIXTURE ENTHALPY    *
    2 H1=7.16*T+0.0005*T**2+4.E4/T-2313.
      H2=10.38*T+1.27E-3*T**2+1.42E5/T-3683.
      H3=13.70*T+3.21E-3*T**2+3.12E5/T-5417.
      H=4.1868*(H1*X1+H2*X2+H3*X3)
      RETURN
      END
```

```
      SUBROUTINE LHR(T,X2,LH)                                           LHR
************************************************************************LHR
*                                                                      *LHR
*     UPDATED 4/15/78                                                  *LHR
*     LHR - LATENT HEAT ROUTINE                                        *LHR
*                                                                      *LHR
************************************************************************LHR
*     ROUTINE IS CALLED BY *LHR(T,X2,LH)* WHERE T-TEMP.(K), X2-MOLE FR.*LHR
*     OF SO2 (T AND X2 ARE SPECIFIED BY THE CALLING PROG.),LH-LATENT   *LHR
*     HEAT(KJ/KMOLE)TO BE CALCULATED.                                  *LHR
*     BASIC DATA WHERE TAKEN FROM NICKLESS. LATENT HEATS AS FUNCTION OF*LHR
*     TEMP. ARE CALCULATED ACCORDING TO PERRY$S CHEM. ENG. H.B.,5TH. ED*LHR
*     (1973),PG.3-239,EQ.3-53. THE EXPONENT WAS TAKEN AS 0.545 (RATHER *LHR
*     THEN 0.38),WHICH RESULTED FROM CALCS.FOR BOTH SO2 AND SO3 FROM   *LHR
*     ACTUAL REPORTED DATA OF LH(T) GIVEN BY EITHER NICKLESS OR BY     *LHR
*     LANGE$S H.B. OF CHEMISTRY ED.J.A.DEAN,MGH 1973.                  *LHR
*     THE LH FOR THE MIXTURE IS CALCULATED ACCORDING TO PERRY$S EQ.3-57*LHR
*     (PG.3-239), LH=LH2*X2+LH3*X3. FINAL RESULTS CONVERTED INTO KJ/MOL*LHR
*     DATA USED -                                                      *LHR
*         SO2  TC=430K, TB=263K, LH(263)=6.00KCAL/MOLE                 *LHR
*         SO3  TC=491K, TB=318K, LH(318)=9.75KCAL/MOLE                 *LHR
*NOMENCLATURE=                                                         *LHR
*     LH        OVERALL LATENT HEAT (KJ/KMOL)                          *LHR
*     LH2       LATENT HEAT OF SO2 AT GIVEN T                          *LHR
*     LH3       LATENT HEAT OF SO3 AT GIVEN T                          *LHR
*     T         TEMP. OF STREAM FOR WHICH LH IS CALC.                  *LHR
*     X2        MOLE FRACTION OF SO2 IN STREAM                         *LHR
*     X3        MOLE FRACTION OF SO3 IN STREAM                         *LHR
************************************************************************LHR
      REAL LH,LH2,LH3                                                   LHR
      X3=1.-X2                                                          LHR
      IF(T-430.)1,2,2                                                   LHR
    2 IF(T-491.)5,6,6                                                   LHR
    5 LH2=0.                                                            LHR
      GO TO 7                                                           LHR
    1 LH2=6.0*((430.-T)/167.)**0.545                                    LHR
    7 LH3=9.75*((491.-T)/173.)**0.545                                   LHR
      LH=4186.8*(LH2*X2+LH3*X3)                                         LHR
      GO TO 4                                                           LHR
    6 LH=0.                                                             LHR
      PRINT 3,T                                                         LHR
    3 FORMAT(/3X,*LHR ROUTINE HAS BEEN CALLED TO CALC. LH FOR MIX. ABOVELHR
     1 THE CRITICAL PT. SET LH=0. T=*,F7.2)                             LHR
    4 RETURN                                                            LHR
      END                                                               LHR
```

```
      SUBROUTINE VKCR(P,T,K2,K3)                                        VKCR  10
************************************************************************VKCR  20
*                                                                      *VKCR  30
*     UPDATED 4/15/78                                                  *VKCR  40
*         VKCR - VOLATILITY K CONSTANT ROUTINE                         *VKCR  50
*                                                                      *VKCR  60
************************************************************************VKCR  70
*     ROUTINE IS CALLED BY *CALL VKCR(P,T,K2,K3)* WHERE P IS TOTAL     *VKCR  80
*     PRESSURE AND T IS TEMPERATURE. BOTH T AND P ARE SPECIFIED BY THE *VKCR  90
*     CALLING PROGRAM. K2 AND K3 ARE THE VOLATILITY K CONSTANTS OF SO2 *VKCR 100
*     AND SO3 RESPECTIVELY WHICH ARE CALCULATED BY THE ROUTINE.        *VKCR 110
*     IT IS ASSUMED THAT SO2 AND SO3 FORM IDEAL SYSTEM,I.E.THE COMPONEN*VKCR 120
*     OF THE MIXTURE OBEY RAOULT$S AND DALTON$S LAWS=                  *VKCR 130
*         PI=P*YI=PSI*XI                                               *VKCR 140
*         KI=YI/XI=PSI/P                                               *VKCR 150
*     WHERE-                                                           *VKCR 160
*     I   ONE OF THE MIXTURE COMPONENTS (I=2 FOR SO2, I=3 FOR SO3)     *VKCR 170
*     KI  VOLATILITY CONSTANT OF I                                     *VKCR 180
*     P   TOTAL SYSTEM PRESSURE                                        *VKCR 190
*     PI  PARTIAL PRESSURE OF COMPONENT I IN GAS                       *VKCR 200
*     PSI VAPOR PRESSURE OF PURE LIQUID I                              *VKCR 210
*     T   TEMPERATURE                                                  *VKCR 220
*     XI  MOLE FRACTION OF I IN LIQUID                                 *VKCR 230
*     YI  MOLE FRACTION OF I IN GAS                                    *VKCR 240
*     PROGRAM USES E2 AND E3 AS INTERMEDIATE VARIABLES FOR THE EXPONENTSVKCR 250
*     OF 10 IN CALCULATING PS2 AND PS3 RESPECTIVELY.                   *VKCR 260
************************************************************************VKCR 270
*     NOMENCLATURE                                                     *VKCR 280
*     E2         EXPONENT POWER FOR ESTIMATING PS2                     *VKCR 290
*     E3         EXPONENT POWER FOR ESTIMATING PS3                     *VKCR 300
*     K2         VOLATILITY CONSTANT OF SO2                            *VKCR 310
*     K3         VOLATILITY CONSTANT OF SO3                            *VKCR 320
*     P          TOTAL SYSTEM PRESSURE                                 *VKCR 330
*     PS2        VAPOR PRESSURE OF PURE LIQ. SO2                       *VKCR 340
*     PS3        VAPOR PRESSURE OF PURE LIQ. SO3                       *VKCR 350
*     T          STREAM TEMP.                                          *VKCR 360
************************************************************************VKCR 370
*     DATA REFERENCE=                                                  *VKCR 380
*     G.NICKLESS, INORGANIC SULFUR CHEMISTRY, ELSEVIER - 1968          *VKCR 390
*                    PG.373 FOR SO2, PG.392 FOR SO3                    *VKCR 400
*     PROGRAM ASSUMES THAT T IS IN (K) AND P IN (BAR).                 *VKCR 410
*     SEE BPTR SUBROUTINE FOR DETAILES.                                *VKCR 420
************************************************************************VKCR 430
      REAL K2,K3                                                        VKCR 440
      E2=12.0754-1867.52/T-0.015865*T+0.000015574*T**2                  VKCR 450
      PS2=10.**E2*1.0133/76.                                            VKCR 460
      K2=PS2/P                                                          VKCR 470
      E3=4.2719-965.78/(T-93.)                                          VKCR 480
      PS3=10.**E3*1.0133                                                VKCR 490
      K3=PS3/P                                                          VKCR 500
      RETURN                                                            VKCR 510
      END                                                               VKCR 520
```

```
      SUBROUTINE BPTR(P,X2,TT)                                          BPTR  10
***********************************************************************BPTR  20
*                                                                      *BPTR  30
*     UPDATED 4/15/78                                                  *BPTR  40
*         BPTR - BUBBLE POINT TEMPERATURE ROUTINE                      *BPTR  50
*                                                                      *BPTR  60
***********************************************************************BPTR  70
*                                                                      *BPTR  80
*     ROUTINE IS CALLED BY*CALL BPTR(P,X2,T)* WHERE P IS THE TOTAL     *BPTR  90
*     PRESSURE, X2 COMPOSITION OF THE SO2-SO3 LIQUIDE MIXTURE (X2=MOL  *BPTR 100
*     FR. OF SO2) AND T IS THE BOILLING PT. OF THE MIXTURE (BUBBLE PT.)*BPTR 110
*     VAPOR PRESSURE CORRELATIONS WHERE TAKEN FROM G.NICKLESS,INORGANIC*BPTR 120
*     SULFUR CHEMISTRY,ELSEVIER-1968, P-373 FOR SO2,P-392 FOR SO3.     *BPTR 130
*     THE ACTUAL NUMERICAL VALUES OF THE ROUTINE PARAMETERS ARE MODIFIEDBPTR 140
*     TO ACCEPT TEMP. IN (K) AND P IN (BAR).                           *BPTR 150
*     ROUTINE ASSUMES IDEAL SYSTEM= TOTAL VAPOR P = PSO2+PSO3 WHERE    *BPTR 160
*     PSOI=PS(T,I)*XI WHERE I=SO2,SO3. PS(T,I)=SATURATION VAP. PRESSURE*BPTR 170
*     OF COMPONENT I AT TEMP. T.                                       *BPTR 180
***********************************************************************BPTR 190
*     LOGIC FLOW -                                                     *BPTR 200
*     FIRST GUESS FOR T IS DONE BY SELECTING THE PROPER RANGE ACCORDING*BPTR 210
*     TO THE PRESSURE P(BAR), I.E. I=1 FOR P BETWEEN 0 AND 10 (0,10)   *BPTR 220
*     I=2 FOR P=(10,20),I=3 FOR P=(20,30),I=4 FOR P=(30,40),I=5 FOR P  *BPTR 230
*     OVER 40BAR. PROGRAM IS ESSENTIALLY LIMITTED TO P=50BAR.          *BPTR 240
*FIRST GUESS FOR BUBBLE POINT (BP) IS TAKEN TO BE EQ. TO TI OF THE     *BPTR 250
*PARTICULAR RANGE.  NEWTON RAPHSON SCHEME IS USED FOR CONVERGENCE.     *BPTR 260
***********************************************************************BPTR 270
*     NOTATIONS -                                                      *BPTR 280
*     A         CONST. PARAMETER  IN VAP. PRESS. POLINOMINAL EQ.       *BPTR 290
*     B         CONST. PARAMETER  IN VAP. PRESS. POLINOMINAL EQ.       *BPTR 300
*     C         CONST. PARAMETER  IN VAP. PRESS. POLINOMINAL EQ.       *BPTR 310
*     C2        FACTOR TO CONVERT VAPOR PRESSURE INTO BARS             *BPTR 320
*     C3        FACTOR TO CONVERT VAPOR PRESSURE INTO BARS             *BPTR 330
*     D         CONST.PARAMETER  IN VAP.PRESSURE POLINOMINAL EQ.       *BPTR 340
*     DPT       DENOMINATOR IN LAST EQ. FOR DT                         *BPTR 350
*     DP2      CONTRIBUTION OF SO2 TO THE CALCULATED DPT               *BPTR 360
*     DP3      CONTRIBUTION OF SO2 TO THE CALCULATED DPT               *BPTR 370
*     DT  DIFFERENTIAL TEMP. CHANGE IN T SEARCHING LOOP                *BPTR 380
*     E         CONST.PARAMETER  IN VAP.PRESSURE POLINOMINAL EQ.       *BPTR 390
*     EX2 EXPONENT OF 10 IN SO2 VAP.PRESSURE EQUATION                  *BPTR 400
*     EX3 EXPONENT OF 10 IN SO3 VAP.PRESSURE EQUATION                  *BPTR 410
*     G         CONST.PARAMETER  IN VAP.PRESSURE POLINOMINAL EQ.       *BPTR 420
*     H         CONST.PARAMETER  IN VAP.PRESSURE POLINOMINAL EQ.       *BPTR 430
*     I   DO LOOP INDEX I=1,M                                          *BPTR 440
*     J   NO. OF THE PRESSURE RANGE WITHIN T IS SEARCHED FOR           *BPTR 450
*     M   MAX. PERMISSABLE ITERATIONS IN DO LOOP                       *BPTR 460
*     P   TOTAL PRESSURE GIVEN BY THE CALLING PROGRAM                  *BPTR 470
*     PP2 SATURATED VAPOR PRESSURE OF SO2 AT TEMP T (EQUILIBRIUM)      *BPTR 480
*     PP3 SATURATED VAPOR PRESSURE OF SO3 AT TEMP T (EQUIL.)           *BPTR 490
*     PT  TOTAL PRESSURE CALC. BY THE ROUTINE                          *BPTR 500
*     T   CALC. TEMP (K)                                               *BPTR 510
*     TENLN     NATURAL LOG OF 10.                                     *BPTR 520
```

```
*      TI         TEMP. AT THE LOWER LIMIT OF A PARTICULAR RANGE          *BPTR 530
*      TT         EXIT BP TEMP.                                           *BPTR 540
*      X2  MOLE FRACTION OF SO2 IN THE LIQUID MIXTURE                     *BPTR 550
*      X3  MOLE FRACTION OF SO3 IN THE LIQUID MIXTURE                     *BPTR 560
*                                                                         *BPTR 570
**************************************************************************BPTR 580
      DIMENSION T(31),TI(5)                                               BPTR 590
      DATA TI/333.,375.,393.,413.,433./                                   BPTR 600
      DATA A,B,C,D/12.0754,18,7.52,0.015865,0.000015574/                  BPTR 610
      DATA E,G,H/4.2719,945.78,93./                                       BPTR 620
      DATA C2,C3/0.01333,1.0133/                                          BPTR 630
      DATA TENLN,M/2.302585,30/                                           BPTR 640
      IF(X2)10,11,11                                                      BPTR 650
   11 IF(X2-1.)15,15,12                                                   BPTR 660
   10 PRINT 16,X2                                                         BPTR 670
   16 FORMAT(/3X,*WRONG X2=*,E11.4,* ASSUME X2=0. , CONTINUE.*)           BPTR 680
      X2=0.                                                               BPTR 690
      GO TO 15                                                            BPTR 700
   12 PRINT 17,X2                                                         BPTR 710
   17 FORMAT(/3X,*WRONG X2=*,E11.4,* ASSUME X2=1. , CONTINUE.*)           BPTR 720
      X2=1.                                                               BPTR 730
   15 X3=1.-X2                                                            BPTR 740
*FIND RANGE. TRANCATED P/10+1 IS THE RANGE NO.                            *BPTR 750
      J=1+P/10.                                                           BPTR 760
      T(1)=TI(J)                                                          BPTR 770
      DO 1 I=1,M                                                          BPTR 780
      EX2=A-B/T(I)-C*T(I)+D*T(I)**2                                       BPTR 790
      EX3=E-G/(T(I)-H)                                                    BPTR 800
      PP2=C2*10.**EX2                                                     BPTR 810
      PP3=C3*10.**EX3                                                     BPTR 820
      PT=P-X2*PP2-X3*PP3                                                  BPTR 830
      DP2=TENLN*PP2*(B/T(I)**2-C+2.*D*T(I))                               BPTR 840
      DP3=TENLN*PP3*G/((T(I)-H)**2)                                       BPTR 850
      DPT=-DP2-DP3                                                        BPTR 860
      DT=PT/DPT                                                           BPTR 870
      T(I+1)=T(I)-DT                                                      BPTR 880
      TT=T(I+1)                                                           BPTR 890
      IF(ABS(DT)-0.05)2,2,1                                               BPTR 900
    1 CONTINUE                                                            BPTR 910
*. ASSUME CONVERGENCE                                                     *BPTR 920
    2 RETURN                                                              BPTR 930
      END                                                                 BPTR 940
```

APPENDIX C. (Continued)

SAMPLE PRINTOUT OF RESULTS

The following is a sample printout of the calculations at the base case conditions. To simplify the presentation, some parts were rearranged and repetitive printings of iterated calculations were omitted. The order of the printed results is preserved, however. Brief notes of explanation are also attached.

The program first prints the input data.

```
                MEBP PROGRAM
INPUT DATA

NON-CHANGING DATA?P(1),P(5),P(21),T24,T27     11.000     40.000     11.000    573.000    693.000

FIRST APPROX?T(1),X2(1),F(5),       X2(5),X2(18)   364.000        .047       5.800        .020        .010

SPECIFICATION? DT56,TWMAX,TMIN,PRSO2,XD,
   140.000  1153.000   333.000       .980       .990

TOLERANCES? EPSF5,EPST5?       .0500      .5000

GENERAL? N= 45    NOP= 30    NH=18
INCREMENTS OF STUDIED PARAMS. TWMAX,DTD56,TMIN? 20.0  1   25.0  1   10.0  1
INCREMENTS OF STUDIED PARAMS. DELP, NOP?           5.0  1
```

The program next enters the HTS - LTS loop. The printout is rather lengthy; only the last iteration is attached.

```
HTS ROUTINE

CONVERGENCE ON F(5) AND T(5)? DF5=  .3366E-01   DT5=  .6220E+01HTS ROUTIN

CONVERGENCE ON F(5) AND T(5)? DF5= -.3055E-02   DT5=  .2339E-03HTS ROUTIN

CLR ROUTINE
INPUTS? NI= 6   NG=14   NL=16   T(OUT)= 333.00

RESULTS OF CLR    ROUTINE
  SN         F          X1          X2          X3          T          H

   6      .6484E+01 .1499E+00 .3247E+00 .5254E+00 .1147E+04 .5028E+05

  14      .1124E+01 .8649E+00 .1010E+00 .3412E-01 .3330E+03 .1101E+04

  16      .5360E+010.           .3717E+00 .6283E+00 .3330E+03-.2967E+05

CONDENSER LOAD? CL=  .4838E+06

CTR ROUTINE
INPUTS? NI= 7   NG= 8   NL= 9   CL=  .9198E+05

RESULTS OF CTR    ROUTINE
  SN         F          X1          X2          X3          T          H

   7      .6484E+01 .1499E+00 .3247E+00 .5254E+00 .5928E+03 .1524E+05

   8      .5066E+01 .1919E+00 .3552E+00 .4529E+00 .4176E+03 .5548E+04

   9      .1418E+010.           .2157E+00 .7843E+00 .4176E+03-.15[illegible]E+05

CONVERGENCE ACCURACY? CL=  .9198E+05   COMPARE TO CCL=  .9200E+05

CLR ROUTINE
INPUTS? NI= 8   NG=10   NL=11   T(OUT)= 393.37

RESULTS OF CLR    ROUTINE
  SN         F          X1          X2          X3          T          H
```

```
    8        .5066E+01 .1919E+00 .3552E+00 .4529E+00 .4176E+03 .5548E+04

   10        .2338E+01 .4166E+00 .3639E+00 .2194E+00 .3934E+03 .3809E+04

   11        .2728E+010.           .3477E+00 .6523E+00 .3934E+03-.1848E+05

 CONDENSER LOAD? CL=   .6960E+05

 CLR ROUTINE
 INPUTS? NI=10    NG=12    NL=13    T(OUT)= 343.00

 RESULTS OF CLR     ROUTINE
   SN              F          X1          X2          X3            T          H

   10        .2338E+01 .4166E+00 .3639E+00 .2194E+00 .3934E+03 .3809E+04

   12        .1267E+01 .7691E+00 .1966E+00 .3422E-01 .3430E+03 .1470E+04

   13        .1072E+010.           .5617E+00 .4383E+00 .3430E+03-.2424E+05

 CONDENSER LOAD? CL=   .3302E+05

 CLR ROUTINE
 INPUTS? NI=12    NG=14    NL=15    T(OUT)= 333.00

 RESULTS OF CLR     ROUTINE
   SN              F          X1          X2          X3            T          H

   12        .1267E+01 .7691E+00 .1966E+00 .3422E-01 .3430E+03 .1470E+04

   14        .1210E+01 .8052E+00 .1755E+00 .1922E-01 .3330E+03 .1118E+04

   15        .5678E-010.           .6461E+00 .3539E+00 .3330E+03-.2425E+05

 CONDENSER LOAD? CL=   .1886E+04

  DISTILLATION COLUMN

 FEED ENTERS BETWEEN PLATES? 10 AND 11

 CTR ROUTINE
 INPUTS? NI= 8    NG=10    NL=11    CL=   .9269E+05

 RESULTS OF CTR     ROUTINE
   SN              F          X1          X2          X3            T          H

    8        .5066E+01 .1919E+00 .3552E+00 .4529E+00 .4176E+03 .5548E+04

   10        .1738E+01 .5594E+00 .2988E+00 .1418E+00 .3785E+03 .2974E+04

   11        .3328E+010.           .3847E+00 .6153E+00 .3785E+03-.2096E+05

 CONVERGENCE ACCURACY? CL=   .9269E+05    COMPARE TO CCL=   .9269E+05

 CLR ROUTINE
 INPUTS? NI=10    NG=12    NL=13    T(OUT)= 343.00

 RESULTS OF CLR     ROUTINE
   SN              F          X1          X2          X3            T          H

   10        .1738E+01 .5594E+00 .2988E+00 .1418E+00 .3785E+03 .2974E+04
```

```
   12        .1267E+01 .7675E+00 .1988E+00 .3375E-01 .3430E+03 .1470E+04

   13        .4713E+000.           .5677E+00 .4323E+00 .3430E+03-.2412E+05

 CONDENSER LOAD? CL=  .1469E+05

 CLR ROUTINE
 INPUTS? NI=12    NG=14    NL=15    T(OUT)= 333.0

 RESULTS OF CLR     ROUTINE
  SN             F          X1          X2          X3           T           H

   12        .1267E+01 .7675E+00 .1988E+00 .3375E-01 .3430E+03 .1470E+04

   14        .1209E+01 .8039E+00 .1773E+00 .1887E-01 .3330E+03 .1118E+04

   15        .5732E-010.           .6525E+00 .3475E+00 .3330E+03-.2412E+05

 CONDENSER LOAD? CL=  .1893E+04

 OVERALL MAT. BAL. RESULTS IN X2(2) OF? .0321   COMPARE TO ASSUMED?  .0327

 END OF HTS  RTN.

 LTS ROUTINE

 CTR ROUTINE
 INPUTS? NI=28    NG=29    NL=43    CL=   .2701E+05

 CCL WAS CALLED TO CALC. FOR NONCONDENSIBLE MIXTURE. LOAD CALC. ON BASIS
 OF GAS ENTHALPY CHANGE ONLY.  T(J)= 400.85    CL=  .2701E+05

 RESULTS OF CTR     ROUTINE
  SN             F          X1          X2          X3           T           H

   28        .1066E+01 .7629E-02 .6606E-01 .9263E+00 .7771E+03 .3095E+05

   29        .1066E+01 .7629E-02 .6606E-01 .9263E+00 .4008E+03 .5618E+04

   43     0.         0.         0.         0.            .4008E+030.

 CONVERGENCE ACCURACY? CL=  .2701E+05   COMPARE TO CCL=  .2701E+05

 CTR ROUTINE
 INPUTS? NI=37    NG=41    NL=42    CL=   .4950E+04

 CCL WAS CALLED TO CALC. FOR NONCONDENSIBLE MIXTURE. LOAD CALC. ON BASIS
 OF GAS ENTHALPY CHANGE ONLY.  T(J)= 400.85    CL=  .4950E+04

 RESULTS OF CTR     ROUTINE
  SN             F          X1          X2          X3           T           H

   37        .1954E+00 .7629E-02 .6606E-01 .9263E+00 .7771E+03 .3095E+05

   41        .1954E+00 .7629E-02 .6606E-01 .9263E+00 .4008E+03 .5618E+04

   42     0.         0.         0.         0.            .4008E+030.

 CONVERGENCE ACCURACY? CL=  .4950E+04   COMPARE TO CCL=  .4950E+04

 CTR ROUTINE
 INPUTS? NI=38    NG=29    NL=43    CL=   .2206E+05
```

```
CCL WAS CALLED TO CALC. FOR NONCONDENSIBLE MIXTURE. LOAD CALC. ON BASIS
OF GAS ENTHALPY CHANGE ONLY.  T(J)= 400.85   CL=  .2206E+05

RESULTS OF CTR     ROUTINE
  SN          F          X1          X2          X3          T          H

   38      .8709E+00 .7629E-02 .6606E-01 .9263E+00 .7771E+03 .3095E+05

   29      .8709E+00 .7629E-02 .6606E-01 .9263E+00 .4008E+03 .5618E+04

   43    0.          0.          0.          0.          .4008E+03 .

CONVERGENCE ACCURACY? CL=  .2206E+05   COMPARE TO CCL=  .2206E+05

CTR ROUTINE
INPUTS? NI=39   NG=30   NL=31   CL=  .1805E+05

RESULTS OF CTR     ROUTINE
  SN          F          X1          X2          X3          T          H

   39      .1066E+01 .7629E-02 .6606E-01 .9263E+00 .4008E+03 .5618E+04

   30      .5781E+00 .1492E-01 .9468E-01 .8904E+00 .3820E+03 .4475E+04

   31      .4882E+000.           .3120E-01 .9688E+00 .3820E+03-.2657E+05

CONVERGENCE ACCURACY? CL=  .1805E+05   COMPARE TO CCL=  .1638E+05

CLR ROUTINE
INPUTS? NI=30   NG=32   NL=33   T(OUT)= 343.00

RESULTS OF CLR     ROUTINE
  SN          F          X1          X2          X3          T          H

   30      .5781E+00 .1492E-01 .9468E-01 .8904E+00 .3820E+03 .4475E+04

   32      .1027E-01 .6219E+00 .1213E+00 .2568E+00 .3430E+03 .1665E+04

   33      .5678E+000.           .9529E-01 .9047E+00 .3430E+03-.3327E+05

CONDENSER LOAD? CL=  .2146E+05

CLR ROUTINE
INPUTS? NI=32   NG=34   NL=35   T(OUT)= 333.00

RESULTS OF CLR     ROUTINE
  SN          F          X1          X2          X3          T          H

   32      .1027E-01 .6219E+00 .1213E+00 .2568E+00 .3430E+03 .1665E+04

   34      .9050E-02 .7056E+00 .1211E+00 .1733E+00 .3330E+03 .1220E+04

   35      .1219E-020.           .1226E+00 .8774E+00 .3330E+03-.3460E+05

CONDENSER LOAD? CL=  .4822E+02

END OF LTS  RTN.

CALC. ARE REPEATED IF ANY OF THE FOLLOWING CONDS. IS NOT SATISFIED?
IF(ABS(2.0F(36)-F(1))-0.015)  F(36)= .10572E+01   F(1)= .21118E+01
IF(ABS(X2(1)-X2(36))-0.008)   X(36)= .65726E-01   X(1)= .65986E-01
IF(ABS(T(1)-T(36))-1.0)       T(36)= .36169E+03   T(1)= .36154E+03
```

Program then prints the High Temperature Reactor results. The terms used in the heading are defined below.

NOS - number of the section
L - length down the reactor (m)
TW - outside wall temperature of tube (^{o}K)
TS - inside wall temperature of tube (^{o}K)
TB - bulk temperature of stream (^{o}K)
Q - total heat absorbed up to this section
QR - heat absorbed due to reaction up to this section
QS - sensible heat absorbed up to this section
C - actual conversion of SO_3 up to this section
YSO_3 - mole fraction SO_3
YSO_2 - mole fraction SO_2
YO_2 - mole fraction O_2

The routine then prints the equilibrium conversion at the conditions of the catalyzed wall of each section.

```
PARAMETERS STUDIED? TWMAX=1153.0  TMIN=333.0  DTD56=140.0  PHTS=40.0

      HIGH TEMP REACTOR DESIGN-COMPUTATION RESULTS

  NOS       L       TW        TS        TB        Q           QR          QS             C         Y-SO3      Y-SO2     Y-O2

   1      .20    1061.7    1053.3    1006.8   .7314E+03   .4620E+03   .2693E+03     0.000      .967       .033      0.000
   2      .40    1063.9    1055.7    1010.5   .1450E+04   .9190E+03   .5313E+03      .006      .959       .038      .003
   3      .60    1066.2    1058.1    1014.1   .2157E+04   .1371E+04   .7862E+03      .012      .95        .044      .006
   4      .80    1068.3    1060.4    1017.7   .2852E+04   .1818E+04   .1034E+04      .018      .942       .050      .009
   5     1.00    1070.5    1062.6    1021.1   .3535E+04   .2260E+04   .1275E+04      .024      .933       .055      .011
   6     1.20    1072.5    1064.8    1024.5   .4206E+04   .2697E+04   .151 E+04      .030      .925       .061      .014
   7     1.40    1074.6    1067.0    1027.7   .4867E+04   .3129E+04   .1738E+04      .036      .917       .066      .017
   8     1.60    1076.5    1069.1    1030.9   .5516E+04   .3556E+04   .1960E+04      .041      .909       .071      .020
   9     1.80    1078.5    1071.1    1034.0   .6154E+04   .3978E+04   .2176E+04      .047      .901       .076      .022
  10     2.00    1080.3    1073.1    1037.1   .6781E+04   .4395E+04   .2386E+04      .053      .893       .082      .025
  11     2.20    1082.2    1075.1    1040.0   .7397E+04   .4807E+04   .2590E+04      .058      .886       .087      .027
  12     2.40    1084.0    1077.0    1042.9   .8004E+04   .5215E+04   .2789E+04      .064      .878       .092      .030
  13     2.60    1085.7    1078.9    1045.7   .8600E+04   .5618E+04   .2982E+04      .069      .871       .097      .033
  14     2.80    1087.5    1080.7    1048.5   .9186E+04   .6016E+04   .3170E+04      .075      .864       .101      .035
  15     3.00    1089.1    1082.5    1051.2   .9762E+04   .6409E+04   .3354E+04      .080      .856       .106      .037
  16     3.20    1090.8    1084.3    1053.8   .1033E+05   .6797E+04   .3532E+04      .086      .849       .111      .040
  17     3.40    1092.4    1086.0    1056.3   .1089E+05   .7181E+04   .3705E+04      .091      .842       .116      .042
  18     3.60    1094.0    1087.7    1058.8   .1143E+05   .7560E+04   .3874E+04      .096      .835       .120      .044
  19     3.80    1095.5    1089.3    1061.2   .1197E+05   .7935E+04   .4038E+04      .101      .829       .125      .047
  20     4.00    1097.0    1090.9    1063.6   .1250E+05   .8304E+04   .4198E+04      .107      .822       .129      .049
  21     4.20    1098.5    1092.5    1065.9   .1302E+05   .8670E+04   .4353E+04      .112      .815       .133      .051
  22     4.40    1099.9    1094.0    1068.2   .1354E+05   .9030E+04   .4505E+04      .117      .809       .138      .053
  23     4.60    1101.3    1095.5    1070.3   .1404E+05   .9387E+04   .4652E+04      .122      .802       .142      .056
  24     4.80    1102.7    1097.0    1072.5   .1453E+05   .9738E+04   .4796E+04      .127      .796       .146      .059
  25     5.00    1104.0    1098.4    1074.6   .1502E+05   .1009E+05   .4936E+04      .132      .790       .150      .060
  26     5.20    1105.3    1099.9    1076.6   .1550E+05   .1043E+05   .5072E+04      .136      .784       .154      .062
  27     5.40    1106.6    1101.2    1078.6   .1597E+05   .1077E+05   .5205E+04      .141      .778       .158      .064
```

28	5.60	1107.9	1102.6	1080.6	.1644E+05	.1110E+05	.5334E+04	.146	.772	.162	.066
29	5.80	1109.1	1103.9	1082.5	.1689E+05	.1143E+05	.5460E+04	.151	.766	.166	.068
30	6.00	1110.3	1105.2	1084.3	.1734E+05	.1176E+05	.5582E+04	.155	.760	.170	.070
31	6.20	1111.5	1106.5	1086.1	.1778E+05	.1208E+05	.5702E+04	.16	.754	.174	.072
32	6.40	1112.7	1107.7	1087.9	.1821E+05	.1240E+05	.5818E+04	.164	.749	.178	.074
33	6.60	1113.8	1108.9	1089.6	.1864E+05	.1271E+05	.5931E+04	.169	.743	.181	.076
34	6.80	1114.9	1110.1	1091.3	.1906E+05	.1302E+05	.6042E+04	.173	.738	.185	.077
35	7.00	1116.0	1111.3	1092.9	.1947E+05	.1332E+05	.6149E+04	.178	.732	.188	.079
36	7.20	1117.1	1112.4	1094.5	.1988E+05	.1363E+05	.6254E+04	.182	.727	.192	.081
37	7.40	1118.1	1113.5	1096.1	.2028E+05	.1392E+05	.6357E+04	.186	.722	.195	.083
38	7.60	1119.1	1114.6	1097.6	.2067E+05	.1422E+05	.6457E+04	.191	.717	.199	.084
39	7.80	1120.1	1115.7	1099.1	.2106E+05	.1451E+05	.6554E+04	.195	.712	.202	.086
40	8.00	1121.1	1116.7	1100.6	.2144E+05	.1479E+05	.6649E+04	.199	.707	.205	.088
41	8.20	1122.1	1117.8	1102.0	.2182E+05	.1507E+05	.6741E+04	.203	.702	.209	.089
42	8.40	1123.0	1118.8	1103.4	.2218E+05	.1535E+05	.6832E+04	.207	.697	.212	.091
43	8.60	1123.9	1119.7	1104.8	.2255E+05	.1563E+05	.6920E+04	.211	.692	.215	.093
44	8.80	1124.8	1120.7	1106.1	.2290E+05	.1590E+05	.7006E+04	.215	.688	.218	.094
45	9.00	1125.7	1121.7	1107.4	.2325E+05	.1616E+05	.7090E+04	.219	.683	.221	.096
46	9.20	1126.6	1122.6	1108.7	.2360E+05	.1643E+05	.7172E+04	.223	.679	.224	.097
47	9.40	1127.4	1123.5	1109.9	.2394E+05	.1669E+05	.7252E+04	.227	.674	.227	.099
48	9.60	1128.2	1124.4	1111.2	.2427E+05	.1694E+05	.7330E+04	.23	.670	.23	.100
49	9.80	1129.1	1125.3	1112.4	.2460E+05	.1720E+05	.7406E+04	.234	.665	.233	.102
50	10.00	1129.9	1126.1	1113.5	.2493E+05	.1745E+05	.7480E+04	.238	.661	.236	.103
51	10.20	1130.6	1127.0	1114.7	.2525E+05	.1769E+05	.7553E+04	.241	.657	.238	.105
52	10.40	1131.4	1127.8	1115.8	.2556E+05	.1794E+05	.7624E+04	.245	.653	.241	.106
53	10.60	1132.2	1128.6	1116.9	.2587E+05	.1817E+05	.7693E+04	.249	.649	.244	.107
54	10.80	1132.9	1129.4	1117.9	.2617E+05	.1841E+05	.7761E+04	.252	.645	.246	.109
55	11.00	1133.6	1130.2	1119.0	.2647E+05	.1864E+05	.7827E+04	.256	.641	.249	.11
56	11.20	1134.3	1131.0	1120.0	.2677E+05	.1887E+05	.7891E+04	.259	.637	.252	.111
57	11.40	1135.	1131.7	1121.0	.2705E+05	.1910E+05	.7955E+04	.262	.633	.254	.113
58	11.60	1135.7	1132.4	1122.0	.2734E+05	.1932E+05	.8016E+04	.266	.629	.257	.114

59	11.80	1136.4	1133.2	1122.9	.2762E+05	.1954E+05	.8077E+04	.269	.626	.259	.115
60	12.00	1137.[illegible]	1133.9	1123.9	.2790E+05	.1976E+05	.8136E+04	.272	.622	.262	.116
61	12.20	1137.7	1134.6	1124.8	.2817E+05	.1998E+05	.8193E+04	.276	.618	.264	.118
62	12.40	1138.3	1135.3	1125.7	.2844E+05	.2019E+05	.8250E+04	.279	.615	.266	.119
63	12.60	1138.9	1135.9	1126.6	.2870E+05	.2040E+05	.8305E+04	.282	.611	.269	.120
64	12.80	1139.6	1136.6	1127.5	.2896E+05	.2060E+05	.8359E+04	.285	.608	.271	.121
65	13.00	1140.2	1137.2	1128.3	.2922E+05	.2080E+05	.8411E+04	.288	.605	.273	.122
66	13.20	1140.7	1137.9	1129.1	.2947E+05	.2100E+05	.8463E+04	.291	.601	.275	.123
67	13.40	1141.3	1138.5	1129.9	.2972E+05	.2120E+05	.8514E+04	.294	.598	.278	.124
68	13.60	1141.9	1139.1	1130.7	.2996E+05	.2140E+05	.8563E+04	.297	.595	.280	.126
69	13.80	1142.4	1139.7	1131.5	.3020E+05	.2159E+05	.8611E+04	.300	.591	.282	.127
70	14.00	1143.0	1140.3	1132.3	.3044E+05	.2178E+05	.8659E+04	.303	.588	.284	.128
71	14.20	1143.5	1140.9	1133.0	.3067E+05	.2196E+05	.8705E+04	.306	.585	.286	.129
72	14.40	1144.1	1141.4	1133.8	.3090E+05	.2215E+05	.8750E+04	.308	.582	.288	.130
73	14.60	1144.6	1142.0	1134.5	.3112E+05	.2233E+05	.8795E+04	.311	.579	.290	.131
74	14.80	1145.1	1142.5	1135.2	.3135E+05	.2251E+05	.8838E+04	.314	.576	.292	.132
75	15.00	1145.6	1143.1	1135.9	.3156E+05	.2268E+05	.8881E+04	.317	.573	.294	.133
76	15.20	1146.1	1143.6	1136.6	.3178E+05	.2286E+05	.8922E+04	.319	.570	.296	.134
77	15.40	1146.6	1144.1	1137.2	.3199E+05	.2303E+05	.8963E+04	.322	.568	.298	.135
78	15.60	1147.0	1144.6	1137.9	.3220E+05	.2320E+05	.9003E+04	.324	.565	.299	.136
79	15.80	1147.5	1145.1	1138.5	.3241E+05	.2336E+05	.9042E+04	.327	.562	.301	.137
80	16.00	1148.0	1145.6	1139.1	.3261E+05	.2353E+05	.9081E+04	.329	.559	.303	.137
81	16.20	1148.4	1146.1	1139.8	.3281E+05	.2369E+05	.9118E+04	.332	.557	.305	.138
82	16.40	1148.8	1146.6	1140.4	.3300E+05	.2385E+05	.9155E+04	.334	.554	.307	.139
83	16.60	1149.3	1147.1	1141.0	.3320E+05	.2401E+05	.9191E+04	.337	.552	.308	.14
84	16.80	1149.7	1147.5	1141.5	.3339E+05	.2416E+05	.9227E+04	.339	.549	.310	.141
85	17.00	1150.1	1148.0	1142.1	.3358E+05	.2432E+05	.9261E+04	.342	.547	.312	.142
86	17.20	1150.5	1148.4	1142.7	.3376E+05	.2447E+05	.9295E+04	.344	.544	.313	.143
87	17.40	1150.9	1148.8	1143.2	.3394E+05	.2461E+05	.9329E+04	.346	.542	.315	.143
88	17.60	1151.3	1149.3	1143.8	.3412E+05	.2476E+05	.9362E+04	.349	.539	.316	.144
89	17.80	1151.7	1149.7	1144.3	.3430E+05	.2491E+05	.9394E+04	.351	.537	.318	.145

```
90    18.00   1152.1   1150.1   1144.8 .3447E+05 .2505E+05 .9425E+04     .353     .535     .320     .146
91    18.20   1152.5   1150.5   1145.3 .3464E+05 .2519E+05 .9456E+04     .355     .532     .321     .147
92    18.40   1152.9   1150.9   1145.8 .3481E+05 .2533E+05 .9486E+04     .357     .530     .323     .147
93    18.60   1153.2   1151.3   1146.3 .3498E+05 .2546E+05 .9516E+04     .359     .528     .324     .148
94    18.80   1153.6   1151.7   1146.8 .3514E+05 .2560E+05 .9545E+04     .362     .526     .325     .149
95    19.00   1153.9   1152.1   1147.3 .3530E+05 .2573E+05 .9573E+04     .364     .524     .327     .150
96    19.00      0.0      0.0   1147.7 0.        0.        0.             .364     .521     .328     .150
 THERMAL POWER ABSORBED BY GAS-  .2299E+03MW-THERMAL)      SOURCE TEMP.=1176.4(K)  DIFF=-.2897E-02MW
```

Equilibrium conversion at wall conditions in each section of the High Temperature Reactor

L - length down the reactor, m

EC - equilibrium conversion

L	EC
.20	.2370
.40	.2912
.60	.2953
.80	.2993
1.00	.3032
1.20	.3071
1.40	.3109
1.60	.3146
1.80	.3183
2.00	.3218
2.20	.3253
2.40	.3288
2.60	.3321
2.80	.3354
3.00	.3387
3.20	.3418
3.40	.3450
3.60	.3480
3.80	.3510
4.00	.3539
4.20	.3568
4.40	.3596
4.60	.3623
4.80	.3650
5.00	.3676
5.20	.3702
5.40	.3727
5.60	.3752
5.80	.3777
6.00	.3800
6.20	.3824
6.40	.3846
6.60	.3869
6.80	.3891
7.00	.3912
7.20	.3933
7.40	.3954
7.60	.3974
7.80	.3994
8.00	.4013
8.20	.4032
8.40	.4051
8.60	.4069
8.80	.4087
9.00	.4105
9.20	.4122
9.40	.4139
9.60	.4155
9.80	.4172
10.00	.4188
10.20	.4203
10.40	.4219
10.60	.4234
10.80	.4248

```
      L          EC                                L          EC
    11.00       .4263                            15.20       .4511

    11.20       .4277                            15.40       .4520

    11.40       .4291                            15.60       .4530

    11.60       .4304                            15.80       .4539

    11.80       .4318                            16.00       .4548

    12.00       .4331                            16.20       .4557

    12.20       .4344                            16.40       .4566

    12.40       .4356                            16.60       .4574

    12.60       .4369                            16.80       .4583

    12.80       .4381                            17.00       .4591

    13.00       .4393                            17.20       .4599

    13.20       .4405                            17.40       .4607

    13.40       .4416                            17.60       .4615

    13.60       .4427                            17.80       .4623

    13.80       .4439                            18.00       .4630

    14.00       .4449                            18.20       .4638

    14.20       .4460                            18.40       .4645

    14.40       .4471                            18.60       .4652

    14.60       .4481                            18.80       .4660

    14.80       .4491                            19.00       .4667

    15.00       .4501                            19.00       .4667


         HTR RETURNS WITH?          F(6)       T(6)          P(6)
                                    6.482    1147.729       40.000


           X1(6)       X2(6)       X3(6)        FC          TWM
           .150        .327        .524        .364      1153.929
```

The program then prints the steam turbine results. All flows in the scheme of Fig. 3.5. are shown for four modes of operation: normal daytime; normal night (large turbine, no actual power generation); normal night (small turbine); and seasonal storage (nighttime at normal daytime output).

```
TMIN(K)= 333.      H12(BTU/LB)= 1089.      P12(PSIA)=  2.331

 DAY-TIME OPERATION.

WATER TO BOILER        334805.9
SEAL LEAK - 1             393.7
SEAL LEAK - 2             114.4
SEAL LEAK - 3            3383.3
SEAL LEAK - 4            1301.5
SEAL LEAK - 5             468.8
HP - EXTRACTION         32227.9
REHEATER FLOW          296916.4
IP-FLOW AT VALVE       297310.1
IP TOTAL FLOW          300693.5
SEAL LEAK - 6             517.3
IP EXTRACTION           10524.7
VAP.+DIST. STEAM       205833.4
LP TOTAL FLOW           83818.0
TOTAL CONDENSATE         1558.2

DIRECT STEAM GEN. TO STORAGE RATIO=1.0500

POWER GENERATED AT HP TURBINE= 23.61
POWER GENERATED AT LP TURBINE=  7.28
TOTAL POWER GENERATED        = 30.89

NIGHT-TIME OPERATION

LARGE TURBINE AT 3.5P.C. OF DAY-TIME FLOW

R= .2466E-02   R1= .1748E-01

WATER TO BOILER          5852.0
SEAL LEAK - 1               6.9
SEAL LEAK - 2               2.0
SEAL LEAK - 3              59.1
SEAL LEAK - 4              22.7
SEAL LEAK - 5               8.2
HP - EXTRACTION           563.3
REHEATER FLOW            5189.7
IP-FLOW AT VALVE         5196.6
IP TOTAL FLOW            5255.8
SEAL LEAK - 6               9.0
IP EXTRACTION             641.2
VAP.+DIST. STEAM            0.0
LP TOTAL FLOW            4605.5
TOTAL CONDENSATE         4624.7

POWER GENERATED AT HP TURBINE=    .41
POWER GENERATED AT LP TURBINE=    .40
TOTAL POWER GENERATED        =    .81
```

```
POWER RATE AT SMALL TURBINE DURING 16 HRS AT NIGHT.

R= .4584E-01    R1= .3249E+00

WATER TO BOILER       108791.2
SEAL LEAK - 1            127.9
SEAL LEAK - 2             37.2
SEAL LEAK - 3           1099.4
SEAL LEAK - 4            422.9
SEAL LEAK - 5            152.3
HP - EXTRACTION        10472.1
REHEATER FLOW          96479.4
IP-FLOW AT VALVE       96667.4
IP TOTAL FLOW          97706.7
SEAL LEAK - 6            168.1
IP EXTRACTION          11920.2
VAP.+DIST. STEAM           0.0
LP TOTAL FLOW          85618.5
TOTAL CONDENSATE       85976.1

POWER GENERATED AT HP TURBINE=  7.67
POWER GENERATED AT LP TURBINE=  7.43
TOTAL POWER GENERATED        = 15.11

TURBINE AT SEASONAL STORAGE OP. CONDITIONS

DISCHARGE AT FULL LOAD 8.245HRS. NEEDS 1.941 DAYS OF STORAGE TO
RUN 16 HRS AT FULL LOAD

R= .9374E-01    R1= .6645E+00

WATER TO BOILER       222476.9
SEAL LEAK - 1            261.6
SEAL LEAK - 2             76.0
SEAL LEAK - 3           2248.2
SEAL LEAK - 4            864.8
SEAL LEAK - 5            311.5
HP - EXTRACTION        21415.2
REHEATER FLOW         197299.5
IP-FLOW AT VALVE      197561.1
IP TOTAL FLOW         199809.3
SEAL LEAK - 6            343.7
IP EXTRACTION          24376.6
VAP.+DIST. STEAM           0.0
LP TOTAL FLOW         175089.0
TOTAL CONDENSATE      175820.2

POWER GENERATED AT HP TURBINE= 15.69
POWER GENERATED AT LP TURBINE= 15.20
TOTAL POWER GENERATED        = 30.89
```

The results of the distillation column are then printed.

```
  DISTILLATION COLUMN
 INPUT DATA
STREAM          F          T            P           H            C           Q
FEED            2.573    391.083     40.000-18776.293           .359
BOTTOM                                                                   45212.440
DISTILLATE                                                      .990
 P=10.78    PRSO2= .980     N= 30

  RESULTS OF THE DISTILLATION COLUMN

  FLASH RESULTS? TFF= 363.68   FL=  .7022E+04   FX2= .2833   FV=  .2240E+04   FY2= .5959

  HEAT INPUT TO REBOILER IS NOT ENOUGH.  QR-MIN SHOULD  BE OVER     .4521E+02  MW
  DIST. COL. IS CALCUL. FOR QR-MIN

  FEED ENTERS BETWEEN PLATES? 1  AND 11
  OUTPUT?
  REBOILER? B=  .1659E+01    XB= .011    TB=383.4    QR=  .4521E+05
  FEED?     F=  .2573E+01    XF= .359    TF=391.1
  CONDENSER?D=  .9141E+00    XD= .990    TD=333.0    QC=  .5703E+05
  PLATES CONDITIONS
   J     T          L            X          HL             V           Y          HV

   1   383.4    .5972E+04     .011    -.2663E+05     .5199E+04     .036      .4680E+04

   2   382.4    .1117E+05     .022    -.2664E+05     .5220E+04     .070      .4557E+04

   3   381.0    .1119E+05     .039    -.2664E+05     .5243E+04     .118      .4429E+04

   4   379.2    .1121E+05     .061    -.2663E+05     .5285E+04     .178      .4260E+04

   5   376.9    .1126E+05     .090    -.2660E+05     .5362E+04     .250      .4060E+04

   6   374.5    .1132E+05     .124    -.2648E+05     .5447E+04     .339      .3848E+04

   7   371.7    .1142E+05     .163    -.2636E+05     .5551E+04     .408      .3625E+04

   8   369.0    .1152E+05     .202    -.2619E+05     .5663E+04     .477      .3422E+04

   9   366.6    .1163E+05     .238    -.2600E+05     .5765E+04     .534      .3254E+04

  10   364.7    .1174E+05     .268    -.2583E+05     .8092E+04     .582      .3123E+04

  11   362.6    .4801E+04     .302    -.2561E+05     .8225E+04     .620      .2986E+04

  12   358.5    .4934E+04     .373    -.2506E+05     .8561E+04     .699      .2728E+04

  13   351.1    .5276E+04     .517    -.2368E+05     .9250E+04     .816      .2306E+04

  14   342.3    .5959E+04     .720    -.2126E+05     .1009E+05     .920      .1858E+04

  15   336.3    .6803E+04     .886    -.1899E+05     .1065E+05     .974      .1578E+04

  16   333.7    .7364E+04     .966    -.1781E+05     .1089E+05     .993      .1460E+04
  NO.OF PLATES M=16    DEVIATION FROM XD= .0035    DEVIATION FROM V= -.6403E-09
```

Finally, the program prints in Tables 1 and 2 following values of the process stream flows, compositions, temperatures, pressures, and enthalpies. The details of the low temperature (nighttime) reactors are then printed. The last two tables are then repeated for flows corresponding to the daytime rate of power generation, in this case 30.89 MW_e.

```
PARAMETERS STUDIED? TWMAX=1153.0  TMIN=333.0  DTD56=140.0  PHTS=40.0

TABLE-1,MATERIAL AND ENERGY DATA FOR THE DAYTIME HIGH TEMPERATURE SIDE
STORAGE SYSTEM

 STREAM COMPOSITION  (MOL PR.)  TEMP.  PRESSURE  FLOW    ENTHALPY
   NO.     O2      SO2     SO3     (K)      (BAR) (KMOL/S)(KJ/KMOL)

    1     0.00     .07     .93    361.5    11.0     1.03 -30199.5

    2     0.00     .03     .97    375.2    40.0     2.69 -28003.2

    3     0.00     .03     .97    443.2    40.0     2.69 -11317.7

    4     0.00     .03     .97    443.2    40.0     2.69   8262.8

    5     0.00     .03     .97   1006.8    40.0     2.69  49476.3

    6      .15     .33     .52   1147.7    40.0     3.16  50278.0

    7      .15     .32     .53    592.8    40.0     3.16  15241.8

    8      .19     .36     .45    417.6    40.0     2.47   5547.8

    9     0.00     .22     .78    417.6    40.0      .69 -15004.1

   10      .56     .30     .14    378.5    40.0      .85   2973.7

   11     0.00     .38     .62    378.5    40.0     1.62 -20957.0

   12      .77     .20     .03    343.0    40.0      .62   1470.1

   13     0.00     .57     .43    343.0    40.0      .23 -24124.9

   14      .80     .18     .02    333.0    40.0      .59   1118.3

   15     0.00     .65     .35    333.0    40.0      .03 -24124.5

   16     0.00     .36     .64    391.1    40.0     2.57 -18776.3

   17     0.00     .99     .01    333.7    10.8      .91 -17809.2

   18     0.00     .01     .99    383.4    10.8     1.66 -26626.5

HEAT EXCHANGER LOAD (KW)?
C1L= 44865.855   VAP1L= 52650.271   HE1L=110819.380   RCL= 45212.440
BFWHL= 1558.230   TRIMMER=  6523.535   QRFS= 11259.464

SUMMARY OF EFFICIENCIES AT THE CHOSEN PARAMETERS

E1=  .2631
E2=  .5337
E3=  .5789
```

TABLE-2,MATERIAL AND ENERGY BALANCES FOR THE NIGHT TIME OPERATION OF THE LOW TEMPERATURE SIDE

STREAM	COMPOSITION	(MOL PR.)		TEMP.	PRESSURE	FLOW	ENTHALPY
NO.	O2	SO2	SO3	(K)	(BAR)	(KMOL/S)	(KJ/KMOL)
21	0.00	.99	.01	333.7	11.0	.46	-17809.2
22	0.00	.99	.01	333.7	11.0	.46	1460.1
23	.80	.18	.02	333.0	40.0	.29	1118.3
24	.80	.18	.02	573.0	40.0	.29	9303.6
25	.01	.99	.01	333.7	11.0	.46	1457.8
26	.32	.67	.01	354.7	11.0	.76	2138.8
27	.32	.67	.01	693.0	11.0	.76	16365.5
28	.01	.07	.93	777.1	11.0	.52	30949.0
29	.01	.07	.93	400.8	11.0	.42	5618.3
30	.01	.09	.89	382.0	11.0	.28	4475.2
31	0.00	.03	.97	382.0	11.0	.24	-26570.8
32	.02	.11	.87	381.3	11.0	.22	4409.5
33	0.00	.04	.96	381.3	11.0	.06	-26609.4
34	.71	.11	.18	333.0	11.0	.01	1217.2
35	0.00	.11	.89	333.0	11.0	.21	-34816.7
36	0.00	.07	.93	361.7	11.0	.52	-30175.2
37	.01	.07	.93	777.1	11.0	.10	30949.0
38	.01	.07	.93	777.1	11.0	.42	30949.0
39	.01	.07	.93	400.8	11.0	.52	5618.3
40	.80	.18	.02	396.2	11.0	.29	3204.0
41	.01	.07	.93	400.8	11.0	.10	5618.3
42	0.00	0.00	0.00	400.8	0.0	0.00	0.0
43	0.00	0.00	0.00	400.8	0.0	0.00	0.0
44	0.00	0.00	0.00	0.0	0.0	0.00	0.0
45	0.00	0.00	0.00	0.0	0.0	0.00	0.0

HEAT EXCHANGERS LOAD (KW)? RECUP= 10761.049 VAP= 8806.663
BFW= 1831.551 TRIM= 8356.963 HE2= 2414.515

ENERGY PRODUCED AT NIGHT? QAAN= .4034E+05 GTW= .1799E+04(KW)

RECEIVER LOAD TQA= 112.2(MW-THRM)

```
RESULTS OF THE LOW TEMP. REACTORS SYSTEM
    NO.      O2        SO2        SO3       (K)       (BAR)  (KMOL/S)(KJ/KMOL)

    50      .32       .67        .01     693.0      11.0        .76  16365.5

    51      .22       .48        .29    1150.3      11.0        .66  44834.6

    52      .22       .48        .29     693.0      11.0        .66  18975.0

    53      .13       .31        .55    1016.3      11.0        .60  42057.5

    54      .13       .31        .55     693.0      11.0        .60  21362.6

    55      .06       .17        .76     912.2      11.0        .55  38590.5

    56      .06       .17        .76     693.0      11.0        .55  23324.3

    57      .02       .09        .90     815.4      11.0        .53  33426.4

    58      .02       .09        .90     752.3      11.0        .53  28798.2

    59      .01       .07        .93     777.1      11.0        .52  30949.0

    60      .01       .07        .93     777.1      11.0        .52  30949.0
Q 1 .1716E+05Q 2 .1234E+05Q 3 .8407E+04Q 4 .2431E+04Q 50.
X         .367X          .418X          .489X          .531X          .233
LTR CONVERSION. C= .932
```

TABLE-2, MATERIAL AND ENERGY BALANCES FOR THE NIGHT TIME OPERATION OF THE LOW TEMPERATURE SIDE

STREAM NO.	COMPOSITION (MOL FR.) O2	SO2	SO3	TEMP. (K)	PRESSURE (BAR)	FLOW (KMOL/S)	ENTHALPY (KJ/KMOL)
21	0.00	.99	.01	333.7	11.0	.89	-17809.2
22	0.00	.99	.01	333.7	11.0	.89	1460.1
23	.80	.18	.02	333.0	40.0	.57	1118.3
24	.80	.18	.02	573.0	40.0	.57	9303.6
25	.01	.99	.01	333.7	11.0	.90	1457.8
26	.32	.67	.01	354.7	11.0	1.47	2138.8
27	.32	.67	.01	693.0	11.0	1.47	16365.5
28	.01	.07	.93	777.1	11.0	1.01	30949.0
29	.01	.07	.93	400.8	11.0	.82	5618.3
30	.01	.09	.89	382.0	11.0	.55	4475.2
31	0.00	.03	.97	382.0	11.0	.46	-26570.8
32	.02	.11	.87	381.3	11.0	.42	4409.5
33	0.00	.04	.96	381.3	11.0	.12	-26609.4
34	.71	.11	.18	333.0	11.0	.01	1217.2
35	0.00	.11	.89	333.0	11.0	.41	-34816.7
36	0.00	.07	.93	361.7	11.0	1.00	-30175.2
37	.01	.07	.93	777.1	11.0	.18	30949.0
38	.01	.07	.93	777.1	11.0	.82	30949.0
39	.01	.07	.93	400.8	11.0	1.01	5618.3
40	.80	.18	.02	396.2	11.0	.57	3204.0
41	.01	.07	.93	400.8	11.0	.18	5618.3
42	0.00	0.00	0.00	400.8	0.0	0.00	0.0
43	0.00	0.00	0.00	400.8	0.0	0.00	0.0
44	0.00	0.00	0.00	0.0	0.0	0.00	0.0
45	0.00	0.00	0.00	0.0	0.0	0.00	0.0

HEAT EXCHANGERS LOAD (KW)?   RECUP= 20882.928   VAP= 17090.240
BFW= 3554.315   TRIM= 16217.551   HE2= 4685.616

ENERGY PRODUCED AT NIGHT? QAAN= .7828E+05   GTW= .3492E+04(KW)

RECEIVER LOAD TQA= 446.3(MW-THRM)

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