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SALINE: A FORTRAN COMPUTER PROGRAM FOR THE PROCESS DESIGN OF SALINE WATER CONVERSION PLANTS USING THE MULTI-STAGE, FLASH-EVAPORATION PROCESS

W.L. Griffith and R.M. Keller

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This report was prepared by

W. L. Griffith
and
R. M. Keller

The Oak Ridge Y-12 Plant

for the ORNL Nuclear Desalination Program.

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AUTHOR'S NOTE

It should be emphasized that this report describes an early version of what the Catalytic Construction Company considers at this time to be their current program. A program of this complexity is almost continually in a state of revision. Changes have been made to refine the computational procedures and to eliminate features of the code which the reader may consider unnecessarily restrictive. These modifications include:

a. The sea-water temperature, sea-water solids concentration, and performance ratio may be supplied as input data.

b. The number of heat rejection stages is automatically varied during optimization.

c. The power requirements for miscellaneous pumps are calculated, and the specification of hydraulic losses as input data has been expanded.

d. An option to adjust the stage length rather than brine velocity has been provided.

e. The economic routines have been expanded for improved pricing of stage configurations and utility costs.

f. Some of the equations used to calculate physical properties have been improved.

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ABSTRACT

This report describes a FORTRAN IV computer program developed by the Catalytic Construction Company and modified by the authors. This program performs heat balance, material balance, and cost calculations on saline water conversion plants using the multi-stage, flash-evaporation process. The code is a modified revision of a program written by the Bechtel Corporation for OSW.[1]

Under the simplifying assumptions inherent in the mathematical model, a complete heat and material balance is calculated by a stage-to-stage numerical technique from the design parameters supplied. Costs are calculated from these results and the economic data supplied. Optimum design parameters which minimize total cost over a 30-year period can be determined either by a series of computer runs or by an optimization procedure supplied.

Details of the numerical procedure, program options, and usage are presented. Results obtained with an IBM 7090 from typical design data and a complete listing of the FORTRAN program are included.

SALINE: A FORTRAN COMPUTER PROGRAM FOR THE PROCESS DESIGN OF SALINE WATER CONVERSION PLANTS USING THE MULTI-STAGE, FLASH-EVAPORATION PROCESS

1. IDENTIFICATION

SALINE: Water Conversion Plant Design

Machine: IBM - 7090

Language: FORTRAN IV

Catalytic Construction Company
Philadelphia, Pennsylvania

June 1, 1965

2. PURPOSE

SALINE is a computer program to calculate design parameters and costs associated with evaporators utilizing the multi-stage, flash-evaporation process for saline water conversion.

3. RESTRICTIONS

3.1 Hardware

SALINE is written for an IBM 7090 with the following hardware:

a. On-line tape units: Standard IBSYS monitor input and output tapes.
b. On-line printer.
c. Off-line card-to-tape.
d. Off-line tape-to-card.
e. Off-line tape-to-printer.

3.2 System

The program is written entirely in FORTRAN IV language. There are no programmed pauses or stops. All input is by magnetic tape, and all output is by magnetic tape and the on-line printer.

Since the source language is FORTRAN IV, it would be possible to compile and execute this code on a wider class of machines. However, unless otherwise stated, use of the program with an IBM 7090 and the IBSYS monitor system is presumed.

3.3 Inherent Limitations

As a result of the numerical approach and the tailoring of the program to a particular set of engineering and cost assumptions, several restrictions are inherent in the present version of the program which cannot be changed without additional programming effort. These include:

1. Heat and material balance solutions are restricted to nearly equal heat-transfer surface areas in each of the heat recovery stages (within one per cent of the mean stage area).

2. The recycle flow in the heat recovery section is forced to equal the tube-side flow in the heat reject section on a heat capacity basis.

3. The salt concentration of the sea water is fixed at 3.5 per cent.

4. Subroutines are provided to calculate heat transfer coefficients, pumping head losses, unit cost of brine heater surface, and costs based on engineering and cost assumptions utilized for specific projects.

5. The maximum number of stages allowable is 100.

4. METHOD

4.1 Development of Program

In general, the computer program is a modification of a program developed by the Bechtel Corporation.[1] Modifications were developed by the Catalytic Construction Company and, to a lesser extent, by the authors.

Principal modifications by the Catalytic Construction Company were:[2]

1. The source language was translated from FORTRAN II to FORTRAN IV.

2. The concentration ratio was redefined as the ratio of the salt concentration in the effluent stream to the salt concentration in the inlet sea water. (Previously the recycle stream concentration instead of the effluent stream concentration was used.)

3. The method of calculating the overall heat transfer coefficients was changed. The inside film coefficient was based on an expression given by Perry.[3] The other resistances were based on an empirical fit to a curve supplied by the OSW. (See Fig. 3)

4. The cost calculation was augmented to include:

   a. Operating costs.
   b. Capital costs independent of stage configuration.
   c. Separate capital costs for the recycle pumps and "other" pumps.
   d. A specified fixed-charge rate on capital investment.
   e. An empirical allowance for indirect charges and construction-money interest was added to the direct capital investment.
   f. A routine to calculate the unit cost of brine heater surface was included.
   g. An 80 per cent load factor was applied to the operating costs.

5. The pump-head calculations were modified to consider changes in density with salt concentration, entrance and exit losses through the tube bundles, and other static and friction losses.

6. Provision was made for the use of "steel" evaporator stages above 16.0 psia instead of 26.5 psia.

Further modifications were made by the authors to make the program less restrictive and correct a number of minor errors. The modifications included:

1. Allowance for a variable number of heat-reject stages.

2. Improvements to the optimization routine.

3. Correction of minor errors in the heat and material balance calculations.

4. Miscellaneous changes to facilitate sense-switch options and tape assignments when operating under the IBM IBJOB processor for a 7090.

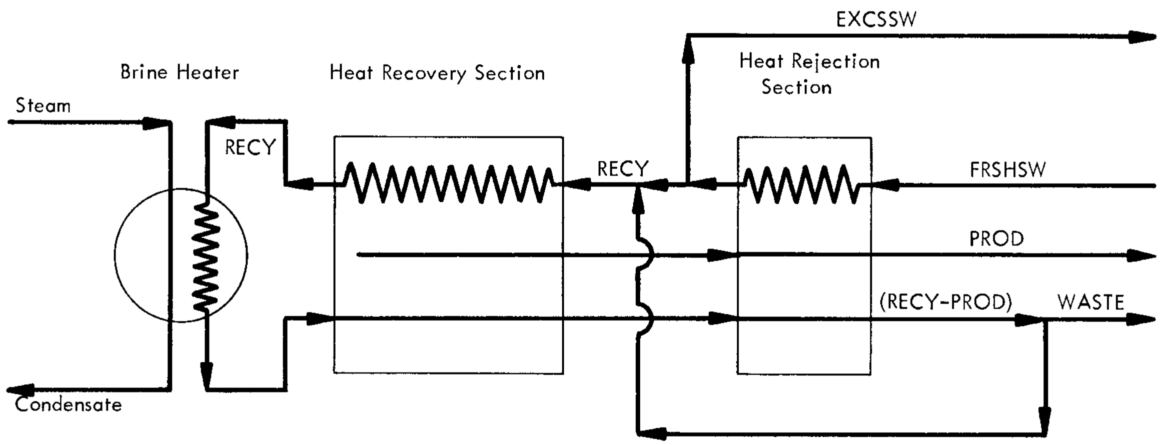
5. Allowance for a condenser-tube length in the heat-rejection section different from the tube length in the heat-recovery section.

6. Provision for a variable load factor to be applied to the operating costs.

4.2 Description of Program

The problem is basically the calculation of a heat and material balance in the evaporator by a stage-to-stage numerical technique from the design parameters given. Costs are then calculated from these results and the economic parameters supplied.

The process arrangement inherent in the mathematical model utilized is shown in Fig. 1. The heat and material balance solutions are specific for multi-stage, flash evaporators of a modular design and feature equal heat-transfer areas for the heat-recovery stages.



PROD	Product
WASTE	Discarded brine
FRSHSW	Fresh sea water for cooling and makeup (3.5% salt)
EXCSSW	Excess sea water discarded
RECY	Recycle brine flowing through heat recovery section inside tubes to brine heater
CONRAT	Concentration ratio, salt in WASTE/salt in sea
Q	Ratio of FRSHSW/RECY
RECRAT	Recycle ratio, lb recycle/lb product, RECY/PROD

Fig. 1. Water Plant Flow Diagram.

The independent variables and cost parameters utilized are presented in Table 1. Two important independent variables, the terminal temperature difference in the first stage, TTD_1, and the total number of stages, NSTG, are varied automatically by the program. Restraints are supplied to restrict the domain of these variables. The other independent variables and cost parameters are supplied as input data.

Based on these independent variables, the design and cost parameters shown in Table 2 are calculated.

Table 1 - Summary of Independent Variables and Cost Parameters

Variable	Units
Variables Automatically Varied By the Program	
Total number of stages in plant	
Terminal temperature difference in the first stage	F
Fixed Parameters Supplied as Input Data	
Fresh water production rate of plant	gal/day
Number of heat rejection stages	
Temperature of brine leaving brine heater	F
Sea water temperature	F
Concentration ratio	
Pressure of saturated steam supplied to brine heater	psia
Outside diameter of condenser tubes	in
Wall thickness of condenser tubes	in
Condenser tube length in a heat recovery stage	ft
Condenser tube length in a heat rejection stage	ft
Outside diameter of brine heater tubes	in
Wall thickness of brine heater tubes	in
Velocity of recycle brine in brine heater	ft/sec
Pressure drop in brine heater header	ft of brine
Unit cost of steam	dollars/million Btu
Unit cost of electric power	dollars/kwh
Unit cost of condenser area	dollars/ft^2
Maximum brine heater load	millions of Btu/unit hr
Unit cost of concrete evaporators	dollars/stage
Unit cost of steel evaporators	dollars/stage
Unit cost of recycle pump	dollars/hp
Unit cost of other pumps	dollars/hp
Fixed capital investment	millions of dollars
Annual rate of return on capital	per cent
Other operating costs	millions of dollars/year
Operating load factor	fraction

Table 2 - Process Variables and Costs Calculated

Variable	Units
Recycle ratio[a]	
Brine flow leaving each stage	thousands of lb/hr
Production rate for each stage	thousands of lb/hr
Cumulative production rates	thousands of lb/hr
Salt concentration in brine leaving each stage	per cent
Absolute pressure in each stage	psia
Vapor flow rate in each stage	ft^3/sec
Boiling point elevation of brine leaving each stage	F
Temperature of flashing brine leaving each stage	F
Temperature of distillate leaving each stage	F
Temperature of recycle brine leaving each stage	F
Terminal temperature difference for each stage	F
Log-mean driving force in each stage	F
Rate of heat transfer in each stage	thousands of Btu/hr stage
Overall heat transfer coefficient in each stage	Btu/hr F ft^2
Condenser area in each stage	ft^2
Total condenser area	ft^2
Brine heater area	ft^2
Number of condenser tubes per heat recovery stage	
Number of condenser tubes per heat rejection stage	
Number of tubes in the brine heater	
Weight of condenser tubes per heat recovery stage	lb
Weight of condenser tubes per heat rejection stage	lb
Weight of tubes in the brine heater	lb
Velocity of recycle brine in the heat recovery section[a]	ft/sec
Velocity of sea water in the heat rejection section[a]	ft/sec
Pumping head loss in heat recovery section	psi
Pumping head loss in heat rejection section	psi
Pumping head loss in the brine heater	psi
Total pumping head loss	psi
Direct structure cost	millions of dollars
Direct cost of condenser surface	millions of dollars
Total pumping power	thousands of hp
Direct cost of pumps	millions of dollars
Direct brine heater cost	millions of dollars
Total capital cost including indirect	millions of dollars
Total steam cost for 30 years	millions of dollars
Total electric power cost for 30 years	millions of dollars
Total capital cost for 30 years	millions of dollars
Grand total cost for 30 years	millions of dollars
Unit cost of fresh water[b]	dollars/thousand gallons

[a]An initial estimate must be supplied as input to start the trial-and-error calculation.

[b]Calculated only for the optimum case.

Two principal modes of procedure are available with the program. These modes determine the procedure used by the computer to automatically vary NSTG and TTD_1 as summarized below.

1. Matrix mode - An array of solutions is calculated by varying NSTG and TTD_1 by prescribed, constant increments over the specified domain. The sequence of solutions start with the minimum values of NSTG and TTD_1 specified. (The initial starting values for NSTG and TTD_1 needed with the optimization mode are not used.)

2. Optimization mode - Given a starting point for NSTG and TTD_1, minimum and maximum values for NSTG and TTD_1, and initial values for incrementing these variables, a sequence of solutions is calculated by utilizing a routine which varies NSTG or TTD_1 by a method of steepest descent until a minimum total cost for a thirty-year period is reached.

The different approaches offered by these modes can be better understood by considering the following simple design situation.

A preliminary design for a desalination plant of a given capacity using the multi-stage, flash-evaporation process is to be prepared. Optimum values for NSTG and TTD_1 are to be determined based on the following design parameters:

Specifications for NSTG		
Starting point		30
Minimum value		20
Maximum value		40
Initial step size		10
Specifications for TTD_1		
Starting point	(F)	10
Minimum value	(F)	5
Maximum value	(F)	15
Initial step size	(F)	5
Number of heat-reject stages		5
Sea-water temperature (F)		75
Concentration ratio		1.7

In addition, specific values for all of the other design variables and cost parameters listed in Table 1 are chosen. Also, it is necessary to supply an initial guess for some of the dependent variables as shown in Table 2 to start the iterative procedure.

If the matrix mode is chosen, nine solutions are calculated for the following combinations of NSTG and TTD_1, respectively: (20,5), (20,10), (20,15), (30,5), (30,10), (30,15), (40,5), (40,10), and (40,15). Should it be desirable to consider a variation say in the number of heat rejection stages, the above calculation would be repeated for the values desired. The same would be true if a variation in any of the other design parameters is to be considered. The optimum point may be pinpointed by interpolation or by additional computer solutions in a neighborhood of the optimum point of the matrix calculated.

Alternatively, if the optimization mode is chosen, the calculation would begin at the starting values for NSTG and TTD_1 specified. The initial step sizes specified would be used to vary these variables for the first several solutions in the sequence; however, as the optimum is approached the step size is reduced. The procedure is continued for an indefinite number of solutions until a point sufficiently close to a minimum is reached. As with the matrix mode, if a variation in other design parameters is to be considered, the calculation would be repeated for the values desired.

In summary, the matrix mode obtains information at points evenly spaced over the domain of NSTG and TTD_1, whereas, the optimization mode obtains information concentrated in a neighborhood of the optimum point. Also, the optimization mode will probably find the optimum point in less time than the matrix mode although little will be known about plant characteristics far removed from the optimum.

4.3 Numerical Procedure

4.3.1 Heat and Material Balance Calculations

4.3.1.1 Subroutine CALHMB - The computational flow and approach are essentially the same as used by Bechtel[1]. An asterisk is inserted in the margin to denote an equation which differs from the one used by the Bechtel code.

1. Initialize

   a. Production (P_i) in each stage is initialized to the average.

   b. A linear temperature profile for the temperature of the distillate ($TDIST_i$) is set up between the following approximations for the first and last stages.

$$TDIST_1 = TFBO - BPE_{TFBO,CRECY} - \frac{TFBO - 100}{NSTG}$$

$$TDIST_{NSTG} = TSEA + TFBO - TDIST_1$$

c. QFIX = 0

2. Loop I (Determine P_i to within 0.1 per cent of P_1)

a. Calculate for stage 1

1) Average heat capacity

$$CPBAR = (CP_{TFBO, CRECY} + CP_{TDIST_1, C_1})/2$$

2) Temperature drop of flashing brine

$$DTFB_1 = P_1 \left(\frac{\lambda\, TDIST}{CPBAR} - BPE_1 \right)/RECY$$

3) Temperature of flashing brine, TFB_i

4) Flow rate of flashing brine (leaving), FB_i

5) Concentration of flashing brine, C_i

6) Boiling point elevation including a constant of 0.7F for approach to equilibrium, BPE_i

7) Temperature rise across brine heater

$$DTHEAT = TTD_1 + BPE_1 + DTFB_1$$

8) Heat transferred in brine heater

$$QHEAT = (DTHEAT)(RECY)(CP_{TFBO, CRECY})$$

b. Calculate the production in the heat rejection sections; if this is the first time through or if this is the first time after returning from loop 3; otherwise, proceed from 2.c.

* 1) Fresh sea water

$$FRSHSW = (RECY)(CPTSEA, CRECY)/CP_{TSEA, 3.5}$$

* 2) Waste, discarded concentrated brine

$$WASTE = \frac{PROD}{CONTRAT - 1.0}$$

* 3) Excess sea water, discarded

$$EXCSSW = FRSHSW - WASTE - PROD$$

* 2. b. 4) Heat leaving in product stream; quantity above reference temperature TSEA

$$QPROD = (PROD)(CP_{mean,\ 0.0})(TDIST_{NSTG} - TSEA)$$

* 5) Heat leaving in concentrated waste

$$QWASTE = (WASTE)(CP_{mean,\ CO})(TDIST_{NSTG} + BPE_{NSTG} - TSEA)$$

* 6) Quantity of heat (above reference temperature TSEA) leaving in discarded sea water

$$QEXCSS = QHEAT - QPROD - QWASTE$$

* 7) The amount of heat that must be transferred to the sea water in each stage must include both the heat that will leave in the excess stream and the heat that will be recycled in the makeup stream.

$$QPERST = \frac{(QEXCSS)(FRSHSW)}{(M)(EXCSSW)} + QFIX$$

8) Calculate for all heat rejection stages starting with the last.

a) Calculate the product made in the stage. The term containing $DIST_i$ accounts for reflashing of the distillate. The 1.8 is an approximate value for (CP)(BPE), a small factor introduced by the boiling point elevation.

$$P_i = \frac{QPERST - (DIST_i)(CP_{TDIST_i,\ 0.0})(TDIST_{i-1} - TDIST_i)}{\lambda\ DIST_i - 1.8}$$

b) The distillate in the previous stage

$$DIST_{i-1} = DIST_i - P_i$$

c. Adjust production in heat recovery stages

1) If Loop 2 has not been previously reached,

$$P_i' = P_i + \frac{PROD - PREJ}{NSTG - M}$$

and proceed from 2.d.

2) If Loop 2 has been previously reached,

$$P_i' = P_i + \frac{PREJ - PREK}{NSTG - M + 1}$$

d. Test to see if P_1 is within 0.1 per cent of P_i'.

1) If not, return to 2.a.

2) If so, proceed from 3.a.

3. Loop 2 (5 times or less if areas within 1 per cent of mean area).

a. Calculate for stage 1

1) Flow rate of distillate leaving

$$DIST_1 = P_1$$

2) Temperature of distillate

$$TDIST_1 = TFB_1 - BPE_1$$

3) Temperature of recycle brine leaving

$$TRB_1 = TDIST_1 - TTD_1$$

4) Heat transferred. There is no reflashing in stage 1.

$$Q_1 = P_1 \; \lambda_{TDIST}$$

5) Vapor pressure of steam

6) Temperature rise of recycle brine

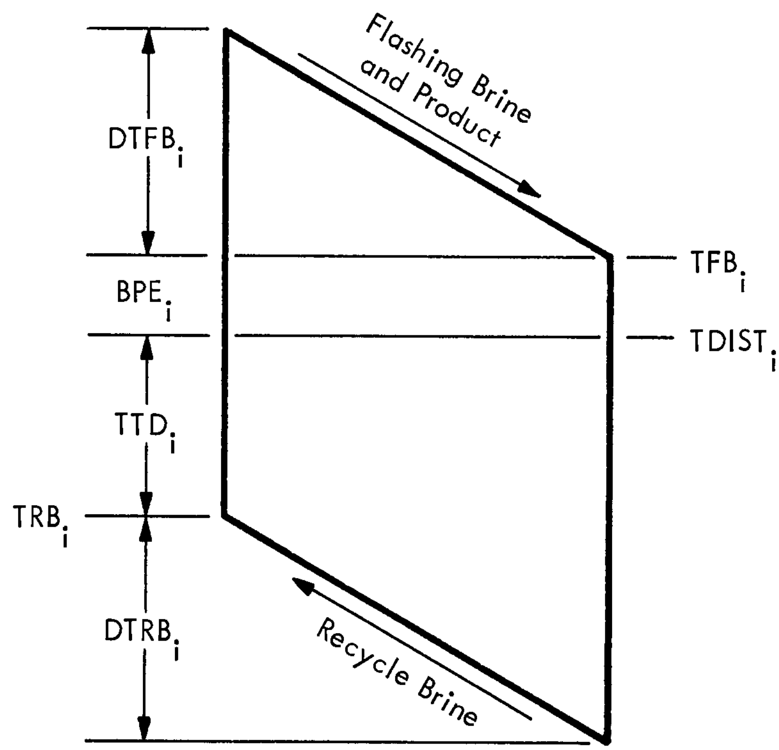
$$DTRB_1 = \frac{Q_1}{RECY \; CP_{TRB_1, CRECY}}$$

7) Area

$$A_1 = \frac{Q_1}{(U_1)\,(ALMTD_1)}$$

3. b. Calculate for rest of stages in heat recovery section.

Steps 1) through 13) give the general method used for stage-to-stage heat and material balance calculations in both the heat recovery and heat rejection sections. Fig. 2 presents the temperature relationships in a typical stage.



TFB_i - Temperature of flashing brine leaving stage i
$TDIST_i$ - Temperature of the distillate leaving the stage
TRB_i - Temperature of recycle brine leaving the stage
$DTFB_i$ - Temperature drop of flashing brine
BPE_i - Boiling point elevation and losses (loss = 0.7° F)
TTD_i - Terminal temperature difference of stage
$DTRB_i$ - Temperature rise of recycle brine (Δt_{rb})

Fig. 2. Temperatures in a Stage.

3. b. 1) Flow rate of flashing brine leaving.

$$FB_i = FB_{i-1} - P_i$$

2) Concentration leaving

$$C_i = \frac{SALT}{FB_i}$$

3) Flow rate of distillate

$$DIST_i = DIST_{i-1} + P_i$$

4) Average heat capacity

$$CPBAR = (CP_{TFB_{i-1}, C_{i-1}} + CP_{TDIST_i, C_i}) / 2$$

5) Temperature drop of flashing brine

$$DTFB_i = \frac{P_i \left(\frac{\lambda_{TDIST_i}}{CPBAR} - BPE_i \right)}{FB_{i-1}}$$

6) Temperature of flashing brine

$$TFB_i = TFB_{i-1} - DTFB_i$$

7) Boiling point elevation

8) Temperature of distillate

$$TDIST_i = TFB_i - BPE_i$$

9) Temperature of recycle brine leaving

$$TRB_i = TRB_{i-1} - DTRB_{i-1}$$

10) Terminal temperature difference

$$TTD_i = TDIST_i - TRB_i$$

3. b. 11) Heat exchanged

$$Q_i = P_i \ \lambda_{TDIST_i} + DIST_{i-1} \ CP_{TDIST_{i-1,0}} (TDIST_{i-1} - TDIST_i)$$

The second term accounts for the reflashing and cooling of the distillate.

12) Temperature rise of recycle brine

$$DTRB_i = \frac{Q_i}{RECY \ CP_{TRB_{i,CRECY}}}$$

13) Area

$$A_i = \frac{Q_i}{(U_i)(ALMTD_i)}$$

c. Calculate the number of tubes and the velocity in the heat recovery section. For details see Section 4.3.1.3.

d. Test to see if all areas are within 1 per cent of the average area.

1) If so, proceed from 4.a.

2) If not, proceed from 3.e.

e. Adjust production in heat recovery stage

$$P_i' = \frac{P_i}{2} \left[\frac{AVEA}{A_i} + 1 \right]$$

f. Test to determine if total adjusted production is within 0.01 per cent of total plant production minus production from heat rejection section.

1) If so, return to 2.a.

2) If not, proceed from 3.h.

g. Adjust production in each heat recovery stage

$$P_i'' = P_i' \left(\frac{PREC}{\Sigma P_i} \right)$$

3. h. Test number of times 3.g. has been performed.

   1) If less than five, return to 2.a.

   2) If five, proceed from 4.a.

4. Loop 3 (velocity in heat rejection stages agrees within 0.1 per cent)

   a. Calculate flow rate of streams (see Fig. 1).

      1) Fresh sea water, FRSHSW

      2) Waste, discarded concentrated brine, WASTE

      3) Excess sea water, discarded, EXCSSW

   b. Calculate for the heat rejection stages

      1) through 13)

      Same as 3.b.1) through 13).

   c. Calculate number of tubes and velocity in heat rejection section. For details see Section 4.3.1.3 .

   e. Test if velocity is within 0.1 per cent of previous velocity.

      1) If not, return to 2.a.

      2) If so, proceed from 5.a.

5. Loop 4 (match sea temperature within 0.01 degree).

   a. Test if calculated temperature of the sea agrees to within 0.01 F with the input value.

      1) If so, proceed from 6.a.

      2) If not, proceed from 5.b.

   b. Adjust recycle stream

$$RECY' = \frac{RECY}{2}\left[\frac{TRB_1 - TSEA_0}{TRB_1 - TSEA} + 1\right]$$

5. c. Calculate new recycle ratio

$$RECRAT = \frac{RECY'}{PROD}$$

d. Return to 2.a.

6. Loop 5 (match the temperature of flashing brine leaving the heat-rejection section to the temperature of recycle brine entering the heat-recovery section).

* a. Calculate the middle stage of the reject section

MID = NSTG - (M-1)/2

* b. Calculate heat adjustment for each reject section stage

$$QFIX = \frac{FRSHSW \; CP_{TRB_{MID,3.5}} \; (TFB_{NSTG} - TRB_{NSTG+1-M})}{M}$$

* c. Determine if either TFB_{NSTG} matches $TRB_{NSTG+1-M}$ to within 0.01 F or if the correction has been attempted 3 times before

1) If either are true, proceed from 7.a.

2) If neither are true, return to 2.a.

7. Brine Heater Design Calculations

a. Calculate heater area

$$AHEAT = \frac{QHEAT}{(UHEAT)\,(ALMDTH)}$$

b. Calculate steam required

$$STEAM = \frac{QHEAT}{\lambda_{TSTM}}$$

c. Calculate number of tubes required in heater

$$TUBESH = \frac{RECY}{(XAH)\,(VHEAT)\,(3600\ sec/hr)\,(62.4\ lb/ft.^3)}$$

7. d. Calculate tube length, TUBELH

8. Calculate pressure and vapor flow rate in each stage, $PSIA_i$ and CFS_i, respectively.

9. Calculate weight of tubes in heat recovery section, heat rejection section, and brine heater; WGT, WGTR, and WGTH, respectively.

10. Calculate pressure drops. For details, see Section 4.3.2 .

4.3.1.2 Subroutine OVRALU - Outlined below is the method used to calculate the overall heat transfer coefficient. In general, they are different from those used by Bechtel. Noteworthy, is the use of a polynomial fit to data submitted by OSW, based on the Point Loma Demonstration Plant, to calculate the sum total of the following heat transfer resistances as a function of temperature:[a]

1. Steam-side condensing
2. Steam-side fouling
3. Tube wall
4. Brine-side fouling

Fig. 3 shows these combined heat transfer resistances as a function of temperature.

$$Y_1 = \frac{(V\ ID)^{0.2}}{(160. + 1.92\ TRB)\ (V)},$$ see equation 28 in Reference 3.

$$X_3 = 0.1024768 \times 10^{-2} - 0.7473939 \times 10^{-5} TDIST + 0.999077 \times 10^{-7}\ TDIST^2 - 0.430046 \times 10^{-9}\ TDIST^3 + 0.6206744 \times 10^{-12}\ TDIST^4$$

$$U = \frac{1}{(Y_1 + X_3)}$$

where:

V = velocity of brine, ft/sec.
X_3 = empirical fit to other heat-transfer resistance, hr F ft^2 Btu^{-1}.

[a] See Reference (2) p 7.

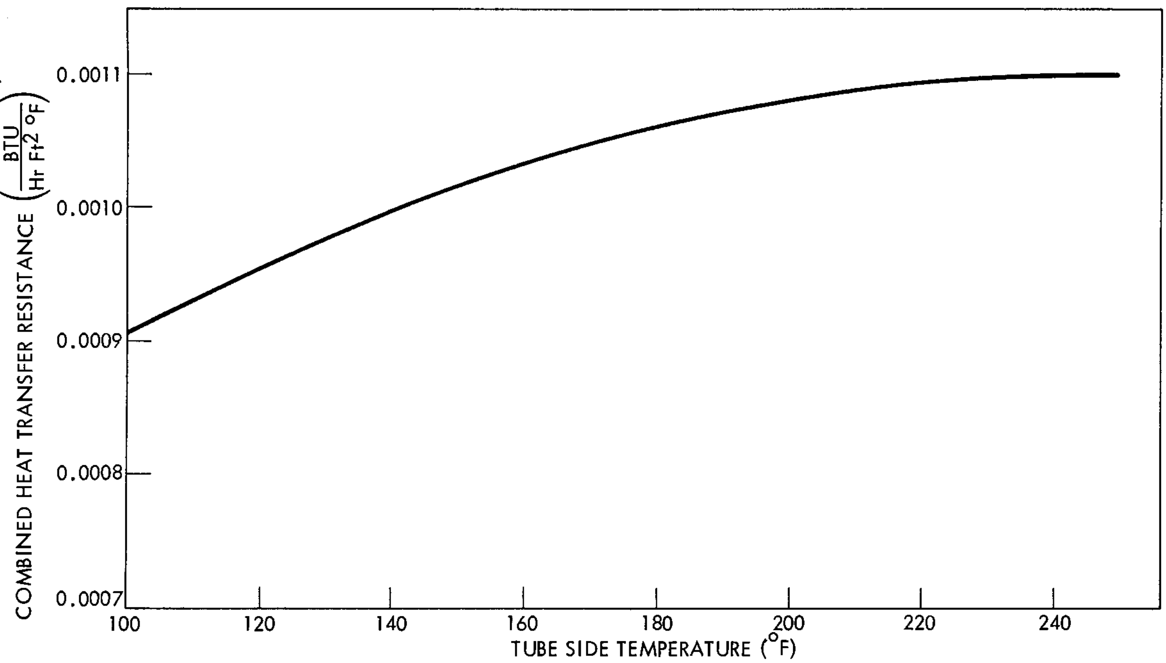


Fig. 3. Combined Heat Transfer Resistance Used in Water.

4.3.1.3 Subroutine AREADJ - This routine calculates the number of condenser tubes and the associated brine velocities.

Heat Recovery Section

The following input is used by this routine:

1. Tube length, heat recovery section, TUBEL
2. Outside diameter of tubes, OD
3. Wall thickness of tubes, THICK
4. Average area in a heat recovery stage, AVEA

The following are calculated for use as described in paragraph 3.c. in Section 4.3.1.1.

1. Number of tubes, TUBES
2. Velocity of recycle brine, VILRB

Heat Rejection Section

The following input is used:

1. Tube length, heat rejection section, TUBELR
2. Outside diameter of tubes, OD
3. Wall thickness of tubes, THICK
4. Average area in a heat rejection stage, AVEA

The following calculations are made for use as described in paragraph 4.c. in Section 4.3.1.1.

1. Number of tubes, TUBESR
2. Velocity of sea water in tubes, VHREJ

If the velocity exceeds 7.0 ft/sec, it is set to 7.0 ft/sec and the tube length and number of tubes are recalculated for the same area.

4.3.2 Pressure Drop Calculations (Subroutine HDLOSS)

Outlined below are the equations used to calculate head losses. Equations which are different from those used by Bechtel[1] are noted by an asterisk in the left margin. The reader should keep in mind that these equations to calculate head losses were tailored to a specific application, and modifications may be necessary to meet the user's requirements.

$$A_1 = \frac{1}{d_1^{\;1.206}} \qquad \text{heat recovery}$$

$$A_2 = \frac{1}{d_2^{1.206}}$$ heat rejection

$$S_1 = \sum_{i = NSTG - M + 1}^{NSTG} (T_i)^{-0.252}$$

$$S_2 = \sum_{i=1}^{M} (T_i)^{-0.252}$$

* $$H_1 = 0.00041622(I_1)(A_1)(S_1)(V_1^{1.794}) + \frac{V_1^2 \rho_{RB}^{(NSTG-M)}}{49.6} + 17.3$$

* $$H_2 = 0.00041622(I_2)(A_2)(S_2)(V_2^{1.794}) + \frac{V_2^2 \rho_{SEA}^{M}}{49.6} + 14.6$$

$$A_3 = \frac{1}{d_3^{1.206}}$$

$$H_5 = \frac{0.00041622(I_3)(A_3)(V_3^{1.794})}{TFBO^{0.252}} + \left(HDREQL + \frac{V_3^2}{21.448}\right)\left(\frac{\rho_{RB}}{2.31}\right)$$

$$H_t = P_1 - P_n + H_5 + H_1$$

4.3.3 Economic Considerations (Subroutine COST)

Costs are calculated based on the following cost parameters, which are supplied at execution time as input.

Steam cost, ACOST
Power cost, BCOST
Condenser surface cost, CCOST
Structure cost for concrete stages, ECOST
Structure cost for steel stages, G
Recycle pump cost, FCOST
Other pump cost, FCOSTM
Fixed capital investment, Z
Other operating costs, ZX
Rate of return, QOOOFL
Load factor, FLOAD

The relations used to calculate the costs involved for the i^{th} design case:

1. Calculate structure cost

$$STRCST = ECOST\,(NSTG_i - NPRES_i) + G \cdot NPRES_i$$

2. Calculate condenser surface cost

$$CONDAC = CCOST \cdot AC_i$$

3. Calculate pumping power and pump cost

   a. Recycle pump power

$$REC_{HP} = \frac{DPR_i \cdot R_i}{728,434.7 \cdot SPGRV\,(CONC)} \quad \text{where}$$

$$CONC = \left(\frac{1 - PROD}{R_i}\right) CONRAT$$

   b. Other pump power

$$CONPHP = (89.2 \times 10^{-6})\,PROD + \frac{PROD \quad \dfrac{CONRAT}{CONRAT - 1}}{728,434.7 \cdot SPGRV\,(1.0)}$$

3. c. Total pump power

$$PUMPHP = CONPHP + REC_{HP}$$

d. Pump cost

$$PMPCST = PUMPHP \cdot FCOST + REC_{HP} \cdot FCOSTM$$

4. Calculate brine heater cost

a. The iterative subroutine, HTCOST is used to calculate the unit cost of brine heater surface, HAREAC, as a function of

Maximum brine heat load, DCOST (millions of Btu/hr unit)
Steam rate to brine heater, STM_i (lb/hr)
Steam temperature to brine heater, TSTM (F)
Area brine heater, AH_i (ft^2)

$$HTCOST = 131.2 - \frac{Q}{18.0}(25.8 + Q)$$

where

$$Q = \frac{AH_i}{10^5 - AN}, \text{ and}$$

AN is the smallest integer greater than 0 such that

$$\frac{STM_i \cdot AMDA(TSTM)}{10^6\ AN} \leq DCOST$$

b. The brine heat cost is calculated from HTCOST by

$$HAREAC = (HTCOST)(AN_i)$$

5. Calculate total capital cost

The first term adds the additional indirect capital cost to the computed capital cost. The relative amount of indirect capital decreases with increasing direct capital. The last term allows for differences in the cost of capital during plant construction under the assumption that plants with larger capacity require longer construction periods.

$$TOTCAP = T'\,(1.364 - (1.4 \times 10^{-9})\left[1 + \frac{(75 + GPD) \cdot .0175}{90}\right]$$

where: $T' = STRCST + CONDAC + PMPCST + HAREAC + 10^6 Z$, and

$GPD = PROD \cdot 2.88 \times 10^{-6}$

6. Calculate steam cost for 30 years

$$STMCST = ACOST \cdot STM_i \cdot AMDA\ (TSTM) \cdot 210.24 \times 10^{-3} \cdot (FLOAD/0.8)$$

7. Calculate power cost for 30 years

$$POWCST = 156,815.97\ PUMPHP \cdot BCOST \cdot (FLOAD/0.8)$$

8. Calculate the allowance for return on investment for 30 years

$$CAP30Y = 30 \cdot TOTCAP \cdot QOOOFL/100$$

9. Calculate total cost for 30 years

$$TOTAL = STMCST + POWCST + CAP30Y + ZX \cdot 30 \cdot 10^6$$

4.3.4 Program Control and Parameter Adjustment

4.3.4.1 - Main Program SALINE - Initial entry is made to this routine which controls the overall logical flow of the program. This must be assigned by the sequence of the program deck or by an appropriate $ENTRY card which is recognized by the IBJOB processor.

In general, this routine consists of series of calling sequences to the various subprograms where the calculations are performed. The order in which the subprograms are called is dependent upon the program options selected. These options are discussed in more detail in Section 5. Details of the overall program flow are outlined below.

1. Read the card that contains the sense switch settings. (Unless the FORTRAN version of SSWTCH, is removed from the program deck).

2. Call subroutine INPUT which reads in cards 1, 2, 3, and 4. Execution is terminated in INPUT if there are no more data. (i.e., end of file encountered on input tape.)

3. Initialize the following variables:

   a. II = 0
   b. NTEST = 0
   c. NPLANT = 0
   d. NCASE = 1

4. Call subroutine ADJUST which is described in paragraph 4.3.4.2. Subroutine ADJUST reads card number 5 the first time and sets the following parameters: number of stages and terminal temperature difference. The parameter adjustment routine, ADJUST, calls the optimization routine, GENOPT, if this program option is selected, to determine the variable to be varied and the appropriate step size.

5. Check to see if an optimum solution was found by ADJUST.

   a. If optimum found, proceed from 13.
   b. If optimum not found or if this is a matrix run, proceed from 6.

6. Call subroutine CALHMB to calculate a complete heat and material balance.

7. Call subroutine INTOUT which stores economic information and increases counter NCASE by one. If the number of cases stored equals 100 (the maximum number dimensioned in the storage arrays), the cost summary of these 100 cases is outputed. The identification variable, NPLANT, is incremented by 1 and the case number, NCASE, is reset to 1 and the calculation is continued.

8. Check to see if optimization is desired.

   a. If not, proceed from 10.
   b. If so, proceed from 9.

9. Call subroutine COST which reads cards 6, 7, and 8 the first time and calculates the necessary costs. No output is written.

10. Is output for the heat and material balance desired?

    a. If not, proceed from 12.
    b. If desired, proceed from 11.

11. Call subroutine FINOUT to write out the results of the heat and material balance calculations.

12. Should the run be terminated?

    a. If not, return to 4.
    b. If so, proceed from 22. If the sense switches are used, this is caused by placing sense switch 6 down. If the program option card is used in place of the sense switches, this branch is never taken.

13. Should the results of the heat and material balance calculations be printed out out for the optimum case?

    a. If not, proceed from 22.
    b. If so, proceed from 14.

14. Call subroutine FINOUT to write out the heat and material balance variables for the optimum case.

15. Proceed from step 22.

16. Call subroutine COST to write out the cost of water for the optimum case from a matrix.

17. Call subroutine CALHMB to recalculate the heat and material balance for the optimum case from the matrix.

18. Call subroutine FINOUT to write out the results of the heat and material balance recalculations for the optimum case of the matrix.

19. Increase counter NCASE by one.

20. Is sense switch 4 down?

    a. If not, return to 2.
    b. If so, proceed from 21.

21. Set NPLANT = 0

22. Call subroutine COST to read cards 6, 7, and 8 if necessary. The costs are calculated and written on the output tape.

23. Is NPLANT zero?

    a. If so, return to 2.
    b. If not, proceed from 24

24. Is this an optimization?

    a. If so, return to 2.
    b. If not, proceed from 16.

4.3.4.2 Subroutine ADJUST - The purpose of this routine is to automatically vary the total number of stages in the plant, NSTG, and the terminal temperature difference in the first stage, TTD_1, over the domain desired. The two modes available to vary these parameters are:

1. Matrix mode - An array of solutions is calculated by varying NSTG and TTD_1 by prescribed, constant increments over the specified domain. The sequence of solutions start with the minimum values of NSTG and TTD_1 specified. (The initial starting values for NSTG and TTD_1 needed with the optimization mode are not used.)

2. Optimization mode - Given a starting point for NSTG and TTD_1, minimum and maximum values for NSTG and TTD_1, and initial values for incrementing these variables, a sequence of solutions is calculated by utilizing a routine which varies NSTG or TTD_1 by a method of steepest descent until a minimum total cost for a 30-year period is reached. With this mode, the variable to be adjusted and the size of the increment is calculated by the optimization routine (GENOPT) called from ADJUST. Because only integer values for NSTG are possible, additional solutions are calculated near the apparent optimum.

The mode desired is selected with Program Option B as described in Section 5.1.1.

4.3.4.3 Subroutine GENOPT - This routine utilizes a method of steepest descent to vary TTD_1 and NSTG until the values of these variables are reached which produce a minimum total cost in dollars for a 30-year period, TOTAL, within the domain specified in the input data. More precisely, this minimum cost is found by varying TTD_1 and NSTG until a maximum value of the function $f(TTD_1, NSTG)$ is found where:

$$f(TTD_1, NSTG) = 10^{10}/TOTAL.$$

The routine is written in a general manner and could be modified to handle more than two variables (i.e., maximize $f(X_1, X_2, \ldots, X_n)$ although the computing time to find an optimum would be increased.

The logic used in this routine and the computational approach utilized to calculate the maximum value of $f(X_1, X_2)$ are summarized in the flow diagram presented in Fig. 8 in Section 6.

4.3.5 Calculation of Physical Properties

Subroutines are provided in the program to calculate the physical properties of water, steam, and brine used in the heat balance, mass balance, and pressure drop calculations. Details of the basic relationships used are presented in the following sections:

4.3.5.1 Thermodynamic Properties of Water and Steam - Outlined below are the relationships used to calculate the thermodynamic properties of water and steam. Frequently, the calculation of a physical property involves the calculation of additional properties by the associated procedures. Likewise, from these basic relationships, additional properties such as heat of vaporization are calculated.

1. Pressure of Saturated Steam as a Function of Temperature (Subroutine PSTEAM)

Steltz and Silvestri[4] gave the following equation for temperatures from 50 to 200 F. Although they recommend a slightly different equation for temperatures above 200 F, the equation given was checked and found to be satisfactory up to 300 F.

$$\mathrm{Log}_{10}\left(\frac{P_c}{p}\right) = \frac{x}{T_k}\left(\frac{a + bx + cx^3}{1 + dx}\right)$$

where:

a	=	3.2437814
b	=	5.86826×10^{-3}
c	=	1.1702379×10^{-5}
d	=	2.1878462×10^{-3}
p	=	pressure, atm
T_k	=	temperature, K
P_c	=	critical pressure = 218.167 atm
T_c	=	critical temperature = 647.27 K
x	=	$T_c - T_k$

2. Temperature of Saturated Steam as a Function of Pressure (TSTEAM)

The iterative numerical procedure outlined below is used:

A. $F = \log_{10}\left(\frac{3206.1822}{P'}\right)$

where:

P' = saturation pressure, psia

B. $T' = 350.0$

C. $T = T'$

D. $X = 647.27 - T$

E. $$T' = \frac{647.27}{\left[\left(\frac{0.0021878462\,(F)\,(X) + F}{1.1702379 \times 10^{-8} X^3 + 0.00586826X + 3.2437814}\right) + 1.0\right]}$$

F. Check to see if T' matches T within 0.001 K

a. If so, proceed from G.
b. If not, return to C.

G. $T = 1.8T' - 459.688$, to convert temperature on the Kelvin scale to temperature on the Fahrenheit scale.

3. Enthalpy of Water at the Boiling Point as a Function of Temperature (HSATL)

The equation given is slightly different from the one developed by Steltz and Silvestri for the temperature range 50 to 360F. The fit was checked and found to be good through 300F.

$$H = -31.92 + 1.0011833T - 3.0833326 \times 10^{-5}T^2 + 4.666663 \times 10^{-8}T^3 + 3.333334 \times 10^{-10}T^4$$

where:

T = temperature, F

H = enthalpy of water, Btu/lb

4. Heat Capacity of Water as a Function of Temperature (CPB)

The heat capacity of water is calculated from the derivative of the above equation used to calculate the enthalpy at the boiling point by the following relation:

$$CPW = 1.011833 - 6.1666652 \times 10^{-5}T + 1.3999989 \times 10^{-7}T^2 + 1.3333336 \times 10^{-9}T^3$$

5. Enthalpy of Superheated Steam as a Function of Temperature and Pressure (HSUPST)

The following relationship is given by Schnackel[5].

$$h = F + 0.043557 \left[F_0 P + \frac{B_0}{2}\left(\frac{P'}{T}\right)^2 \left\{-B_6 + B_0 \left(B_2 - B_3 + 2B_7 \frac{B_0}{2}\left(\frac{P}{T}\right)^2\right)\right\}\right] .$$

where:

P' = pressure, int. atmos., abs.

T = temperature, K

B_0 = $1.89 - B_1$

B_1 = $\frac{2641.62}{T} \; 10^{(80870/T^2)}$

B_2 = 82.546

B_3 = $\frac{162460}{T}$

B_6 = $B_0B_3 - 2F_0\,(B_2 - B_3)$

B_7 = $2F_0(B_4 - B_5) - B_0B_5$

F_0 = $1.89 - B_1\left(\frac{372420}{T^2} + 2\right)$

F = $775.596 + 0.63296T + 0.000162467T^2 + 47.3635 \log_{10}T$

6. Cubic Feet per Second of Steam as a Function of Temperature, Pressure, and Flow Rate (CUFTSC)

The equation for the volumetric flow rate of steam is based on a perfect gas-law-type relationship.

$$CFS = (0.00016545478)\,(T)\,\left(\frac{W}{P}\right)$$

where:

T = temperature, R

W = flow rate, lbs/hr

P = pressure, psia

4.3.5.2 Brine Properties - Outlined below are the basic relationships used to calculate the physical properties of brine.

1. Heat Capacity of Brine as a Function of Temperature and Concentration (CPB)

The heat capacity of brine is obtained by applying a factor dependent upon the solids concentrations and temperature to the heat capacity of pure water at the desired temperature.

$$CPB = \left[1.0 - C\,(0.011311 - 0.00001146\ T) \right] CPW$$

where:

T	=	temperature, F
C	=	concentration, per cent solids
CPW	=	heat capacity of water at temperature T

2. Boiling Point Elevation as a Function of Temperature and Concentration (DELBP)

A constant 0.7 F is added to the boiling point elevation to allow for approach to equilibrium and losses in the demister. Table 3 presents values of the boiling point elevation calculated by this routine without the factor of 0.7 F. In general, the values calculated are lower than reported in some recent investigations.

$$\text{Log}_e\ (\gamma) = A + BT + DT^2$$

where:

$$A = -0.26095438 - .055744363C + .0035589404C^2$$

$$B = 1.2154745 \times 10^{-4} + 6.4301725 \times 10^{-5}C + 0.2009258 \times 10^{-6}C^2$$

$$D = 1.5076632 \times 10^{-6} - 3.9646057 \times 10^{-7}\ C - 9.3361829 \times 10^{-9}C^2$$

and:

$$BPE = \frac{6.81464 \times 10^{-4} C\ T_R^{\ 2}\left[1 + \dfrac{\log_e\ (\gamma)}{2}\right]}{\lambda} + 0.7$$

γ	=	activity coefficient of brine
T	=	temperature, F

Table 3. Boiling Point Elevation in Degrees Centigrade Calculated with Equations Provided

Temperature		Solids Concentration (weight per cent)										
(F)	(C)	2.0	3.5	4.0	6.0	8.0	10.0	12.0	16.0	20.0	25.0	28.0
77	25	0.172	0.292	0.331	0.490	0.659	0.847	1.065	1.636	2.455	3.954	5.171
86	30	0.178	0.303	0.344	0.510	0.686	0.883	1.112	1.714	2.578	4.165	5.452
104	40	0.192	0.326	0.371	0.550	0.741	0.956	1.209	1.873	2.833	4.598	6.032
122	50	0.206	0.350	0.398	0.590	0.797	1.031	1.307	2.036	3.095	5.046	6.635
140	60	0.220	0.375	0.426	0.632	0.854	1.107	1.406	2.202	3.363	5.508	7.257
158	70	0.235	0.400	0.454	0.674	0.912	1.184	1.507	2.371	3.635	5.981	7.896
176	80	0.250	0.425	0.483	0.717	0.971	1.262	1.608	2.540	3.911	6.464	8.551
194	90	0.266	0.451	0.512	0.760	1.029	1.339	1.709	2.709	4.189	6.952	9.216
212	100	0.281	0.478	0.542	0.804	1.088	1.415	1.809	2.877	4.465	7.444	9.890
230	110	0.298	0.505	0.572	0.847	1.146	1.491	1.907	3.042	4.740	7.937	10.569
248	120	0.315	0.532	0.603	0.890	1.203	1.565	2.002	3.203	5.010	8.427	11.247
266	130	0.332	0.559	0.634	0.933	1.258	1.636	2.094	3.359	5.272	8.911	11.923
284	140	0.349	0.587	0.664	0.975	1.312	1.704	2.181	3.506	5.525	9.384	12.590
302	150	0.367	0.615	0.695	1.017	1.364	1.769	2.262	3.644	5.765	9.844	13.243
320	160	0.385	0.642	0.725	1.057	1.413	1.828	2.337	3.771	5.990	10.284	13.878
356	180	0.422	0.698	0.786	1.132	1.501	1.930	2.460	3.980	6.377	11.088	15.066
392	200	0.460	0.753	0.845	1.200	1.570	2.001	2.538	4.112	6.655	11.749	16.099
428	220	0.500	0.807	0.901	1.255	1.614	2.030	2.554	4.138	6.781	12.207	16.907
464	240	0.542	0.860	0.954	1.295	1.625	2.003	2.489	4.023	6.703	12.338	17.402
500	260	0.587	0.910	1.002	1.314	1.591	1.901	2.313	3.716	6.345	12.188	17.468
536	280	0.635	0.959	1.044	1.304	1.495	1.696	1.985	3.143	5.601	11.460	16.934
572	300	0.691	1.005	1.078	1.255	1.313	1.344	1.439	2.191	4.302	9.973	15.543

BPE	=	boiling point elevation, F
C	=	total dissolved solids, per cent by weight
T_R	=	temperature, R
λ	=	heat of vaporization of pure water at same temperature, Btu/lb

3. Specific Gravity of Brine as a Function of Concentration (SPGRV)

The specific gravity of brine, calculated by the following equation, is used in the head loss calculations.

$$\rho = \frac{528.05 + 8.55S + S^2}{525.0}$$

where:

S = concentration of salt in the brine relative to sea water

4.4 Nomenclature Used in Description of Program

A	-	Area of stage (ft^2)
AC	-	Condenser area (ft^2)
ACOST	-	Steam unit cost ($\$/10^6$ Btu)
AH	-	Brine heater area (ft^2)
AHEAT	-	Area of brine heater (ft^2)
ALMTD	-	Log mean temperature difference (F)
AMDA	-	Latent heat of vaporization (Btu/lb)
AVEA	-	Average area per stage (H^2)
BCOST	-	Power unit cost ($/kwh)
BPE	-	Boiling point elevation (F)
C	-	Concentration of salt (per cent)
CAP30Y	-	Allowance for return on investment in 30 years ($)
CCOST	-	Condenser surface unit cost ($\$/ft^2$)
CO	-	Concentration of salt in discarded brine (per cent)
CONC	-	Ratio of concentration of solids in recycle stream to concentration in sea water
CONDAC	-	Total condenser surface cost ($)
CONPHP	-	Power requirements for other pumps (hp)
CONRAT	-	Concentration ratio
CP	-	Heat capacity (Btu/lb F)
CPBAR	-	Average heat capacity (Btu/lb F)
CRECY	-	Concentration of salt in recycle brine (per cent)

d_1	-	Inside diameter of heat recovery condenser tubes, (ft)
d_2	-	Inside diameter of heat rejection condenser tubes, (ft)
d_3	-	Inside diameter of brine heater tubes (ft)
DCOST	-	Maximum brine unit heat load (millions of Btu/hr unit)
DIST	-	Distillate flow rate (lb/hr)
DPR	-	Total pressure drop through recycle pump (psi)
DTFB	-	Temperature drop of flashing brine in each stage (F)
DTHEAT	-	Temperature rise of recycle brine through brine heater (F)
DTRB	-	Temperature rise of recycle brine in each stage (F)
ECOST	-	Unit structure cost for concrete stages ($/stage)
ERR	-	Tolerable error in optimization (see text)
EXCSSW	-	Discarded sea water flow rate (lb/hr)
$f(X_1, X_2)$	-	Function to be optimized
FB	-	Flashing brine flow rate (lb/hr)
FCOST	-	Recycle pump unit cost ($/hp)
FCOSTM	-	Other pump unit cost ($/hp)
FLOAD	-	Load factor (fraction of time operated)
FRSHSW	-	Fresh sea water input flow rate (lb/hr)
G	-	Structure unit cost for steel type stages ($/stage)
GPD	-	Product rate (millions of gallons per day)
H_1	-	Pressure drop through the heat recovery section (psi)
H_2	-	Pressure drop through the heat rejection section (psi)
H_5	-	Pressure drop through the brine heater (psi)
H_t	-	Head at pumps (psi)
HAREAC	-	Brine heater surface unit cost ($\$/ft^2$)
HDREQL	-	Pressure drop for header losses to and from brine heater, (ft of brine)
l_1	-	Length of tubes in a heat recovery stage (ft)
l_2	-	Length of tubes in a heat rejection stage (ft)
l_3	-	Length of brine heater tubes (ft)
ILAST	-	Last value of ITERAT
ISET	-	Flag
ITERAT	-	Number of iterations performed
LL_1	-	Lower limit on X_1
LL_2	-	Lower limit on X_2
M	-	Number of heat rejection stages
NPRES	-	Number of "steel" stages
NSTG	-	Total number of stages
P	-	Production of stage (lb/hr)
P_1	-	Absolute pressure in first stage (psia)
P_n	-	Absolute pressure in last stage (psia)
PMPCST	-	Total capital cost of pumps ($)
PREC	-	Total plant production minus heat rejection production (lb/hr)
PREJ	-	Former value of PREC (lb/hr)
PREK	-	New value of PREC (lb/hr)

PROD	-	Total production of plant (lb/hr)
PUMPHP	-	Total pump power requirements (hp)
Q	-	Heat transfer in stage (Btu/hr)
QEXCSS	-	Heat leaving in stream EXCSSW above temperature TSEA (Btu/hr)
QFIX	-	A heat correction to adjust temperatures (Btu/hr)
QHEAT	-	Heat transfer of brine heater (Btu/hr)
QOOOFL	-	Annual rate of return (per cent)
QPERST	-	Heat transferred in each heat rejection stage (Btu/hr)
QPROD	-	Heat leaving in product stream (Btu/hr)
QWASTE	-	Heat leaving in stream WASTE (Btu/hr)
R	-	Recycle rate through brine heater (lb/hr)
REC	-	Recycle pump power requirement (hp)
RECRAT	-	Recycle ratio (lb recycle/lb product)
RECY	-	Recycle flow rate (lb/hr)
SALT	-	Amount of salt in recycle brine stream (hundredths of a lb/hr)
SPGRV	-	Specific gravity of brine
STEAM	-	Steam rate to brine heater (lb/hr)
SUM	-	Sum of absolute values of slopes f_1 and f_2
STM	-	Steam rate to brine heater (lb/hr)
STRCST	-	Structure cost ($)
T_i	-	Temperature of flashing brine in the ith stage (F)
TDIST	-	Temperature of distillate in stage (F)
TFBO	-	Temperature of flashing brine from heater (F)
TFB	-	Temperature of flashing brine in stage (F)
TOTAL	-	Total cost for 30 years ($)
TOTCAP	-	Total capital cost ($)
TRB	-	Temperature of recycle brine in stage (F)
TSEA	-	Sea water temperature (F)
TSEAO	-	Calculated sea water temperature, $TRB_{NSTG} - DTRB_{NSTG}$ (F)
TSTM	-	Temperature of steam to the brine heater (F)
TTD	-	Terminal temperature difference of stage (F)
TUBESH	-	Total number of tubes in brine heater
U	-	Overall heat transfer coefficient in stage (Btu/hr-ft^2)
UL_1	-	Upper limit on X_1
UL_2	-	Upper limit on X_2
V_1	-	Velocity of recycle brine in heat recovery section (ft/sec)
V_2	-	Velocity of recycle brine in heat rejection section (ft/sec)
V_3	-	Velocity of recycle brine in heater (ft/sec)
VHEAT	-	Velocity of recycle brine in brine heater (ft/sec)
WASTE	-	Discarded concentrated brine flow rate (lb/hr)
X_1	-	Terminal temperature difference, TTD_1
X_2	-	Number of stages, NSTG
X_3	-	Empirical fit to heat transfer resistances
XAH	-	Internal cross sectional area of heater tubes (ft^2)
XSAV	-	Storage of independent variable X_1 or X_2

Z	-	Fixed capital investment (millions of dollars)
ZX	-	Other operating costs (millions of dollars per year)
ΔMAX	-	Maximum of the change in $f(X_1, X_2)$ computed as a result of moving one step with each variable
ΔMIN	-	Minimum of the change in $f(X_1, X_2)$ computed as a result of moving one step with each variable
λ	-	Latent heat of vaporization (Btu/lb)
ρRB	-	Specific gravity of recycle brine
ρSEA	-	Specific gravity of sea water

Subscript of λ or CP represents temperature at which value is obtained. Subscript of other parameters represent stage to which value applies.

5. USAGE

The program is written entirely in FORTRAN IV language. All computer runs at Oak Ridge have been made using the IBJOB processor running under an IBSYS basic monitor system on an IBM 7090. Since only standard input and output tapes are utilized, any 7090 computer having the minimum requirements to run this system is adequate. The computer runs for the Catalytic Construction Company were made on an IBM 7044 computer[2]. Since the source language is entirely FORTRAN IV, it is probably possible to compile and execute this code on a wider class of machines with only minor modifications. However, unless otherwise specified, usage with an IBM 7090 using the IBJOB processor is presumed.

5.1 Input

5.1.1 Program Options

Program options were originally selected by sense switches. A FORTRAN subroutine has been added to read these options from an additional data card for each computer run rather than setting the sense switches by operator action during execution. The original system may be utilized by merely removing this subroutine (FSSWTH) from the program deck. There are no programmed stops or control cards in the present version to stop the machine for operator action; however, this would be a simple matter to implement.

The program options and the format for the program option card (or alternative sense switch settings) are described in Table 4. Only one program option card can be included in a computer run, and it is the first data card read by the machine.

Table 4. Description of Program Options

Option	Selection Format and Logical Result
A.	Column 1 of the program option card blank (alternatively sense switch 1 up)- Normal solution.
	A 1-punch in colum 1 of the program option card (alternatively sense switch 1 down) - A list (on the peripheral punch tape) of sea water temperature, recycle ratio, and estimated sea water temperature is obtained for each return from the subroutine CALHMB.
B.	Column 2 of the program option card blank (alternatively sense switch 2 up) - An array of solutions is calculated by varying the total number of stages, NSTG, and the terminal temperature difference in the first stage, TTD_1, by prescribed increments over the domain specified in the input data.
	A 1-punch in column 2 of the program option card (alternatively sense switch 2 down) - Given a starting point for NSTG and TTD_1 and initial values for incrementing these variables in the input data, a sequence of solutions is calculated utilizing subroutine GENOPT which varies NSTG or TTD_1 by a method of steepest descent, until a minimum total cost for 30 years within the domain prescribed by the input data is reached. Because only integer values for NSTG are permitted, additional solutions are obtained near the optimum determined by GENOPT.
C.	Column 3 of the program option card blank (alternatively sense switch 3 up)- Normal solution.
	A 1-punch in column 3 of the program option card. (alternatively sense switch 3 down) - The output listing of the results of each heat and material balance case is suppressed.
D.	Column 5 of the program option card blank (alternatively sense switch 5 up)- Normal solution.
	A 1-punch in column 5 of the program data card (alternatively sense switch 5 down) - The output listing of the heat and material balance solution of the optimum (solution with lowest cost for 30-year period in sequence calculated) is suppressed.
E.	Not available with program option card. However, accidental termination of the run by the operator with sense switch setting is prevented. If operating with manual sense switch settings, the run can be terminated by putting sense switch 6 down. The cost summary for calculations completed is obtained and a normal exit occurs.

5.1.2 Design Criteria

The input data required for each design case is described in Table 5. As may be seen from Table 5, a set of eight data cards is required for each case. These sets of data cards follow the program option card described previously.

5.2 Output

In general, the types of output which may be obtained are:

1. Heat and material balance results.
2. Power requirements and cost estimates.
3. On-line output to monitor computer runs.

5.2.1 Heat and Material Balance Results

In addition to printing the principal input parameters, the following overall plant parameters are obtained:

1. Recycle ratio (lb recycle/lb product)
2. Total condenser area (ft^2)
3. Total recycle brine pump head (psi)

For every stage the following parameters are obtained:

1. Flashing brine flow rate leaving the stage (thousands of lbs/hr)
2. Total distillate flow rate leaving the stage (thousands of lbs/hr)
3. Recycle brine flow rate through the stage (thousands of lbs/hr)
4. Salt concentration of flashing brine (wt per cent)
5. Distillate produced in the stage (thousands of lbs/hr)
6. Stage pressure (psia)
7. Vapor flow rate (ft^3/sec)
8. Boiling point elevation (F)
9. Temperature of flashing brine leaving the stage (F)

Table 5. Summary of Input Data

Card	Column	Format	Title	Units	Variable Name
1	1-72	12A6	Title (6th line of heading)		TITLE (12)
2	1-10	F10.4	Production rate for plant *	gal/day	PROD
	11-20	F10.4	Temperature of flashing brine from brine heater	F	TFBO
	21-30	F10.4	Sea water temperature	F	TSEA
	31-40	F10.4	Concentration ratio	salt in effluent / salt inlet (sea)	CONRAT
	41-50	F10.4	Recycle ratio	lb recycle/lb product	RECRAT
	51-60	F10.4	Terminal temperature difference of first stage	F	ATTD
	61-70	F10.4	Pressure of steam to brine heater	psia	PSTM
	71-72	I2	Total number of stages in plant		NSTG
3	1-10	F10.4	OD of tubes in condenser bundles	inches	OD
	11-20	F10.4	Tube wall thickness, condenser	inches	THICK
	21-30	F10.4	Tube length (stage in heat recovery section)	ft/stage	TUBEL
	31-40	F10.4	OD of tubes in heater	inches	ODH
	41-50	F10.4	Tube wall thickness, brine heater	inches	THICKH
	51-60	F10.4	Velocity of recycle brine in brine heater	ft/sec	VHEAT
	61-70	F10.4	Tube length (stage in heat rejection section)	ft	TUBELR
	71-72	I2	Number of heat rejection stages		M
4	1-10	F10.4	Velocity of recycle brine in heat recovery section	ft/sec	VILRB
	11-20	F10.4	(not used in program)		FCOLD
	21-30	F10.4	(not used in program)		FHOT
	31-40	F10.4	Pressure drop, header losses to and from brine heater	ft of brine	HDREQL
5	1-10	F10.4	Minimum temperature, matrix	F	TMIN
	11-20	F10.4	Maximum temperature, matrix	F	TMAX
	21-30	F10.4	Increment for matrix	F	TDEL
	31-40	F10.4	Optimization error limit		ERR
	41-45	I5	Minimum number stages		NMIN
	46-50	I5	Maximum number of stages		NMAX
	51-55	I5	Stage increment for matrix solution		NDEL
6	1- 9	F9.0	List heading (12 or less) only listed		PLANT
	10-19	F9.0	Cost of steam	$\$/10^6$ Btu	ACOST
	19-27	F9.0	Cost of power	$/kwh	BCOST
	28-36	F9.0	Cost of condenser area	$\$/ft^2$	CCOST
	37-45	F9.0	Maximum brine heater load	10^6 Btu/hr unit	DCOST
	46-54	F9.0	Cost of concrete evaporators	$/stage	ECOST
	55-63	F9.0	Cost of recycle pumps	$/hp	FCOST
	64-72	F9.0	Cost of steel evaporators	$/stage	G
7	1-72	12A6	Line 6, description, cost list		TITLE (12)
8	1- 9	F9.0	Annual rate of return	per cent	Q000FL
	10-18	F9.0	Fixed capital investment	10^6 $	Z
	19-27	F9.0	Other pumps, costs	$/hp	FCOSTM
	28-36	F9.0	Other operating costs	10^6 $/year	ZX
	37-45	F9.0	Load factor	fraction	FLOAD

* Converted internally to pounds per hour.

10. Temperature of distillate stream leaving the stage (F)
11. Temperature of recycle brine leaving the stage (F)
12. Terminal temperature difference (F)
13. Log-mean driving force (F)
14. Heat transferred in the stage (thousands of Btu/hr-stage)
15. Overall heat transfer coefficient (Btu/hr-ft^2-F)
16. Condenser area (ft^2)

In addition to input design criteria, the design conditions presented for the heat-recovery section, heat-rejection section, and the brine heater are:

1. Number of tubes
2. Velocity of brine in tubes (ft/sec)
3. Weight of tubes in each section[a] (lb)
4. Pressure drop through section

For the brine heater the following additional design results are presented:

1. Temperature rise through brine heater (F)
2. Overall heat-transfer coefficient (Btu/hr-ft^2-F)
3. Log-mean driving force (F)
4. Heat requirement of heater (millions of Btu/hr)
5. Steam requirement of heater (lb/hr)

The above output is normally obtained for each point in the matrix mode or each trial solution in the optimization mode. These results may be suppressed with options C and D as described in Table 4.

5.2.2 - Power Requirements and Cost Summary

For each design case a summary of the power requirements and costs is obtained which include:

1. Structure direct capital cost (millions of dollars)
2. Condenser area (millions of square feet)

[a]Based on a tube density of 534 lbs/ft^3

3. Condenser surface direct capital cost (millions of dollars)
4. Total pump power (thousands of hp)
5. Brine heater area (thousands of square feet)
6. Brine heater capital cost (millions of dollars)
7. Total capital cost including indirect (millions of dollars)
8. Steam cost for 30 years (millions of dollars)
9. Power cost for 30 years (millions of dollars)
10. Total cost for 30 years (millions of dollars)

5.2.3 On-Line Output

Optional on-line output may be obtained to monitor the computer runs by utilizing Option A as described in Table 4.

5.3 Operating Instructions

Initial entry is made to the routine SALINE which controls the overall flow of the program. When an object deck is used, this must be assured by the sequence of the deck or with an appropriate $ENTRY card which is recognized by the IBJOB processor.

A typical program deck arrangement is presented in Fig. 4.

In general, little difficulty has been experienced with the numerical procedure, although, in several design situations the trial-and-error procedure resulted in negative temperature differences. The computer run is terminated when this occurs. Specification of a higher recycle ratio in the input data has been found to be helpful in reaching a solution.

Because of specific application requirements or the availability of better design data, it is probable that users of this program will wish to make modifications. For modifications to the pressure drop calculations, heat transfer coefficient calculations, sea water properties, costs, etc., where the numerical procedure is localized in simple subroutines, replacement or changing of the subroutines involved should suffice and probably can be accomplished in most instances without difficulty. However, for modifications which require numerous changes, considerably more programming and "debugging" effort may be required.

5.4 Example

A typical design case was processed using the data shown in Fig. 5. on the keypunch form designed for this program. The computer output is presented in Fig. 6.

6. CODING INFORMATION

The running time depends on the design parameters specified (number of stages, etc.). A typical design case involving 25 stages requires about 40 sec.

A flow diagram summarizing the logic and computational approach used in the optimization routine are presented in Fig. 7. The nomenclature used is described in Section 4.4.

A complete listing of the FORTRAN statements is presented in Fig. 8.

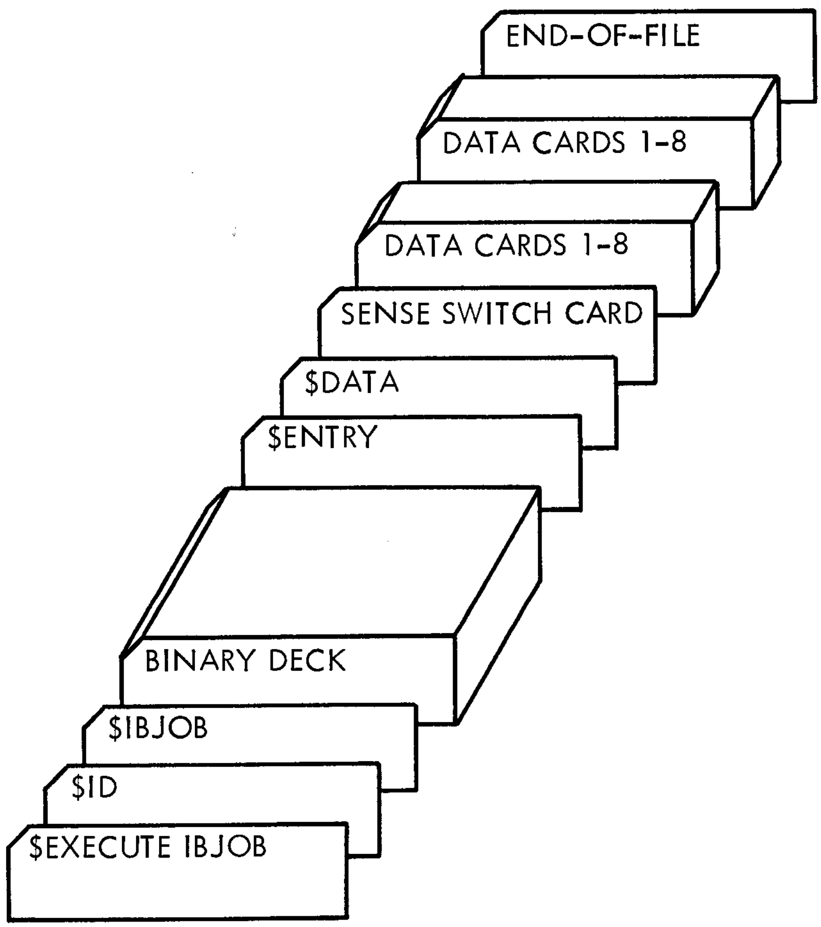


Fig. 4. Typical IBJOB Deck Setup.

CATALYTIC SALINE PROGRAM INPUT DATA FORM

Request ______________ Written By ______________ Date ______________

CARD	Columns	Field	Entry
1.	1–72	Description	SAMPLE PRØBLEM USING UNIØN CARBIDE VERSIØN ØF PRØGRAM
2.	1–10	PROD, gal/day	250000000.
	11–20	TFBO, °F	250.0
	21–30	TSEA, °F	65.0
	31–40	CONRAT	2.0
	41–50	RECRAT	7.9
	51–60	ATTD, °F	17.0992
	61–70	PSTM, psia	35.429
	71–72	NSTG	46
3.	1–10	OD, inch	1.0
	11–20	THICK, inch	0.049
	21–30	TUBEL, ft	4.96
	31–40	ODH, inch	1.0
	41–50	THICKH, inch	0.049
	51–60	VHEAT, ft/sec	6.0
	61–70	TUBELR, ft	6.92
	71–72	M	8
4.	1–10	VILRB, ft/sec	6.0
	11–20	(Unused)	
	21–30	(Unused)	
	31–40	HDREQL, ft	29.8
	41–45	NTUBES	16
5.	1–10	TMIN, °F	17.0992
	11–20	TMAX, °F	17.1
	21–30	TDEL, °F	1.0
	31–40	ERR	0.001
	41–45	NMIN	46
	46–50	NMAX	46
	51–55	NDEL	1
6.	1–9	PLANT	1.
	10–18	ACOST, $/Btu x 10-6	0.055
	19–27	BCOST, $/kwh	0.002
	28–36	CCOST, $/ft²	2.73
	37–45	DCOST, Btu x 10-6/hr unit	1700.0
	46–54	ECOST, $/stage	171000.0
	55–63	FCOST, $/hp	47.0
	64–72	G, $/stage	171000.0
7.	1–72	Description, Cost	SAMPLE PRØBLEM USING UNIØN CARBIDE VERSIØN ØF PRØGRAM
8.	1–9	QOOOFL, %	7.0
	10–18	Z, $ x 10-6	0.0
	19–27	FCOSTM, $/hp	45.0
	28–36	ZX, $ x 10-6/yr	0.0
	37–45	FLOAD, load factor	0.90

Fig. 5. Input Data Form. (Data for sample problem shown).

CATALYTIC CONSTRUCTION COMPANY

PHILADELPHIA, PENNSYLVANIA

OSW SALINE WATER CONVERSION STUDY

CATALYTIC CONSTRUCTION COMPANY CONTRACT 40840

ORIGINAL BECHTEL PROGRAM AS MODIFIED BY CATALYTIC

SAMPLE PROBLEM USING UNION CARBIDE VERSION OF PROGRAM

PRODUCTION 250.0 MMGAL/DAY, 86805555. LBS/HR.

RECYCLE RATIO 7.04 LBS/LB PRODUCT

CONCENTRATION RATIO 2.00, TOTAL NUMBER OF STAGES IS 46

TEMPERATURE OF FLASHING BRINE FROM BRINE HEATER IS 250.00 DEG F.

SEA WATER TEMPERATURE IS 65.00 DEG F. APPROXIMATE TTD 17.10 DEG F.

STAGE NO.	FLASHING BRINE,MLB/HR	DISTILLATE PROD,MLB/HR	RECYCLE BRINE,MLB/HR	CONCENTRATION WT. PERCENT	PRODUCTION M LB/HR	PRESSURE PSIA	VAPOR FLOW CU FT/SEC	BOILING POINT ELEV. DEG F.
1	608798.	2264.	611062.	6.0279	2264.	26.8529	9821.52	2.3032
2	606549.	4513.	611062.	6.0503	2249.	25.1564	10359.62	2.2933
3	604316.	6746.	611062.	6.0726	2233.	23.5477	10934.37	2.2832
4	602098.	8964.	611062.	6.0950	2218.	22.0236	11548.87	2.2730
5	599896.	11166.	611062.	6.1174	2202.	20.5811	12206.55	2.2627
6	597709.	13353.	611062.	6.1398	2186.	19.2169	12911.15	2.2523
7	595538.	15524.	611062.	6.1621	2171.	17.9279	13666.82	2.2417
8	593383.	17679.	611062.	6.1845	2155.	16.7111	14478.07	2.2310
9	591244.	19818.	611062.	6.2069	2139.	15.5635	15349.90	2.2202
10	589120.	21942.	611062.	6.2293	2124.	14.4820	16287.78	2.2093
11	587012.	24050.	611062.	6.2517	2108.	13.4637	17297.76	2.1983
12	584919.	26143.	611062.	6.2740	2093.	12.5058	18386.50	2.1871
13	582841.	28221.	611062.	6.2964	2078.	11.6054	19561.33	2.1759
14	580778.	30284.	611062.	6.3188	2063.	10.7599	20830.37	2.1646
15	578730.	32332.	611062.	6.3411	2048.	9.9667	22202.56	2.1531
16	576697.	34365.	611062.	6.3635	2033.	9.2231	23687.78	2.1416
17	574678.	36384.	611062.	6.3858	2019.	8.5267	25296.97	2.1300
18	572674.	38388.	611062.	6.4082	2004.	7.8751	27042.21	2.1182
19	570683.	40379.	611062.	6.4305	1990.	7.2661	28936.90	2.1064
20	568707.	42355.	611062.	6.4529	1976.	6.6973	30995.83	2.0945
21	566745.	44317.	611062.	6.4752	1962.	6.1666	33235.43	2.0825
22	564796.	46266.	611062.	6.4976	1949.	5.6720	35673.86	2.0704
23	562861.	48200.	611062.	6.5199	1935.	5.2115	38331.30	2.0583
24	560940.	50122.	611062.	6.5422	1921.	4.7832	41230.05	2.0461
25	559032.	52030.	611062.	6.5645	1908.	4.3853	44394.87	2.0338
26	557138.	53924.	611062.	6.5869	1894.	4.0161	47853.21	2.0214
27	555257.	55805.	611062.	6.6092	1881.	3.6737	51635.44	2.0090
28	553389.	57673.	611062.	6.6315	1868.	3.3568	55775.31	1.9965
29	551535.	59527.	611062.	6.6538	1854.	3.0637	60310.09	1.9839
30	549694.	61367.	611062.	6.6761	1841.	2.7929	65281.08	1.9713
31	547867.	63194.	611062.	6.6983	1827.	2.5432	70734.00	1.9587
32	546054.	65008.	611062.	6.7206	1813.	2.3130	76719.35	1.9460
33	544255.	66807.	611062.	6.7428	1799.	2.1013	83292.87	1.9332
34	542470.	68592.	611062.	6.7650	1785.	1.9067	90516.17	1.9205
35	540699.	70363.	611062.	6.7871	1771.	1.7281	98456.91	1.9077
36	538943.	72119.	611062.	6.8092	1756.	1.5645	107189.66	1.8949

Fig. 6. Output for Sample Problem.

37	537202.	73860.	611062.	6.8313	1741.	1.4147	116796.22	1.8820
38	535476.	75585.	611062.	6.8533	1726.	1.2779	127366.27	1.8692
			HEAT REJECTION SECTION					
			RAW SEA WATER					
39	534044.	77017.	594263.	6.8717	1432.	1.1726	114599.10	1.8584
40	532619.	78443.	594263.	6.8901	1426.	1.0748	123806.29	1.8477
41	531200.	79862.	594263.	6.9085	1419.	0.9842	133893.35	1.8369
42	529787.	81275.	594263.	6.9269	1413.	0.9002	144956.52	1.8260
43	528380.	82681.	594263.	6.9454	1406.	0.8225	157103.72	1.8152
44	526980.	84082.	594263.	6.9638	1400.	0.7506	170456.26	1.8043
45	525586.	85475.	594263.	6.9823	1394.	0.6842	185150.68	1.7934
46	524199.	86863.	594263.	7.0008	1388.	0.6230	201340.79	1.7825

Fig. 6. (Continued)

STAGE NO.	TEMP FLASHING BRINE, DEG F	TEMP DIST PROD, DEG F	TEMP RECYCLE BRINE, DEG F	TERMINAL TEMP DIFFERENCE, F	LOG MEAN TEMP DIFFERENCE, F	HEAT TRANSFER MBTU/STAGE	OVERALL U BTU/FT2/F/HR	AREA SQ FT/STAGE
1	246.35	244.05	226.95	17.0992	18.8773	2149681.	619.60	183789.
2	242.71	240.41	223.28	17.1361	18.9155	2149042.	617.97	183848.
3	239.06	236.77	219.60	17.1732	18.9536	2148041.	616.24	183908.
4	235.40	233.13	215.92	17.2104	18.9916	2146727.	614.43	183970.
5	231.75	229.49	212.24	17.2476	19.0293	2145146.	612.55	184033.
6	228.09	225.84	208.56	17.2848	19.0667	2143338.	610.62	184097.
7	224.44	222.20	204.87	17.3219	19.1038	2141345.	608.65	184161.
8	220.78	218.55	201.19	17.3589	19.1406	2139200.	606.66	184226.
9	217.13	214.91	197.51	17.3956	19.1771	2136937.	604.65	184291.
10	213.47	211.26	193.83	17.4321	19.2131	2134584.	602.64	184356.
11	209.82	207.62	190.15	17.4682	19.2488	2132167.	600.63	184421.
12	206.16	203.98	186.47	17.5040	19.2840	2129706.	598.63	184486.
13	202.51	200.33	182.80	17.5394	19.3188	2127221.	596.65	184551.
14	198.86	196.69	179.12	17.5745	19.3531	2124725.	594.68	184616.
15	195.21	193.06	175.45	17.6091	19.3870	2122232.	592.73	184682.
16	191.56	189.42	171.78	17.6432	19.4203	2119747.	590.81	184747.
17	187.91	185.78	168.11	17.6770	19.4533	2117276.	588.91	184813.
18	184.27	182.15	164.44	17.7103	19.4857	2114819.	587.04	184880.
19	180.62	178.51	160.77	17.7432	19.5178	2112376.	585.18	184948.
20	176.98	174.88	157.11	17.7756	19.5493	2109939.	583.35	185017.
21	173.34	171.25	153.45	17.8077	19.5804	2107501.	581.53	185088.
22	169.70	167.63	149.79	17.8394	19.6111	2105049.	579.71	185160.
23	166.06	164.00	146.13	17.8707	19.6414	2102567.	577.90	185235.
24	162.42	160.38	142.48	17.9018	19.6713	2100037.	576.09	185312.
25	158.79	156.76	138.82	17.9325	19.7009	2097436.	574.27	185392.
26	155.16	153.14	135.17	17.9631	19.7301	2094739.	572.42	185475.
27	151.53	149.52	131.53	17.9935	19.7590	2091917.	570.54	185562.
28	147.90	145.91	127.88	18.0237	19.7876	2088937.	568.63	185654.
29	144.28	142.30	124.25	18.0540	19.8160	2085764.	566.66	185750.
30	140.67	138.69	120.61	18.0842	19.8443	2082359.	564.62	185851.
31	137.05	135.09	116.98	18.1146	19.8723	2078681.	562.51	185957.
32	133.44	131.50	113.35	18.1451	19.9002	2074685.	560.30	186069.
33	129.84	127.91	109.73	18.1759	19.9281	2070322.	557.98	186187.
34	126.25	124.33	106.12	18.2071	19.9560	2065543.	555.55	186312.
35	122.66	120.75	102.51	18.2387	19.9839	2060294.	552.97	186443.
36	119.08	117.19	98.92	18.2708	20.0118	2054522.	550.25	186581.
37	115.51	113.63	95.33	18.3036	20.0399	2048170.	547.35	186726.
38	111.95	110.08	91.75	18.3372	20.0682	2041180.	544.27	186878.
							TOTAL AREA	7033468.
			HEAT REJECTION SECTION					
39	108.98	107.13	88.18	18.9464	20.3607	1702720.	512.94	163037.
40	106.01	104.17	85.28	18.8843	20.2986	1702724.	510.00	164478.
41	103.04	101.21	82.39	18.8216	20.2359	1702728.	506.91	165992.
42	100.07	98.25	79.49	18.7584	20.1728	1702733.	503.67	167586.
43	97.10	95.28	76.59	18.6948	20.1091	1702737.	500.25	169266.
44	94.13	92.32	73.69	18.6306	20.0449	1702741.	496.65	171039.
45	91.15	89.36	70.79	18.5659	19.9802	1702744.	492.86	172911.
46	88.18	86.39	67.89	18.5008	19.9150	1702748.	488.88	174891.
							TOTAL AREA	1349200.
							GRAND TOTAL AREA	8382668.

Fig. 6. (Continued)

```
                         BRINE HEATER DATA

STEAM PRESSURE    35.4 PSIA, STEAM TEMPERATURE  260.0 DEG F.
TEMPERATURE RISE OF BRINE THROUGH HEATER  23.048 DEG F.  LOG MEAN TEMPERATURE DIFFERENCE  19.279
OVERALL HEAT TRANSFER COEFFICIENT    676.50 BTU/FT2/F/HR
HEAT REQUIREMENT OF HEATER IS   13558.394 MMBTU/HR, AREA REQUIREMENT OF HEATER IS 1039544. SQ.FT.

STEAM REQUIREMENT  14444006. LB/HR
STEAM ECONOMY RATIO IS   6.01 LBS PRODUCT/LB STEAM

                         DESIGN DATA

                         HEAT RECOVERY SECTION

NUMBER OF TUBES PER STAGE IS142540.
VELOCITY OF RECYCLE BRINE IN TUBES IS  4.301 FT/SEC
PRESSURE DROP THROUGH THIS SECTION IS   38.67 PSI
LENGTH OF TUBES IS  4.96 FEET
OUTSIDE DIAMETER OF TUBES IS 1.0000 INCHES
WALL THICKNESS OF TUBES IS 0.0490 INCHES
TOTAL WEIGHT OF TUBES IN EACH STAGE IS  383919. POUNDS

                         HEAT REJECTION SECTION

NUMBER OF TUBES PER STAGE IS157447.
VELOCITY OF RAW SEA WATER IN TUBES IS  3.786 FT/SEC
PRESSURE DROP THROUGH THIS SECTION IS   18.03 PSI
LENGTH OF TUBES IS  4.09 FEET
OUTSIDE DIAMETER OF TUBES IS 1.0000 INCHES
WALL THICKNESS OF TUBES IS 0.0490 INCHES
TOTAL WEIGHT OF TUBES IN EACH STAGE IS  349816. POUNDS

                         BRINE HEATER

TOTAL NUMBER OF TUBES IN HEATER IS102166.
VELOCITY OF RECYCLE BRINE IN TUBES IS  6.000 FT/SEC
PRESSURE DROP THROUGH THIS SECTION IS   16.43 PSI
LENGTH OF TUBES IS 38.87 FEET
OUTSIDE DIAMETER OF TUBES IS 1.0000 INCHES
WALL THICKNESS OF TUBES IS 0.0490 INCHES
TOTAL WEIGHT OF TUBES IN BRINE HEATER IS 2156238. POUNDS

TOTAL RECYCLE BRINE PUMP HEAD IS    81.34 PSI
```

Fig. 6. (Continued)

```
CATALYTIC CONSTRUCTION COMPANY
PHILAOELPHIA,  PENNSYLVANIA
OSW SALINE WATER CONVERSION STUDY
CATALYTIC CONSTRUCTION COMPANY CONTRACT 40840
# ORIGINAL BECHTEL PROGRAM AS MODIFIED BY CATALYTIC #

SAMPLE PROBLEM USING UNION CARBIDE VERSION OF PROGRAM

250.0 MMGAL/DAY WATER PLANT - ECONOMIC STUDY


COST BASIS FOR STUOY


FIXED CHARGES CALCULATED AT  7.00 PERCENT

COST OF STEAM IS $0.055/MMBTU

COST OF POWER IS $0.00200/KWH


COST OF CONDENSER SURFACE IS $2.730/SQFT

MAXIMUM BRINE HEATER LOAD IS 1700. MMBTU/HR PER UNIT

COST OF CONCRETE EVAPORATORS IS $ 171000./STAGE

COST OF RECYCLE PUMPS IS $ 47.00/HP,  OTHER PUMPS $  45.00/HP

OTHER FIXED CAPITAL INVESTMENT IS $   0.      MILLION

OTHER OPERATING COSTS ARE $   0.      MILLION/YR

COST OF STEEL EVAPORATORS IS $ 171000./STAGE
FOR EACH STAGE WITH THE PRESSURE GREATER THAN 16.0 PSIA
```

Fig. 6. (Continued)

CASE NO.	NO. STA-GES	TTD DEG F.	STRUCT-URE COST MM $	COND. AREA MMSQFT	COST OF TUBES MM $	TOTAL PUMP H.P. M HP	TOTAL PUMP COST MM $	BRINE HEATER AREA M SQFT	BRINE HEATER COST MM $	TOTAL CAPITAL COST MM $	STEAM COST MM $ 30 YRS	POWER COST MM $ 30 YRS	CAPITAL COST MM $ 30 YRS	TOTAL COST MM $ 30 YRS
1 1	46	17.1	7.87	8.38	22.88	83.6	3.891	1039.5	5.543	55.87	176.4	29.48	117.3	323.19

CATALYTIC CONSTRUCTION COMPANY
PHILADELPHIA, PENNSYLVANIA
OSW SALINE WATER CONVERSION STUDY
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ORIGINAL BECHTEL PROGRAM AS MODIFIED BY CATALYTIC

SAMPLE PROBLEM USING UNION CARBIDE VERSION OF PROGRAM

PLANT 1, CASE 1 IS OPTIMUM DESIGN IN MATRIX

46 STAGES AND 17.10 TTD.

WATER COST IS $ 0.131/MGAL

Fig. 6. (Continued)

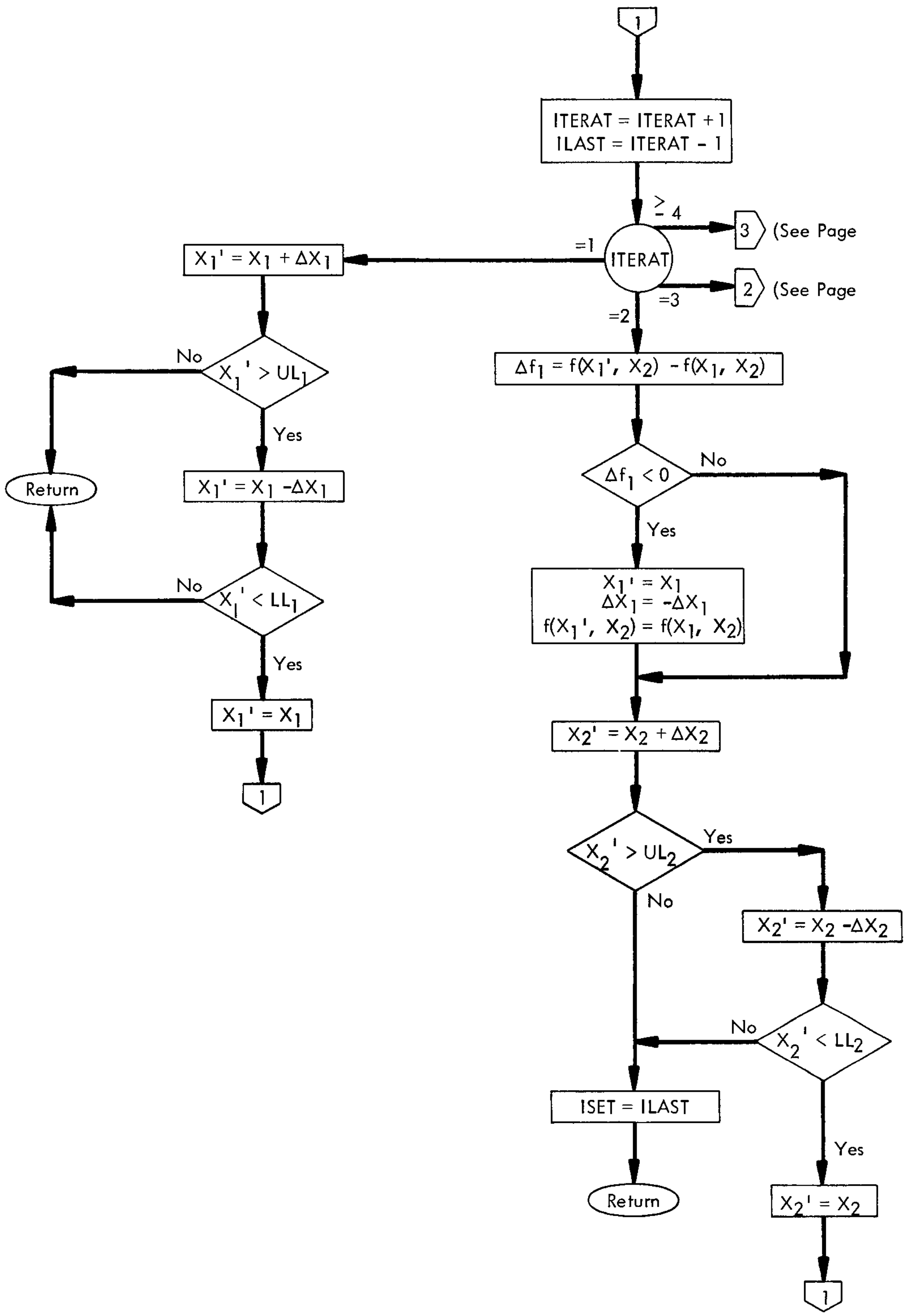

Fig. 7. Subroutine GENOPT.

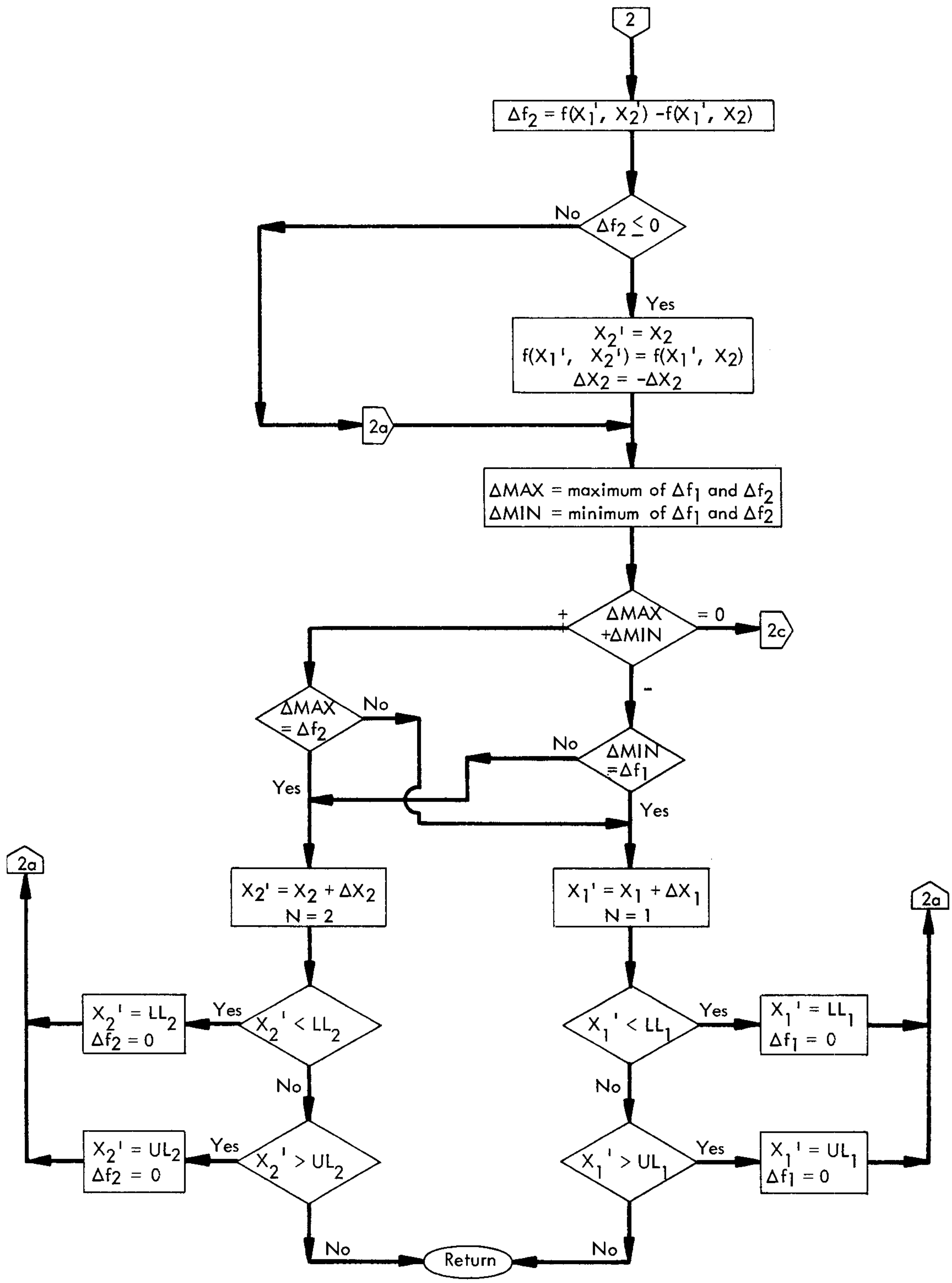

Fig. 7. (Continued)

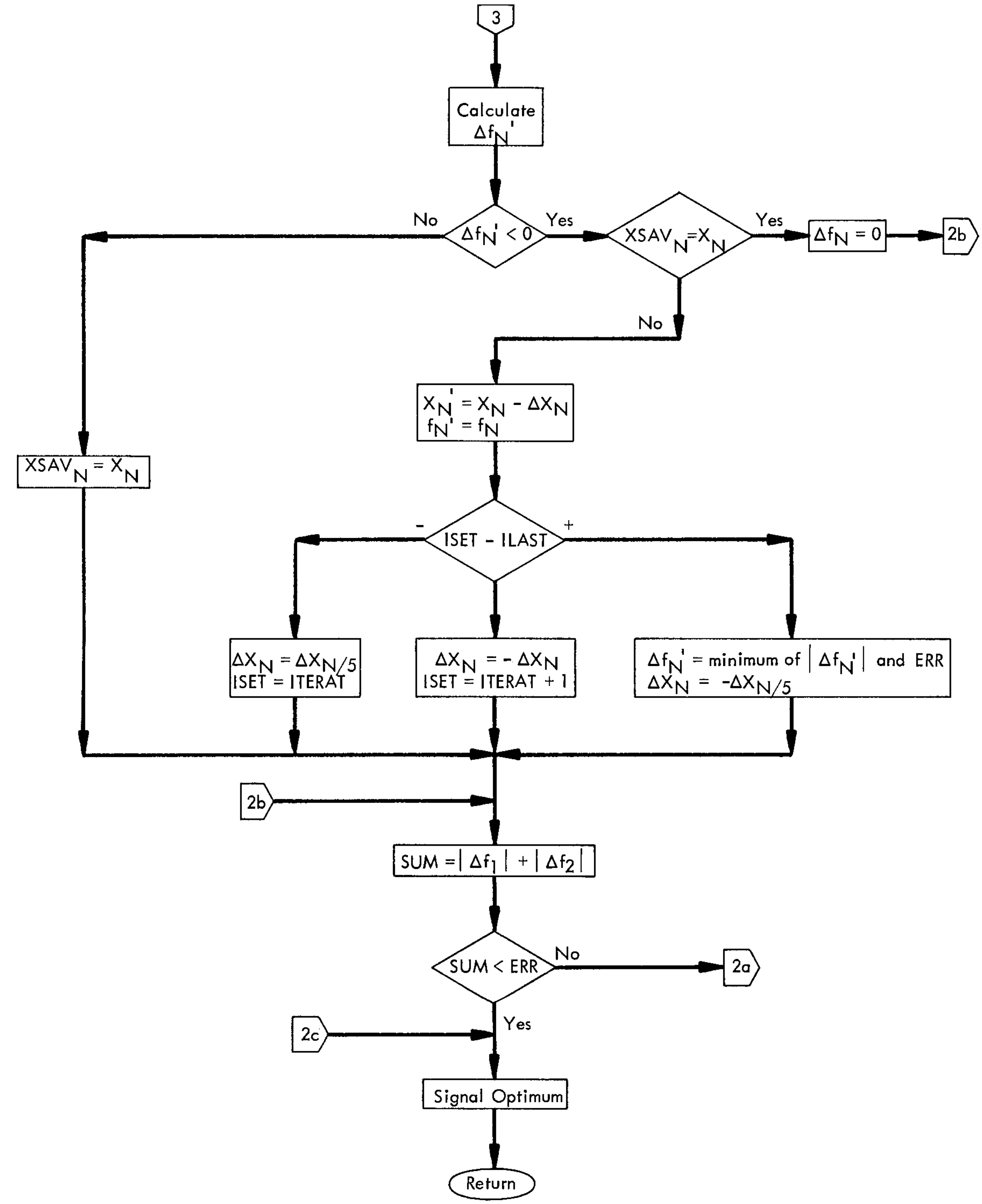

Fig. 7. (Continued)

```
 MAIN
C
CMAIN           MAIN PROGRAM FOR OSW SALINE WATER CONVERSION PLANT
C
C     PRD      1/7/63
C     2/14/64 DRM ( CATALYTIC )
C
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
      DIMENSION N(100),T(100),AC(100),R(100),DPR(100),DPS(100),AH(100),
     1STM(100),NPRES(100),S(100)
      COMMON  A      , ALMTD  , BPE    , C       , CFS    , DIST
      COMMON  DTFB   , DTRB   , FB     , P       , PSIA   , Q
      COMMON  TDIST  , TFB    , TITLE  , TRB     , TTD    , U
      COMMON ACCST,AHEAT      ,ATTD,BCOST, CCOST,CONRAT
      COMMON  DTHEAT , FCOST  , FOULFC , M       , NSTG   , NTUBES
      COMMON  PCOST  , PROC   , PSTM   , QHEAT   , RECRAT , STEAM
      COMMON  TCOST  , TFBO   , TSEA   , TSTM    , UHEAT  , VCOST
      COMMON  VILRB  , FRSHSW , WASTE  , RECY    , SECONR , ALMTDH
      COMMON  QOOOFL, XAMOD  , EQLMOD , NMOD   , PDROP  , OD
      COMMON  ODH    , TUBEL  , TUBELH , TUBES   , TUBESR , TUBESH
      COMMON  VHREJ  , VHEAT  , WGT    , WGTR    , WGTH   , PDROPR
      COMMON  PDROPH , THICK  , THICKH , VELHDR  , HDREQL , TPDROP
      COMMON  TUBELR , N      , T      , AC      , R      , DPR
      COMMON  S      , DPS    , AH     , STM     , NPLANT , NPRES
      COMMON  TOTAL  , II
      EQUIVALENCE (TFBO,TFBO)
C     USE SENSE SWITCH SUBR. AVOID PAUSE.  4 READS FIRST CARD.0#UP,1#DN
      CALL SSWTCH( 4,-1)
C     NO CARD WILL BE READ IF REAL SWITCHES, ROUTINE FSSWTH ARE USED.
C     PAUSE 7531             REPLACED BY A CARD READ ONLY ONCE. CARD 0.
 0001 CALL INPUT
      II#0
      NTEST #0
      NPLANT #0
      NCASE #1
 0002 CALL ADJUST (NTEST)
      IF(NTEST)4,4,15
    4 CALL CALHMB
      C ALL INTOUT(NCASE)
      CALL SSWTCH(2,KOOOFX)
       GO TO(6,3),KOOOFX
    6 CALL COST(NCASE,0)
    3 CALL SSWTCH(3,KOOOFX)
       GO TO(8,7),KOOOFX
    7 CALL FINOUT
    8 CALL SSWTCH(6,KOOOFX)
       GO TO(5,2),KOOOFX
   15 CALL SSWTCH(5,KOOOFX)
       GO TO(5,16),KOOOFX
   16 CALL FINOUT
    5 GO TO 12
   10 KOOOFX#-1
      NXXX#NCASE
      CALL COST(NCASE,KOOOFX)
      NSTG#N(NCASE)
      ATTD#T(NCASE)
      CALL CALHMB
```

Fig. 8. SALINE Source Program.

```
      CALL FINOUT                                                       MAIN0590
      NCASE#NXXX                                                        MAIN0600
      NCASE#NCASE+1                                                     MAIN0610
C     SWITCH 4 AND ROUTINE CKPNT REMOVED(RMK).                          MAIN0620
      GO TO 1                                                           MAIN0630
   12 CALL SLITET(3,KOOOFX)                                             MAIN0640
      CALL CCST(NCASE,1)                                                MAIN0650
      CALL SLITET(3,KOOOFX)                                             MAIN0660
      GO TO (1,13),KOOOFX                                               MAIN0670
   13 CALL SSWTCH(2,KOOOFX)                                             MAIN0680
      GO TO (1,10),KOOOFX                                               MAIN0690
      END                                                               MAIN0700
```

```
 SWCH                                                                   SWCH0000
      SUBROUTINE SSWTCH (NO,K)                                          SWCH0010
    1 FORMAT(6I1)                                                       SWCH0020
      DIMENSION L(6)                                                    SWCH0030
C     SWITCH 4 NOT USED. READ CARD IF 4 CALLED. INITIALIZE DUMMY SWITCHESWCH0040
      IF(NO-4)2,10,2                                                    SWCH0050
    2 IF(MIN0(NO,7-NO))10,10,5                                          SWCH0060
    5 K#IABS(L(NO)-1)+1                                                 SWCH0070
      RETURN                                                            SWCH0080
   10 READ (5,1) (L(I),I#1,6)                                           SWCH0090
      L(6)#0                                                            SWCH0100
      RETURN                                                            SWCH0110
      END                                                               SWCH0120
```

Fig. 8. (Continued)

```
 SB01
C
CINTOUT        ROUTINE TO STORE INFORMATION NEEDED FOR ECONOMIC ROUTINE
C
C     PRD     4/1/63          OSW  SALINE WATER PLANT    JOB 4427-9
C     2/14/64 DRM ( CATALYTIC )
C
      SUBROUTINE INTOUT(NCASE)
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
      DIMENSION N(100),T(100),AC(100),R(100),DPR(100),DPS(100),AH(100),
     1STM(100),NPRES(100),S(100)
      COMMON A     , ALMTD  , BPE    , C      , CFS    , DIST
      COMMON DTFB  , DTRB   , FB     , P      , PSIA   , Q
      COMMON TDIST , TFB    , TITLE  , TRB    , TTD    , U
      COMMON ACOST,AHEAT    ,ATTD,BCOST, CCOST,CONRAT
      COMMON DTHEAT , FCOST , FOULFC , M      , NSTG   , NTUBES
      COMMON PCOST , PROD   , PSTM   , QHEAT  , RECRAT , STEAM
      COMMON TCOST , TFBO   , TSEA   , TSTM   , UHEAT  , VCOST
      COMMON VILRB , FRSHSW , WASTE  , RECY   , SECONR , ALMTDH
      COMMON QOODFL,XAMOD,EQLMOD,NMOD,PDROP,ID,ODH
      COMMON TUBEL , TUBELH , TUBES  , TUBESR , TUBESH , VHREJ
      COMMON VHEAT , WGT    , WGTR   , WGTH   , PDROPR , PDROPH
      COMMON THICK , THICKH , VELHDR , HDREQL , TPDROP , TUBELR
      COMMON N     , T      , AC     , R      , DPR    , S
      COMMON DPS   , AH     , STM    , NPLANT , NPRES  , TOTAL
      EQUIVALENCE (TFBO,TFBO)
      N(NCASE) #NSTG
      T (NCASE)#TTD(I)
      R(NCASE) # RECY
      DPR(NCASE)#TPDROP
      S(NCASE) # FRSHSW
      DPS(NCASE)#PDROPR
      AH(NCASE) #AHEAT
      STM(NCASE)#STEAM
      NPRES(NCASE)#0
      AC(NCASE) #0.0
      DO 4 I#1,NSTG
      AC(NCASE) # AC(NCASE) +A(I)
      IF( PSIA(I)-16.0)4,3,3
    3 NPRES(NCASE) # NPRES(NCASE) +1
    4 CONTINUE
      NCASE # NCASE +1
      IF(NCASE-100) 2,2,1
    1 CALL COST(100,1)
      NCASE #1
      NPLANT # NPLANT +1
    2 RETURN
      END
```

Fig. 8. (Continued)

```
 SBD2
C
CADJUST               ADJUSTMENT OF SYSTEM PARAMETERS ,ATTD AND NSTG
C
C      PRD      OSW  SALINE WATER CONVERSION PLANT   1/25/63
C      2/14/64 DRM ( CATALYTIC )
C
       SUBROUTINE ADJUST(NTEST)
       DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
       DIMENSION N(100),T(100),AC(100),R(100),DPR(100),DPS(100),AH(100),
     1 STM(100),NPRES(100),S(100)
       DIMENSION X(4),XM(4),XN(4),XD(4),DX(4)
       COMMON  A       , ALMTD  , BPE     , C       , CFS     , DIST
       COMMON  DTFB    , DTRB   , FB      , P       , PSIA    , Q
       COMMON  TDIST   , TFB    , TITLE   , TRB     , TTD     , U
       COMMON ACCST,AHEAT       ,ATTD,BCOST, CCOST,CONRAT
       COMMON  DTHEAT  , FCOST  , FOULFC  , M       , NSTG    , NTUBES
       COMMON  PCCST   , PROD   , PSTM    , QHEAT   , RECRAT  , STEAM
       COMMON  TCOST   , TFBO   , TSEA    , TSTM    , UHEAT   , VCOST
       COMMON  VILRB   , FRSHSW , WASTE   , RECY    , SECONR  , ALMTDH
       COMMON  COOOFL, XAMOC  , EQLMOD , NMOD    , PDROP   , OD
       COMMON  ODH     , TUBEL  , TUBELH  , TUBES   , TUBESR  , TUBESH
       COMMON  VHREJ   , VHEAT  , WGT     , WGTR    , WGTH    , PDROPR
       COMMON  PDRCPH  , THICK  , THICKH  , VELHDR  , HDREQL  , TPDROP
       COMMON  TUBELR  , N      , T       , AC      , R       , DPR
       COMMON  S       , DPS    , AH      , STM     , NPLANT  , NPRES
       COMMON  TOTAL   , II
       EQUIVALENCE (TFB0,TFBO)
       IF(II-5) 1,20,1
     1 READ          (5,10) TMIN,TMAX,TDEL,ERR,NMIN,NMAX,NDEL
       II#5
       ITEST#0
       ITERAT # 0
C      START MATRIX AT MINIMUM VALUES
    46 X(1) #ATTD
       X(2) # NSTG
       CALL SSWTCH (2,KOOOFX)
       GO TO (16,15),KOOOFX
    15 X(2)#NMIN
       X(1)#TMIN
    16 XM(1)# TMAX
       XM(2)# NMAX
       XN(1)# TMIN
       XN(2)# NMIN
       XD(1)# TDEL
       XD(2)# NDEL
       GO TO 9
    20 CALL SSWTCH(2,KOOOFX)
        GO TO(2,21),KOOOFX
    21 CALL SLITET(1,KOOOFX)
    22 X(2)#NSTG+NDEL
       IF(X(2)-FLOAT(NMAX)) 4,4,23
    23 X(2)#NMIN
       X(1)#ATTD+TDEL
       IF(X(1)-TMAX) 3,3,26
    26 NTEST#1
       RETURN
```

Fig. 8. (Continued)

```
 2 IF(ITEST)21,32,21                                           SB020590
32 CBJECT #(1.0 E 10)/TOTAL                                    SB020600
   CALL GENOPT(CBJECT,2,X,XM,XN,DX,ITERAT,ERR*OBJECT,XD)       SB020610
 3 ATTD # X(1)                                                 SB020620
 4 NSTG # X(2)+0.5                                             SB020630
   X(2)#NSTG                                                   SB020640
   CALL SLITET(1,KOOOFX)                                       SB020650
    GC TC(6,9),KOOOFX                                          SB020660
 6 CALL SSWTCH (2,KOOOFX)                                      SB020670
   GC TO (36,26),KOOOFX                                        SB020680
36 ITEST#1                                                     SB020690
   NDEL#2                                                      SB020700
   TDEL#2.*ABS(XC(1))                                          SB020710
   ATTD#ATTC-ABS(XC(1))                                        SB020720
   IF(ATTC-TMIN)42,43,43                                       SB020730
42 ATTD#TMIN                                                   SB020740
43 TMAX#ATTD+TCEL                                              SB020750
   TMIN#ATTD                                                   SB020760
   NSTG#NSTG-1                                                 SB020770
   IF(NSTG-NMIN)44,45,45                                       SB020780
44 NSTG#NMIN                                                   SB020790
45 NMAX#NSTG+2                                                 SB020800
   NMIN#NSTG                                                   SB020810
   GC TC 46                                                    SB020820
 9 RETURN                                                      SB020830
10 FORMAT( 4F10.4,3I5 )                                        SB020840
11 FORMAT( 7F10.4)                                             SB020850
   END                                                         SB020860
```

Fig. 8. (Continued)

```
 SB03
C
CCALHMB        ROUTINE TO CALCULATE HEAT AND MATERIAL BALANCE IN SALINE
C              WATER CONVERSION PLANT          JOB 4427-9
C
C     2/14/64 DRM ( CATALYTIC )
C     PRD          1/11/63
      SUBROUTINE CALHMB
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
      DIMENSION PP(100),CQ(100),AA(100),DDTFB(100)
      COMMON  A      , ALMTD  , BPE    , C      , CFS    , DIST
      COMMON  DTFB   , DTRB   , FB     , P      , PSIA   , Q
      COMMON  TDIST  , TFB    , TITLE  , TRB    , TTD    , U
      COMMON ACOST,AHEAT      ,ATTD,BCOST, CCOST,CONRAT
      COMMON  DTHEAT , FCOST  , FOULFC , M      , NSTG   , NTUBES
      COMMON  PCCST  , PROD   , PSTM   , QHEAT  , RECRAT , STEAM
      COMMON  TCOST  , TFBO   , TSEA   , TSTM   , UHEAT  , VCOST
      COMMON  VILRB  , FRSHSW , WASTE  , RECY   , SECONR , ALMTDH
      COMMON  QOOOFL, XAMOD  , EQLMOD , NMOD, PDROP  , OD
      COMMON  ODH    , TUBEL  , TUBELH , TUBES  , TUBESR , TUBESH
      COMMON  VHREJ  , VHEAT  , WGT    , WGTR   , WGTH   , PDROPR
      COMMON  PDROPH , THICK  , THICKH , VELHDR , HDREQL , TPDROP
      COMMON  TUBELR
      EQUIVALENCE (TFBO,TFBO)
      EQUIVALENCE (CO,CO)
C     MAKE M AN INPUT VARIABLE, NUM OF HEAT REJ STAGES. RMK  4/7/65
C     MAKE TUBELR VARIABLE INPUT. TUBE LENGTH, HEAT REJ SECTION 4/7/65
C     TUBELR#TUBEL    NO LONGER EQUAL  * *  RMK  4/7/65
      ISTOP#0
      NCOUNT# 0
      NTEST#0
      LOOPI#0
      NFIX#0
      RECY# RECRAT*PROD
      CO# 3.5*CONRAT
      SALT # 3.5*CONRAT*(RECY-PROD)
      CRECY# SALT/RECY
C     QUIT USING BPERRN. USE BECHTEL METHOD FOR REFLASHING PROD, BPE.
C *** ACON# 1.0/((1.0-CO/100.0)*RECRAT*FLOAT(NSTG))
C *** CCON#  (TFBO-100.0  )* CO/(100.0*RECRAT)
      BPE(1)#2.3
      BPE(NSTG)# 1.8
C *** BPERRN# ACON*( BPE(NSTG) -CCON)
      TTD(1)#ATTD
      DO 2 I#1,NSTG
 0002 P(I)# PROD/FLOAT(NSTG)
      DIST(NSTG)#PROD
      L # NSTG + 1 - M
      K # NSTG - M
      MID#(L+NSTG)/2
      TRB(L)#0.0
      TDIST(1)# TFBO-DELBP(TFBO,CRECY)-(TFBO-100.0)/FLOAT(NSTG)
      TDIST(NSTG)#TSEA+TFBO-TDIST(1)
      DELTD# (TDIST(1)-TDIST(NSTG))/FLOAT(NSTG-1)
      QFIX#0.0
      DO 40 I#2,NSTG
   40 TDIST(I)# TDIST(I-1) - DELTD
```

Fig. 8. (Continued)

```
C
C     I   POINT OF RETURN FOR LOOPS.
C
    I PO#P(I)
      CALL SLITE (0)
      CPBAR # (CPB(TFBO,CRECY)+CPB(TDIST(I),C(I)))/2.0
C *** DTFB(I)#P(I)*AMDA(TDIST(I))/(CPB(TFBO,CRECY)*RECY) - BPERRN
      DTFB(I)# P(I)*(AMDA(TDIST(I))/ CPBAR - BPE(I)) /RECY
      TFB(I)#TFBO-DTFB(I)
      FB(I)#RECY-P(I)
      C(I)#SALT/FB(I)
      BPE(I)#DELBP(TFB(I),C(I))
      DTHEAT#TTD(I)+BPE(I)+DTFB(I)
      QHEAT#DTHEAT*RECY*CPB(TFB(I),CRECY)
      IF(LOOPI)106,106,108
  106 LOOP#I
      FRSHSW #(RECY*CPB(TSEA,CRECY))/CPB(TSEA,3.5)
      WASTE#PROD/(CONRAT-1.)
      EXCSSW#FRSHSW-WASTE-PROD
      QPROD#PROD*CPB(((TDIST(NSTG)+TSEA)/2.),0.)*(TDIST(NSTG)-TSEA)
      QWASTE#WASTE*CPB(((TDIST(NSTG)+BPE(NSTG)+TSEA)/2.),CO)*(TDIST
     1(NSTG)+BPE(NSTG)-TSEA)
      QEXCSS #QHEAT-QPROD-QWASTE
C     QFIX ADJUSTS PRODUCTION SO TFB(NSTG)#TRB(L)
      QPERST#(QEXCSS*FRSHSW )/(FLOAT(M)*EXCSSW) + QFIX
      DO 107 I#1,M
      J#NSTG+1-I
      JJ#J-1
      P(J)#(QPERST-(DIST(J)*CPB(TDIST(J),0.)*(TDIST(JJ)-TDIST(J)))))/
     1(AMDA(TDIST(J))-1.8)
  107 DIST(JJ)#DIST(J)-P(J)
  108 IF(NCOUNT)11,11,12
   12 PREK#0.0
      DO 112 I#L,NSTG
  112 PREK#PREK + P(I)
      DO 13 I#1,K
   13 P(I)#P(I)+(PREJ-PREK)/FLOAT(L)
      PREJ#PREK
      GO TO 14
   11 CONTINUE
      PREJ#0.0
      DO 111 I#L,NSTG
  111 PREJ#PREJ + P(I)
      DO 3 I# 1,K
    3 P(I) #(PROD-PREJ)/(FLOAT(K))
   14 CONTINUE
      IF(ABS(P(I)-PO)/P(I)-0.001) 50,50,1
   50 CONTINUE
      CALL SLITE (1)
      NEGT#0
      NCOUNT#NCOUNT+1
      DIST(1)#P(1)
      TDIST(I)#TFB(I)-BPE(I)
      TRB(I)#TDIST(I)-TTD(I)
      Q(I)#P(I)*AMDA(TDIST(I))
      PSIA(I)#PSTEAM(TDIST(I))
C *** DTRB(I)#DTFB(I)+BPERRN
      DTRB(I)# Q(I)/ (CPB(TRB(I),CRECY)*RECY)
      ALMTD(I)#DTRB(I)/(ALOG((TTD(I)+DTRB(I))/TTD(I)))
      U(I)#OVRALU(TRB(I),VILRB,OD,THICK,TDIST(I),1,CRECY)
```

Fig. 8. (Continued)

```
      A(I)#Q(I)/(U(I)*ALMTD(I))
      TOTA#A(I)
C     LOOP TC CALCULATE REST OF HEAT RECOVERY STAGES.  RECOVERY LOOP.
      DO 4 I#2,K
      J# I-1
      FB(I)# FB(J)- P(I)
      C(I) # SALT/FB(I)
      DIST(I)# DIST(J)+P(I)
C *** PRDRAT#CPB(TFB(J),C(I))*FB(J)
C *** DTFB(I)# P(I)*AMDA(TDIST(I))/PRDRAT -BPERRN
C *** PRDRAT#CPB(TDIST(J),0.0)*DIST(J)/PRDRAT+1.0
      CPBAR # (CPB(TFB(J),C(J))+CPB(TDIST(I),C(I)))/2.0
      DTFB(I)# P(I)*(AMDA(TDIST(I))/ CPBAR - BPE(I)) /FB(J)
      TFB(I) # TFB(J)-DTFB(I)
      BPE(I) # DELBP(TFB(I),C(I))
      TDIST(I)#TFB(I)-BPE(I)
      TRB(I)# TRB(J) - DTRB(J)
      TTD(I)# TDIST(I)- TRB(I)
C *** Q(I)    # P(I)* AMDA(TDIST(I)) *PRDRAT
C *** DTRB(I)# DTFB(I) + BPERRN
      Q(I)#P(I)*AMDA(TDIST(I))+DIST(J)*CPB(TDIST(J),0.0)*(TDIST(J)-
     1   TDIST(I))
      DTRB(I)# Q(I)/  (CPB(TRB(I),CRECY)*RECY)
      IF(TTD(I))101,100,102
  100 TTD(I)#0.1
  101 NEGT#I
C     SET NEGT# STAGE NUMBER WHERE TTD NEGATIVE
  102 ALMTD(I)# DTRB(I)/(ALOG((ABS(TTD(I))+DTRB(I))/ABS(TTD(I))))
      U(I)    # OVRALU(TRB(I),VILRB,OD,THICK,TDIST(I),I,CRECY)
      A(I)    # Q(I)/(U(I)*ALMTD(I))
      TOTA    # TOTA + A(I)
    4 CONTINUE
      AVEA # TOTA/FLOAT(K)
      CALL AREADJ(AVEA,1)
      IF(NCOUNT-1) 23,23,24
   23 CONTINUE
      VHREJ# VILRB
   24 CONTINUE
      DO 5 I#1,K
      IF(ABS(AVEA-A(I))/AVEA-0.01) 5,5,6
 0005 CONTINUE
      GO TO 10
 0006 TPROD# 0.0
      AERR# ABS(AVEA-A(I))/AVEA
C *** CCON#(TFB0-TFB(NSTG))* C0/(100.0*RECRAT)
C *** BPERRN# ACCN*( BPE(NSTG) -CCON)
      ISTOP#ISTOP+1
      DO 7 I#1,K
      P(I) # P(I)*(AVEA/A(I) +1.0)/2.0
 0007 TPROD# TPROD + P(I)
      PREC#PROD-PREJ
      IF(ABS(TPROD-PREC)/PREC-.0001) 1,1,8
    8 DO 9 I#1,K
 0009 P(I) # P(I)*PREC/TPROD
      IF(ISTOP-4) 1,1,41
   41 CALL SSWTCH(1,KOOOFX)
      GO TO(42,10),KOOOFX
C     REPLACE FOR DEBUGGING IF DESIRED.
C  42 PRINT 43,      AVEA,AERR
   42 GO TO 10
```

Fig. 8. (Continued)

```
C   43 FORMAT(17H AVERAGE AREA IS  F10.0,18H ERROR IN AREA IS 2PF6.3,29X)
C
C      HEAT REJECTION SECTION
C
   10 CONTINUE
      ISTCP#0
      LOOPI#0
      CALL SLITE (2)
      CPSW # CPB(TSEA,3.5)
      FRSHSW # RECY*CPB(TSEA,CRECY)/CPSW
      WASTE#PROD /(CONRAT-1.0)
      EXCSSW # FRSHSW -WASTE -PROD
      TOTA#0.0
      DO 16 I#L,NSTG
      J#I-1
      FB(I)# FB(J)- P(I)
      C(I) # SALT/FB(I)
      DIST(I)# DIST(J)+P(I)
C *** PRDRAT#CPB(TFB(J),C(I))*FB(J)
C *** DTFB(I)# P(I)*AMDA(TDIST(I))/PRDRAT -BPERRN
C *** PRDRAT#CPB(TDIST(J),0.0)*DIST(J)/PRDRAT+1.0
      CPBAR # (CPB(TFB(J),C(J))+CPB(TDIST(I),C(I)))/2.0
      DTFB(I)# P(I)*(AMDA(TDIST(I))/ CPBAR - BPE(I)) /FB(J)
      TFB(I) # TFB(J)-DTFB(I)
      BPE(I) # DELBP(TFB(I),C(I))
      TDIST(I)#TFB(I)-BPE(I)
      TRB(I)# TRB(J) - DTRB(J)
      TTD(I)# TDIST(I)- TRB(I)
      Q(I)#P(I)*AMDA(TDIST(I))+DIST(J)*CPB(TDIST(J),0.0)*(TDIST(J)-
     1   TDIST(I))
      DTRB(I)# Q(I)/ (CPB(TRB(I), 3.5 )*RECY)
C *** Q(I)    # P(I)* AMDA(TDIST(I)) *PRDRAT
C *** DTRB(I)# DTFB(I) + BPERRN
C      SET NEGT# STAGE NUMBER WHERE TTD NEGATIVE
      IF(TTD(I))301,300,302
  300 TTD(I)#0.1
  301 NEGT#I
  302 ALMTD(I)# DTRB(I)/(ALOG((ABS(TTD(I))+DTRB(I))/ABS(TTD(I))))
   18 U(I)# CVRALU(TRB(I),VHREJ,OD,THICK,TDIST(I),I,3.5)
      A(I)    # Q(I)/(U(I)*ALMTD(I))
      TOTA#TOTA+A(I)
   16 CONTINUE
      AVEA # TOTA/FLOAT(M)
      VREJO#VHREJ
      CALL AREADJ(AVEA,2)
C**22 CCON#(TFBO-TFB(NSTG))* CO/(100.0*RECRAT)
C *** BPERRN# ACON*( BPE(NSTG) -CCON)
   22 IF(ABS(VHREJ-VREJO)/VHREJ-.001) 32,32,1
   32 CONTINUE
  310 CALL SLITE (3)
      CALL ADJRR(NTEST)
      SALT # 3.5*CONRAT*(RECY-PROD)
      CRECY# SALT/RECY
      IF(NTEST) 1,1,33
C      QFIX ADJUSTS PRODUCTION SO TFB(NSTG)#TRB(L)
   33 QFIX#(FRSHSW*CPB(TRB(MID),3.5)*(TFB(NSTG) -TRB(L)))/ FLOAT(M)
      NFIX#NFIX+1
      IF( ABS(TRB(L)-TFB(NSTG)) .LT. 0.01) GO TO 311
C      GO BY IF NOT FIXED IN  3 TRIES.
      IF(NFIX .LT. 4 ) GO TO 1
```

Fig. 8. (Continued)

```
6911 FORMAT( 49H1   CFIX FAILED TO FIX TEMPERATURES IN   3 TRIES.   )    SB032390
     WRITE (6,6911)                                                      SB032400
 311 CALL SLITE (4)                                                      SB032410
C    WRITE A NOTE IF TTD WAS NEGATIVE ON LAST PASS. GET OFF.             SB032420
     IF(NEGT)200,201,200                                                 SB032430
6001 FORMAT( 8H1   NEGT#,I3,34H  LAST STAGE TTD NEGATIVE, GET OFF)       SB032440
 200 WRITE (6,6001) NEGT                                                 SB032450
     STOP                                                                SB032460
 201 M#M                                                                 SB032470
C                                                                        SB032480
C    BRINE HEATER CALCULATION                                            SB032490
C                                                                        SB032500
     TSTM # TSTEAM(PSTM)                                                 SB032510
     DTHEAT# TFBO-TRB(1)                                                 SB032520
     ALMTDH# DTHEAT/(ALOG((TSTM-TRB(1))/(TSTM-TFBO)))                    SB032530
     UHEAT# OVRALU(TFBO,VHEAT,ODH,THICKH,TSTM,0,CRECY)                   SB032540
     AHEAT # QHEAT/(UHEAT*ALMTDH)                                        SB032550
     STEAM # QHEAT/ AMDA(TSTM)                                           SB032560
     DO 21 I#1,NSTG                                                      SB032570
     PSIA(I)# PSTEAM(TDIST(I))                                           SB032580
0021 CFS(I)#CUFTSC(TDIST(I),PSIA(I),P(I))                                SB032590
     XAH#(.785398 *(ODH -2.0*THICKH)**2)/144.0                           SB032600
     TUBESH  # RECY/(224640.0*XAH*VHEAT)                                 SB032610
     TUBELH  # AHEAT/(TUBESH*ODH*0.261799)                               SB032620
     WGT  # TUBES*TUBEL*THICK*(OD-THICK)*11.6532                         SB032630
     WGTR#TUBESR*TUBELR*THICK*(OD-THICK)*11.6532                         SB032640
     WGTH #TUBESH*TUBELH*THICKH*(ODH-THICKH)*11.6532                     SB032650
     CALL HDLOSS(M)                                                      SB032660
     RETURN                                                              SB032670
     END                                                                 SB032680
```

Fig. 8. (Continued)

```
 SB04
C
CADJRR              ADJUSTMENT OF RECYCLE RATIO TO GET FEASIBLE SOLUTION
C
C      PRD     1/19/63          SALINE WATER CONVERSION PLANT
C      2/14/64 DRM ( CATALYTIC )
C
      SUBROUTINE ACJRR(NTEST)
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
      COMMON  A      , ALMTD  , BPE    , C      , CFS    , DIST
      COMMON  DTFB   , DTRB   , FB     , P      , PSIA   , Q
      COMMON  TDIST  , TFB    , TITLE  , TRB    , TTD    , U
      COMMON  ACOST,AHEAT     ,ATTD,BCOST, CCOST,CONRAT
      COMMON  DTHEAT , FCOST  , FOULFC , M      , NSTG   , NTUBES
      COMMON  PCOST  , PROD   , PSTM   , QHEAT  , RECRAT , STEAM
      COMMON  TCOST  , TFBO   , TSEA   , TSTM   , UHEAT  , VCOST
      COMMON  VILRB  , FRSHSW , WASTE  , RECY   , SECONR , ALMTDH
      COMMON  Q000FL, XAMOD  , EQLMOD , NMOD   , PDROP
      EQUIVALENCE (TFBO,TFBO)
      TSEAO # TRB(NSTG)-DTRB(NSTG)
      IF(ABS(TSEAO-TSEA)-0.01 ) 10, 10, 3
    3 RECY#RECY*((TRB(1)-TSEAO)/(TRB(1)-TSEA)+1.0)/2.0
      RECRAT # RECY/PROD
      CALL SSWTCH(1,K000FX)
       GO TO(1,9),K000FX
C     DONT WRITE ON-LINE NOW. REPLACE IF DESIRED FOR DEBUGGING.
C   1 PRINT  2,    TSEAO,TSEA,RECRAT
    1 GO TO 9
    2 FORMAT(  3F15.4,35X)
   10 NTEST #1
    9 RETURN
      END
```

Fig. 8. (Continued)

```
 SB05
C
CGENOPT          GENRAL NON-LINEAR OPTIMIZATION PROGRAM
C                OBJECT IS THE DEPENDENT VARIABLE  (TO BE MAXIMIZIED )
C                NVAR  IS THE NUMBER OF INDEPENT VARIABLES TO BE ADJUSTED
C     X IS THE VECTOR DENOTING THE INSTANTANIOUS VALUE OF EACH IND VAR
C                XMAX IS THE UPPER LIMIT ON EACH X
C                XMIN IS THE LOWER LIMIT ON EACH X
C                DODX IS THE SLOPE FOR EACH X AROUND THE CURRENT POINT
C                ITERAT IS THE NUMBER OF ITERATIONS PERFORMED
C                ERR  IS THE ERROR LIMIT
C                DELX IS THE DELTA FOR EACH X  (ADJUSTMENT)
C                SENSE LIGHT 1 IS TURNED ON WHEN OPTIMUM IS REACHED
C     P R DANFORTH       4/1/63
C
      SUBROUTINE GENOPT( OBJECT,NVAR,X,XMAX,XMIN,DODX,ITERAT,ERR,DELX)
      DIMENSION X(2),XMAX(2),XMIN(2),DODX(2),DELX(2),XSAV(2)
C     DIMENSION X(2),XMAX(2),XMIN(2),DODX(2),DELX(2)
      CALL SLITET(1,KOOOFX)
       GO TO(100,100),KOOOFX
  100 ITERAT # ITERAT +1
      ILAST # ITERAT-1
      IF(ITERAT-NVAR) 1,1,8
C
C     CALCULATE INITIAL SLOPES FOR ALL INDEPENDENT VARIABLES
C
    1 IF(ILAST) 4,4,2
    2 DODX(ILAST) # (OBJECT-OBJO)
      IF(DODX(ILAST)) 3,4,4
    3 X(ILAST)# X(ILAST)- DELX(ILAST)
      DELX(ILAST)#-DELX(ILAST)
      OBJECT # OBJO
      XSAV(ILAST)#X(ILAST)
    4 X(ITERAT)# X(ITERAT) + DELX(ITERAT)
      XSAV(ITERAT)#X(ITERAT)
      IF(X(ITERAT) - XMAX(ITERAT) ) 7,7,5
    5 X(ITERAT)# X(ITERAT) -2.0*DELX(ITERAT)
      IF(X(ITERAT)-XMIN(ITERAT) ) 6,7,7
    6 X(ITERAT)# X(ITERAT) + DELX(ITERAT)
      DELX(ILAST)#-DELX(ILAST)
      OBJO # OBJECT
      GO TO 100
    7 OBJO # OBJECT
      ISET#ILAST
      RETURN
    8 IF(ILAST-NVAR) 9,9,21
    9 DODX(ILAST) # (OBJECT- OBJO)
      IF(DODX(ILAST)) 10,10,11
   10 X(ILAST) # X(ILAST) - DELX(ILAST)
      OBJECT  # OBJO
      DELX(ILAST)#-DELX(ILAST)
      XSAV(ILAST)#X(ILAST)
C
C     CALCULATE STEEPEST ASSENT  (MAXIMUM ABSOLUTE VALUE OF SLOPES )
C
   11 DMIN # DODX(1)
      DMAX#DMIN
      MIN  # 1
      MAX  # 1
```

Fig. 8. (Continued)

```
      DO 15 I#2,NVAR                                                    SB050590
      IF(DODX(I)-DMIN) 12,13,13                                         SB050600
   12 DMIN # DODX(I)                                                    SB050610
      MIN  # I                                                          SB050620
      GO TO 15                                                          SB050630
   13 IF(DODX(I)-DMAX) 15,15,14                                         SB050640
   14 DMAX # DODX(I)                                                    SB050650
      MAX  # I                                                          SB050660
   15 CONTINUE                                                          SB050670
      IF(DMAX +DMIN) 16,25,18                                           SB050680
   16 X(MIN) # X(MIN) + DELX(MIN)                                       SB050690
      N# MIN                                                            SB050700
      IF(X(MIN)-XMIN(MIN)) 17,30,30                                     SB050710
   30 IF(X(MIN)-XMAX(MIN)) 20,20,31                                     SB050720
   31 X(MIN) # XMAX(MIN)                                                SB050730
      GO TO 37                                                          SB050740
   17 X(MIN)# XMIN(MIN)                                                 SB050750
   37 DODX(MIN) # 0.0                                                   SB050760
      GO TO 11                                                          SB050770
   18 X(MAX) # X(MAX) + DELX(MAX)                                       SB050780
      N# MAX                                                            SB050790
      IF(X(MAX)-XMIN(MAX)) 32,32,33                                     SB050800
   32 X(MAX) # XMIN(MAX)                                                SB050810
      GO TO 38                                                          SB050820
   33 CONTINUE                                                          SB050830
      IF(X(MAX)-XMAX(MAX)) 20,20,19                                     SB050840
   19 X(MAX)# XMAX(MAX)                                                 SB050850
   38 DODX( MAX) #0.0                                                   SB050860
      GO TO 11                                                          SB050870
   20 OBJO # OBJECT                                                     SB050880
      RETURN                                                            SB050890
C                                                                       SB050900
C     CHECK FOR OPTIMUM  ( SUM OF ABSF(SLOPES) LESS THAN ERROR LIMIT)   SB050910
C                                                                       SB050920
   21 N#N                                                               SB050930
      DODX(N) # CBJECT- OBJO                                            SB050940
      IF(DODX(N)) 22,36,36                                              SB050950
   36 XSAV(N)#X(N)                                                      SB050960
      GOTO 23                                                           SB050970
   22 IF(XSAV(N)-X(N))34,35,34                                          SB050980
   35 DODX(N)#0.                                                        SB050990
      GO TO 23                                                          SB051000
   34 X(N)# X(N)-DELX(N)                                                SB051010
      OBJECT#OBJO                                                       SB051020
      IF(ISET-ILAST) 26,27,28                                           SB051030
   26 ISET#ITERAT                                                       SB051040
      DELX(N)# DELX(N)/5.0                                              SB051050
      GO TO 23                                                          SB051060
   27 DELX(N)# -DELX(N)                                                 SB051070
      ISET#ITERAT+1                                                     SB051080
      GO TO 23                                                          SB051090
   28 DOMIN # 2.0*ERR/FLOAT(NVAR)                                       SB051100
      DODX(N)# AMIN1(ABS(DODX(N)),DOMIN)                                SB051110
      DELX (N) #-DELX(N)/5.0                                            SB051120
   23 SUMDC #0.0                                                        SB051130
      DO 24 I#1,NVAR                                                    SB051140
   24 SUMDO # SUMDC + ABS(DODX(I))                                      SB051150
      IF(SUMDC -ERR) 25,25,11                                           SB051160
C                                                                       SB051170
C     OPTIMUM SOLUTION   TURN ON SENSE LIGHT 1                          SB051180
```

Fig. 8. (Continued)

```
C
   25 CALL SLITE (1)
      RETURN
      END
```

```
 SB06
C
CCOST          ECCNCMIC ANALYSIS OF PREVIOUS OSW RUNS
C
C      PRD    4/1/63          OSW SALINE WATER CONVERSION PLANT,  4427-9
C      2/14/64 DRM ( CATALYTIC )
C
C      30 YEAR AMCRTIZATION CASE       5/13/63
       SUBRCUTINE COST(NCASE,IOUT)
       DIMENSION EXTRA(1767)
       DIMENSION N(100),T(100),AC(100),R(100),DPR(100),DPS(100),AH(100),
      1STM(100),NPRES(100),S(100)
       DIMENSION TITLE(12)
       DIMENSION TVCST(100,5)
       COMMCN  EXTRA
       COMMCN  N       , T      , AC      , R       , DPR     , S
       COMMCN  DPS     , AH     , STM     , NPLANT , NPRES   , TOTAL
       EQUIVALENCE (CONRAT,EXTRA(1718)),(TFBO,EXTRA(1732))
       EQUIVALENCE (PROD,EXTRA(1726)),(TSTM,EXTRA(1734))
       EQUIVALENCE (TF80,TFBO)
       GPD#PRCD*2.88E-6
       I F(NPLANT) 10,10,11
   10  READ           (5,100)PLANT,ACOST,BCOST,CCOST,DCOST,ECOST,FCOST,G
       NPLANT#PLANT
       IF(NPLANT) 38,38,39
   38  CALL SLITE(3)
       RETURN
   39  READ(5,101)(TITLE(I),I#1,12)
       READ           (5,105)Q000FL,Z,FCOSTM,ZX,FLOAD
       F#FLOAD/0.80
C      READ FLOAD FRCM CARD 8. FRACTION OF TIME OPERATED. MAX# 1.0
C      F IS RATIO TC 0.8 SINCE 0.8 IS ALREADY PUT INTO MANY CONSTANTS.
   11  IF(IOUT) 50,9,17
    9  I#NCASE-1
       STRCST #  ECCST*FLOAT(N(I)-NPRES(I)) +G*FLOAT(NPRES(I))
       CONDAC #  CCCST*AC(I)
       CONC#(1.0-PROD/R(I))*CONRAT
       CONPHP#PROD*89.2E-6 +
      1 (DPS(I)*(S(I)-PROD*CONRAT/(CONRAT-1.0))/SPGRV(1.0))/728432.7
       PUMPHP#CONPHP+(DPR(I)*R(I)/SPGRV(CONC))/728432.7
       PMPCST#FCOST*PUMPHP+(FCOSTM-FCOST)*CONPHP
       HAREAC # HTCOST(DCOST,STM(I),TSTM,AH(I)) *AH(I)
       TOTCAP # STRCST + CONDAC + PMPCST + HAREAC+Z*1.0E+6
       TOTCAP#TOTCAP*(1.364-TOTCAP*1.4E-9)
       TOTCAP#TOTCAP*(1.0+(75.0+GPD)*0.0175/90.0)
       STMCST#ACOST*STM(I)*AMDA(TSTM)*210.24E-3 *F
       POWCST # PUMPHP*BCOST *156815.97 *F
       CAP30Y#TOTCAP*0.30*Q000FL
       TOTAL  #  STMCST + POWCST + CAP30Y +ZX*30.0E+6
       TVCST(I,1)#TOTAL
       TVCST(I,2)#STMCST
       TVCST(I,3)#POWCST
       TVCST(I,4)#CAP30Y
       TVCST(I,5)#TOTCAP
       CALL SSWTCH(2,K000FX)
        GO TO(19,22),K000FX
C      DONT PRINT ONLINE NOW. REPLACE IF DESIRED.
C  19  PRINT  102,    TOTAL,N(I),T(I)
   19  GO TO 22
```

Fig. 8. (Continued)

```
   17 WRITE (6,1)
      NCASE#NCASE-1
      WRITE (6,2)(TITLE(I),I#1,12)
      WRITE (6,5) GPD,Q000FL
      WRITE (6,6) ACOST,BCOST,CCOST,DCOST,ECOST,FCOST,FCOSTM,Z,ZX
      DO 12 I#1,NCASE
      IF(NPRES(I))12,12,13
   12 CONTINUE
      GO TO 24
   13 WRITE (6,7)G
   24 WRITE (6,3)
   14 DO 21 I#1,NCASE
      STRCST #  ECCST*FLOAT(N(I)-NPRES(I)) +G*FLOAT(NPRES(I))
      CONDAC #  CCOST*AC(I)
      CONC#(1.0-PRCD/R(I))*CONRAT
      CONPHP#PROC*89.2E-6 +
     1 (DPS(I)*(S(I)-PROD*CONRAT/(CONRAT-1.0))/SPGRV(1.0))/728432.7
      PUMPHP#CONPHP+(DPR(I)*R(I)/SPGRV(CONC))/728432.7
      PMPCST#FCOST*PUMPHP+(FCOSTM-FCOST)*CONPHP
      HAREAC # HTCCST(DCOST,STM(I),TSTM,AH(I)) *AH(I)
      TOTCAP # STRCST + CONDAC + PMPCST + HAREAC+Z*1.0E+6
      TOTCAP#TOTCAP*(1.364-TOTCAP*1.4E-9)
      TOTCAP#TOTCAP*(1.0+(75.0+GPD)*0.0175/90.0)
      STMCST#ACOST*STM(I)*AMDA(TSTM)*210.24E-3 *F
      POWCST # PUMPHP*BCOST *156815.97 *F
      CAP30Y#TOTCAP*0.30*Q000FL
      TOTAL  #  STMCST + POWCST + CAP30Y +ZX*30.0E+6
      TVCST(I,1)#TCTAL
      TVCST(I,2)#STMCST
      TVCST(I,3)#POWCST
      TVCST(I,4)#CAP30Y
      TVCST(I,5)#TCTCAP
      IF(I-51) 20,16,20
   16 WRITE (6,3)
   20 WRITE (6,4)NPLANT,I,N(I),T(I),STRCST,AC(I),CONDAC,PUMPHP,PMPCST,AH
     1(I),HAREAC,TCTCAP,STMCST,POWCST,CAP30Y,TOTAL
   21 CONTINUE
   22 RETURN
   50 TOTAL#1.0E+20
      DO 52 I#1,NCASE
      IF(TVCST(I,1)-TOTAL) 51,52,52
   51 K000FX#I
      TOTAL#TVCST(I,1)
   52 CONTINUE
      NCASE#K000FX
      WRITE (6,1)
      WRITE (6,2) (TITLE(I),I#1,12)
      WCST#TCTAL/(30.0*365.0*0.80*GPD*1000.0*F)
      WRITE (6,60) NPLANT,NCASE,N(NCASE),T(NCASE),WCST
C     DELETE PNCHC WHICH PRINTS ON LINE OR PUNCHES CARD.
C*    CALL PNCHC(Q000FL,ACOST,BCOST,N(NCASE),T(NCASE),WCST,STM(NCASE),
C*   1   GPD,TVCST(NCASE,1),TVCST(NCASE,2),TVCST(NCASE,3),TVCST(NCASE,4)
C*   2   ,TVCST(NCASE,5) )
      RETURN
   60 FORMAT(//30X,5HPLANT I3,6H, CASE I3,18H IS OPTIMUM DESIGN
     1 10H IN MATRIX//29X,I3,11H STAGES AND F6.2,5H TTD.   //
     2  30X,15HWATER COST IS $ F6.3,5H/MGAL  //)
    1 FORMAT(1H1,44X,30HCATALYTIC CONSTRUCTION COMPANY / 45X,
     1  27HPHILADELPHIA,  PENNSYLVANIA   )
    2 FORMAT(    45X,33HOSW SALINE WATER CONVERSION STUDY/ 45X,
```

Fig. 8. (Continued)

```
  1 45HCATALYTIC CONSTRUCTION COMPANY CONTRACT 4084C/        45X,      SB061190
  2 53H# CRIGINAL BECHTEL PROGRAM AS MODIFIED BY CATALYTIC #            SB061200
  3 //45X,12A6//)                                                      SB061210
 3 FORMAT(120H1                      STRUCT-  COND.   COST    TOTAL   TSB061220
  1OTAL    BRINE HEATER    TOTAL    STEAM    POWER  CAPITAL    TOTAL   SB061230
  2   /    120H  CASE  NO.    TTD     URE     AREA     OF       PUMP  PSB061240
  3UMP    --------------- CAPITAL  COST    COST    COST     COST      SB061250
  4   /    120H         STA-          COST              TUBES    H.P.  CSB061260
  5OST     AREA    COST     COST    MM $     MM $    MM $      MM $    SB061270
  6   /    120H    NO.  GES    DEG F.  MM $    MMSQFT  MM $      M HP  MSB061280
  7M $     M SCFT  MM $     MM $     30 YRS   30 YRS  30 YRS   30 YRS  SB061290
  8   /1H )                                                            SB061300
 4 FORMAT( 1H   I2,     I3,     I5,      F7.1,      -6P  F9.2,2F8.2,-3P SB061310
  1F8.1,     -6PF8.3,       -3PF8.1,       -6PF8.3,      F8.2,     F8.1, SB061320
  2       F8.2,      F8.1,       F10.2)                                SB061330
 5 FORMAT(29X,F6.1,40H MMGAL/DAY WATER PLANT - ECONOMIC STUDY ///      SB061340
  1 30X,20HCOST BASIS FOR STUDY ///30X,                                SB061350
  2 27HFIXED CHARGES CALCULATED AT F6.2,8H PERCENT //)                 SB061360
 6 FORMAT(30X,18HCOST OF STEAM IS $  F5.3,                             SB061370
  16H/MMBTU//30X,18HCOST OF POWER IS $ F7.5,4H/KWH ///30X,30HCOST OF  SB061380
  2CONDENSER SURFACE IS $ F5.3,5H/SQFT  //30X,                         SB061390
  3  28HMAXIMUM BRINE HEATER LOAD IS F6.0,18H MMBTU/HR PER UNIT        SB061400
  4 //30X,33HCOST OF CONCRETE EVAPORATORS IS $ F8.C,6H/STAGE//30X,     SB061410
  526HCOST OF RECYCLE PUMPS IS $F6.2,19H/HP,  OTHER PUMPS $F7.2,3H/HPSB061420
  6  //                                                                SB061430
  7 30X,35HOTHER FIXED CAPITAL INVESTMENT IS $F9.4,8H MILLION //       SB061440
  8 30X,27HOTHER OPERATING COSTS ARE $ F9.4,11H MILLION/YR  //)        SB061450
 7 FORMAT(30X,30HCOST OF STEEL EVAPORATORS IS $ F8.C,6H/STAGE /        SB061460
  1 30X,55HFOR EACH STAGE WITH THE PRESSURE GREATER THAN 16.0 PSIA//)SB061470
 8 FORMAT(1H1 )                                                        SB061480
100 FORMAT(8F9.0)                                                      SB061490
101 FORMAT(12A6 )                                                      SB061500
102 FORMAT(13H TCTAL COST#$ -6PF9.4,12H MILLION, AT I4, 8H STAGES,  OPSB061510
  1F6.3, 7H F TTC ,21X)                                                SB061520
105 FORMAT(5F9.0)                                                      SB061530
    END                                                                SB061540
```

Fig. 8. (Continued)

```
 SB07
C
COVRALU        FUNCTION TO CALCULATE OVERALL HEAT TRANSFER COEFFICIENT
C              OF CONDENSING TUBES         U# F(T),  T  DEG F.
C
C       2/14/64 DRM ( CATALYTIC )
C       PRD      1/14/63
        FUNCTICN  OVRALU(T,V,OD,TH,G)
        DIMENSION TITLE(12),FB(100),DIST( 100),C(1C0),P(100),PSIA(100),CFS(
      1100),BPE(100),TFB(100),TRB( 100),TDIST(100),TTD(100),ALMTD(100),Q(1
      200),U(100),A(100),DTRB(100),DTFB(100)
        COMMCN  A      , ALMTD  , BPE    , C       , CFS    , DIST
        COMMCN  DTFB   , DTRB   , FB     , P       , PSIA   , Q
        COMMCN  TDIST  , TFB    , TITLE  , TRB     , TTD    , U
        COMMCN ACOST,AHEAT      ,ATTD,BCOST, CCOST,CONRAT
        COMMCN  DTHEAT , FCOST  , FOULFC , M       , NSTG   , NTUBES
        COMMCN  PCOST  , PROD   , PSTM   , QHEAT   , RECRAT , STEAM
        COMMCN  TCOST  , TFBO   , TSEA   , TSTM    , UHEAT  , VCOST
        COMMCN  VILRB  , FRSHSW , WASTE  , RECY    , SECONR , ALMTDH
        COMMCN QOODFL,XAMOD,EQLMOD,NMOD,PDROP,ODX5
        COMMCN  ODH    , TUBEL  , TUBELH , TUBES   , TUBESR , TUBESH
        COMMCN  VHREJ  , VHEAT  , WGT    , WGTR    , WGTH   , PDROPR
        COMMCN  PDROPH , THICK  , THICKH , VELHDR  , HDREQL , TPDROP
        EQUIVALENCE (TFBO,TFBO)
        FOULFC #  ACCST + BCOST*T
        X3#(((G*.6206744E-12-.430046E-9)*G+.999077E-7)*G-.7473939E-5)*G
        X3#X3+.1024768E-02
        X1#(160.0+1.92*T)*V/((V*(OD-TH-TH))**0.2)
        OVRALU #1.0/(X3+1.0/X1)
        RETURN
        END
```

Fig. 8. (Continued)

```
 SB08
C
CINPUT          INPUT ROUTINE FOR OSW SALINE WATER CONVERSION PLANT
C
C      PRD       1/7/63
C      2/14/64 DRM ( CATALYTIC )
C
      SUBROUTINE INPUT
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
      COMMCN  A      , ALMTD  , BPE    , C      , CFS    , DIST
      COMMCN  DTFB   , DTRB   , FB     , P      , PSIA   , Q
      COMMCN  TDIST  , TFB    , TITLE  , TRB    , TTD    , U
      COMMCN ACOST,AHEAT      ,ATTD,BCOST, CCOST,CONRAT
      COMMCN  DTHEAT , FCOST  , FOULFC , M      , NSTG   , NTUBES
      COMMCN  PCOST  , PROD   , PSTM   , QHEAT  , RECRAT , STEAM
      COMMCN  TCCST  , TFBO   , TSEA   , TSTM   , UHEAT  , VCOST
      COMMCN  VILRB  , FRSHSW , WASTE  , RECY   , SECONR , ALMTDH
      COMMCN  Q000FL, XAMOD  , EQLMOD , NMOD   , PDROP  , OD
      COMMCN  ODH    , TUBEL  , TUBELH , TUBES  , TUBESR , TUBESH
      COMMCN  VHREJ  , VHEAT  , WGT    , WGTR   , WGTH   , PDROPR
      COMMCN  PDRCPH , THICK  , THICKH , VELHDR , HDREQL , TPDROP
      COMMCN  TUBELR
      EQUIVALENCE (TFBO,TFBO)
    1 READ          (5,10)  (TITLE(I),I#1,12)
      READ          (5,11)  PROD,TFBO,TSEA,CONRAT,RECRAT,ATTD,PSTM,NSTG
      IF(PROD) 3,3,2
    3 STOP
C     READ TUBELR INTO COMMON FROM CARD 3, COL 61-70. RMK  4/7/65
    2 READ          (5,11)  OD,THICK,TUBEL,ODH,THICKH,VHEAT,TUBELR,M
C     READ M INTO COMMON FROM CARD 3. COL 71-72. RMK 6/10/65
      READ          (5,13)  VILRB,FCOLD,FHOT,HDREQL,NTUBES
C     FCOLD, FHOT ARE NOT USED IN HEAT TRANSFER COEFFICIENT.
      PROD#PROD/2.88
      ATUBE # TUBEL*OD*0.261799
      BCOST # (FHOT-FCOLD)/(TFBO-TSEA)
      ACOST # FHOT - BCOST*TFBO
 0010 FORMAT(12A6)
 0011 FORMAT(7F10.4,I2)
 0012 FORMAT(7F10.4)
   13 FORMAT(4F10.4,2I5)
      RETURN
      END
```

Fig. 8. (Continued)

```
 SB09                                                                     SB090000
C                                                                         SB090010
CAREADJ            ADJUSTMENT OF AREA TO GET CONSTANT MODULAR AREA        SB090020
C                                                                         SB090030
C     PRD        1/18/63                                                  SB090040
C     2/14/64 DRM ( CATALYTIC )                                           SB090050
C                                                                         SB090060
      SUBROUTINE AREADJ(AVEA,N)                                           SB090070
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(SB090080
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1 SB090090
     200),U(100),A(100),DTRB(100),DTFB(100)                               SB090100
      COMMON  A      , ALMTD  , BPE    , C      , CFS    , DIST           SB090110
      COMMON  DTFB   , DTRB   , FB     , P      , PSIA   , Q              SB090120
      COMMON  TDIST  , TFB    , TITLE  , TRB    , TTD    , U              SB090130
      COMMON ACOST,AHEAT      ,ATTD,BCOST, CCOST,CONRAT                   SB090140
      COMMON  DTHEAT , FCOST  , FOULFC , M      , NSTG   , NTUBES         SB090150
      COMMON  PCOST  , PROD   , PSTM   , QHEAT  , RECRAT , STEAM          SB090160
      COMMON  TCOST  , TFBO   , TSEA   , TSTM   , UHEAT  , VCOST          SB090170
      COMMON  VILRB  , FRSHSW , WASTE  , RECY   , SECONR , ALMTDH         SB090180
      COMMON  QOOOFL, XAMOD  , EQLMOD , NMOD   , PDROP  , OD              SB090190
      COMMON  ODH    , TUBEL  , TUBELH , TUBES  , TUBESR , TUBESH         SB090200
      COMMON  VHREJ  , VHEAT  , WGT    , WGTR   , WGTH   , PDROPR         SB090210
      COMMON  PDROPH , THICK  , THICKH , VELHDR , HDREQL , TPDROP         SB090220
      COMMON  TUBELR                                                      SB090230
      EQUIVALENCE (TFBO,TFBO)                                             SB090240
C     TUBELR#TUBEL                NO LONGER EQUAL     RMK  4/7/65         SB090250
      ATUBE# TUBEL*OD*0.261799                                            SB090260
      RTUBE#TUBELR*OD*0.261799                                            SB090270
      R # OD/2.0-THICK                                                    SB090280
      XAREA # 3.141592*R*R                                                SB090290
      GO TO ( 1,2),N                                                      SB090300
 0001 TUBES #  AVEA/ATUBE                                                 SB090310
      TXAREA# XAREA* TUBES /144.0                                         SB090320
      VILRB # RECY/(TXAREA*224640.0)                                      SB090330
      RETURN                                                              SB090340
 0002 TUBESR#  AVEA/RTUBE                                                 SB090350
      TXAREA# XAREA*TUBESR /144.0                                         SB090360
      VHREJ # FRSHSW/(TXAREA*224640.0)                                    SB090370
      IF(VHREJ-7.0) 4,4,3                                                 SB090380
    3 VHREJ#7.0                                                           SB090390
      TXAREA#FRSHSW/(VHREJ*224640.0)                                      SB090400
      TUBESR# 144.0*TXAREA/XAREA                                          SB090410
      RTUBE#AVEA/TUBESR                                                   SB090420
      TUBELR#RTUBE/(OD*0.261799)                                          SB090430
    4 CONTINUE                                                            SB090440
      RETURN                                                              SB090450
      END                                                                 SB090460
```

Fig. 8. (Continued)

```
 SBIO
C
CFINOUT        FINAL OUTPUT OF SALINE WATER CONVERSION PLANT
C
C      PRD    1/14/63
C      2/14/64 DRM ( CATALYTIC )
C
       SUBROUTINE FINOUT
       DIMENSION TITLE(12),FB(100),DIST( 100),C( 100),P( 100),PSIA(100),CFS(
      1100),BPE(100),TFB(100),TRB( 100),TDIST( 100),TTD( 100),ALMTD(100),Q(1
      200),U(100),A(100),DTRB( 100),DTFB( 100)
       COMMON  A      , ALMTD  , BPE    , C      , CFS     , DIST
       COMMON  DTFB   , DTRB   , FB     , P      , PSIA    , Q
       COMMON  TDIST  , TFB    , TITLE  , TRB    , TTD     , U
       COMMON ACOST,AHEAT       ,ATTD,BCOST, CCOST,CONRAT
       COMMON  DTHEAT , FCOST  , FOULFC , M      , NSTG    , NTUBES
       COMMON  PCOST  , PROD   , PSTM   , QHEAT  , RECRAT  , STEAM
       COMMON  TCOST  , TFBO   , TSEA   , TSTM   , UHEAT   , VCOST
       COMMON  VILRB  , FRSHSW , WASTE  , RECY   , SECONR  , ALMTDH
       COMMON  QOOOFL, XAMOD  , EQLMOD , NMOD   , PDROP  , OD
       COMMON  ODH    , TUBEL  , TUBELH , TUBES  , TUBESR  , TUBESH
       COMMON  VHREJ  , VHEAT  , WGT    , WGTR   , WGTH    , PDROPR
       COMMON  PDROPH , THICK  , THICKH , VELHDR , HDREQL  , TPDROP
       COMMON  TUBELR
       EQUIVALENCE (TFB0,TFBO)
       RECY # RECRAT*PROD
       ASUBT#PROD*2.88E-6 +0.005
       ASSUB#0.0
       WRITE (6,1)
       WRITE (6,2)(TITLE(I),I#1,12)
       WRITE (6,3)ASUBT,PROD,RECRAT,CONRAT,NSTG,TFBO,TSEA,ATTD
       WRITE (6,4)
       ASUBT#0.0
       K# NSTG-M
       L# K+1
       DO 20 I#1,K
 0020  WRITE (6,5)I,FB(I),DIST(I),RECY,C( I),P( I),PSIA(I),CFS(I),BPE(I)
       WRITE (6,6)
       DO 21 I#L,NSTG
 0021  WRITE (6,5)I,FB(I),DIST(I),FRSHSW,C( I),P( I),PSIA(I),CFS(I),BPE(I)
       WRITE (6,7)
       DO 22 I#1,K
       WRITE (6,8)I,TFB(I),TDIST(I),TRB( I),TTD(I),ALMTD(I),Q(I),U(I),A(I)
 0022  ASUBT# ASUBT+A(I)
       WRITE (6,9)A SUBT
       DO 23 I#L,NSTG
       WRITE (6,8)I,TFB(I),TDIST(I),TRB( I),TTD(I),ALMTD(I),Q(I),U(I),A(I)
       ASUBT#ASUBT+A(I)
 0023  ASSUB#ASSUB+A(I)
       WRITE (6,10)ASSUB,ASUBT
       WRITE (6,11)
       WRITE (6,12)PSTM,TSTM,DTHEAT, ALMTDH,UHEAT,QHEAT,AHEAT
       SECONR# PROD/STEAM
       WRITE (6,13)STEAM,SECONR
       WRITE (6,14)TUBES,VILRB,PDROP,TUBEL,OD,THICK,WGT
       WRITE (6,15)TUBESR,VHREJ,PDROPR,TUBELR,OD,THICK,WGTR
       WRITE (6,16)TUBESH,VHEAT,PDROPH,TUBELH,ODH,THICKH,WGTH
       WRITE (6,17)TPDROP
```

Fig. 8. (Continued)

```
      RETURN                                                            SBI00590
    1 FORMAT(1H1,44X,30HCATALYTIC CONSTRUCTION COMPANY //45X,           SBI00600
     1  27HPHILADELPHIA,   PENNSYLVANIA //)                             SBI00610
    2 FORMAT(     45X,33HOSW SALINE WATER CONVERSION STUDY//45X,        SBI00620
     1 45HCATALYTIC CONSTRUCTION COMPANY CONTRACT 4C840//       45X,    SBI00630
     2 53H# CRIGINAL BECHTEL PROGRAM AS MODIFIED BY CATALYTIC #         SBI00640
     3 //45X,12A6//)                                                    SBI00650
 0003 FORMAT( 25X,11HPRODUCTION                                          SBI00660
     1 F6.1,11H MMGAL/DAY,F14.0,8H LBS/HR.//25X,13HRECYCLE RATIO F6.2,  SBI00670
     215H LBS/LB PRCDUCT //25X,20HCONCENTRATION RATIO  F5.2,28H, TOTAL NSBI00680
     3UMBER CF STAGES IS I3// 25X,51HTEMPERATURE OF FLASHING BRINE FROM SBI00690
     4BRINE HEATER IS F6.2, 8H DEG F. //25X,25HSEA WATER TEMPERATURE IS SBI00700
     5F6.2,26H DEG F.   APPROXIMATE TTD  F6.2, 8H DEG F. //)            SBI00710
 0004 FORMAT(120H STAGE   FLASHING    DISTILLATE     RECYCLE     CONCENSBI00720
     1TRATION  PRODUCTION      PRESSURE     VAPOR FLOW    BOILING POINT  /SBI00730
     2 120H  NO.  BRINE,MLB/HR   PROD,MLB/HR  BRINE,MLB/HR     WT. PERCENSBI00740
     3T  M LB/HR           PSIA          CU FT/SEC       ELEV. DEG F.      /)SBI00750
    5 FORMAT(I3,7X,-3P3(F10.0,4X),0PF10.4,4X,-3PF10.0,4X,0PF10.4,4X,F10.SBI00760
     12,4X,F10.4)                                                       SBI00770
    6 FORMAT(45X,23HHEAT REJECTION SECTION / 34X,16H  RAW SEA WATER  /) SBI00780
 0007 FORMAT(120HISTAGE TEMP FLASHING  TEMP  DIST    TEMP RECYCLE   TERMISBI00790
     1NAL TEMP LOG MEAN TEMP HEAT TRANSFER   OVERALL U        AREA      /SBI00800
     2 120H  NO.  BRINE, DEG F   PROD, DEG F  BRINE, DEG F  DIFFERENCE, SBI00810
     3F DIFFERENCE, F  MBTU/STAGE    BTU/FT2/F/HR      SQ FT/STAGE      /)SBI00820
 0008 FORMAT(1X,I5,3(F10.2,4X),2(F10.4,4X),-3PF10.0,4X,0PF10.2,4X,F10.0)SBI00830
 0009 FORMAT( 93X,11HTOTAL AREA  F10.0 / 45X,22HHEAT REJECTION SECTION/)SBI00840
 0010 FORMAT( 93X,11HTOTAL AREA  F10.0// 87X,17HGRAND TOTAL AREA  F10.0)SBI00850
 0011 FORMAT( 1H1,44X,18HBRINE HEATER DATA //)                          SBI00860
 0012 FORMAT(  20X,15HSTEAM PRESSURE  F6.1,25H PSIA, STEAM TEMPERATURE  SBI00870
     1F6.1, 8H DEG F.  /20X,41HTEMPERATURE RISE OF BRINE THROUGH HEATER SBI00880
     2 F7.3,41H DEG F.  LOG MEAN TEMPERATURE DIFFERENCE  F7.3 / 20X,35HOSBI00890
     3VERALL HEAT TRANSFER COEFFICIENT    F8.2,14H BTU/FT2/F/HR   /20X,30HSBI00900
     4HEAT REQUIREMENT OF HEATER IS -6PF11.3,41H MMBTU/HR, AREA REQUIREMSBI00910
     5ENT OF HEATER IS 0PF8.0,7H SQ.FT. //)                             SBI00920
 0013 FORMAT( 20X,18HSTEAM REQUIREMENT  F10.0, 6H LB/HR /20X,23HSTEAM ECSBI00930
     1ONCMY RATIO IS F6.2,22H LBS PRODUCT/LB STEAM //)                  SBI00940
   14 FORMAT( 1H0 44X,11HDESIGN DATA //45X 21HHEAT RECOVERY SECTION //20SBI00950
     1X,28HNUMBER CF TUBES PER STAGE IS F7.0/20X,37HVELOCITY OF RECYCLE SBI00960
     2BRINE IN TUBES IS F7.3, 8H FT/SEC / 20X,37HPRESSURE DROP THROUGH TSBI00970
     3HIS SECTION IS F8.2, 5H PSI  / 20X,18HLENGTH OF TUBES IS F6.2,6H FSBI00980
     4EET / 20X,29HOUTSIDE DIAMETER OF TUBES IS F6.4, 7H INCHES / 20X,27SBI00990
     5HWALL THICKNESS OF TUBES IS F6.4, 7H INCHES / 20X,38HTOTAL WEIGHT SBI01000
     6OF TUBES IN EACH STAGE IS F9.0, 7H POUNDS  //)                    SBI01010
   15 FORMAT(1H0 44X,23HHEAT REJECTION SECTION //                     20SBI01020
     1X,28HNUMBER CF TUBES PER STAGE IS F7.0/20X,37HVELOCITY OF RAW SEA SBI01030
     2WATER IN TUBES IS F7.3, 8H FT/SEC / 20X,37HPRESSURE DROP THROUGH TSBI01040
     3HIS SECTION IS F8.2, 5H PSI  / 20X,18HLENGTH OF TUBES IS F6.2,6H FSBI01050
     4EET / 20X,29HOUTSIDE DIAMETER OF TUBES IS F6.4, 7H INCHES / 20X,27SBI01060
     5HWALL THICKNESS OF TUBES IS F6.4, 7H INCHES / 20X,38HTOTAL WEIGHT SBI01070
     6OF TUBES IN EACH STAGE IS F9.0, 7H POUNDS  //)                    SBI01080
   16 FORMAT(1H0 44X,13HBRINE HEATER          //              20X,34HTOSBI01090
     1TAL NUMBER OF TUBES IN HEATER IS  F7.0/20X,37HVELOCITY OF RECYCLE SBI01100
     2BRINE IN TUBES IS F7.3, 8H FT/SEC / 20X,37HPRESSURE DROP THROUGH TSBI01110
     3HIS SECTION IS F8.2, 5H PSI  / 20X,18HLENGTH OF TUBES IS F6.2,6H FSBI01120
     4EET / 20X,29HOUTSIDE DIAMETER OF TUBES IS F6.4, 7H INCHES / 20X,27SBI01130
     5HWALL THICKNESS OF TUBES IS F6.4, 7H INCHES / 20X,40HTOTAL WEIGHT SBI01140
     6OF TUBES IN BRINE HEATER IS F9.0, 7H POUNDS  //)                  SBI01150
   17 FORMAT(20X,33HTOTAL RECYCLE BRINE PUMP HEAD IS F8.2, 5H PSI //)   SBI01160
      END                                                               SBI01170
```

Fig. 8. (Continued)

```
 SB11
C
CHDLOSS         SUBROUTINE TO CALCULATE HEAD LOSS IN RECYCLE PUMP
C
C      PRD        1/24/63           OSW SALINE WATER CONVERSION PLANT
C      2/14/64 DRM ( CATALYTIC )
C
      SUBROUTINE HDLOSS(M)
      DIMENSION TITLE(12),FB(100),DIST(100),C(100),P(100),PSIA(100),CFS(
     1100),BPE(100),TFB(100),TRB(100),TDIST(100),TTD(100),ALMTD(100),Q(1
     200),U(100),A(100),DTRB(100),DTFB(100)
      COMMON  A      , ALMTD  , BPE    , C      , CFS    , DIST
      COMMON  DTFB   , DTRB   , FB     , P      , PSIA   , Q
      COMMON  TDIST  , TFB    , TITLE  , TRB    , TTD    , U
      COMMON ACOST,AHEAT      ,ATTD,BCOST, CCOST,CONRAT
      COMMON DTHEAT,FCOST,FOULFC,MX5,NSTG,NTUBES
      COMMON  PCOST  , PROD   , PSTM   , QHEAT  , RECRAT , STEAM
      COMMON  TCOST  , TFB0   , TSEA   , TSTM   , UHEAT  , VCOST
      COMMON  VILRB  , FRSHSW , WASTE  , RECY   , SECONR , ALMTDH
      COMMON  Q000FL, XAMOD  , EQLMOD , NMOD   , PDROP  , OD
      COMMON  ODH    , TUBEL  , TUBELH , TUBES  , TUBESR , TUBESH
      COMMON  VHREJ  , VHEAT  , WGT    , WGTR   , WGTH   , PDROPR
      COMMON  PDROPH , THICK  , THICKH , VELHDR , HDREQL , TPDROP
      COMMON  TUBELR
      EQUIVALENCE (TFB0,TFBO)
      L#NSTG-M
      TSUM#0.0
      DO 1 I#1,L
    1 TSUM#TSUM+TFB(I)**(-0.252)
      DIAM#((OD-2.0*THICK)/12.0)**(-1.206)
      PDROP# 0.00041622*TUBEL*DIAM*TSUM*(VILRB**1.794)
      CONC#(RECRAT-1.0)*CONRAT/RECRAT
      PDROP#PDROP+VILRB*VILRB*SPGRV(CONC)*FLOAT(L)/49.6+17.3
      L#L+1
      TSUM#0.0
      DO 2 I#L,NSTG
    2 TSUM#TSUM+TFB(I)**(-0.252)
      PDROPR# 0.00041622*TUBELR*DIAM*TSUM*(VHREJ**1.794)
      PDROPR#PDROPR+VHREJ*VHREJ*SPGRV(1.0)*FLOAT(M)/49.6+14.6
      DIAM#((ODH-2.0*THICKH)/12.0)**(-1.206)
      HLOSSH#        (TUBELH*DIAM*(VHEAT**1.794)/(TFB0**.252))*.00041622
      PDROPH#HLOSSH+(HDREQL+VHEAT*VHEAT/21.448)*SPGRV(CONC)/2.31
      TPDROP# PSIA(1)-PSIA(NSTG)+PDROPH+PDROP
      RETURN
      END
```

Fig. 8. (Continued)

```
 SB12
C
CLAMDA          FUNCTION TO CALCULATE HEAT OF VAPORIZATION OF WATER
C
C                              LAMDA # F( T,C), T- DEG. F, C- PERCNT NACL
C     2/14/64 DRM ( CATALYTIC )
C     PRD        1/11/63
      FUNCTION  AMDA(T)
      P# PSTEAM(T)
      HL# HSATL(T)
      HV# HSUPST(P,T)
       AMDA# HV-HL
      RETURN
      END
```

```
 SB13
C
      FUNCTION GAMMA (T,Q)
      AA#-.26095438E+00
      AB#-.55744363E-01
      AC# .35589404E-02
      BA# .12154745E-03
      BB# .64301725E-04
      BC# .92009258E-05
      CA#-.15076632E-05
      CB#-.39646057E-06
      CC#-.93361829E-08
      A#AA+Q*(AB+Q*AC)
      B#BA+Q*(BB+Q*BC)
      C#CA+Q*(CB+Q*CC)
      GAMMA#A+T*(B+T*C)
      RETURN
      END
```

```
 SB14
C
CDELBP         FUNCTION TO CALCULATE BOILING POINT ELEVATION DUE TO SALT
C     SALINE WATER PROJECT     JOB 4413
C
C     T# DEG F    , C# PERCENT NACL (OR DISOLVED SOLIDS )
      FUNCTION DELBP(T,C)
      P#PSTEAM(T)
      TT#T+ 460.0
      VAPLHT # HSUPST( P,T) -HSATL(T)
      GAM # 1.0 +      (GAMMA(T,C))/2.0
C     0.7 F IS ADDED TO EQUILIBRIUM BPE TO ALLOW FOR APPROACH TO
C     EQUILIBRIUM AND PRESSURE DROP IN THE DEMISTER.
      DELBP# .631464E-03*C*TT*TT*GAM/VAPLHT +0.7
      RETURN
      END
```

Fig. 8. (Continued)

```
 SB15
C
CCPB             FUNCTION TO CALCULATE HEAT CAPACITY OF BRINE SOLUTION
C
C                    CPB# F(T,C),  T- DEG F , C- PERCNT NACL
C       PRD      1/11/63
        FUNCTICN CPB(T,C)
C       CHANGE CP TC CERIVATIVE OF ENTHALPY, HSATL.
        CPW# ((T*1.3333336E-9 + 1.3999989E-7)*T - 6.1666652E-5)*T
      1  + 1.0011833
C       MULTIPLY PURE WATER CP BY FACTOR FOR C. (TALKED TO CATALYTIC)
        CPB # CPW*(1.0 - C*(0.011311 - 0.00001146*T))
        RETURN
        END
```

```
 SB17
        FUNCTICN CUFTSC(T,P,A)
CCUFTSC                FUNCTION TO CALCULATE CFS OF STEAM
C
C             CFS#  CUFTSC(T,P,A), T- CEG F , P- PSIA, A- LB/HR
C       PRD        1/14/63
C
        C# 10.731/64857.6
        TT# T+460.0
        CUFTSC #  C*TT*A/P
        RETURN
        END
```

```
 SB19
C
C       SUBPROGRAMS TO ESTABLISH STEAM PROPERTIES
C
C
C       2/14/64 DRM ( CATALYTIC )
C
C       FUNCTICN SUBPROGRAM TO CALC VAPOR PRESSURE OF WATER
        FUNCTICN PSTEAM(T)
C       T IN DEG F, PRESS WILL BE IN PSIA
        TABSK#(T+459.688)/1.8
        X#647.27-TABSK
        PSTEAM#3206.1822/EXP(2.3025851*X*(3.2437814 +X*(C.CC586B26+X*X*
      1  1.1702379E-8))/(TABSK+.21878462E-C2*TABSK*X))
        RETURN
        END
```

Fig. 8. (Continued)

```
 SB20                                                                       SB200000
C      FUNCTICN SUBPROGRAM TO CALC ENTHALPY OF SUPERHEATED STEAM            SB200010
       FUNCTICN HSUPST(P,T)                                                 SB200020
C      P IN PSIA, T IN DEG F, ENTHALPY WILL BE BTU/LB                       SB200030
       ATM#P/14.696                                                         SB200040
       TABSK#(T+459.688)/1.8                                                SB200050
       TSQ#TABSK*TABSK                                                      SB200060
       POTSC#ATM*ATM/TSQ                                                    SB200070
       B1#2641.62/TABSK*EXP(2.3025851*80870.0/TSQ)                          SB200080
       B0#1.89-B1                                                           SB200090
       F0#1.89-B1*(372420.0/TSQ+2.0)                                        SB200100
       F#775.5963+0.63296*TABSK+.162467E-03*TSQ+20.569573*ALOG(TABSK)       SB200110
       B3#162460.0/TABSK                                                    SB200120
       F02#FC+F0                                                            SB200130
       B3M#82.546-B3                                                        SB200140
       B6#B0*B3-FC2*B3M                                                     SB200150
       B7#F02*0.21828*TABSK-(F02+B0)*126970.0/TABSK                         SB200160
       HSS1#B3M+B7*BC*POTSQ                                                 SB200170
       HSUPST#F+0.043557*(F0*ATM+0.5*B0*POTSQ*(HSS1*B0-B6))                 SB200180
       RETURN                                                               SB200190
       END                                                                  SB200200
```

```
 SB21                                                                       SB210000
C      FUNCTICN SUBPROGRAM TO CALC ENTHALPY OF WATER AT BOILING POINT       SB210010
       FUNCTICN HSATL(T)                                                    SB210020
C      T IN DEG F, ENTHALPY WILL BE IN BTU/LB                               SB210030
       HSATL#(((T*3.333334E-10+4.666663E-8)*T-3.0833326E-5)*T+1.C011833     SB210040
     1  )*T-31.92                                                           SB210050
       RETURN                                                               SB210060
       END                                                                  SB210070
```

```
 SB22                                                                       SB220000
C      FUNCTICN SUBPROGRAM TO CALC SAT TEMP OF STEAM                        SB220010
       FUNCTICN TSTEAM(P)                                                   SB220020
C      P IN PSIA, TSTEAM WILL BE IN CEG F                                   SB220030
       F#ALOG10(3206.1822/P)                                                SB220040
       TSTEAM#350.0                                                         SB220050
     1 T#TSTEAM                                                             SB220060
       X#647.27-T                                                           SB220070
       TSTEAM#647.27/((F*X*.21878462E-02+F)/((X*X*1.17C2379E-8+.00586826)SB220080
     1     *X+3.2437814)+1.0)                                               SB220090
       IF(ABS(TSTEAM-T)-0.001) 2,1,1                                        SB220100
     2 TSTEAM#TSTEAM*1.8-459.688                                            SB220110
       RETURN                                                               SB220120
       END                                                                  SB220130
```

Fig. 8. (Continued)

```
 SB23                                                                    SB230000
C                                                                        SB230010
C      FUNCTICN SUBPROGRAM FOR SPECIFIC GRAVITY OF BRINE                 SB230020
C       AS A FUNCTICN OF THE CONCENTRATION RATIO                         SB230030
C      2/14/64 DRM ( CATALYTIC )                                         SB230040
C                                                                        SB230050
       FUNCTICN SPGRV(R)                                                 SB230060
       SPGRV#((R+8.55)*R+528.05)/525.0                                   SB230070
       RETURN                                                            SB230080
       END                                                               SB230090
```

```
 SB24                                                                    SB240000
C                                                                        SB240010
C      SUBPROGRAM TO CALCULATE UNIT COST OF BRINE HEATER SURFACE         SB240020
C      DRM 2/14/64   ( CATALYTIC )                                       SB240030
C                                                                        SB240040
       FUNCTICN HTCOST(BIG,S,T,AREA)                                     SB240050
       Q#S*AMDA(T)*1.0E-6                                                SB240060
       AN#1.0                                                            SB240070
       GO TO 3                                                           SB240080
     2 AN#AN+1.0                                                         SB240090
     3 IF(Q/AN-BIG) 4,4,2                                                SB240100
     4 C#AREA*0.00001/AN                                                 SB240110
       HTCOST#(131.2-C*(25.8+Q))/18.0                                    SB240120
       RETURN                                                            SB240130
       END                                                               SB240140
```

Fig. 8. (Continued)

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