# EUR 4252 e
Part I

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

# HDP 2 - A DIGITAL PROGRAM CALCULATING THE SURFACES AND THE EFFICIENCIES OF A HEAT EXCHANGER COUPLED WITH A TURBINE AT NOMINAL POWER AND AT PART LOAD

Part I: Description of the code version HD 2 calculating the nominal power characteristics

by

W. BALZ, C. BONA and S. GECCHELIN

1969

ORGEL Program

Joint Nuclear Research Center
Ispra Establishment - Italy

ORGEL Project
and
Scientific Data Processing Center - CETIS

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— in parallel with the superheater,
— in parallel with the superheater, boiler and economizer.

The heat exchanger may be of the drum boiler or Benson boiler type. The primary coolant which in the actual code version may be OM 2 or HB 40 is assumed to flow on the shell side in counterflow to the steam or water.

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**ABSTRACT**

The code HDP 2 is a digital program calculating the surfaces and the efficiencies of a heat exchanger coupled with a turbine at nominal power and at part load.

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— in series with the superheater,
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**KEYWORDS**

H-CODES
EFFICIENCY
HEAT EXCHANGERS
TURBINES

## PREFACE

The code HDP 2 is described in two parts which will be published separately. In Part I, the code version HD 2 is described which determines the characteristics of the steam plant at nominal power. The version HD 2 is operational and tested.

The final code version HDP 2 which treats also the part load behaviour of the plant is actually being tested and will be published later.

## TABLE OF CONTENTS

## 1. Basic features of the code

HD 2 is a code calculating the steady state characteristics of a steam plant at full power. Main results of a calculation are the surfaces of each heat exchanger section (eco, boiler, superheater, reheater) which are needed to produce a given gross electric power. Besides this a detailed description of the thermodynamic conditions in the turbine and of the preheater system is given.

Different steam cycles may be treated :

- cycles with or without reheating by primary coolant
- reheater in series with the superheater (the primary coolant passes first the superheater then the reheater)
- reheater is in parallel with the superheater
- reheater is in parallel with the superheater, boiler and economizer

The possible reheater arrangements are shown in fig. 1.

The heat exchanger may be of the drum boiler type or Benson boiler type in which the primary coolant and water or steam are in counterflow. Water and steam are assumed to flow on the tube side.

The heat transfer coefficients are calculated from the given tube geometry for each section (diameter, wall thickness) and from the velocities which are also given for the tube and shell side. As in the code geometrical details of the heat exchanger are not considered, it is assumed that the given velocities may be obtained by a suitable arrangement of the tubes (number of tubes, pitch) or by baffles.

The correlations programmed for the heat transfer on the shell side of the tube correspond to cross flow as it may be assumed for helically wounded tubes or vertical tubes with baffles.

The pressure drop in the heat exchanger and in the circuit is taken into account as a fraction of the local pressure which is given for each section of the heat exchanger and of the circuit.

The physical properties of two primary coolants are programmed actually : OM2 and HB40 with a high boiler content to be specified.

The water/steam properties foreseen in the code are valid over the whole range of interest.

It should be mentioned that the code may easily be adapted to other heat exchanger configurations or primary coolants by changing the corresponding subroutines.

For studies which refer only to the turbine-preheater arrangement an additional code version (HD 2 - TP) was developed. The mathematical formulation is the same as for HD 2 with exception of the QT-diagram and the heat exchanger which are not considered. Data resulting from the QT-diagram are input values.

## 2. Mathematical formulation

The calculation procedure may be subdivided in three blocks for each of which the mathematical formulation is briefly described. For variables which are input or output values of the code the same symbols are taken as in the code (see APPENDIX I).

## 2.1. QT-diagram

In fig. 2 a QT-diagram is shown for a steam cycle with reheating, the reheater being in series with the superheater. It shows the temperature evolution on the primary and secondary side in function of the heat exchanged. The code is made such that the primary temperatures at the heat exchanger inlet and outlet, the steam pressure at the turbine inlet and the pinch points are input values. The feed water temperature and the reheating temperature are determined from heat balances. The total heat exchanged is given by :

$$QE + QB + QR + QS = QP \qquad (1)$$

Introducing the mass flows and enthalpies, equation (1) may be written :

$$\begin{aligned} GS \, [(ESOE - ESIE) + (ESOB - ESIB) + (ESOS - ESIS)] \\ + BETA.GS\,(ESOR - ESIR) = GP\,(EPIS - EPOE) \end{aligned} \qquad (2)$$

where BETA is the ratio of the mass flow through the reheater and superheater.

Assuming that no heat losses occur between two heat exchanger sections it is :

$$ESOE = ESIB$$
$$ESOB = ESIS$$

Then equation (2) becomes :

$$(ESOS - ESIE) + BETA.(ESOR - ESIR) = \frac{GP}{GS}\,(EPIS - EPOE) \qquad (2a)$$

The enthalpies on the water/steam side depend from the local pressure and temperature. For the primary coolant the pressure influence is negligible. As it had been said before, the pressure drop is not calculated by the code but is imposed as a given fraction of the local pressure. For example, the pressure drop in the economizer results from :

$$PSOE = DPECO \cdot PSIE$$

$$\Delta p_{ECO} = PSIE - PSOE = (1 - DPECO) \cdot PSIE$$

the DP-values are given for each section of the heat exchanger and of the steam circuit. In this way, starting from the pressure at the turbine inlet which is an input value the pressures at the boundary between two sections are calculated.

As the calculation of the local pressure is independent from the QT-diagram, the heat balances are written in the following, only as a function of the temperatures.

Equation (2a) becomes then :

$$ESOS(TSOS) - ESIE(TSIE) + BETA \cdot [ESOR(TSOR) - ESIR(TSIR)] = \frac{GP}{GS} [EPIS(TPIS) - EPOE(TPOE)] \qquad (3)$$

the unknowns in eq. (3) are TSIE, TSOR and GP/GS. BETA depends from the preheater arrangement. It is equal to 1 in case there is no HP-preheater. TSIR results from the steam conditions at the HP-turbine outlet.

For the temperature TSIE another heat balance may be made. The heat exchanged in the economizer is equal to :

$$GP [EPIE(TPIE) - EPOE(TPOE)] = GS [ESOE(TSOE) - ESIE(TSIE)]$$

one gets :

$$ESIE(TSIE) = \frac{GP}{GS} [EPOE(TPOE) - EPIE(TPIE)] + ESOE(TSOE) \qquad (4)$$

The temperature TSOE may be calculated from the local pressure if one assumes that the water leaving the economizer is just saturated.

The temperature TPIE is obtained from

$$TPIE = TSOE + PINCHE$$

The temperature TSOR results from a heat balance made for the superheater :

$$GP[EPIS(TPIS) - EPOS(TPOS)] = GS[ESOS(TSOS) - ESIS(TSIS)]$$

$$EPOS(TPOS) = \frac{GS}{GP}[ESIS(TSIS) - ESOS(TSOS)] + EPIS(TPIS) \quad (5)$$

Neglecting again heat losses between two sections, it is :

$$EPOS = EPIR \qquad \text{or} \qquad TPOS = TPIR$$

and finally one gets :

$$TSOR = TPOS - PINCHR$$

From equations (3), (4), and (5) all unknowns may be determined. As the temperature TSIR and the mass flow ratio BETA are results of the turbine and preheater calculation an iterative calculation procedure becomes necessary.

For the other reheater arrangements the calculation of the QT-diagram becomes simpler (see fig. 3). In case there is no reheater equation (5) is not needed.

With the reheater in parallel the temperature TSOR results directly from the pinch point condition. As shown in fig.3 for this arrangement it was assumed that the primary coolant leaves the superheater and the reheater with the same temperature.

For the reheater being in parallel to eco, boiler and superheater two independent QT-diagrams exist : one for the eco, boiler and superheater, the other for the reheater. From the first one results the final feed water temperature as in the case without reheater. For the QT-diagram of the reheater all temperatures are known. Again the assumption was made that the primary coolant leaves the economizer and reheater with the same temperature.

## 2.2. Turbine preheater arrangement

The turbine-preheater arrangement is shown in fig. 4.

### 2.2.1. Preheaters

The final feed water temperature TSIE results from the QT-diagram, the condenser temperature is an input value.

The feed water temperature at the inlet of the first preheater (in the sense of the feed flow) may be higher by a value DTC than the condenser temperature. DTC which is an input datum represents a temperature difference resulting from an external heat source like a generator or moderator cooling system.

It is possible to impose the number of preheaters (NPR) or the feed water temperature rise in one preheater (DTPR). In both cases the temperature rise is equal for each preheater.

In case temperature rise is fixed, the number of preheaters results from :

$$NPR = \frac{TSIE - (TC + DTC)}{DTPR}$$

Taking the nearest integer for NPR the effective temperature rise is slightly different. The number of preheaters being established the feed water temperature after each preheater is easily determined.

To determine the pressure of the bled steam condensing in the preheater a pinch (PINCH) is assumed by which the saturation temperature of the condensing steam must be higher than the feed water temperature after the preheater :

$$TPR = TF + PINCH$$

A QT-diagram for a preheater is shown in fig. 5.

Due to the pressure drop between preheater and turbine tapping the pressure at the turbine is :

$$PTUR = \frac{PPR}{DPTPR}$$

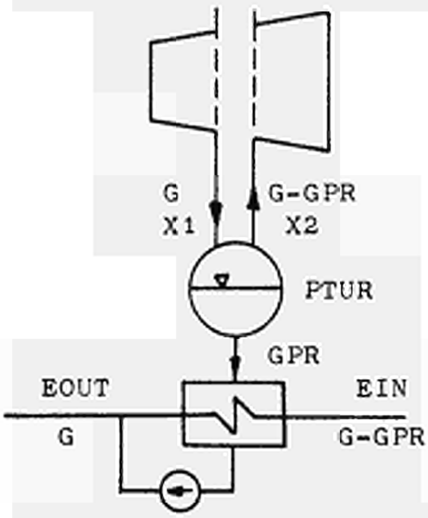
where DPTPR is a given value which is constant for all bleeding lines of the same turbine cylinder.

For the degasifier the pinch point is zero as steam and feed water are in direct contact. The degasifier is placed at a temperature of about 150°C.

After all bled steam tapping pressures are fixed the corresponding steam enthalpies may be determined from the turbine expansion (see chapter 2.2.2.) and the bled steam mass flows can be calculated. For sake of simplicity it was assumed that the condensated bled steam is pumped back into the main feed line directly after each preheater (see fig. 4). The temperature after the mixing of both mass flows is considered as the feed water temperature after a preheater.

If in a point of a steam tapping the steam moisture exceeds a certain value, a moisture reduction is foreseen. For the bled steam mass flow calculation it is assumed that the extracted water is taken for preheating.

For the general case of a turbine tapping with water extraction the bled steam mass flow is obtained from a heat balance which is illustrated in the figure below.




The water extraction is symbolized by a drum in which the steam enters with a certain steam quality X1. The steam goes back to the turbine with a new quality X2, the mass flow being reduced by GPR.

The mass flow going to the preheater may be subdivided in a water and a steam flow which are :

$$GW = G(1 - X1) - (G - GPR)(1 - X2)$$

$$GST = G \cdot X1 - (G - GPR)\, X2$$

From a heat balance made for the reheater for which it is assumed that the bled steam condensate is pumped into the main feed line behind each preheater one gets :

$$GPR = G \cdot \frac{EOUT - EIN + (X2 - X1)\,[EVSAT(PTUR) - ELSAT(PTUR)]}{X2 \cdot EVSAT(PTUR) + (1 - X2)\, ELSAT(PTUR) - EIN}$$

PTUR is the pressure in the turbine tapping point.

The moisture reduction expressed as X1 - X2 is obtained from

$$X2 = X1 + ETAEXT (1 - X1)$$

where ETAEXT is the separation efficiency.

## 2.2.2. Turbine

Several turbine cylinders are possible. An eventual reheater must be placed between the first and the second one. Between two cylinders a pressure drop and heat loss may occur which has to be specified in the input.

If from the preheater calculation a bled steam tapping pressure was found which is close to the final pressure of a cylinder the latter is automatically taken equal to the tapping pressure.

The turbine expansion starts from the inlet steam conditions which take into account eventual pressure or heat losses between heat exchanger and turbine. The expansion line is determined from subexpansions which take place between two subsequent pressures. These pressures may be bled steam pressures or cylinder end pressures (see fig. 6). With the turbine expansion efficiency which is an input value for each cylinder the enthalpy after each subexpansion is calculated.(°) Before each subexpansion it is checked whether the steam moisture doesn't exceed a maximum admissible value. Otherwise a water extraction is foreseen (see chapter 2.2.1.).

After the expansion line is established and the bled steam mass flows are determined, the following values are calculated.

--------------------

(°) For wet steam the efficiency is reduced by DETA (see App.I) for each percent of average moisture.

- Expansion work

$$STOT = \sum_{j=1}^{NZONE} \sum_{i=1}^{NE(J)} (HTUR(J,i) - HFE(J,i)) . GT(J,i) \quad [kcal/s]$$

where

NZONE = number of cylinders

NE(J) = number of subexpansions in the $J^{th}$ cylinder

HTUR(J,i) = enthalpy at the beginning of the $i^{th}$ expansion in the $J^{th}$ cylinder [kcal/kg]

HFE(J,i) = enthalpy at the end of the $i^{th}$ expansion in the $J^{th}$ cylinder [kcal/kg]

GT(J,i) = corresponding mass flow [kg/s]

- Turbine outlet loss

$$OUTLOS = \frac{1}{427} \circ \frac{VTO^2}{2g} \circ GT(NZONE, NE(ZONE)) \quad [kcal/s]$$

- Feed pumping power

The pump head is given by the degasifier pressure, the pressure drop between pump and turbine and the turbine admission pressure.

$$WPP(1) = \frac{(PFD - PD) . G1(ND) . VSLIQ(PD,TD)}{ETAPP(1) . ETAMO(1)} \circ \frac{10^4}{101,98} \quad [kW]$$

where :

PFP = pressure behind the pump [ata]

PD = degasifier pressure [ata]

G1(ND) = mass flow through the feed pump [kg/s]

ND = degasifier index

- Extraction pumping power

The pump head is determined by the degasifier pressure, the condenser pressure and by the pressure drop in the feed line.

$$WPP(2) = \frac{(PCP - PC) \circ G1(NPR + 1) . VSLIQ(PC,TC)}{ETAPP(2) \; . \; ETAMO(2)} \circ \frac{10^4}{101,98} \quad [kW]$$

the symbols have a similar meaning like in the formula for the feed pump.

- Thermodynamic efficiency

$$ETATH = \frac{STOT - OUTLOS}{HETOT}$$

where

HETOT = total heat exchanged [kcal/s]

- Steam cycle gross efficiency

$$ETASB = ETATH \circ ETAMC \circ ETAGEN$$

- Steam cycle net efficiency

$$ETASN = ETASB - \frac{WPP(1) + WPP(2)}{HETOT} \circ \frac{1}{4,185}$$

## 2.3. Heat exchanger

The code is made so that no detailed information about the heat exchanger geometry is needed (or must be determined by the code itself). Only some basic assumptions had to be made concerning the heat transfer calculations :

- the primary and secondary medium are in counterflow
- the primary coolant flows on the shell side
- the tube arrangement is so that in all sections cross flow may be assumed.

The velocities on the shell and tube side were taken as input values assuming that they may be realized by an appropriate choice of the tube pitch, or of the baffle distance or by a suitable tube number. In case of a Benson boiler the velocity on the tube side only for one section(eco or superheater) can be given. The other is calculated as resulting from a constant tube number and tube geometry.

Between two heat exchanger sections a pressure drop may be specified to take into account a possible multi-block arrangement.

The heat transfer correlationsused in the code are :

a) - Primary-shell side

$$Nu = 0.32 \cdot Re^{0.61} \cdot Pr^{0.31}$$

b) - Economizer-tube side

$$Nu = 0.024 \cdot Re^{0.8} \cdot Pr^{0.37}$$

c) - Boiler-tube side

$$\alpha = 40537 \cdot \varphi^{0.72} \cdot p^{0.24} \cdot \frac{1}{4185} \qquad [kcal/sm^2grd]$$

where

$\varphi$ = heat flux $[MW/m^2]$
p = pressure [ata]

d) - Superheater-tube side

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4}$$

The subroutines calculating the heat transfer coefficients may easily be exchanged.

The overall heat transfer coefficient is calculated from the following correlation :

$$\frac{1}{ALFA} = \frac{RE}{RI} \cdot \frac{1}{ALFAI} + RE \cdot \frac{\ln RE/RI}{\lambda} + \frac{1}{ALFAE} + HF$$

where

RE, RI = external and internal tube radius

HF = fouling factor

Finally the (external) tube surface becomes :

$$SURF = Q/(ALFA \cdot DTLB)$$

where

DTLB = logarithmic temperature difference

## 2.4. Physical properties

### 2.4.1. Primary coolant

Two types of coolant are available in the code : OM2 and HB40 with a variable high boiler content. All properties were taken from ref. [1].

#### 2.4.1.1. OM2

Density [g/cm$^3$]

$$\rho = 1.1141 + 12.5 \times 10^{-4}(HB) - 7.7 \times 10^{4} t$$

here and in the following correlations the dimensions are :

[t] = °C [HB] = %

Viscosity [p]

$$\ln \mu = -9.1406 - 2.132 \times 10^{-3}(HB) - 2.302 \times 10^{-4}(HB)^2 + \frac{2.0979 \times 10^3 + 3.739(HB) + 0.4068(HB)^2}{t}$$

Specific heat [J/g°C]

$$Cp = 1.53 + 2.7 \times 10^{-3}\, t$$

From this the enthalpy difference [J/kg] referred to 100°C was obtained :

$$i - i_{100} = 1.53t + 1.35 \times 10^{-3} t^2 - 166.5$$

Thermal conductivity [W/cm°C]

$$\lambda = 1.58 \times 10^{-3} + (t + 273)10^{-7}[-7.89 + 1.65 \log(HB)]$$

2.4.1.2. HB40

Density [g/cm³]

$$\rho = 1.038 + 5.897 \times 10^{-4}(HB) + [-7.887 \times 10^{-4} + 5.162 \times 10^{-6}(HB)]t$$

Viscosity [p]

$$\ln \mu = -9.4957 + 2.6869 \times 10^{-2}(HB) + [2.29608 \times 10^3 - 1.08805 \times 10^1(HB)] \frac{1}{t+273}$$

Specific heat [J/g°C]

$$Cp = 1.448 + 1.594 \times 10^{-3}(HB) + [3.741 - 2.67(HB)]\, 10^{-3}\, t$$

Thermal conductivity  [W/cm°C]

$$\lambda = 1.239x10^{-3} + 4.326x10^{-6}(HB) - 5.063x10^{-7}.t - 3.85x10^{-9}.t(HB)$$

### 2.4.2. Water/Steam

The water/steam properties correspond to those given in VDI-Wasserdampftafeln".

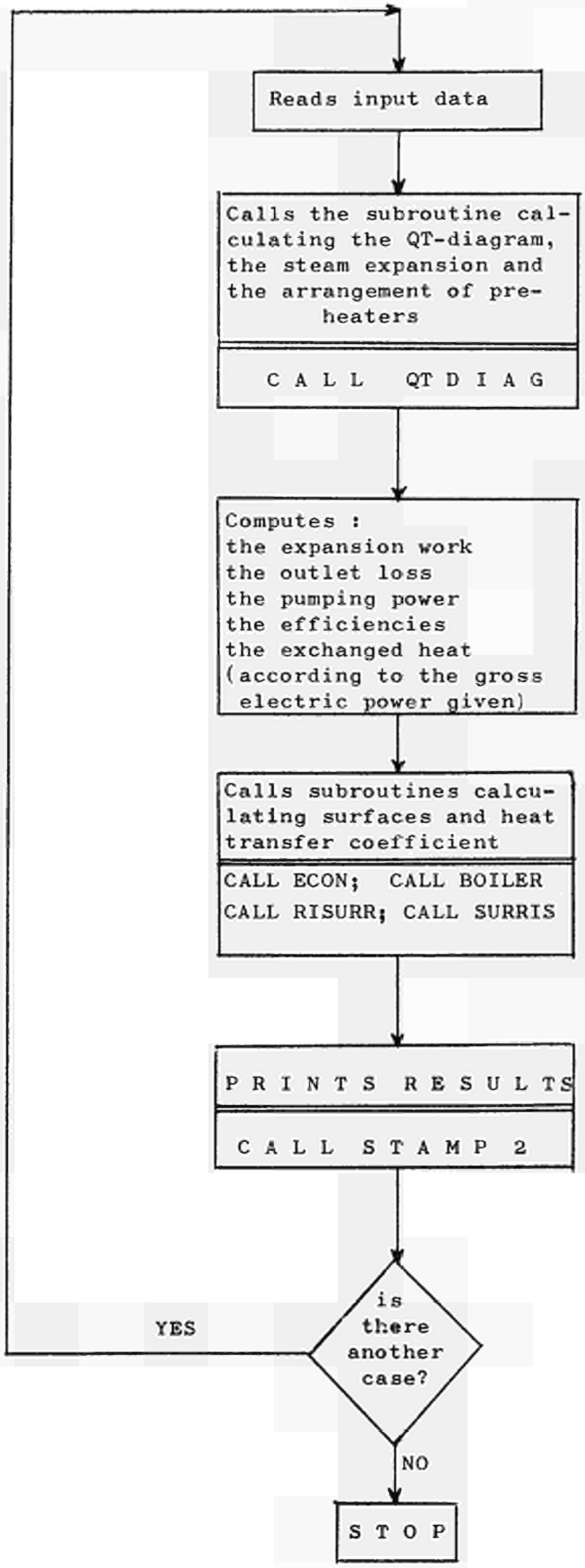
## 3. Program description

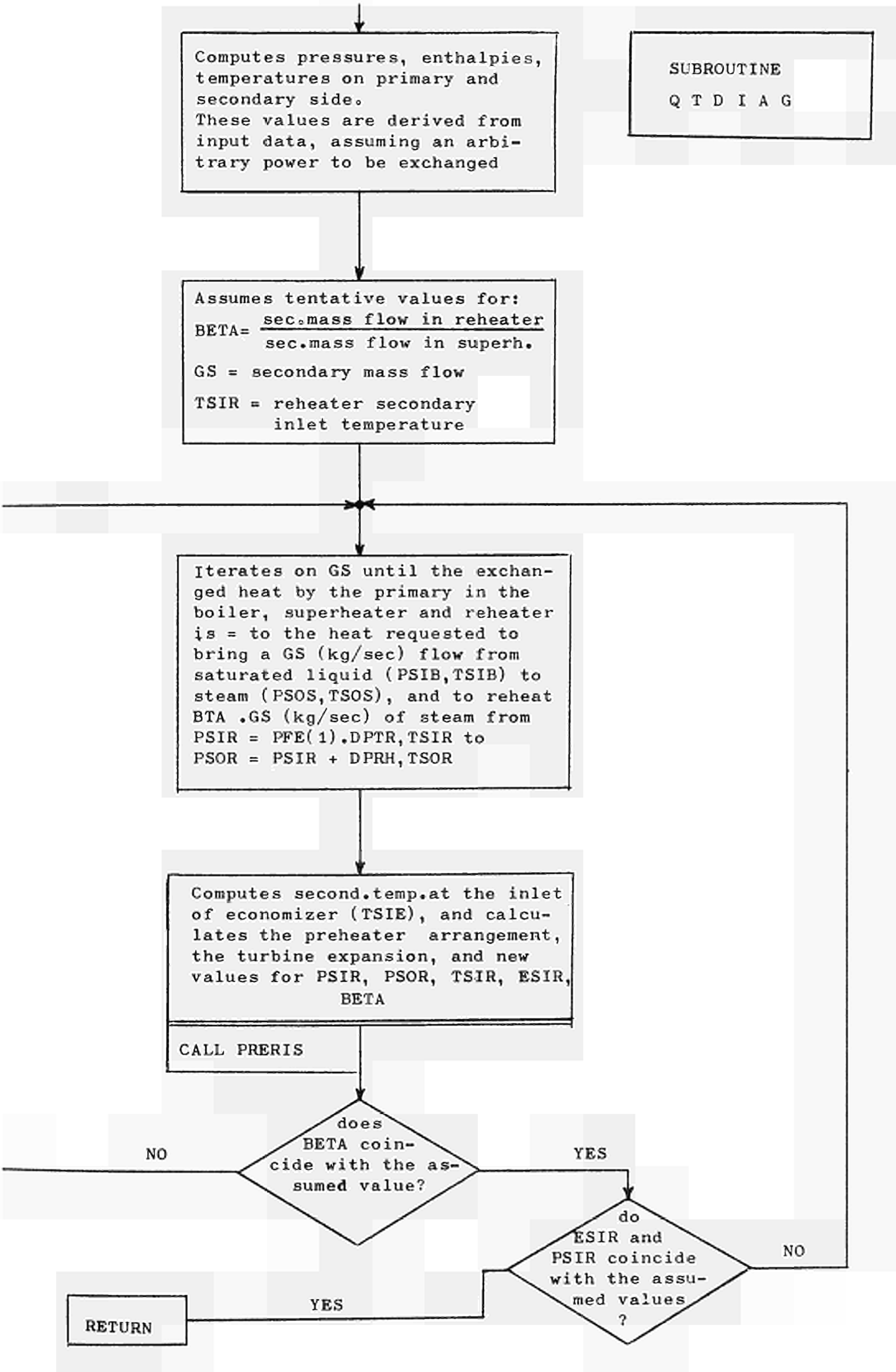
In the following chapter block-diagrams of the main program and the more important subroutines are given. Each block describes a set of equations. The different operations are explained.

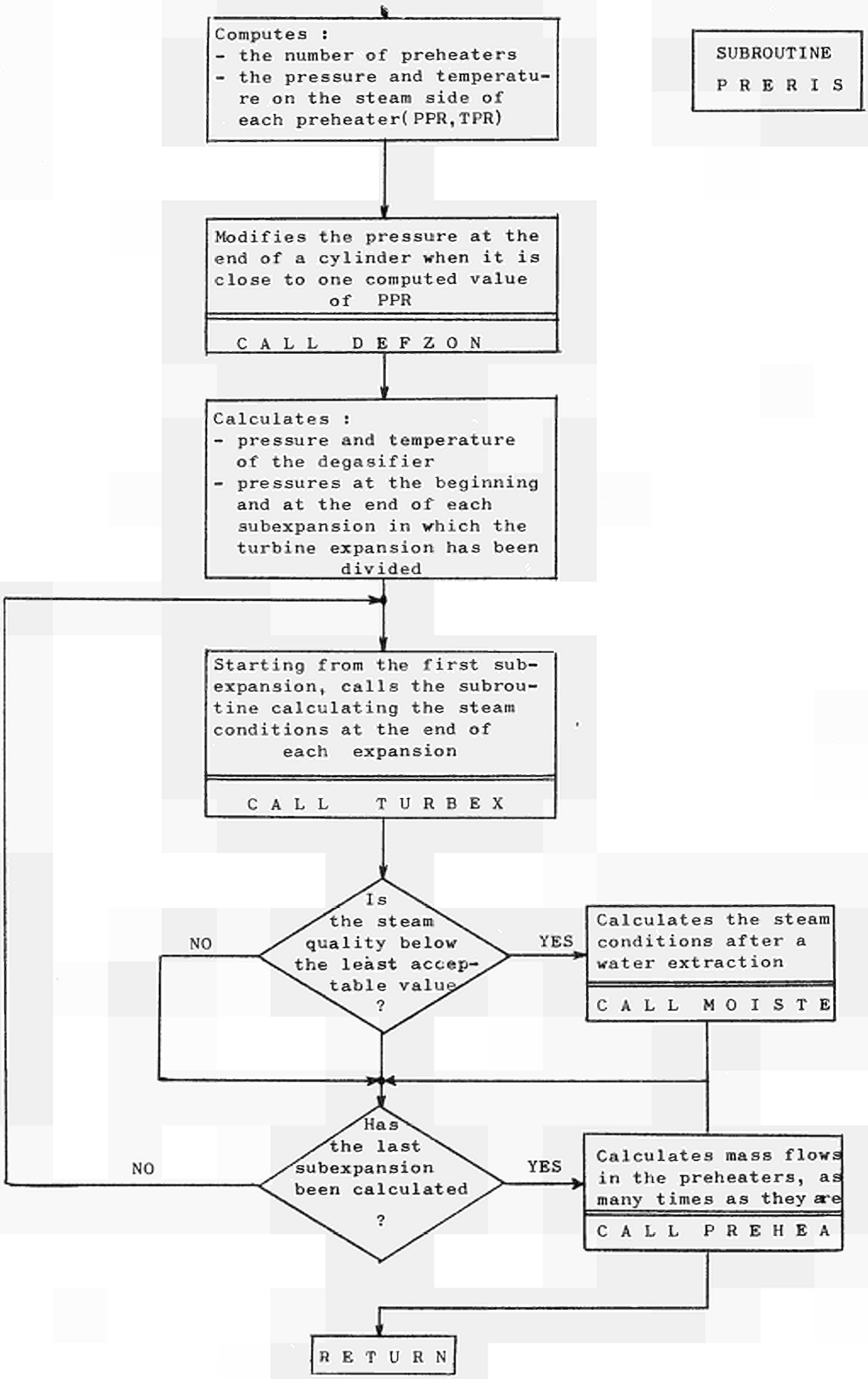
Table 1 gives a list of the functions developed for the calculation of the steam and water characteristics at different temperatures and pressures.

The program version HD2 - TP which treats the turbine preheater arrangement independently from the heat exchanger uses the same subroutines except those regarding the QT-diagram and the surface computation.

MAIN PROGRAM




SUBROUTINE
Q T D I A G
Computes pressures, enthalpies, temperatures on primary and secondary side. These values are derived from input data, assuming an arbitrary power to be exchanged
Assumes tentative values for:
BETA= sec.mass flow in reheater / sec.mass flow in superh.
GS = secondary mass flow
TSIR = reheater secondary inlet temperature
Iterates on GS until the exchanged heat by the primary in the boiler, superheater and reheater is = to the heat requested to bring a GS (kg/sec) flow from saturated liquid (PSIB,TSIB) to steam (PSOS,TSOS), and to reheat BTA .GS (kg/sec) of steam from PSIR = PFE(1).DPTR,TSIR to PSOR = PSIR + DPRH,TSOR
Computes second.temp.at the inlet of economizer (TSIE), and calculates the preheater arrangement, the turbine expansion, and new values for PSIR, PSOR, TSIR, ESIR, BETA
CALL PRERIS
does BETA coincide with the assumed value?
NO
YES
do ESIR and PSIR coincide with the assumed values ?
NO
YES
RETURN



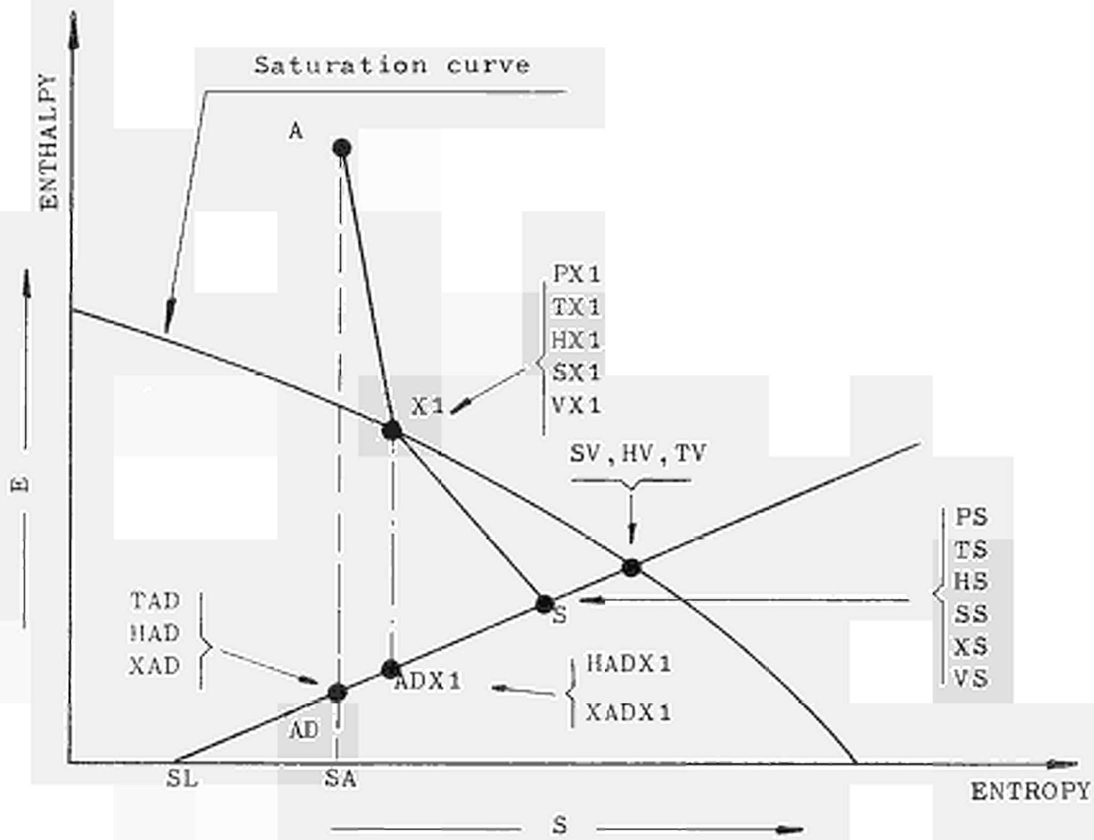
SUBROUTINE PRERIS
Computes :
- the number of preheaters
- the pressure and temperature on the steam side of each preheater (PPR, TPR)
Modifies the pressure at the end of a cylinder when it is close to one computed value of PPR
CALL DEFZON
Calculates :
- pressure and temperature of the degasifier
- pressures at the beginning and at the end of each subexpansion in which the turbine expansion has been divided
Starting from the first subexpansion, calls the subroutine calculating the steam conditions at the end of each expansion
CALL TURBEX
Is the steam quality below the least acceptable value ?
NO
YES
Calculates the steam conditions after a water extraction
CALL MOISTE
Has the last subexpansion been calculated ?
NO
YES
Calculates mass flows in the preheaters, as many times as they are
CALL PREHEA
RETURN

- Input variables of subroutine TURBEX are :

PA, TA, HA, SA, VA, XA, PS, ETA (*), DETA

- Output variables of subroutine TURBEX are :

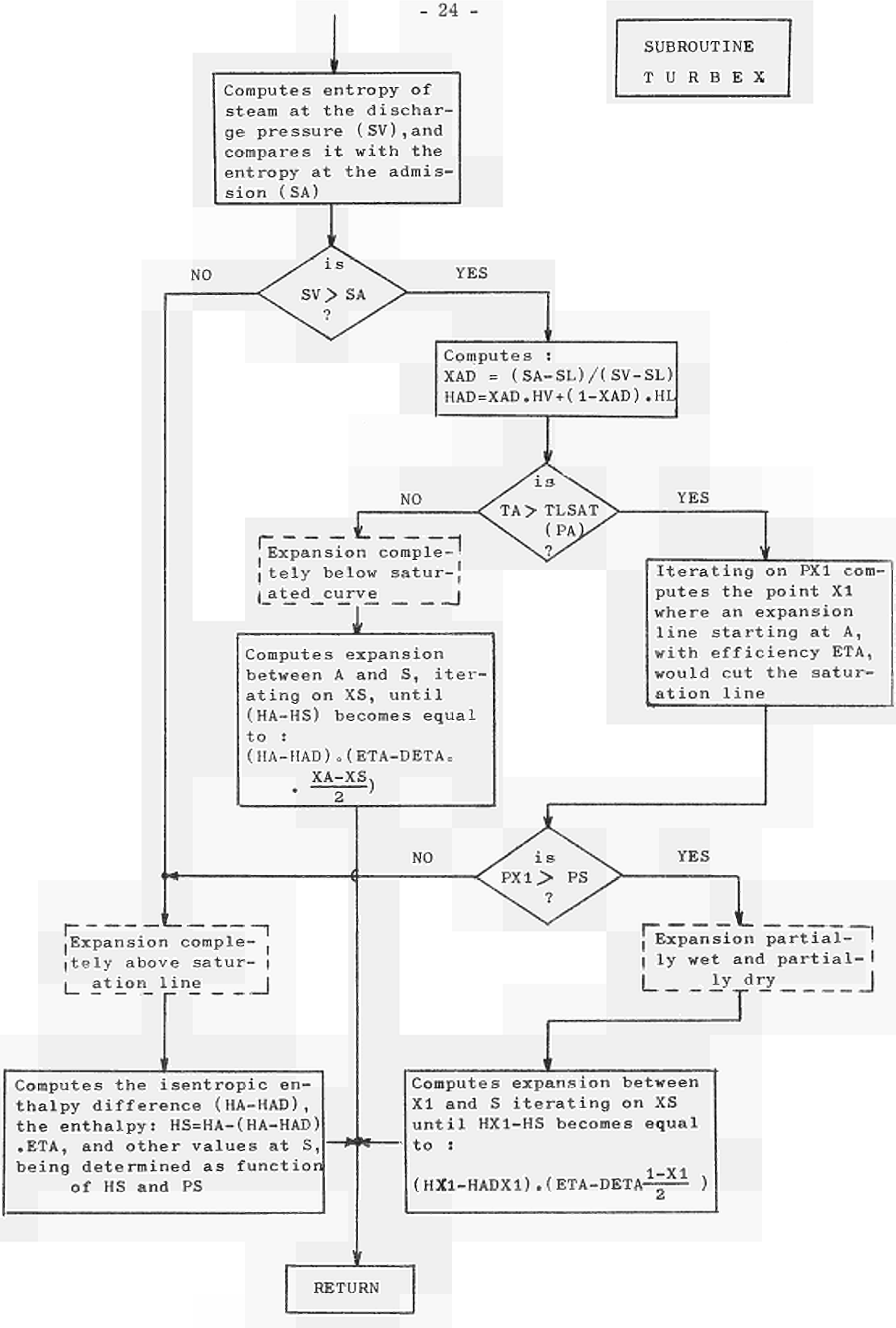
TS, HS, SS, VS, XS, PX1, TX1, HX1, SX1, VX1




Values on the liquid curve and on the saturated steam curve at PS are indicated with a letter followed by L or V, respectively. (For ex. : HL means enthalpy of saturated liquid, HV means enthalpy of saturated steam).

(*) ETA is the expansion efficiency in the dry zone, DETA is the reduction in % of ETA for % of average humidity.

SUBROUTINE
TURBEX



## SUBROUTINE MOISTE :

Calculates characteristics of the steam after a water extraction according to the following formula :

$$X = XIN + ETA \circ (1 - XIN)$$
$$S = X \circ SV + (1 - X) \circ SL$$
$$H = X \circ HV + (1 - X) \circ HL$$
$$V = X \circ VSV + (1 - X) \circ VSL$$

- Input variables :

| | | |
|---|---|---|
| T | = | Temperature of steam |
| XIN | = | Steam quality before water extraction |
| ETA | = | Extraction efficiency |

- Output variables :

| | | |
|---|---|---|
| X | = | Steam quality after water extraction |
| S | = | Steam entropy after water extraction |
| H | = | Steam enthalpy after water extraction |
| V | = | Steam specific volume after water extraction |

- Functions used :

| | | | |
|---|---|---|---|
| SV | = | SVSAT(T) | Entropy of saturated steam at T |
| SL | = | SLSAT(T) | Entropy of saturated water at T |
| HV | = | EVSAT(T) | Enthalpy of saturated steam at T |
| HL | = | ELSAT(T) | Enthalpy of saturated water at T |
| P | = | PSAT(T) | Saturation pressure at T |
| VSV | = | VSVAP(P,T) | Specific volume of saturated steam at T |
| VSL | = | VSLIQ(P,T) | Specific volume of saturated water at T |

## SUBROUTINE PREHEA

Calculates the bled steam mass flow G' according to the formula :

$$G' = \frac{EOUT - EIN + (X2 - X1) \circ (EV - EL)}{X2 \circ EV + (1 - X2) \circ EL - EIN} \cdot G$$

- Input variables :

| | |
|---|---|
| G | Water mass flow at the preheater inlet |
| EOUT | Enthalpy at the preheater outlet |
| EIN | Enthalpy at the preheater inlet |
| P | Pressure at the preheater outlet |
| PTUR | Pressure of steam at the turbine tapping |
| TTUR | Temperature of steam at the turbine tapping |
| HTUR | Enthalpy of steam at the turbine tapping |
| X1 | Steam quality at the turbine tapping |
| X2 | Steam quality after water extraction (When no extraction X2 = X1) |

- Output variables :

| | |
|---|---|
| G' | Bled steam mass flow (including eventual waterextract.) |
| T1 | Feed water temperature after preheater before mixing with bled steam condensate |

- Functions used :

| | | | |
|---|---|---|---|
| EV | = | EVSAT(TTUR) | Enthalpy of saturated steam at TTUR |
| EL | = | ELSATT(TTUR) | Enthalpy of saturated water at TTUR |
| T1 | = | TLIQS(P,T) | Water temperature at P, T |

## SUBROUTINE DEFZON

Compares the pressure at the point where tapping occurs with the pressure corresponding to the end of each cylinder given as input data (PFE), changing the latter in case both values differ less than 10%.

SUBROUTINE ECON

Calculates the heat transfer coefficient and the surface of the economizer with the formulas :

$$ALFAE = \frac{1}{\frac{RE}{Ri} \circ \frac{1}{ALFASE} + \frac{RE}{\lambda} \cdot \ln \frac{RE}{RI} + \frac{1}{ALFAPE} + HF1}$$ and

SURFE = QE / (ALFAE . DTLE)

where :

| | |
|---|---|
| RE | External tube radius |
| Ri | Internal tube radius |
| $\lambda$ | thermal conductivity of the tube material |

- Input variables

| | |
|---|---|
| QE | Heat to be exchanged in the economizer |
| TPIE | Primary side inlet temperature |
| TPOE | Primary side outlet temperature |
| TSIE | Secondary side inlet temperature |
| TSOE | Secondary side outlet temperature |
| PSIE | Secondary side inlet pressure |
| PSOE | Secondary side outlet pressure |
| WPECO | Velocity of primary fluid |
| WSECO | Velocity of secondary fluid |
| DECO | Tube diameter |
| SPECO | Tube wall thickness |
| HF1 | Fouling factor in the economizer |

- Output variables :

| | |
|---|---|
| SURFE | Surface of the economizer |
| ALFAE | Overall heat transfer coefficient |
| DTLE | Logarithmic temperature difference |
| TPME | Primary side average temperature |
| TSME | Secondary side average temperature |

ALFAPE Heat transfer coefficient between primary side and the wall

ALFASE Heat transfer coefficient between secondary side and the wall

- Functions used

ECO1 Calculates the heat transfer coefficient between the primary side and the wall according to the formula :

$$Nu = 0.32 \cdot Re^{0.61} \cdot Pr^{0.31}$$

where

Re = Reynolds number

Pr = Prandtl number

Nu = Nusselt number

Physical characteristics of the fluid are calculated at TPME = (TPIE + TPOE)/2

ECO2 Performsthe same calculations as ECO1, between the wall and the secondary side, according to the formula :

$$Nu = 0.024 \cdot Re^{0.8} \cdot Pr^{0.37}$$

Physical characteristics of the fluid are calculated at TSME = (TSIE + TSOE)/2

SUBROUTINE BOILER

Calculates the heat transfer coefficient and the surface of the boiler.

The subroutine uses the same formulas as the subroutine ECON with exception of that for the secondary heat transfer coefficient, which is :

$$BBOIL2 = 40537 \cdot F^{0.72} \cdot p^{0.24} / 4185$$

where

BBOIL2 = heat transfer coefficient kcal/s $m^2$grd

F = heat flux on the inner tube surface [$MW/m^2$]

p = water/steam pressure [ata]

The other symbols used for the input and output variables correspond to those used for the subroutine ECON. The primary heat transfer coefficient is calculated by the function ABOIL 1 which uses the same formula as ECO 1. Different formulas were defined to be able to exchange the formulas for the different heat exchanger sections independently.

SUBROUTINE SURRIS

Calculates the heat transfer coefficient and the surface of the superheater.

The only difference in comparison with the subroutine ECON is the formula used for the secondary heat transfer coefficient which is :

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4}$$

This formula is evaluated by the function SUR 2. The primary heat transfer coefficient is calculated by the function SUR 1 which in the actual code version is equal to ECO 1.

SUBROUTINE RISURR

Does the same calculations for the reheater. In the actual version it is identical to the subroutine SURRIS.

LIST OF REFERENCES

/ 1 / R.Lopes Cardozo, J.F. Terrien
"Comparaison des deux réfrigérants organiques : OM2, HB40".
Rapport EUR (to be published)

Aknowledgements : The authors wish to thank Mr. M. LECLOUX for his cooperation in testing the code.

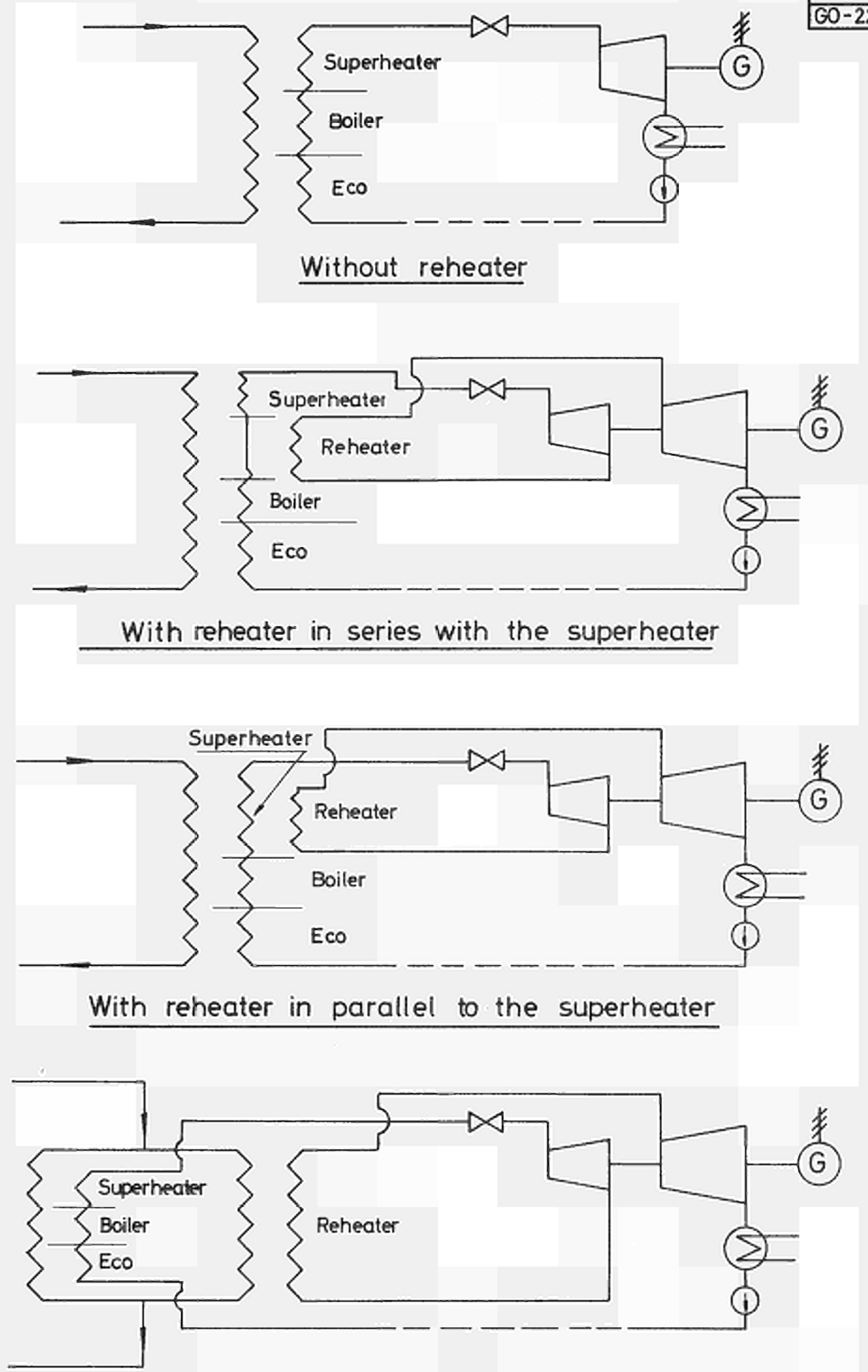
TABLE 1

Functions used for steam and water properties

| | |
|---|---|
| ELIQS(P,T) | water enthalpy at P(kg/cm$^2$), T(°C) |
| ELSAT(T) | saturated water enthalpy (kcal/kg) at T(°C) |
| EVSAT(T) | saturated steam enthalpy (kcal/kg) at T(°C) |
| EVSUR(P,T) | superheated steam enthalpy (kcal/kg) at P(kg/cm$^2$), T(°C) |
| TLIQS(E,P) | water temperature (°C) at E(kcal/kg), P(kg/cm$^2$) |
| TLSAT(P) | saturation temperature (°C) at P(kg/cm$^2$) |
| TEVSUR(E,P) | steam temperature (°C) at E(kcal/kg), P(kg/cm$^2$) |
| TVSUR(P,S) | steam temperature (°C) at P(kg/cm$^2$), S(kcal/kg/°C) |
| PSAT(T) | saturation pressure (kg/cm$^2$) at T(°C) |
| SLSAT(T) | saturated water entropy (kcal/kg/°C) at T(°C) |
| SVSAT(T) | superheated steam entropy (kcal/kg/°C) at T(°C) |
| SVSUR(P,T) | superheated steam entropy (kcal/kg/°C) at P(kg/cm$^2$), T(°C) |

Fig. 1

GO-2281




Without reheater

With reheater in series with the superheater

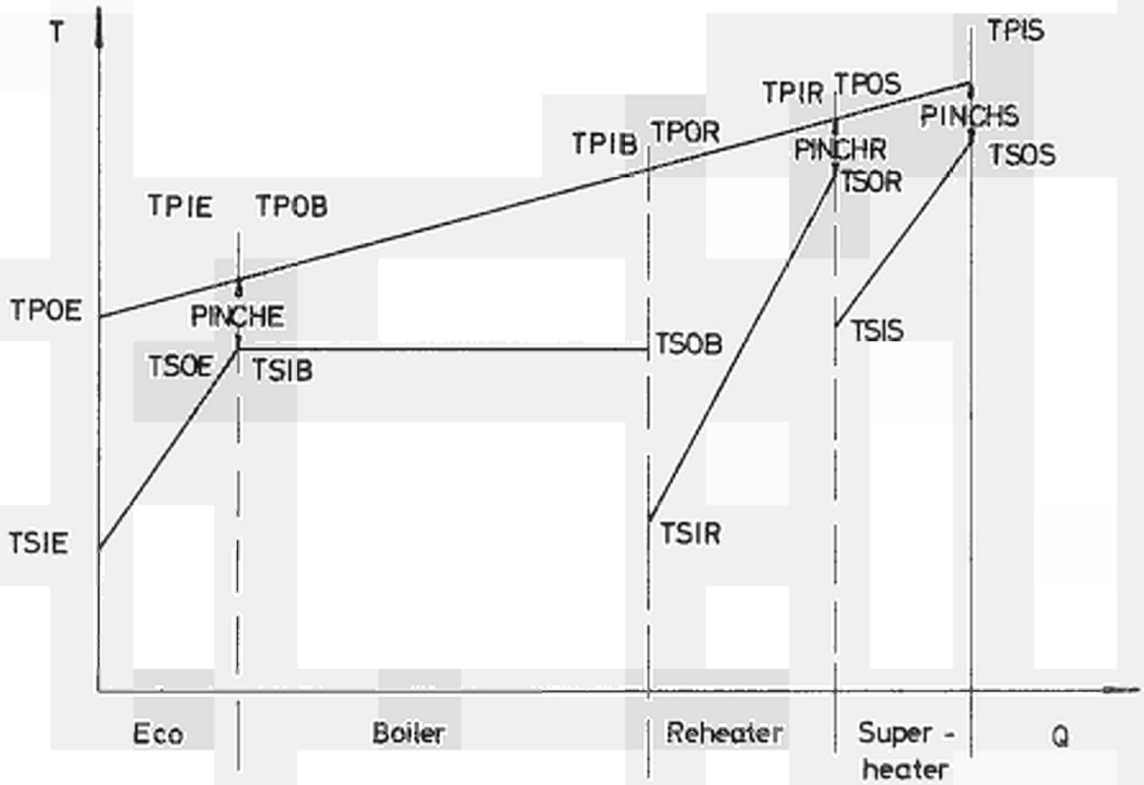
With reheater in parallel to the superheater

With reheater in parallel to Eco, boiler and superheater

Fig. 2
GO -2282

## QT- Diagram

( Reheater in series )



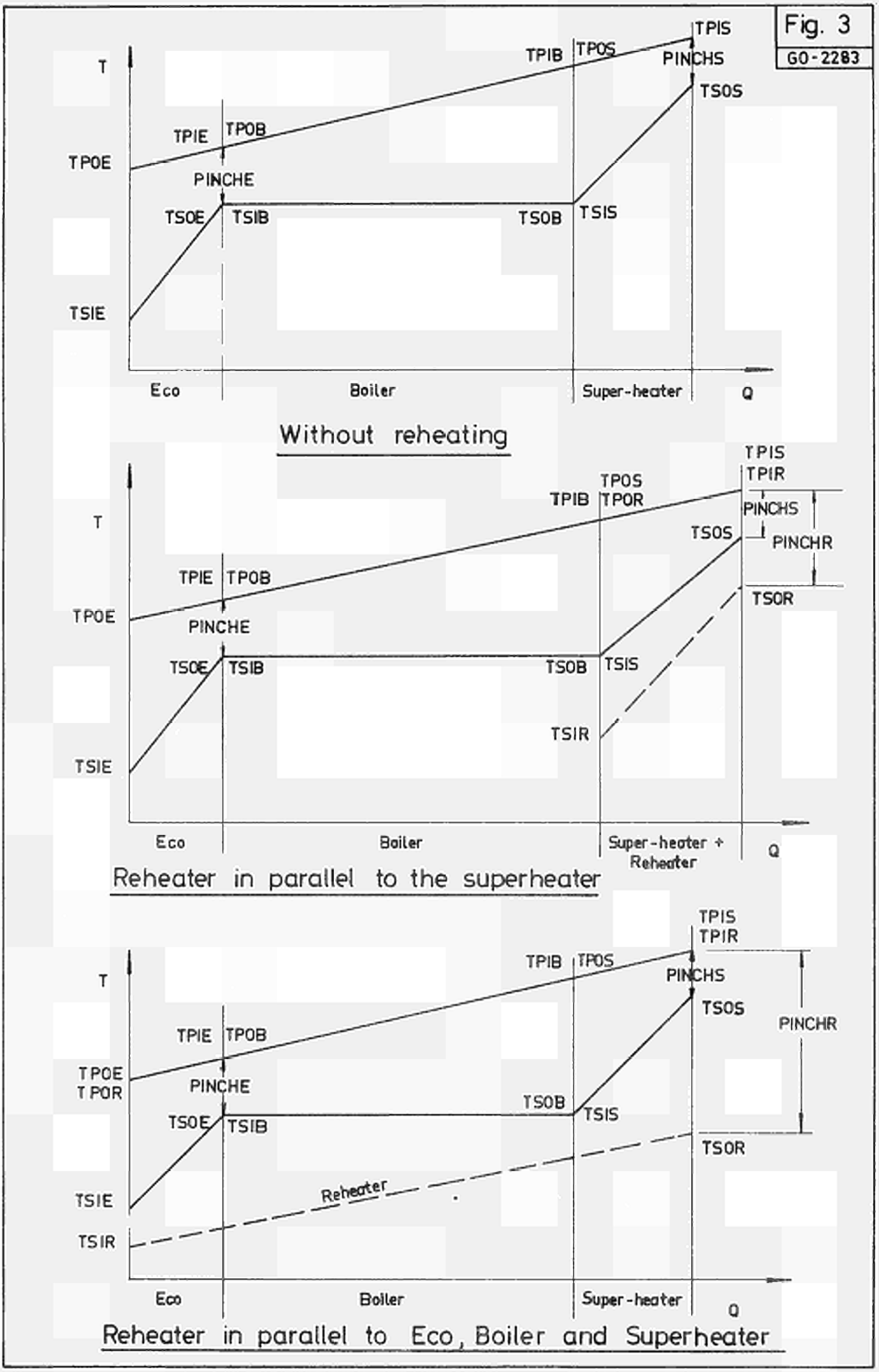
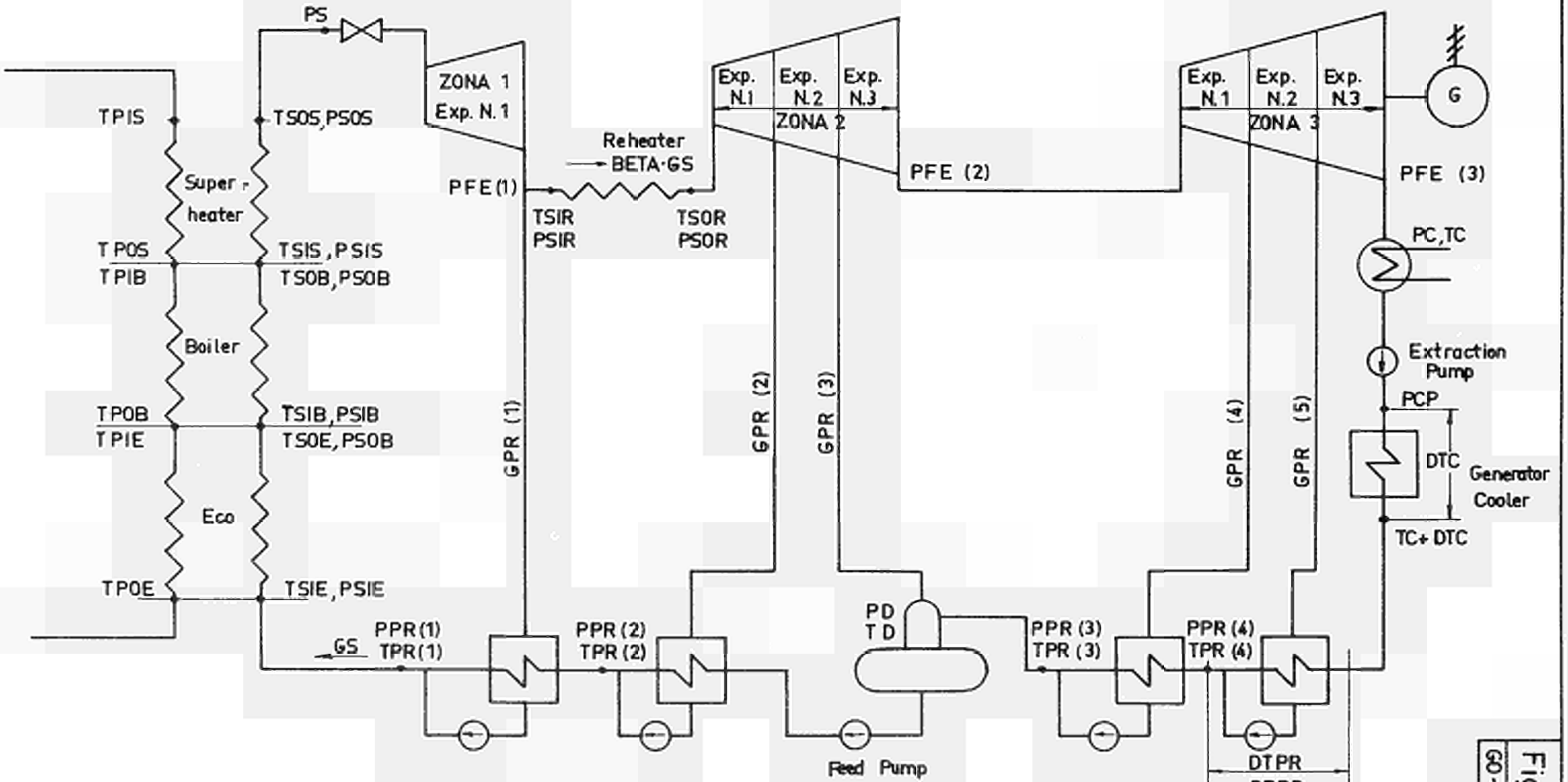



Fig. 3
GO-2283

Without reheating

Reheater in parallel to the superheater

Reheater in parallel to Eco, Boiler and Superheater



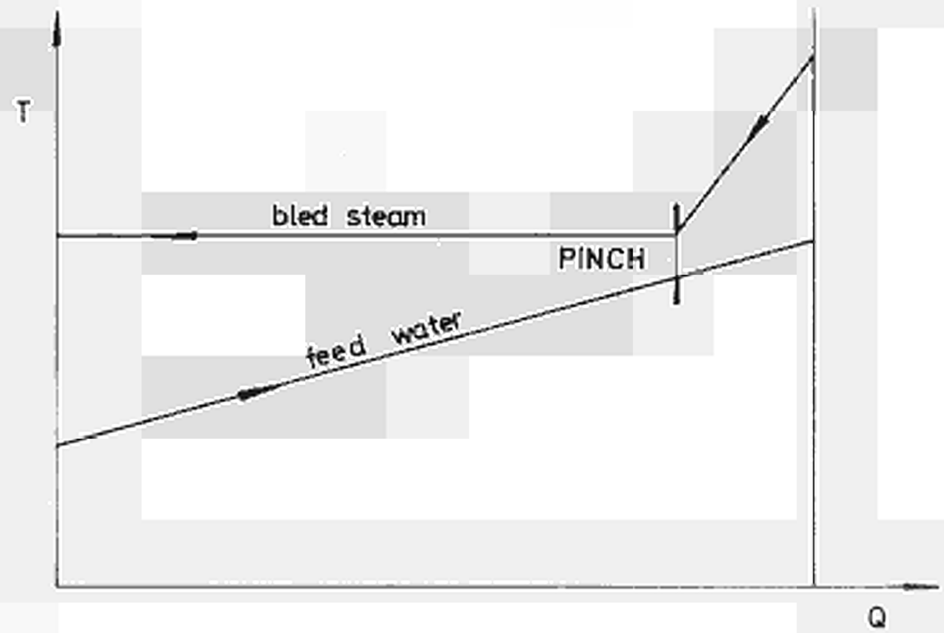

Turbine - Preheater - Arrangement

Fig. 4

GO - 2284

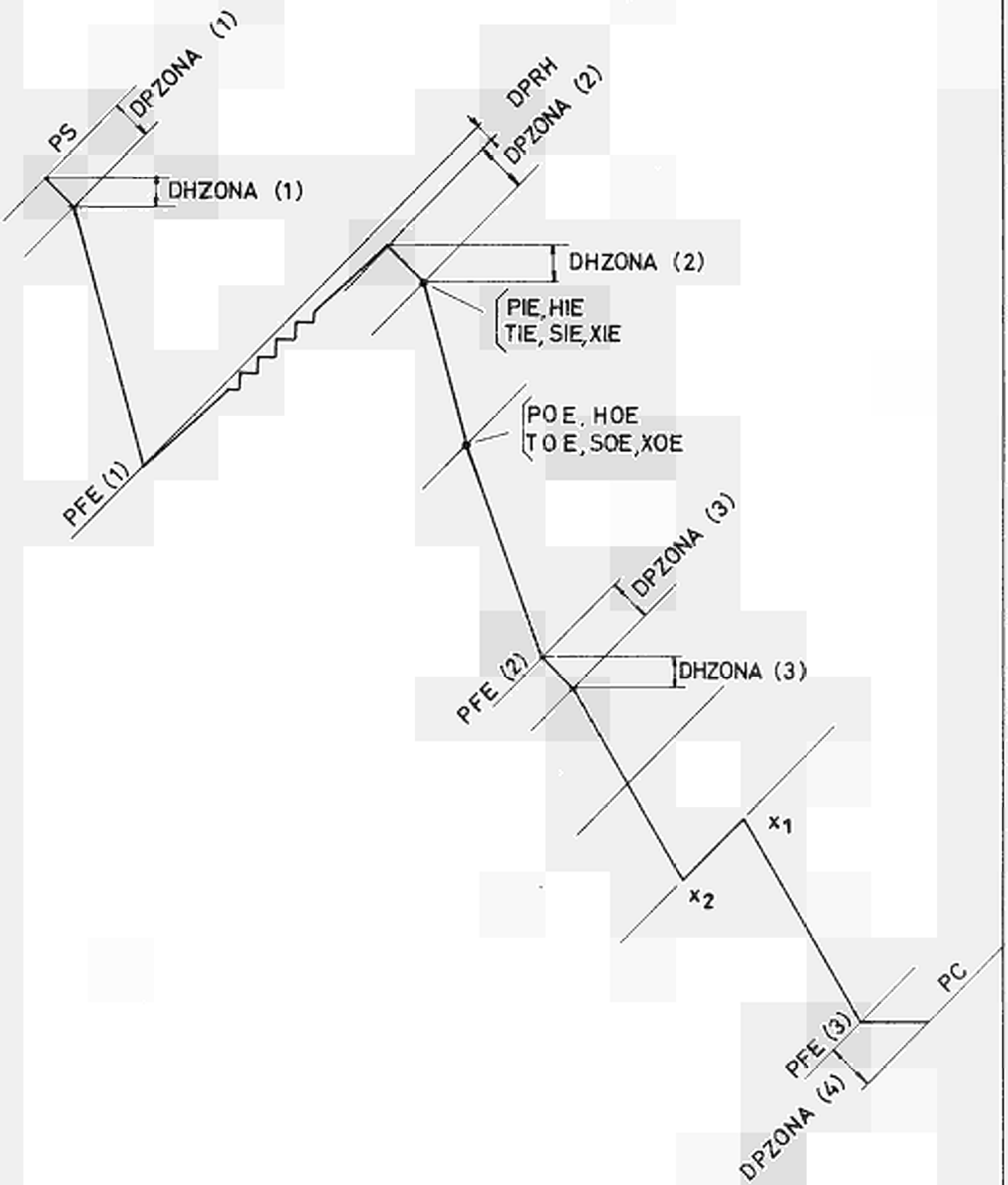
Fig. 5

GO-2285




QT - diagram for a preheater

Fig. 6
GO-2286




Expansion line

## APPENDIX 1 - SYMBOLS

The nomenclature used for the input and output of the code is based on the following system :

### A.I. Data referring to the QT-diagram

- the first letter indicates the physical property
- the second letter indicates if the variable refers to the primary or secondary side
- the third letter indicates the point to which the physical property refers
- the fourth indicates the zone to which the value is referred

for example :

TPIE

means :

Temperature on the Primary side at the Economizer Inlet

The letters used have the following signification :

#### First letter

| | |
|---|---|
| E = enthalpy | kcal/kg |
| G = mass flow | kg/s |
| P = pressure | ata |
| S = entropy | kcal/kg |
| T = temperature | °C |
| V = specific volume | $m^3$/kg |
| X = steam quality | -- |

#### Second letter

P = primary side

S = secondary side

Third letter

I = inlet (in the sense of flow)
O = outlet

Fourth letter

B = boiler
E = economizer
R = reheater
S = superheater

A.II. For the turbine the nomenclature used is the following :

| | | |
|---|---|---|
| First letter | : | indicates the physical property as mentioned above |
| Second letter | : | indicates the beginning or the end of a subexpansion |
| Third letter | : | E = subexpansion<br>SAT = refers to the saturation condition |

A.III. For the preheaters the letters PR are added to the physical properties

## A. IV. Other symbols

Symbols not corresponding to this system are :

| Symbol | Meaning | Dimension |
|---|---|---|
| POWER | gross electric power | MW |
| NEXC | number of heat exchangers | -- |
| OPTION | indicates the heat exchanger arrangement | -- |
| | 1 = no preheater | |
| | 2 = reheater and superheater in series | |
| | 3 = reheater and superheater in parallel | |
| | 4 = reheater in parallel to eco, boiler and superheater | |
| ITYPE | indicates the primary coolant | -- |
| | 1 = OM2 | |
| | 2 = HB40 | |
| PHB | percentage of high boilers | |
| PS | steam pressure at turbine admission valve | ata |
| PC | condenser pressure | ata |
| NZONE | number of turbine cylinders (max. 5) | -- |
| PFE(i) | pressure at outlet of cylinder (i) | ata |
| VTO | turbine outlet velocity | m/s |
| ETA | turbine expansion efficiency(=ETAD) | -- |
| DETA | efficiency correction factor for steam moisture | -- |
| ETAW | ETA corrected for steam moisture | -- |
| ETAEXT | water extraction efficiency | -- |
| XEXTR | steam quality below which moisture reduction is foreseen | -- |
| ETAMO(i) | pump motor efficiency | -- |
| | i = 1 feed pump | |
| | i = 2 extraction pump | |
| ETAPP(i) | pump efficiency | -- |
| ETAMC | turbine/generator mechanical effic. | -- |
| ETAGEN | generator electric efficiency | -- |
| PFP | pressure behind feed pump | at |
| PCP | pressure behind extraction pump | at |

| Symbol | Meaning | Dimension |
|---|---|---|
| GP | total primary flow per HE | kg/s |
| GPS | eco, boiler, superheater primary flow per HE | " " |
| GPR | reheater primary flow per HE | " " |
| GS | live steam flow per HE | " " |
| BETA | ratio reheater to live steam flow | -- |
| DPTR | pressure drop pipes HP-turbine-reheater | -- |
| DPPR | " " for one preheater | $kg/cm^2$ |
| DPSA | " " pipes superheater-turbine | -- |
| DPSH | " " superheater | -- |
| DPRH | " " reheater | -- |
| DPBS | " " between boiler-superh. | -- |
| DPBO | " " boiler | -- |
| DPEB | " " between eco-boiler | -- |
| DPEC | " " eco | -- |
| DPTPR | " " bleeding pipe | -- |
| DPZONA(i) | pressure loss at turbine cylinder(i)inlet | |
| DHZONA(i) | enthalpy " " " " " | kcal/kg |
| DTPR | temperature rise over one preheater | °C |
| DTC | feed water temperature rise by external source | °C |
| NPR | number of preheaters | -- |
| NUPRE | " " " if NUPR=0 the number of preheaters is calculated from DTPR | -- |
| NDG | number of preheater which is the degasifier | -- |
| NS(i) | number of bled tappings in turbine cylinder (i) | -- |
| EF | feed water enthalpy after a preheater | kcal/kg |
| T1 | feed water temperature behind a preheater before the bled steam condensate is added | -- |
| PD | degasifier pressure | ata |
| TD | degasifier temperature | °C |
| PINCH | preheater pinch point | |

| Symbol | Meaning | Dimension |
|---|---|---|
| PINCHE | pinch at economizer outlet | °C |
| PINCHS | pinch at superheater outlet | °C |
| PINCHR | pinch at reheater outlet | °C |
| WPECO | primary coolant velocity in eco | m/s |
| WPEVA | " " " " boiler | m/s |
| WPRSUR | " " " "reheater | m/s |
| WPSUR | " " " superheater | m/s |
| WSECO | water velocity in eco | m/s |
| WSRSUR | steam velocity in reheater | m/s |
| WSSUR | " " in superheater | m/s |
| | | |
| DECO | tube diameter in eco | m |
| DEVA | " " " boiler | m |
| DRSUR | " " " reheater | m |
| DSUR | " " " superheater | m |
| | | |
| SPECO | tube wall thickness in eco | m |
| SPEVA | " " " " boiler | m |
| SPRSUR | " " " " reheater | m |
| SPSUR | " " " " superheater | m |
| | | |
| HF1 | fouling factor in the economizer | $\frac{sec\ °C\ m^2}{kcal}$ |
| HF2 | " " " " boiler | " |
| HF3 | " " " " reheater | " |
| HF4 | " " " " superheater | " |
| | | |
| NUMBER | arbitrary number to identify the case | -- |
| PRINT | a positive value must be taken in case intermediate results are wanted | -- |

## APPENDIX II - NUMERICAL EXAMPLE

In the following the listing is given of a case for which first the complete HD2 calculation was made. Then with the results from the QT-diagram calculation the same case was repeated with the HD2 - TP version.

The steam mass flows obtained from the HD2 calculation correspond to the given electric power (100 MW). In case of the HD2 - TP calculation they refer to 1 kg of live steam.

```
                 *** INPUT DATA   BENSON    * CASE N =  1  OPTION =  3 ***               68/11/13      18.02.44
GROSS ELECT. POWER (MWATT)                  POWER   =  100.00
NUMBER OF EXCHANGERS                        NEXC    =      4
TEMPERATURES (C)                            TPIS    = 370.000
                                            TPOE    = 290.000
                                            TSIR    = 224.100
PINCH POINTS (C)                            PINCHE  =  10.000
                                            PINCHR  =  10.000
                                            PINCHS  =  10.000
                                            PINCH   =   2.000
PRESSURES (KG/CM2) (*)                      PS      =  74.000
                                            PC      =   0.043
                                            PFE(1)  =  23.000
                                            PFE(2)  =   0.048
PRESS. LOSSES(KG/CM2) (**)                  DPZONA(1)=  0.950
                                            DPZONA(2)=  0.925
                                            DPZONA(3)=  0.900
                                             DPTR     =  0.943
                                             DPPR     =  0.200
                                             DPSA     =  0.970
                                             DPSH     =  0.950
                                             DPRH     =  0.960
                                             DPBS     =  1.000
                                             DPBO     =  0.950
                                             DPEB     =  1.000
                                             DPEC     =  0.850
                                            DPTPR     =  0.950, 0.950,
ENTHALPY LOSSES (KCAL/KG)                   DHZONA(1)= 0.0
                                            DHZONA(2)= 0.0
                                            DHZONA(3)= 0.0
EXPANSION CHARACTERISTICS                   N. OF CYLINDERS  2
                                            ETA(1)= 0.83  DETA(1)= 1.00  ETAEXT(1)= 0.20  XEXTR(1)= 0.96
                                            ETA(2)= 0.88  DETA(2)= 1.00  ETAEXT(2)= 0.20  XEXTR(2)= 0.96
EFFICIENCIES                                FEED PUMP EFFICIENCY   = 0.800    CONDEN. PUMP EFFICIENCY   = 0.800
                                            MOTOR EFF.(FEED PUMP)  = 0.900    MOTOR EFF.(CONDEN. PUMP)  = 0.900
                                            TURB./GEN. MECH. EFF.  = 0.990    GENER. ELECTRIC EFFIC.    = 0.988
FOULING FACT. (M2*SEC*C/KCAL)                 ECON.=    0.0   BOIL.=    0.0   RHEAT.=    0.0   SHEAT.=    0.0
OUTLET SPEED  (M/SEC)                       VTO = 250.00
ADDITIONAL PREHEATING (C)                   DTC =   0.0
PERCENTAGE OF HIGH BOILER                   PHB =  30.00
GEOMET. CARACTERIST. OF                     WPE =    1.30   WPB =    1.30   WPR =    2.50   WPS =    1.30
HEAT EXCHANGER                              WSE =    1.00   WSR =   35.00   WSS =   23.83
                                            DEC = 0.0200    DBO = 0.0200    DRE = 0.0200    DSU = 0.0200
                                            SPE =0.00150    SPB =0.00150    SPR =0.00150    SPS =0.00150

   *  THESE DATA MAY BE CHANGED BY THE PROGRAM
   ** RELATIVE  VALUES
```

OUTPUT HD 2 COMPLETE VERSION

********************************************************************************

### *** QT DIAGRAM ***

TEMPERATURE (C) , ENTHALPY (KCAL/KG) , PRESSURE (KG/CM**2)

GP = 358.275 (KG/SEC) GS = 26.942 (KG/SEC) BETA = 1.00 THERM. POW. = 69.374 (MWATT)
GPS= 163.649 (KG/SEC) GPR= 194.623 (KG/SEC)

QE = 3494.4 (KCAL/SEC) QB = 9192.1 (KCAL/SEC) QR = 2110.6 (KCAL/SEC) QS = 1777.0 (KCAL/SEC)

| *** PRIMARY SIDE *** | | | | | | | *** SECONDARY SIDE *** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPIS = | 370.00 | EPIS = | 139.61 | PPIS = | 5.00 | * | TSOS = | 360.00 | ESOS = | 724.85 | PSOS = | 76.29 |
| TPOS = | 351.85 | EPOS = | 128.75 | PPOS = | 5.00 | * | TSIS = | 293.88 | ESIS = | 658.89 | PSIS = | 80.30 |
| TPIR = | 370.00 | EPIR = | 139.61 | PPIR = | 5.00 | * | TSOR = | 360.00 | ESOR = | 754.07 | PSOR = | 20.82 |
| TPOR = | 351.85 | EPOR = | 128.75 | PPOR = | 5.00 | * | TSIR = | 224.10 | ESIR = | 675.73 | PSIR = | 21.69 |
| TPIB = | 351.85 | EPIB = | 128.75 | PPIB = | 5.00 | * | TSOB = | 293.88 | ESOB = | 658.89 | PSOB = | 80.30 |
| TPOB = | 307.47 | EPOB = | 103.10 | PPOB = | 5.00 | * | TSIB = | 297.47 | ESIB = | 317.71 | PSIB = | 84.53 |
| TPIE = | 307.47 | EPIE = | 103.10 | PPIE = | 5.00 | * | TSOE = | 297.47 | ESOE = | 317.71 | PSOE = | 84.53 |
| TPOE = | 290.00 | EPOE = | 93.34 | PPOE = | 5.00 | * | TSIE = | 184.55 | ESIE = | 188.01 | PSIE = | 99.45 |

********************************************************************************

### *** PREHEATER ***

PSIE = 99.447 PFP = 99.647 PD = 4.345 PCP = 4.745 PC = 0.043 (KG/CM**2)

TSIE = 184.554 TD = 145.917 TC = 30.006 (C)

DTPR = 38.637 (C) NPR = 4 NDG = 2
NS( 1)= 0
NS( 2)= 4

| GPR (KG/S) | GPR/GS | PPR(KG/CM2) | TPR (C) | G (KG/S) | G/GS | EF(KCAL/KG) | T1 (C) |
|---|---|---|---|---|---|---|---|
| 7.454 | 0.069 | 11.861 | 184.554 | 107.768 | 1.000 | 188.006 | 184.301 |
| 6.871 | 0.064 | 4.345 | 145.917 | 100.314 | 0.931 | 147.764 | 145.789 |
| 6.379 | 0.059 | 1.426 | 107.280 | 93.443 | 0.867 | 107.452 | 107.040 |
| 7.062 | 0.066 | 0.327 | 68.643 | 87.064 | 0.808 | 68.644 | 68.349 |

********************************************************************************

## *** TURBINE EXPANSION ***

*** CYLINDER N. = 1 , EXPAN. N. = 1 , STEAM FLOW = 107.768 (KG/S) ***

| | | | | |
|---|---|---|---|---|
| PIE | = 70.300 | POE | = 23.000 | (KG/CM2) |
| TIE | = 354.768 | TOE | = 226.658 | (C) |
| HIE | = 724.846 | HOE | = 675.730 | (KCAL/KG) |
| SIE | = 1.497 | SOE | = 1.517 | (KCAL/KG/C) |
| VIE | = 0.036 | VOE | = 0.091 | (M**3/KG) |
| XIE | = 1.000 | XOE | = 1.000 | |
| ETAD | = 0.83 | ETAW | = ***** | |

*** CYLINDER N. = 2 , EXPAN. N. = 1 , STEAM FLOW = 107.768 (KG/S) ***

| | | | | |
|---|---|---|---|---|
| PIE | = 19.260 | POE | = 12.485 | (KG/CM2) |
| TIE | = 358.562 | TOE | = 304.809 | (C) |
| HIE | = 754.069 | HOE | = 729.581 | (KCAL/KG) |
| SIE | = 1.675 | SOE | = 1.681 | (KCAL/KG/C) |
| VIE | = 0.149 | VOE | = 0.211 | (M**3/KG) |
| XIE | = 1.000 | XOE | = 1.000 | |
| ETAD | = 0.38 | ETAW | = ***** | |

*** CYLINDER N. = 2 , EXPAN. N. = 2 , STEAM FLOW = 100.314 (KG/S) ***

| | | | | |
|---|---|---|---|---|
| PIE | = 12.485 | POE | = 4.574 | (KG/CM2) |
| TIE | = 304.809 | TOE | = 195.916 | (C) |
| HIE | = 729.581 | HOE | = 680.911 | (KCAL/KG) |
| SIE | = 1.681 | SOE | = 1.695 | (KCAL/KG/C) |
| VIE | = 0.211 | VOE | = 0.471 | (M**3/KG) |
| XIE | = 1.000 | XOE | = 1.000 | |
| ETAD | = 0.88 | ETAW | = ***** | |

*** CYLINDER N. = 2 , EXPAN. N. = 3 , STEAM FLOW = 93.443 (KG/S) ***

| | | | | | | |
|---|---|---|---|---|---|---|
| PIE | = 4.574 | PESAT | = 1.867 | POE | = 1.501 | (KG/CM2) |
| TIE | = 195.916 | TESAT | = 117.460 | TOE | = 110.810 | (C) |
| HIE | = 680.911 | HESAT | = 644.965 | HOE | = 637.096 | (KCAL/KG) |
| SIE | = 1.695 | SESAT | = 1.708 | SOE | = 1.711 | (KCAL/KG/C) |
| VIE | = 0.471 | VESAT | = 0.962 | VOE | = 1.167 | (M**3/KG) |

```
XIE =   1.000          XESAT =    1.00          XOE =    0.99
ETAD =      0.880               ETAW =      0.875
*******************************************************************************************

 *** CYLINDER N. = 2   ,  EXPAN. N. = 4   ,  STEAM FLOW =  87.064  (KG/S)  ***

PIE   =   1.501         POE   =   0.344        (KG/CM2)
TIE   = 110.810         TOE   =  71.836          (C)
HIE   = 637.096         HOE   = 590.395        (KCAL/KG)
SIE   =   1.711         SOE   =   1.736        (KCAL/KG/C)
VIE   =   1.167         VOE   =   4.434        (M**3/KG)
XIE   =   0.989         XOE   =   0.933
ETAD  =    0.88         ETAW  =    0.84

*** WATER EXTRACTION AT  P = 0.344   ,    T =  71.836   ,   GEXT =   1.242  (KG/SEC)  ***

   X1 =  0.9325        X2 =  0.9460
   H1 =  590.40        H2 =  597.90
   S1 =    1.74        S2 =    1.76
*******************************************************************************************

 *** CYLINDER N. = 2   ,  EXPAN. N. = 5   ,  STEAM FLOW =  80.002  (KG/S)  ***

PIE   =   0.344         POE   =   0.048        (KG/CM2)
TIE   =  71.836         TOE   =  31.855          (C)
HIE   = 597.897         HOE   = 547.303        (KCAL/KG)
SIE   =   1.758         SOE   =   1.800        (KCAL/KG/C)
VIE   =   4.434         VOE   =  26.533        (M**3/KG)
XIE   =   0.946         XOE   =   0.890
ETAD  =    0.88         ETAW  =    0.80

*******************************************************************************************
*******************************************************************************************
```

## *** EFFICIENCIES ***

| | | | | | | |
|---|---|---|---|---|---|---|
| ** | THERMODYNAMIC EFFICIENCY | ** | ETATH | = | 0.36843 | ** |
| ** | STEAM CYCLE GROSS EFFIC. | ** | ETASB | = | 0.36036 | ** |
| ** | STEAM CYCLE NET EFFIC. | ** | ETASN | = | 0.35508 | ** |
| ** | TOT. PUMP. POWER/GROSS ELECT. POWER | ** | NUS1 | = | 0.01466 | ** |
| ** | TOT. PUMP. POWER/THERMAL POWER | ** | NUS2 | = | 0.00528 | ** |
| ** | FEED PUMPING POWER (KW) | ** | | = | 1414.64 | ** |
| ** | CONDENSER PUMPING POWER (KW) | ** | | = | 51.45 | ** |
| ** | OUTLET LOSS | ** | | = | 0.00900 | ** |
| ** | TOTAL SURFACE (M**2) | ** | | = | 1279.05 | ** |

## ** HEAT TRANSFER COEFFICIENTS AND SURFACES **

TYPE OF COOLANT = OM2

| | ECONOM. | | BOILER | | REHEATER | | SUPERHEATER | |
|---|---|---|---|---|---|---|---|---|
| AVER. TEMP. ON PRIMARY SIDE | 298.74 | C | 329.66 | C | 360.93 | C | 360.93 | C |
| AVER. TEMP. ON SECONDARY SIDE | 241.01 | C | 295.68 | C | 292.05 | C | 326.94 | C |
| LOGARITHM. DT | 40.52 | C | 27.30 | C | 46.22 | C | 27.30 | C |
| PRIM. ALFA | 0.615 | KCAL/S/M2/C | 0.649 | KCAL/S/M2/C | 1.015 | KCAL/S/M2/C | 0.681 | KCAL/S/M2/C |
| SEC. ALFA | 2.401 | KCAL/S/M2/C | 3.970 | KCAL/S/M2/C | 0.310 | KCAL/S/M2/C | 0.990 | KCAL/S/M2/C |
| TOTAL ALFA | 0.439 | KCAL/S/M2/C | 0.500 | KCAL/S/M2/C | 0.202 | KCAL/S/M2/C | 0.355 | KCAL/S/M2/C |
| FOULING | 0.0 | S*M2*C/KCAL | 0.0 | S*M2*C/KCAL | 0.0 | S*M2*C/KCAL | 0.0 | S*M2*C/KCAL |
| EXCHANG. HEAT | 3494.4 | KCAL/S | 9192.1 | KCAL/S | 2110.6 | KCAL/S | 1777.0 | KCAL/S |
| SURFACE | 196.58 | M2 | 673.13 | M2 | 225.84 | M2 | 183.50 | M2 |
| PRIMARY SPEED | 1.30 | M/S | 1.30 | M/S | 2.50 | M/S | 1.30 | M/S |
| SECONDARY SPEED | 1.00 | M/S | ******** | M/S | 35.00 | M/S | 23.83 | M/S |
| PRIMARY PRANDTL NUMBER | 1.362437E 01 | | 1.135048E 01 | | 9.646044E 00 | | 9.646044E 00 | |
| SEC. PRANDTL NO | 8.132502E-01 | | | | 1.017570E 00 | | 1.3082[illegible]E 00 | |
| PRIMARY REYNOLD NUMBER | 3.240351E 04 | | 3.977285E 04 | | 9.189494E 04 | | 4.778534E 04 | |
| SEC. REYNOLD NO | 1.272645E 05 | | | | 2.545542E 05 | | 6.513883E 05 | |
| PRIMARY NUSSELT NUMBER | 4.057407E 02 | | 4.344619E 02 | | 6.885017E 02 | | 4.620269E 02 | |
| SEC. NUSSELT NO | 2.696245E 02 | | | | 4.890764E 02 | | 1.146762E 03 | |

*** INPUT DATA ***     68/11/14     14.58.47

CASE N = 1     OPTION = 3

OUTPUT HD 2 - TP

```
TEMPERATURES (C)               TSIE      = 184.554
                               TSOR      = 360.000
                               TSIR      = 224.100
                               TSOS      = 360.000
PINCH POINT (C)                PINCH     =   2.000

PRESSURES (KG/CM2) (*)         PS        =  74.000
                               PC        =   0.043
                               PFE(1)    =  23.000
                               PFE(2)    =   0.048

PRESS. LOSSES(KG/CM2) (**)     DPZONA(1)= 0.950
                               DPZONA(2)= 0.925
                               DPZONA(3)= 0.900

                                DPTR     = 0.943
                                DPPR     = 0.200
                                DPSA     = 0.970
                                DPSH     = 0.950
                                DPRH     = 0.960
                                DPBS     = 1.000
                                DPBO     = 0.950
                                DPEB     = 1.000
                                DPEC     = 0.850
                               DPTPR     = 0.950, 0.950,

ENTHALPY LOSSES (KCAL/KG)      DHZONA(1)= 0.0
                               DHZONA(2)= 0.0
                               DHZONA(3)= 0.0

EXPANSION CHARACTERISTICS      N. OF CYLINDERS  2

                               ETA(1)= 0.83  DETA(1)= 1.00  ETAEXT(1)= 0.20  XEXTR(1)= 0.96
                               ETA(2)= 0.88  DETA(2)= 1.00  ETAEXT(2)= 0.20  XEXTR(2)= 0.96

STEAM OUTLET SPEED (M/SEC)     VTO =  250.00

ADDITIONAL PREHEATING (C)      DTC =    0.0

EFFICIENCIES                   FEED PUMP EFFICIENCY     = 0.800    CONDEN. PUMP EFFICIENCY        = 0.800
                               MOTOR EFF.(FEED PUMP)    = 0.900    MOTOR EFF.(CONDEN. PUMP)       = 0.900
                               TURB./GEN. MECH. EFF.    = 0.990    GENER. ELECTRIC EFFIC.         = 0.988
```

* THESE DATA MAY BE CHANGED BY THE PROGRAM
** RELATIVE VALUES

******************************************************************************************

TEMPERATURE (C) , ENTHALPY (KCAL/KG) , PRESSURE (KG/CM2)

GP = 1.000 (KG/SEC)

BETA = 1.000

******************************************************************************************

*** PREHEATER ***

PSIE = 99.447 PFP = 99.647 PD = 4.345 PCP = 4.745 PC = 0.043 (KG/CM**2)

TSIE = 184.554 TD = 145.917 TC = 30.006 (C)

DTPR = 38.637 (C) NPR = 4 NDG = 2

NS(1)= 0

NS(2)= 4

| GPR (KG/S) | GPR/GS | PPR(KG/CM2) | TPR (C) | G (KG/S) | G/GS | EF(KCAL/KG) | T1 (C) |
|---|---|---|---|---|---|---|---|
| 0.069 | 0.069 | 11.861 | 184.554 | 1.000 | 1.000 | 187.987 | 184.282 |
| 0.064 | 0.064 | 4.345 | 145.917 | 0.931 | 0.931 | 147.764 | 145.789 |
| 0.059 | 0.059 | 1.426 | 107.280 | 0.867 | 0.867 | 107.453 | 107.040 |
| 0.065 | 0.065 | 0.327 | 68.643 | 0.808 | 0.808 | 68.644 | 68.352 |

******************************************************************************************

| | | | | | |
|---|---|---|---|---|---|
| ** THERMODYNAMIC EFFICIENCY | ** | ETATH | = | 0.36848 | ** |
| ** STEAM CYCLE GROSS EFFIC. | ** | ETASB | = | 0.36042 | ** |
| ** STEAM CYCLE NET EFFIC. | ** | ETASN | = | 0.35513 | ** |
| ** TOT. PUMP. POWER/GROSS ELECT. POWER | ** | NUS1 | = | 0.01466 | ** |
| ** TOT. PUMP. POWER/THERMAL POWER | ** | NUS2 | = | 0.00528 | ** |
| ** FEED PUMPING POWER (KW) | ** | | = | 13.12718 | ** |
| ** CONDENSER PUMPING POWER (KW) | ** | | = | 0.47778 | ** |
| ** OUTLET LOSS | ** | | = | 0.00901 | ** |

# APPENDIX III - HOW TO USE THE CODE

## Code characteristics

The program was written in FORTRAN IV for use with an IBM 360/65 computer. The execution time for one case is about 5 ".

## Input preparation

Input is made according to the "namelist" format (1). An example is given in fig. AIII-1 for the code HD2 and in fig. AIII-2 for the version HD2-TP.

- data must be preceded by their name followed by an equal sign. Their order is trivial
- arrays are introduced by name without subscript; items are separated by commas
- data are separated by commas
- the list for each case must begin with "&CASE" punched in column 2 and end with "&END".
- several cases may run in sequence; only data which change must be introduced

In case a Benson boiler is calculated the velocities on the steam/water side for the economizer <u>or</u> for the superheater must be given.

---------------

(1) See IBM-System Reference Library - FORTRAN Language - FORM C28-6515-A

Fig. AIII-1
GO-2279

## Sample input for HD2

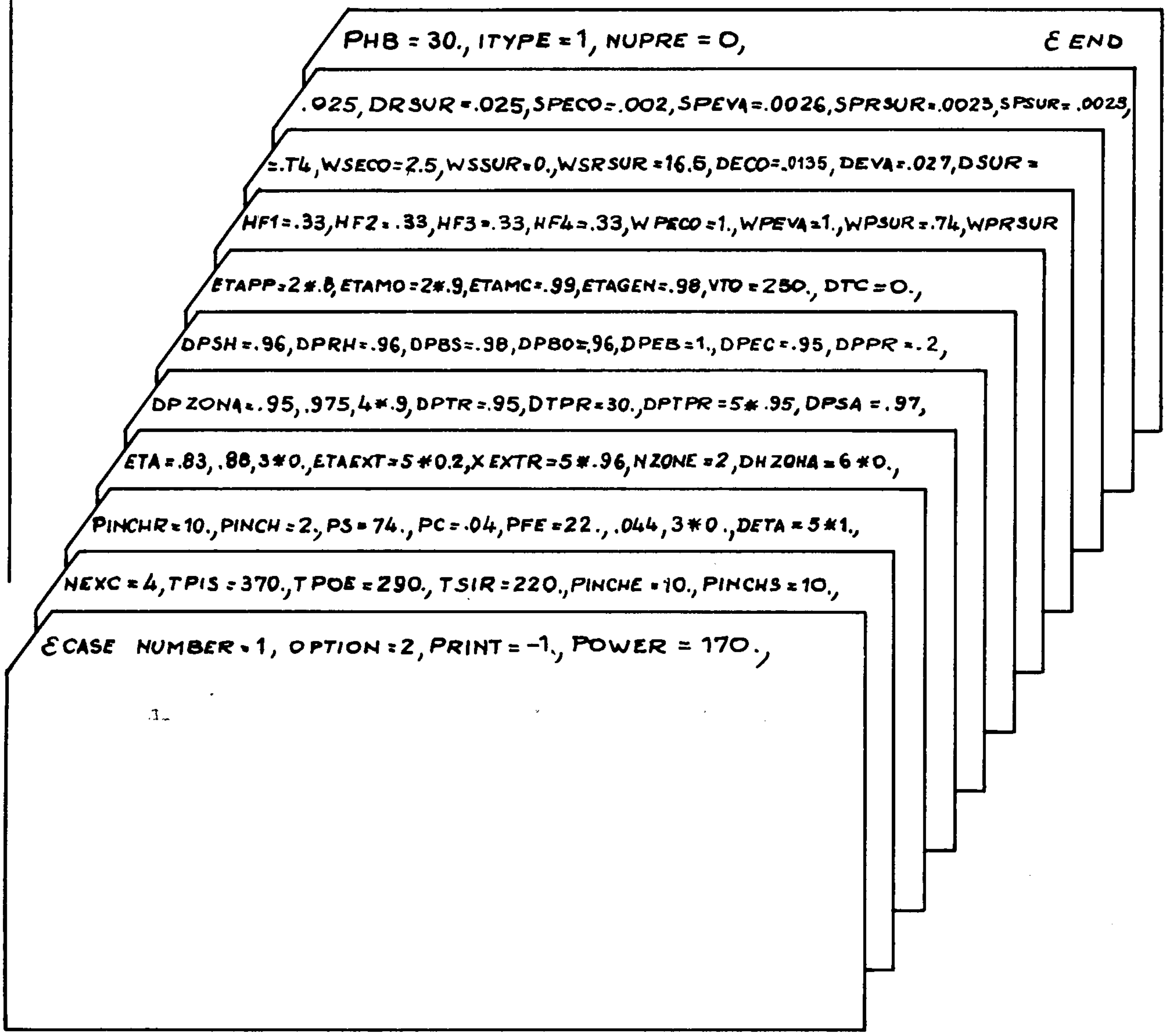
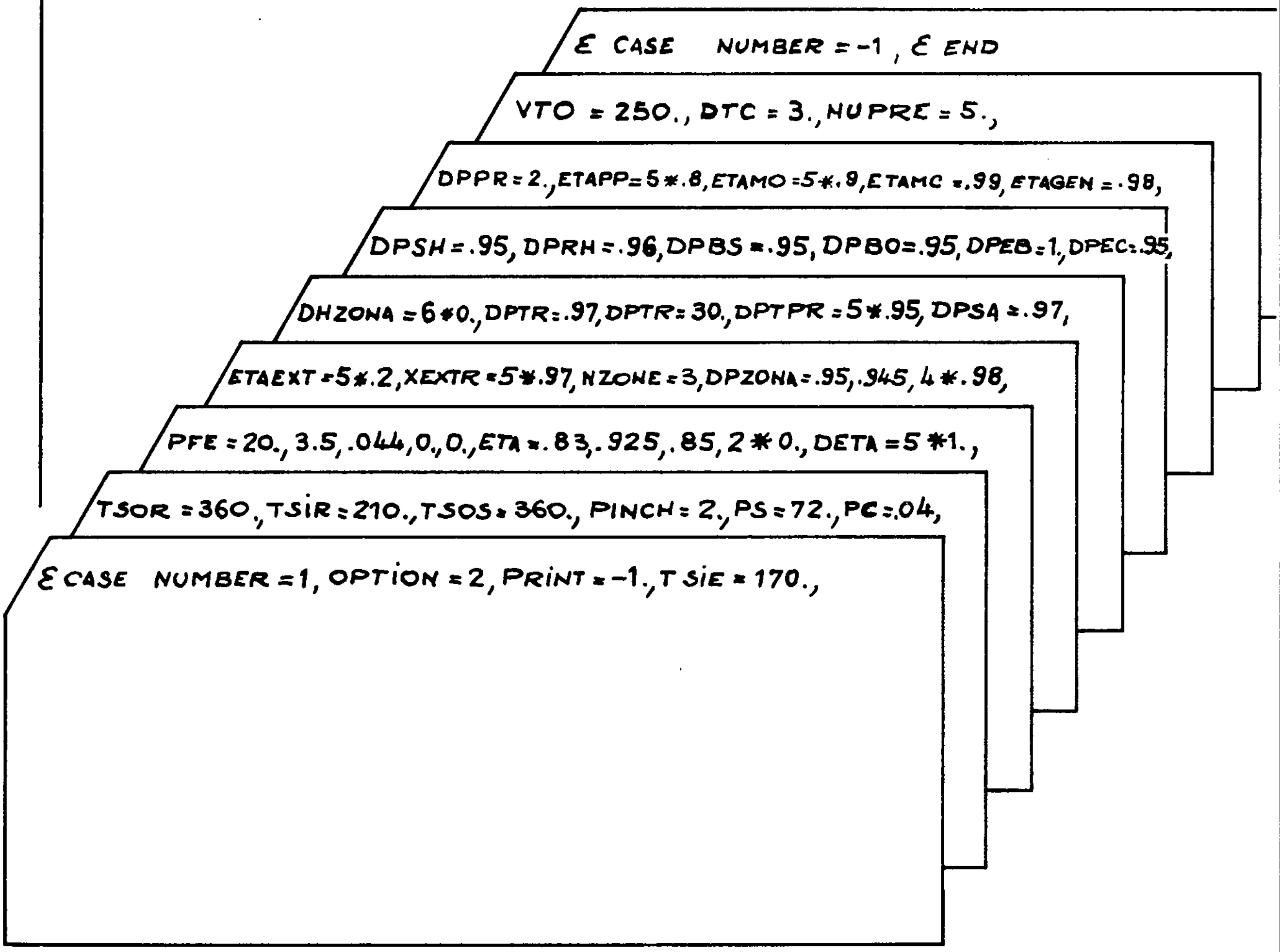


Fig. AIII-2
GO-2280

## Sample input for HD2-TP



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Alfred Nobel

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