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# *A Homogeneous Heat Pipe Design Code*

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# PREFACE

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# A HOMOGENEOUS HEAT PIPE DESIGN CODE

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TABLES



FIGURE



APPENDIX

ABSTRACT

To facilitate parametric performance evaluation of heat pipes in lightweight heat rejection systems, a computer program was developed. This report contains a description of that code along with a user's manual and sample input. It is limited to the analysis and design of homogeneous wick heat pipes, although the annular heat pipe program previously developed is included as part of the heat pipe radiator subroutine in this document.

A HOMOGENEOUS HEAT PIPE ANALYSIS CODE

## I. Introduction

Heat pipes have been successfully used in a variety of high and low heat transfer applications and for isothermal operations. They have been suggested for use in thermionic reactor system concepts to achieve highly reliable lightweight heat rejection systems.[1,2] In order to facilitate evaluation of heat pipes for these concepts and to perform parametric evaluations of alternative heat pipe designs, a computer program was developed to compute heat pipe performance. The code was required for performance predictions for laboratory experiments and to aid in the selection of heat pipe materials and designs for thermionic reactor systems.

This report contains a description of that code along with a user's manual and sample input. A typical heat pipe consists of a closed tube or pipe with an internal wick or screen running the length of the pipe and a small quantity of a liquid working fluid. Heat transfer from the evaporator to the condenser is achieved by vaporization of the working fluid which flows to the condenser of the heat pipe because of the self-induced pressure differential. The fluid condenses and returns from the condenser to the evaporator by capillary pumping in the wick. The heat transferred depends on the fluid circulation rate and latent heat of vaporization. Factors which influence the operation of a heat pipe are the liquid and vapor flow properties of the working fluid, the surface tension of the liquid, the physical dimensions of the vapor and liquid flow spaces, and the geometry of the capillary pumping structure. The performance of most homogeneous heat pipes depends on the capillary pumping capacity of the wick structure and its resistance to liquid flow.

A variety of wick configurations are described elsewhere.[3-5] This report is limited to the analysis and design of homogeneous wick heat pipes. In these designs the capillary wick usually is a screen swaged directly to the inner wall of the heat pipe. In comparison, an annular heat pipe has a thin liquid annulus separating the wick and the heat pipe wall. The annular heat pipe, because it has an open channel for liquid flow, has a much lower liquid pressure drop and, therefore, has a much higher heat transfer capacity. Also, since the wick pore size affects only the pumping power and not the pressure drop, the pore size can be made as small as convenient. An unfortunate characteristic of annular heat pipes is that the pumping power developed by the capillary force in the wick is limited by the largest pore, i.e., this gives the lowest developed pressure head. Thus control of pore size during wick fabrication is critical. This is not true with a homogeneous heat pipe. In a homogeneous pipe an increased pressure drop in the wick is tolerated in order to remove the dependence of pumping pressure head on maximum pore size. The reduced sensitivity of this design to variations in pore size makes fabrication easier and should result in lower heat pipe production costs. Since large numbers of heat pipes must be fabricated for the space radiator applications under consideration, the homogeneous heat pipe is an attractive alternative. A program similar to the one described herein was written to perform analyses of annular heat pipes, and is described in the Thermionic Reactor System Analysis code document.[6] The annular heat pipe program is included as part of the heat pipe radiator subroutine in this document.

## II. Theory

1. Assumptions and Approximations. In order for a heat pipe to function properly the total pumping pressure generated by the wick capillary force must

exceed the sum of the pressure drops in the heat pipe. Thus,

$$\Delta P_{cp} \geq \Delta P_v + \Delta P_\ell + \Delta P_g + \Delta P_m \tag{1}$$

Diagrams of both transverse and longitudinal cross sections of a typical homogeneous heat pipe are shown in Figures 1a and 1b. The equations used to describe the heat pipe performance are given in the following section. The approximations and derivations are indicated where applicable. More complete derivations are given in references 3-5. The equations contained herein are applicable only to heat pipes with a cylindrical cross section.

2. Radial Temperature Drops. The outside evaporator wall temperature is given by T* as shown in Figure 1. This is the surface temperature; thus any radial film temperature drop to the heat sink must be treated separately. The temperature drop through the cylindrical evaporator wall is

$$\Delta T_{t_e} = \frac{Q_e \ln \frac{r_{o_e}}{r_{i_e}}}{2\pi k_{t_e} L_e F_e} \tag{2}$$

The radial temperature drop through the wick is

$$\Delta T_{w_e} = \frac{Q_e \ln \frac{r_{i_e}}{r_v}}{2\pi k_{w_e} L_e F_e} \tag{3}$$

The total radial temperature drop for the evaporator is therefore:

$$\Delta T_e = \frac{Q_e}{2\pi L_e F_e} \left[ \frac{1}{k_{t_e}} \ln \frac{r_{o_e}}{r_{i_e}} + \frac{1}{k_{w_e}} \ln \frac{r_{i_e}}{r_v} \right] \qquad (4)$$

Similarly, the temperature drop through the condenser wall and wick is

$$\Delta T_c = \frac{Q}{2\pi L_c F_c} \left[ \frac{1}{k_{t_c}} \ln \frac{r_{o_c}}{r_{i_c}} + \frac{1}{k_{w_c}} \ln \frac{r_{i_c}}{r_v} \right] \qquad (5)$$

The vapor temperature in the evaporator is

$$T_{v_e} = T^* - \Delta T_e \qquad (6)$$

and the rejection temperature at the outer surface of the condenser is

$$T_c = \bar{T}_{v_c} - \Delta T_c \qquad (7)$$

3. Mass Transport Expressions. The total fluid mass flow rate in the heat pipe is

$$W = \frac{Q}{\lambda} \qquad (8)$$

where $\lambda$ is the heat of vaporization of the working fluid. The mean velocity in the vapor region is

$$\bar{V}_v = \frac{W}{\rho_v \pi r_v^2} \tag{9}$$

The sonic velocity in the heat pipe is determined by the properties and conditions in the heat pipe as

$$V_s = 11,772 \left[\frac{T_v}{M}\right]^{1/2}, \text{ cm/sec} \tag{10}$$

This correlation assumes the ratio of specific heats, K, for the working fluid equals 1.667 for monatomic vapors.

4. <u>Pressure</u>. The static vapor pressure ratio in the evaporator (for points 1 and 2 of Figure 1) is

$$\frac{P_{e_1}}{P_{e_2}} = 1 + N^2 K \tag{11}$$

where N is the mach number of the vapor. Therefore,

$$P_{e_2} = P_{e_1}\left[\frac{1}{1.0 + 1.667\ (N)^2}\right] \tag{12}$$

5. <u>Acceleration Pressure Drop</u>. The total acceleration pressure drop is

$$\Delta P_m = P_{e_1} - P_{e_2}\left[\frac{1.667\ (N)^2}{1.0 + 1.667\ (N)^2}\right] \tag{13}$$

The pressure recovery in the condenser due to decrease in the vapor velocity as a result of condensation of the vapor is estimated to be 40 percent of the acceleration pressure drop in the evaporation.

$$\Delta P_{m-rec} \cong 0.40\ \Delta P_m \qquad (14)$$

The temperature in the condenser section is obtained from the pressure and the equation of state of the working fluid in the condenser.

6. Vapor Flow Pressure Drop. The pressure drop in the flowing vapor is given by the Fanning equation

$$\Delta P_v = \frac{2fG^2L}{g_c \rho D_v} \qquad (15)$$

The length used in these calculations is an effective length of the heat pipe, $L_{eff}$, defined as

$$L_{eff} = \frac{L_e + L_c}{2} + L_a \qquad (16)$$

This definition is used since heat is added over the entire evaporator length and the vapor flow rate increases linearly until the exit of the evaporator (Pt. 2, Fig. 1b) is reached. Conversely, in the condenser section the flow rate decreases linearly as the heat is extracted and the vapor condenses. The Reynolds number for the vapor flow is

$$Re_v = \frac{D_v}{\mu_v} \frac{W}{\pi r_v^2} = \frac{2W}{\pi r_v \mu_v} \tag{17}$$

If $Re_v \leq 2000$, then a laminar flow correlation for the friction factor is used, resulting in a pressure drop of

$$\Delta P_v = \frac{32G\, L_{eff}}{D_v^2} \left(\frac{\mu}{\rho}\right)_v \tag{18}$$

With Re > 2000, turbulent flow correlations are used and the vapor pressure drop is

$$\Delta P_v = \frac{4f_v\, L\, G_v^2}{D_v\, 2\rho_v} = \frac{4}{D_v} \left(\frac{0.0252}{Re^{0.087}}\right) \frac{L_{eff}\, G^2}{2\rho_v} \tag{19}$$

Finally,

$$\Delta P_v = \frac{(0.08) W^{1.913}\, \mu_v^{0.087}\, L_{eff}}{D_v^{4.91}\, \rho_v} \tag{20}$$

7. Liquid Flow Pressure Drop. The liquid phase pressure drop is obtained from

$$\Delta P_\ell = \frac{\mu_\ell\, L_{eff}\, W}{\rho_\ell\, K_w\, A_w} \tag{21}$$

where the flow area is the total cross sectional area of the wick

$$A_w = \pi(r_i^2 - r_v^2) \tag{22}$$

8. Average Condenser Section Conditions. The average pressure of the vapor in the condenser is

$$\overline{P}_{v_c} = P_{v_2} - \Delta P_v + 0.2\left(P_{v_1} - P_{v_2}\right) \tag{23}$$

The average radiator temperature is

$$\overline{T}_r = \overline{T}_c - \frac{Q_c}{2\pi L_c}\left[\frac{1}{k_t} \ln \frac{r_{o_t}}{r_{i_t}} + \frac{1}{k_w} \ln \frac{r_{i_t}}{r_v}\right] \tag{24}$$

$\overline{T}_c$ is obtained from (23) and the equation of state of the working fluid.

9. Available Pumping Pressure. The available pumping pressure depends on the capillary wick pore size and surface tension of the working fluid. The total capillary pumping head available is:

$$\Delta P_{cp} = \frac{2\gamma}{r_p} \tag{25}$$

where $\gamma$ is the liquid surface tension and $r_p$ is the effective pore size in the wick.

10. Empirical Correlations. Several material properties are not available as analytic expressions. These include the permeability, the sintered

thickness of several layers of screen, and the pore size resulting from swaging and sintering of the screen. The data were obtained from tests at JPL. It was found that the data could be conveniently represented by the following expressions:

Wick Permeability

$$\varphi = 0.0371 \left(\frac{1}{S}\right)^{1.6185} \quad cm^2 \tag{26}$$

Layer Thickness

$$t = 10.74 \left(\frac{1}{S}\right)^{1.3553} \quad cm \tag{27}$$

Pore Size

$$r_p = 1.65 \left(\frac{1}{S}\right)^{1.0945} \quad cm \tag{28}$$

In all cases S refers to the screen mesh (available presently only in wires per inch) and the range of validity for the correlation is $50 \leq S \leq 200$.

## III. Program Description

1. Method of Solution. The program provides a convenient method of solving the equations in Section II. The heat input to the pipe is defined by the input data. The equations describing operation of the pipe are solved iteratively to obtain the necessary heat rejection area. A Newton-Raphson iteration scheme is used to provide faster convergence than direct substitution. The iteration is necessary since the pressure drops depend on the pipe

dimensions, hence the length and/or diameter of the heat pipe, while the condenser dimensions depend on the temperature of the condenser. The condenser temperature is fixed by the condenser pressure and the equation of state of the working fluid.

In operation the program computes heat fluxes through the evaporator wall and vapor temperature in the evaporator. From the equation of state, the absolute pressure in the evaporator is computed. From the total heat input and the pipe dimensions the flow rate of the working fluid is computed. Pressure drops and total pumping head available from surface tension correlations are computed. If the available pump head is sufficient to circulate the fluid and therefore transfer the heat, the pressure in the condenser determines the average rejection temperature. This approximation holds well when the major pressure drops are in the liquid phase flow; otherwise, pressure drops and recovery in the condenser cause large temperature variations along the condenser. When this occurs the assumption that a single average temperature can be used to represent the rejection temperature of the heat pipe may be less valid.

2. Built-in Data Correlations. Data on material properties of the wall, and wick and working fluid are built into the code. The available options are:

Wall material - Niobium (NC=1)
Stainless Steel (NC=2)

Working fluid - Potassium (NL=1)
Sodium (NL=2)

The material properties required and the algebraic form of the equations are shown in Table 1. New coefficients must be incorporated if other materials are desired.

## IV. User's Manual

1. Input. A list of the input data required is shown in Table 2. Default values for all parameters are included in the code and are shown in the last column of the table. These default values define a sample problem and the use of a single namelist, $INP$, will cause this default case to be run.

2. Output. The output includes an edit of the input data used for the case in NAMELIST format. The output data provided is a list of the input conditions as well as temperatures, pressures, and pressure drops for the three sections of the heat pipe.

Note that temperature variations in the condenser due to pressure variations along the heat pipe were neglected and a single temperature is used to characterize the condenser. A typical runstream is shown as an appendix.

## V. Nomenclature

| | |
|---|---|
| $A_w$ | Cross-section area of wick |
| D | diameter, cm |
| f | fanning friction factor |
| $F_e$ | fraction of evaporator area available for heat transfer |
| $F_c$ | fraction of condenser area available for heat rejection |
| G | mass flow rate - grams/cm$^2$-sec |
| $g_c$ | dimensional constant |
| K | ratio of specific heat = (1.667 for monatomic fluid) |
| k | thermal conductivity, W/cm-K |
| L | length, cm |
| $L_{eff}$ | effective length of the heat pipe, cm |
| M | molecular weight of the working fluid |
| N | Mach number $(V_v/V_s)$ |
| n | number of layers of screen |
| p | static vapor pressure |
| $\Delta P_{cp}$ | pumping pressure generated by capillary wick, N/cm$^2$ |
| $\Delta P_g$ | pressure drop due to gravity head, N/cm$^2$ |
| $\Delta P_\ell$ | pressure drop in liquid flow, N/cm$^2$ |
| $\Delta P_m$ | pressure drop due to momentum change, N/cm$^2$ |
| $\Delta P_{m\text{-}rec}$ | pressure rise in condenser due to vapor momentum recovery |
| $\Delta P_v$ | pressure drop in vapor flow, N/cm$^2$ |
| Q | total heat carried by pipe, W |
| Re | Reynolds number |
| r | radius, cm |

$r_p$ pore radius in wick, cm

$r_v$ radius of vapor region (= $r_{i_w}$ inside radius of wick)

S screen mesh size (number of wires per inch)

T temperature, $^oK$

T* outside evaporator wall temperature

t thickness of one layer of screen, cm

$\overline{V_v}$ mean vapor velocity, cm/sec

$V_s$ sonic velocity in the vapor, cm/sec

W circulating mass flow rate in the heat pipe, gm/sec

$\gamma$ liquid surface tension

$\lambda$ heat of vaporization of the working fluid, W/gm

$\mu$ viscosity

$\rho$ fluid density, gm/cm$^3$

$\varphi_w$ wick permeability

Subscripts

a adiabatic section

c condenser section

cp capillary pumping

e evaporator section

i inner

$\ell$ liquid

m momentum

o outer

s sonic

| | |
|---|---|
| t | tube wall |
| v | vapor |
| w | wick properties |
| 1 | beginning of evaporator |
| 2 | exit of evaporator |

## VI. References


1. Peelgren, M. L., Kikin, G. M., and Sawyer, D. C., Completely Modular Thermionic Reactor Ion Propulsion System (TRIPS), JPL TM 33-550, May 1972, also in Proceedings of Third International Conference on Thermionic Electrical Power Generation, Vol. I, Julich, FRG, June 5-9, 1972.

2. Kikin, G. M., and Peelgren, M. L., "Test of 50-KW Heat-Pipe Radiator", presented at ASME Winter Annual Meeting, Washington, D.C., Nov. 28-Dec. 2, 1971.

3. Kemme, J. E., Heat Pipe Design Considerations, LA-4221-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, Aug. 1969.

4. Schwartz, H., The Heat Pipe and Its Operation, Internal Report 701-21, Jet Propulsion Laboratory, Pasadena, CA, Jan. 1969.

5. Sockol, P. M., Effects of Interphase Temperature Differences and Wall Friction in High-Temperature Heat Pipes, NASA Lewis Research Center, Cleveland, Ohio, Apr. 1971.

6. Nakashima, A. M., and Sawyer, C. D., Thermionic Nuclear Electric Propulsion System Analysis Code, to be published as JPL TM.

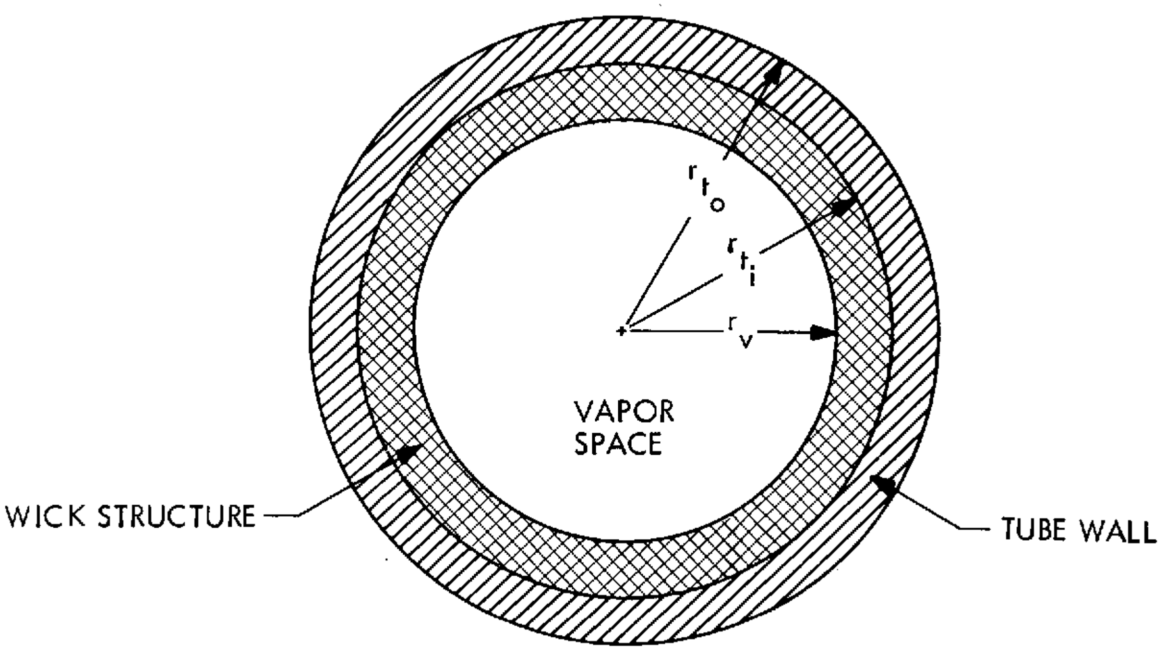
Table 1. Functional data correlations

| Symbol | Variable | Form |
|---|---|---|
| $P(t)$ | pressure (equation of state) | $P(T) = e^{A_1 - A_2(1/T) - A_3 \log T}$ |
| $\gamma$ | surface tension | $A_1 - A_2T$ |
| $\rho_e$ | liquid density | $A_1 + TA_2 + T^2A_3 + T^4A_4$ |
| $\mu_e$ | liquid viscosity | $A_1e^{A_2/T}$ |
| $k_w$ | wall thermal conductivity | $A_1 - A_2T$ |
| $k_\ell$ | liquid conductivity | tabular data |
| $\rho_v$ | vapor density at STP | tabular data |

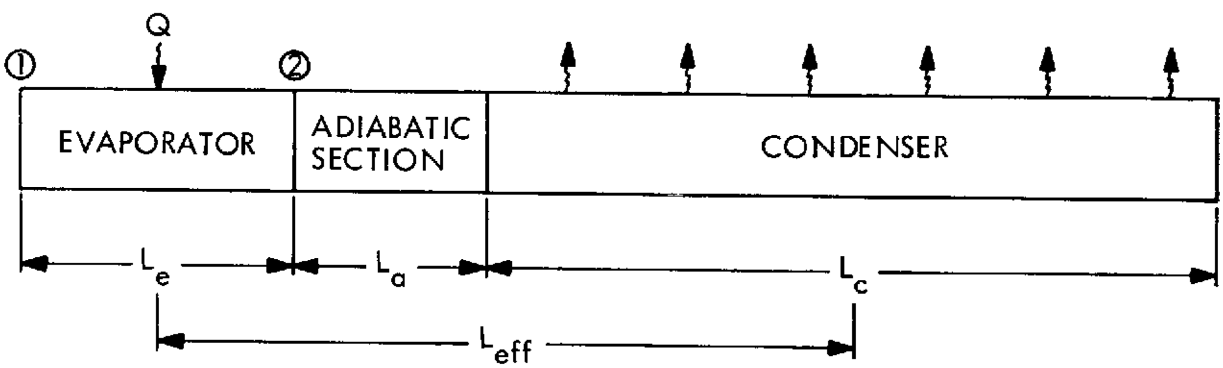
Table 2. Input data for homogeneous heat pipes

| Variable | Fortran Name | Definition | Default Value |
|---|---|---|---|
| $r_{te}$ | RTE | outside radius of evaporator | 0.5 cm |
| $L_e$ | LE | length of evaporator section | 30.0 cm |
| $Q_{in}$ | QIN | total heat rejected | 700 watts |
| $N_\ell$ | NL | working fluid (1 = K, 2 = Na) | 1 |
| $T_\ell$ | TL | liquid thickness | 0.0 cm |
| $T_w$ | TW | wall thickness | 0.02 cm |
| $L_a$ | LA | length of adiabatic section | 0.0 cm |
| $T_{ev}$ | TEVAP | outside surface temperature evaporator | $1000^oK$ |
| $r_p$ | RPST | maximum pore radius* | — |
| $N_c$ | NC | heat pipe wall material (1 = Nb, 2 = SS) | 1 |
| — | MMT | variable FORMAT for output | — |
| $f_e$ | FDE | fraction of evaporator surface available for heat input | 1.0 |
| $f_c$ | FCE | fraction of condenser surface available for heat rejection | 1.0 |
| — | IHPT | homogeneous heat pipe flag (1 = homogeneous heat pipe) | 1 |
| $n_L$ | NSCL | number of screen layers | 1 |
| S | MESH | screen mesh size | 100 |
| K | PERMEA | wick permeability* | — |
| $t_{s\ell}$ | TSL | thickness of single screen layer* | — |

* Computed from correlations if MESH is non zero.




(a) CROSS-SECTION




(b) LONGITUDINAL VIEW

Fig. 1. Heat pipe schematic

## APPENDIX

## TYPICAL RUNSTREAM AND SAMPLE PROBLEM

```
@FOR,IS  HPD,HPD
FOR  S10A-C     06/23/73-18:43:54 (,0)

   MAIN PROGRAM

   STORAGE USED: CODE(1) 001306; DATA(0) 000745; BLANK COMMON(2) 000025

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003    HTPIPE
    0004    NINTR$
    0005    NRNL$
    0006    NWDU$
    0007    NIO2$
    0010    NWNL$
    0011    NERR2$
    0012    NIO1$
    0013    NSTOP$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000002 1L        0001    000044 100L      0001    000203 121L      0001    000262 122L      0001    000355 123L
    0001    000450 124L      0001    000543 125L      0001    000636 126L      0001    000731 127L      0001    001024 128L
    0001    001117 129L      0001    001212 130L      0001    000222 202G      0001    000241 214G      0001    000242 216G
    0001    000277 232G      0001    000327 246G      0001    000337 250G      0001    000372 264G      0001    000422 300G
    0001    000432 302G      0001    000465 316G      0001    000515 332G      0001    000525 334G      0001    000560 350G
    0001    000610 364G      0001    000620 366G      0001    000653 402G      0001    000302 402L      0001    000375 403L
    0001    000470 404L      0001    000563 405L      0001    000656 406L      0001    000751 407L      0001    001044 408L
    0001    001137 409L      0001    001232 410L      0001    000703 416G      0001    000713 420G      0001    000746 434G
    0001    000776 450G      0001    001006 452G      0001    001041 466G      0001    001071 502G      0001    001101 504G
    0001    001134 520G      0001    001164 534G      0001    001174 536G      0001    001227 552G      0001    001257 566G
    0001    001267 570G      0000    000733 900F      0000 R  000145 A         0002 R  000000 B         0000 R  000613 FCE
    0000 R  000612 FDE       0000 I  000611 I         0000 I  000621 ICNT      0000 I  000614 IHPT      0000    000712 INPP
    0000 I  000616 INPRT     0000    000625 INPT      0000 I  000617 ITPRNT    0000 I  000577 I1        0000 I  000610 I10
    0000 I  000600 I2        0000 I  000601 I3        0000 I  000602 I4        0000 I  000603 I5        0000 I  000604 I6
    0000 I  000605 I7        0000 I  000606 I8        0000 I  000607 I9        0000 I  000624 J         0000 R  000075 LA
    0000 R  000622 LC        0000 R  000013 LE        0000 I  000620 M         0000 R  000000 MESH      0000 I  000574 MMT
    0000 I  000133 NC        0000 I  000037 NL        0000 I  000615 NSCL      0000 R  000025 QIN       0000 R  000121 RPST
    0000 R  000623 RTC       0000 R  000001 RTE       0000 R  000107 TEVAP     0000 R  000051 TL        0000 R  000063 TW
```

```
C  MAIN DRIVER PROGRAM FOR HEAT PIPE COMPUTATIONS
      COMMON B(21)
      IMPLICIT REAL (L)
      REAL  MESH
      DIMENSION RTE(10),LE(10),QIN(10),NL(10),TL(10),TW(10),LA(10),
     1TEVAP(10),RPST(10),NC(10),A(9,31),MMT(3)
      DATA I1,I2,I3,I4,I5,I6,I7,I8,I9,I10/10*1/
      DATA (A(1,I),I=1,31)/'RTE','LE','NC','QIN','TL','TW','LA','TEVAP',
     1'RPST','NC','LC','RTC','TVAP','TVAPA','TVAPC','TVMIN','TREJ',
     2'DPVE','DPVMOM','DPVA','DPVC','DPVEX','DPLE','DPLA','DPLC',
     3'DPLCON','DPVT','DPLT','DPTOT','DPST','CON'/
      DATA MMT/'(1H ,A','6,1P00','E12.3)'/
      NAMELIST /INPT/RTE,LE,QIN,NL,TL,TW,LA,TEVAP,RPST,NC,FDE,FCE,
     1       IHPT,NSCL,MESH,INPRT,ITPRNT
      NAMELIST /INPP/IHPT,NSCL,MESH,FDE,FCE
C     IHPT    0/1   ANNULAR/HOMOGENEOUS     DEFAULT=1
      DATA IHPT,MESH,NSCL,FDE,FCE /1,100.,1,1.,1./
      DATA ITPRNT/0/
C
    1 READ(5,INPT)
      WRITE (6,900)
      IF(INPRT.EQ.1)  WRITE (6,INPT)
      IF(INPRT.NE.1)  WRITE (6,INPP)
      WRITE (6,900)
      INPRT=0
      M=1
      ICNT=0
  100 CALL HTPIPE(RTE(I1),LE(I2),LC,QIN(I3),NL(I4),TL(I5),TW(I6),RTC,
     1    LA(I7),TEVAP(I8),RPST(I9),NC(I10),FDE,FCE,IHPT,NSCL,MESH,
     2   ITPRNT)
      WRITE (6,900)
      ICNT=ICNT+1
      A(I1+1,1 )=RTE(I1)
      A(I2+1,2 )=LE(I2)
      A(I3+1,3 )=NL(I3)
      A(I4+1,4 )=QIN(I4)
      A(I5+1,5 )=TL(I5)
      A(I6 +1,6 )=TW(I6)
      A(I7 +1,7 )=LA(I7)
      A(I8 +1,8 )=TEVAP(I8)
      A(I9 +1,9 )=RPST(I9)
      A(I10+1,10)=NC(I10)
      GO TO (121,122,123,124,125,126,127,128,129,130),M
  121 I1=I1+1
      DO 301 I=11,31
  301 A(I1,I)=B(I-10)
      IF(RTE(I1))100,101,100
```

```
00211       101 MMT(2)=MMT(2)+I1-1
00212           WRITE(6,MMT)((A(J,I),J=1,I1),I=1,31)
00223           MMT(2)=MMT(2)-I1+1
00224           I1=1
00225           M=2
00226       122 I2=I2+1
00227           IF(I2.LE.2)GO TO 402
00231           DO 302 I=11,31
00234       302 A(I2,I)=B(I-10)
00236       402 CONTINUE
00237           IF(LE(I2))100,102,100
00242       102 MMT(2)=MMT(2)+I2-1
00243           IF(I2.GT.2)WRITE(6,MMT)((A(J,I),J=1,I2),I=1,31)
00255           MMT(2)=MMT(2)-I2+1
00256           M=3
00257           I2 =1
00260       123 I3=I3+1
00261           IF(I3.LE.2)GO TO 403
00263           DO 303 I=11,31
00266       303 A(I3,I)=B(I-10)
00270       403 CONTINUE
00271           IF(BIN(I3))100,103,100
00274       103 MMT(2)=MMT(2)+I3-1
00275           IF(I3.GT.2)WRITE(6,MMT)((A(J,I),J=1,I3),I=1,31)
00307           MMT(2)=MMT(2)-I3+1
00310           M=4
00311           I3 =1
00312       124 I4=I4+1
00313           IF(I4.LE.2)GO TO 404
00315           DO 304 I=11,31
00320       304 A(I4,I)=B(I-10)
00322       404 CONTINUE
00323           IF(NL(I4))100,104,100
00326       104 MMT(2)=MMT(2)+I4-1
00327           IF(I4.GT.2)WRITE(6,MMT)((A(J,I),J=1,I4),I=1,31)
00341           MMT(2)=MMT(2)-I4+1
00342           M=5
00343           I4 =1
00344       125 I5=I5+1
00345           IF(I5.LE.2)GO TO 405
00347           DO 305 I=11,31
00352       305 A(I5,I)=B(I-10)
00354       405 CONTINUE
00355           IF(TL(I5))100,105,100
00360       105 MMT(2)=MMT(2)+I5-1
00361           IF(I5.GT.2)WRITE(6,MMT)((A(J,I),J=1,I5),I=1,31)
00373           MMT(2)=MMT(2)-I5+1
00374           M=6
00375           I5 =1
00376       126 I6=I6+1
00377           IF(I6.LE.2)GO TO 406
00401           DO 306 I=11,31
00404       306 A(I6,I)=B(I-10)
00406       406 CONTINUE
00407           IF(TW(I6))100,106,100
00412       106 MMT(2)=MMT(2)+I6-1
00413           IF(I6.GT.2)WRITE(6,MMT)((A(J,I),J=1,I6),I=1,31)
00425           MMT(2)=MMT(2)-I6+1
00426           M=7
00427           I6 =1
00430       127 I7=I7+1
00431           IF(I7.LE.2)GO TO 407
00433           DO 307 I=11,31
00436       307 A(I7,I)=B(I-10)
00440       407 CONTINUE
00441           IF(LA(I7))100,107,100
00444       107 MMT(2)=MMT(2)+I7-1
00445           IF(I7.GT.2)WRITE(6,MMT)((A(J,I),J=1,I7),I=1,31)
00457           MMT(2)=MMT(2)-I7+1
00460           M=8
00461           I7 =1
00462       128 I8=I8+1
00463           IF(I8.LE.2)GO TO 408
00465           DO 308 I=11,31
00470       308 A(I8,I)=B(I-10)
00472       408 CONTINUE
00473           IF(TEVAP(I8))100,108,100
00476       108 MMT(2)=MMT(2)+I8-1
00477           IF(I8.GT.2)WRITE(6,MMT)((A(J,I),J=1,I8),I=1,31)
00511           MMT(2)=MMT(2)-I8+1
00512           M=9
00513           I8 =1
00514       129 I9=I9+1
00515           IF(I9.LE.2)GO TO 409
00517           DO 309 I=11,31
00522       309 A(I9,I)=B(I-10)
00524       409 CONTINUE
00525           IF(RPST(I9))100,109,100
00530       109 MMT(2)=MMT(2)+I9-1
00531           IF(I9.GT.2)WRITE(6,MMT)((A(J,I),J=1,I9),I=1,31)
00543           MMT(2)=MMT(2)-I9+1
00544           M=10
00545           I9 =1
00546       130 I10=I10+1
00547           IF(I10.LE.2)GO TO 410
00551           DO 310 I=11,31
00554       310 A(I10,I)=B(I-10)
00556       410 CONTINUE
00557           IF(NC(I10))100,110,100
```

```
00562         110 MMT(2)=MMT(2)+I10-1
00563             IF(I10.GT.2)WRITE(6,MMT)((A(J,I),J=1,I10),I=1,31)
00575             MMT(2)=MMT(2)-I10+1
00576             I10=1
00577             GO TO 1
00600         900 FORMAT (1H1)
00601             END
```

END OF COMPILATION:        NO  DIAGNOSTICS.

```
@FOR,IS  SEARCB,SEARCB
FOR  S10A-C     06/23/73-18:44:00 (,0)
```

SUBROUTINE SEARCB    ENTRY POINT 000202

STORAGE USED: CODE(1) 000240; DATA(0) 000022; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

```
 0003    NERR3$
```

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```
 0001    000170 12L     0001    000040 2L      0001    000113 21L     0001    000125 22L     0001    000104 23L
 0001    000117 24L     0001    000031 4L      0001    000023 5L      0000    000012 INJP$   0000 I 000005 M
 0000 I 000007 N        0000 R 000000 P        0000 R 000006 S        0000 R 000002 X        0000 R 000004 XG
```

```
00101               SUBROUTINE SEARCB(PR,PC,  XX,XU,XL,R,E,K)
00101         CSEARCH
00103               DIMENSION P(2),X(2)
00104               IF(K.NE.0) GO TO 2
00106               K=1
00107               XG=XX
00110               M=1
00111               X(1)=XG
00112               P(1)=PR-PC
00113               IF(P(1).GT.0.)GO TO 4
00115               XL=XG
00116               XG=XG*(1.+R)
00117             5 X(2)=XG
00120               XX=XG
00121               RETURN
00122             4 XU=XG
00123               XG=XG/(1.+R)
00124               GO TO 5
00125             2 M=M+1
00126               IF(M.GE.15) K=(10-M)/5
00130               P(2)=PR-PC
00131               S=(X(2)-X(1))/(P(2)-P(1))
00132               N=0
00133               IF(S.GT.0.)N=1
00135               IF(P(2).GT.0.)GO TO 21
00137               IF(N.GT.0)GO TO 24
00141            23 XU=AMIN1(XU,X(2))
00142               GO TO 22
00143            21 IF(N.GT.0)GO TO 23
00145            24 XL=AMAX1(XL,X(2))
00146            22 XG=X(2)-P(2)*S
00147               IF(ABS(1.-PC/PR).LT.E)GO TO 12
00151               X(1)=X(2)
00152               IF(XG.GT.XU.OR.XG.LT.XL)XG=(XU+XL)*.5
00154               P(1)=P(2)
00155               GO TO 5
00156            12 K=2
00157               GO TO 5
00160               END
```

END OF COMPILATION:        NO  DIAGNOSTICS.

```
@FOR,IS  ENTP,ENTP
FOR  S10A-C     06/23/73-18:44:02 (,0)
```

```
FUNCTION ENTP          ENTRY POINT 000263
         ENTRP         ENTRY POINT 000302
         ENTRP1        ENTRY POINT 000307
         ENT           ENTRY POINT 000312
```

STORAGE USED: CODE(1) 000317; DATA(0) 000045; BLANK COMMON(2) 000000

```
EXTERNAL REFERENCES (BLOCK, NAME)

 0003   EXIT
 0004   NPRT$
 0005   NIO1$
 0006   NIO2$
 0007   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000143 1L        0001   000011 10L       0001   000140 11L       0001   000005 12L       0001   000050 123G
 0001   000072 3L        0001   000206 4L        0000   000005 5F        0001   000201 6L        0000   000012 7F
 0000 R 000000 ENTP      0000 I 000001 I         0000   000017 INJP$     0000 I 000002 J         0000 I 000003 K1
 0000 R 000004 S
```

```
00100      CENS            INTERP FUNCTION FOR SYSTEM STUDY  CDS    NTPO            ENT00100
00101              FUNCTION ENTP(Y,X,N,A,M,K)                                           ENT00200
00103              DIMENSION Y(1),X(1)                                                  ENT00300
00104              INTEGER I                                                            ENT00400
00105              ENTRY ENTRP(A)                                                       ENT00500
00107              ENTRY ENTRP1(Z)                                                      ENT00600
00111              IF(N.GE.2) GO TO 10                                                  ENT00700
00113           12 ENTP=Y(1)                                                            ENT00800
00114              GO TO 11                                                             ENT00900
00115           10 I=1                                                                  ENT01000
00116              IF(K.GT.0)I=N                                                        ENT01100
00120              IF(A.LT.X(I))GO TO 1                                                 ENT01200
00122              DO 2 J=2,N                                                           ENT01300
00125              I=J                                                                  ENT01400
00126              IF(K.GT.0)I=N+1-J                                                    ENT01500
00130            2 IF(A.LE.X(I))GO TO 3                                                 ENT01600
00133              GO TO 4                                                              ENT01700
00134            3 K1=I-1                                                               ENT01800
00135              IF(K.GT.0)K1=I+1                                                     ENT01900
00137              S=(A-X(K1 ))/(X(I)-X(K1 ))                                           ENT02000
00140              ENTRY ENT(Y)                                                         ENT02100
00142              IF(N.LT.2)GO TO 12                                                   ENT02200
00144              ENTP=Y(K1 )+(Y(I)-Y(K1 ))*S                                          ENT02300
00145           11 RETURN                                                               ENT02400
00146            1 IF(M.EQ.0)                                                           ENT02500
00146             1PRINT    5,A,X(I),Y(I)                                               ENT02600
00154            5 FORMAT(13H0****** ENTPL,1P3E14.3)                                    ENT02700
00155              I=2                                                                  ENT02800
00156              IF(K.GT.0)I=N-1                                                      ENT02900
00160            6 IF(M.EQ.0)CALL EXIT                                                  ENT03000
00162              GO TO 3                                                              ENT03100
00163            4 IF(M.EQ.0)                                                           ENT03200
00163             1PRINT    7,A,X(I),Y(I)                                               ENT03300
00171            7 FORMAT(13H0****** ENTPH,1P3E14.3)                                    ENT03400
00172              GO TO 6                                                              ENT03500
00173              END                                                                  ENT03600

      END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,IS  HOPIPE,HOPIPE
FOR  S10A-C     06/23/73-18:44:04 (,0)

SUBROUTINE HTPIPE    ENTRY POINT 001706

STORAGE USED: CODE(1) 002066; DATA(0) 001441; BLANK COMMON(2) 000022

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   ENTP
 0004   NEXP6$
 0005   ALOG
 0006   EXP
 0007   SQRT
 0010   NWDU$
 0011   NIO2$
 0012   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000   000331 1F        0001   000331 100L      0001   000030 110L      0001   001364 130L      0001   000760 131L
 0001   001464 140L      0001   001504 150L      0000   000353 160F      0000   000343 2F        0001   000517 237G
 0001   000720 265G      0001   000700 331L      0001   001323 334G      0001   001477 500L      0001   001732 520L
 0001   001741 521L      0001   000030 70L       0000   000363 90F       0000   000365 901F      0000   000533 902F
 0000   000701 903F      0000   001047 904F      0000   001227 905F      0000 R 000152 AA        0000 R 000167 ALC
 0000 R 000166 ALE       0000 R 000171 AR        0000 R 000123 AW        0002 R 000000 B         0000 R 000115 CON
 0000 R 000132 DENSL     0000 R 000131 DENV      0000 R 000154 DPLA      0000 R 000201 DPLC      0000 R 000172 DPLCON
 0000 R 000202 DPLCT     0000 R 000143 DPLE      0000 R 000013 DPLT      0000 R 000000 DPST      0000 R 000015 DPTOT
 0000 R 000010 DPVA      0000 R 000011 DPVC      0000 R 000204 DPVCT     0000 R 000006 DPVE      0000 R 000147 DPVET
 0000 R 000012 DPVEX     0000 R 000007 DPVMOM    0000 R 000203 DPVREC    0000 R 000014 DPVT      0000 R 000124 DTF
 0000 R 000175 DTFC      0000 R 000127 DTS       0000 R 000173 DTSC      0000 R 000150 DTVET     0000 R 000120 DTW
 0000 R 000177 DTWC      0003 R 000000 ENTP      0000 R 000146 F         0000 R 000210 FF        0001 R 001751 FF
 0000 R 000024 GAM       0000 I 000153 I         0000   001376 INJP$     0000   001366 INJP$     0000 R 000111 K
```

```
0000 R 000062 KL        0000 R 000100 KSS       0000 R 000133 LAMBDA    0000 R 000076 M         0000 R 000142 MDOT
0000 R 000042 MUL       0000 R 000046 MUV       0000 I 000105 NKL       0000 I 000104 NMUV      0000 I 000162 NS
0000   000211 OUTP      0000 R 000116 PERMEA    0000 R 000113 PI        0000 R 000016 PT        0000 R 000130 PVAP
0000 R 000155 PVAPA     0000 R 000161 PVAPC     0000 R 000151 PVMIN     0000 R 000137 QA        0000 R 000135 QACRIT
0000 R 000136 QCRIT     0000 R 000160 QENT      0000 R 000157 QENTR     0000 R 000112 R         0000 R 000145 REVAP
0000 R 000030 RHOL      0000 R 000040 RHOV      0000 R 000126 RSCI      0000 R 000140 RSCIC     0000 R 000163 RSCICC
0000 R 000165 RTCI      0000 R 000206 RTCL      0000 R 000205 RTCU      0000 R 000141 RTEC      0000 R 000117 RTEI
0000 R 000122 RTFI      0000 R 000164 RTFIC     0000 R 000106 SIGMA     0000 R 000121 TFL       0000 R 000174 TFLC
0000 R 000072 TKL       0000 R 000056 TMUV      0000 R 000005 TREJ      0000 R 000207 TREJ1     0000 R 000107 TS
0000 R 000125 TSC       0000 R 000114 TSL       0000 R 000001 TVAP      0000 R 000002 TVAPA     0000 R 000003 TVAPC
0000 R 000200 TVM       0000 R 000004 TVMIN     0000 R 000176 TWC       0000 R 000110 TWOPI     0000 R 000170 VLE
0000 R 000134 VS        0000 R 000156 VVA       0000 R 000144 VVAP
```

```
00000  *DIAGNOSTIC*  THE VARIABLE, RTCU, IS REFERENCED IN THIS PROGRAM, BUT IS NOWHERE ASSIGNED A VALUE.
00000  *DIAGNOSTIC*  THE VARIABLE, RTCL, IS REFERENCED IN THIS PROGRAM, BUT IS NOWHERE ASSIGNED A VALUE.
00101          SUBROUTINE HTPIPE(RTE,LE,LC,QIN,NL,TL,TW,RTC,LA,TEVAP,RPST,NC,
00101         1   FOE,FCE,IHPT,NSCL,MESH,ITPRNT)
00103          IMPLICIT REAL(L,M,K)
00104          COMMON  B(18)
00105          NAMELIST /OUTP/RTE,LE,QIN,NL,TL,TW,LA,TEVAP,RPST,NC,DPST,
00105         1 LC,RTC,TVAP,TVAPA,TVAPC,TVMIN,TREJ,DPVE,DPVMOM,
00105         1DPVA,DPVC,DPVEX,DPLT,DPVT,DPTOT
00106          DIMENSION PT(3,2),GAM(2,2),RHOL(4,2),RHOV(2),MUL(2,2),MUV(4,2),
00106         1TMUV(4),KL(4,2),TKL(4),M(2),KSS(2,2)
00107          DATA PT/16.11149,10398.4,0.53299,17.69932,12767.8,0.61344/
00111          DATA GAM/1.388E-3,6.5E-7,2.283E-3,1.E-6/
00113          DATA RHOL/0.89862, 0.20132E-3, 0.3084E-7, 4.65E-12,1.01164,
00113         10.2205E-3, 0.1923E-7,5.64E-12/
00115          DATA RHOV/.04689,.02765/
00117          DATA MUL/.000657,712.,.000814,836./
00121          DATA MUV,TMUV/9.5E-5,1.14E-4,1.48E-4,2.42E-4,7.2E-5,9.E-5,1.22E-5,
00121         12.3E-5,300.,600.,900.,1500./,NMUV/4/
00125          DATA KL,TKL/.51,.445,.37,.23,.91,.79,.665,.425,300.,500.,800.,
00125         11500./,NKL/4/
00131          DATA M/39.,23./,SIGMA/5.6687E-12/
00134          DATA TS/.02/,TWOPI/6.2831853/,K/1.667/,R/8.317/,PI/3.14159265/
00142          DATA KSS/0.472,0.1127E-3,.088,.157E-3/
00144          P(T,I)=EXP(PT(1,I)-PT(2,I)/T-PT(3,I)*ALOG(T))
00145          GAMMA(T,I)=GAM(I,I)-GAM(2,I)*T
00146          DENL(T,I)=RHOL(1,I)+T*(-RHOL(2,I)+T*(-RHOL(3,I)+T*RHOL(4,I)))
00147          VISL(T,I)=MUL(1,I)*EXP(MUL(2,I)/T)
00150          KWALL(T,I)=KSS(1,I)-KSS(2,I)*T
00151          DATA   TSL/0.02/
00153          CON=0.
00153    C   HOMOGENEOUS HEAT PIPE PROPERTIES  (IHPT=1)
00154          IF(MESH.EQ.0) GO TO 70
00156          RPST=0.825*(1./MESH)**1.0945
00157          PERMEA=0.0371*(1./MESH)**1.6185
00160          TSL=11.7446*(1./MESH)**1.3553
00161       70 CONTINUE
00161    C  EVAPORATOR SECTION
00162      110 RTEI=RTE-TW
00163          TS=TSL*NSCL
00164          DTW=QIN*ALOG(RTE/RTEI)/(KWALL(TEVAP,NC)*TWOPI*LE)/FDE
00165          TFL=TEVAP-DTW
00166          RTFI=RTEI-TL
00167          AW=PI*TS*(2.*RTEI-TS)
00170          DTF=QIN*ALOG(RTEI/RTFI)/(ENTP(KL(1,NL),TKL,NKL,TFL,0,0)*TWOPI*LE)
00170         A  /FDE
00171          TSC=TFL-DTF
00172          RSCI=RTFI-TS
00173          DTS=QIN*ALOG(RTFI/RSCI)/(KWALL(TSC,NC)*TWOPI*LE)/FDE
00174          TVAP=TSC-DTS
00175          PVAP=P(TVAP,NL)
00176          DENV=RHOV(NL)*PVAP/TVAP
00177          DENSL=DENL(TVAP,NL)
00200          LAMBDA=0.01*PVAP*(PT(2,NL)/TVAP-PT(3,NL))*(1./DENV-1./DENSL)
00201          VS=SQRT(K*R*TVAP/M(NL))*3162.27
00202          QACRIT=DENV*VS*LAMBDA/SQRT(2.*(K+1.))
00203          QCRIT=QACRIT*PI*RSCI**2
00204          QA=QIN/(PI*RSCI**2)
00205          IF(QA.LE.0.6*QACRIT)GO TO 100
00207          RSCIC=SQRT(QIN/(PI*0.59*QACRIT))
00210          RTEC=RSCIC+TS+TL+TW
00211          WRITE(6,1)RTEC
00214        1 FORMAT('OCRITICAL HEAT FLUX EXCEEDED. RTE INCREASED TO ',F10.4)
00215          RTE=RTEC
00216          GO TO 110
00217      100 MDOT=QIN/LAMBDA
00220          DPLE =    VISL(TVAP,NL)*MDOT*(LE/2.)/(PERMEA*AW*DENSL)*1.E-5
00221          VVAP=MDOT/(DENV*PI*RSCI**2)
00222          DPVMOM=PVAP*(1.-1./(1.+(VVAP/VS)**2*K))
00223          REVAP=2.*MDOT/(PI*RSCI*ENTP(MUV(1,NL),TMUV,NMUV,TVAP,0,0))
00224          F=FF(REVAP)
00225          DPVE=DENV   *F*LE*VVAP**2/(2.*RSCI)*1.E-5
00226          DPVET=DPVE+DPVMOM
00227          DTVET=TVAP*DPVET/(PVAP*(PT(2,NL)/TVAP-PT(3,NL)))
00230          TVAPA=TVAP-DTVET
00231          DPST=2.*GAMMA(TVAPA,NL)/RPST
00232          TVMIN=TVAPA
00233          PVMIN=PVAP-DPST
00234          PVMIN=AMAX1(PVMIN,.01)
00235          AA=ALOG(PVMIN)
00236          DO 432 I=1,3
00241      432 TVMIN=TVMIN*(1.+(AA-PT(1,NL)+PT(2,NL)/TVMIN+PT(3,NL)*ALOG(TVMIN))
00241         1/(PT(2,NL)/TVMIN-PT(3,NL)))
```

```
C  ADIABATIC SECTION
      DENSL=DENL(TVAPA,NL)
      DPLA=VISL(TVAPA,NL)*MDOT*(LA+64.*TL)/(PERMEA*AW*DENSL)*1.E-5
      PVAPA=PVAP-DPVET
      DENV=RHOV(NL)*PVAPA/TVAPA
      VVA =MDOT/(DENV*PI*RSCI   **2)
      REVAP=2.*MDOT/(PI*RSCI   *ENTP(MUV(1,NL),TMUV,NMUV,TVAPA,0,0))
      F=FF(REVAP)
      DPVA=DENV*F*(LA+64.*RSCI   )*VVA **2/RSCI   *1.E-5
      QENTH=LAMBDA*SQRT(PI*0.5*DENV*DPST)*316.227
      QENT=QENTR*PI*RSCI**2
      IF (LA.GT.0.2) GO TO 331
      DPVA=0.
      DPLA=0.
  331 PVAPC=PVAP-DPVET-DPVA
      AA=ALOG(PVAPC)
      TVAPC=TVAPA
      DO 332 I=1,3
  332 TVAPC=TVAPC*(1.+(AA-PT(1,NL)+PT(2,NL)/TVAPC+PT(3,NL)*ALOG(TVAPC))
     1/(PT(2,NL)/TVAPC-PT(3,NL)))
C  CONDENSER SECTION
      NS=0
      TREJ=0.5*(TVMIN+TVAPC)
      LC=QIN/(1.8*RTE*TREJ**4*SIGMA)
      RSCICC=RSCI
  131 RTFIC=RSCICC+TS
      RTCI=RTFIC+TL
      RTC=RTCI+TW
      DPVEX=DENV*VVA **2*0.5*(1.-(RSCI/RSCICC)**2)**2*1.E-5
C     ALE=PI*TL*(RTFI+RTEI)
      ALE=PI*TSL*(RTFI+RTEI)
C     ALC=PI*TL*(RTFIC+RTCI)
      ALC=PI*TSL*(RTFIC+RTCI)
      VLE=MDOT/(ALE*DENSL)
      AR=ALE/ALC
      DPLCON=DENSL*VLE**2*0.2*(1.-AR)*1.E-5
      DTSC=QIN*ALOG(RTFIC/RSCICC)/(KWALL(TVAPC,NC)*TWOPI*LC)
      TFLC=TVAPC-DTSC
      DTFC=QIN*ALOG(RTCI/RTFIC)/(ENTP(KL(1,NL),TKL,NKL,TFLC,0,0)*TWOPI*
     1LC)
      TWC=TFLC-DTFC
      DTWC=QIN*ALOG(RTC/RTCI)/(KWALL(TWC,NL)*TWOPI*LC)
      TVM=TVMIN
      TREJ= TVAPC -DTSC-DTFC-DTWC
      LC=QIN/(1.8*RTC*TREJ**4*SIGMA)
      DENSL=DENL(TVAPC,NL)
      DPLC=VISL(TVAPC,NL)*MDOT*(LC/2.)/(PERMEA*AW*DENSL)*1.E-5
      DPLCT=DPLC+DPLCON
      DENV=RHOV(NL)*PVAPC/TVAPC
      VVAP=MDOT/(DENV*PI*RSCICC**2)
      REVAP=2.*MDOT/(PI*RSCICC*ENTP(MUV(1,NL),TMUV,NMUV,TVAPC,0,0))
      F=FF(REVAP)
      DPVC=DENV*F*LC*VVAP**2/RSCICC*5.E-6
      DPVREC=0.4*DPVMOM
      DPVCT=DPVC+DPVEX -DPVREC
      DPTOT=DPVET+DPVA+DPVCT+DPLE+DPLA+DPLCT
      PVAPC=PVAP-DPVET-DPVA-0.5*DPVCT
      AA=ALOG(PVAPC)
      DO 334 I=1,3
  334 TVAPC=TVAPC*(1.+(AA-PT(1,NL)+PT(2,NL)/TVAPC+PT(3,NL)*ALOG(TVAPC))
     1/(PT(2,NL)/TVAPC-PT(3,NL)))
      DPVT=DPVET+DPVA+DPVCT
      DPLT=DPLE +DPLA+DPLCT
      NS=NS+1
      IF(NS.GT.20) GO TO 140
      GO TO 130
  130 CONTINUE
      IF(ITPRNT.NE.0)
     AWRITE(6,90 )DPTOT,DPST,RTCU,RTCL,RSCICC,DPVC,F,REVAP,VVAP,DENV
     A             ,DPLC,DENSL,LC,TREJ,DTWC,DTFC,DTSC,TVAPC,TVM,TVMIN
     A             ,PVAPC,DPLCT,DPVCT,DPLCON,AR,VLE,ALC,ALE,DPVEX,DPVA
     A            ,PVAPA,DPLA,RTC,PVMIN,PVAP,DPLE,DPVE,DPVMOM,RTE ,DPVREC
     A            ,QIN,MDOT,AW,TS,QACRIT,QA,QENTR
      IF(ABS(TREJ-TREJ1).LT. 0.1) GO TO 500
      TREJ1=TREJ
      GO TO 131
  140 WRITE(6,2)DPTOT,DPST,RSCICC
    2 FORMAT('0CANNOT CONVERGE ON PORE SIZE ',5E15.4)
      CON=1.
      GO TO 150
  500 WRITE(6,160)
  160 FORMAT('0PUMPING SUFFICIENT.  RTC MAINTAINED.')
  150 CONTINUE
      WRITE(6,901)DPTOT,DPST,RTCU,RTCL,RSCICC,DPVC,F,REVAP,VVAP,DENV
      WRITE (6,902)DPLC,DENSL,LC,TREJ,DTWC,DTFC,DTSC,TVAPC,TVM,TVMIN
      WRITE (6,903)PVAPC,DPLCT,DPVCT,DPLCON,AR,VLE,ALC,ALE,DPVEX,DPVA
      WRITE(6,904)PVAPA,DPLA,RTC,PVMIN,PVAP,DPLE,DPVE,DPVMOM,RTE ,DPVREC
      WRITE(6,905)QIN,MDOT,AW,TS,QACRIT,QA,QENTR
      B(1)=LC
      B(2)=RTC
      B(3)=TVAP
      B(4)=TVAPA
      B(5)=TVAPC
      B(6)=TVMIN
      B(7)=TREJ
      B(8)=DPVE
      B(9)=DPVMOM
      B(10)=DPVA
      B(11)=DPVC
      B(12)=DPVEX
```

```
00556              B(13)=DPLE
00557              B(14)=DPLA
00560              B(15)=DPLC
00561              B(16)=DPLCON
00562              B(17)=DPVT
00563              B(18)=DPLT
00564              B(19)=DPTOT
00565              B(20)=DPST
00566              B(21)=CON
00567              RETURN
00567        C   ***   FORMATS
00570           90 FORMAT(1P10E12.4)
00571          901 FORMAT (' ',5X,'TOTAL PRESURE DROP IN PIPE',10X,'DPTOT',E14.6/
00571             1       ' ',5X,'TOTAL AVAILABLE PRESSURE  ',10X,'DPST ',E14.6/
00571             2       ' ',5X,'                          ',10X,'RTCU  ',E14.6/
00571             3       ' ',5X,'                          ',10X,'RTCL  ',E14.6/
00571             4       ' ',5X,'                          ',10X,'RSCICC',E14.6/
00571             5       ' ',5X,'V PRESSURE DROP CONDENSER ',10X,'DPVC  ',E14.6/
00571             5       ' ',5X,'FRICTION FACTOR           ',10X,'     F',E14.6/
00571             6       ' ',5X,'REYNOLDS NUMBER VAPOR     ',10X,' REVAP',E14.6/
00571             7       ' ',5X,'VELOCITY VAPOR            ',10X,'VVAP  ',E14.6/
00571             8       ' ',5X,'VAPOR DENSITY             ',10X,'DENV  ',E14.6)
00572          902 FORMAT (' ',5X,'LIQUID PRESSURE DROP CONDE',10X,'DPLC  ',E14.6/
00572             1       ' ',5X,'LIQUID DENSITY            ',10X,'DENSL ',E14.6/
00572             2       ' ',5X,'CONDENSER LENGTH          ',10X,'LC    ',E14.6/
00572             3       ' ',5X,'AVG REJECTION TEMPERATURE ',10X,'TREJ  ',E14.6/
00572             4       ' ',5X,'DT CONDENSER WALL         ',10X,'DTWC  ',E14.6/
00572             5       ' ',5X,'DT CONDENSER FILM         ',10X,'DTFC  ',E14.6/
00572             6       ' ',5X,'DT CONDENSER SCREEN       ',10X,'DTSC  ',E14.6/
00572             7       ' ',5X,'VAPOR TEMP CONDENSER      ',10X,'TVAPC ',E14.6/
00572             8       ' ',5X,'                          ',10X,'TVM   ',E14.6/
00572             9       ' ',5X,'                          ',10X,'TVMIN ',E14.6)
00573          903 FORMAT (' ',5X,'PRESSURE IN CONSENSER     ',10X,'PVAPC ',E14.6/
00573             1       ' ',5X,'TOT L PRESSURE DROP COND  ',10X,'DPLCT ',E14.6/
00573             2       ' ',5X,'TOT V PRESSURE DROP       ',10X,'DPV   ',E14.6/
00573             3       ' ',5X,'CONTRACT PRESSURE DROP    ',10X,'DPLCON',E14.6/
00573             4       ' ',5X,'AREA RATIO                ',10X,'AR    ',E14.6/
00573             5       ' ',5X,'LIQUID VELOCITY           ',10X,'VLE   ',E14.6/
00573             6       ' ',5X,'AREA L FLOW  COND         ',10X,'ALC   ',E14.6/
00573             7       ' ',5X,'AREA L FLOW  EVAP         ',10X,'ALE   ',E14.6/
00573             8       ' ',5X,'PRESSURE DROP EXPA N      ',10X,'DPVEX ',E14.6/
00573             9       ' ',5X,'V PRESSURE DROP ADIABATIC ',10X,'DPVA  ',E14.6)
00574          904 FORMAT (' ',5X,'PRESSURE IN ADIABATIC SEC ',10X,'PVAPA ',E14.6/
00574             1       ' ',5X,'L PRESS DROP ADIAB        ',10X,'DPLA  ',E14.6/
00574             2       ' ',5X,'                          ',10X,'RIC   ',E14.6/
00574             3       ' ',5X,'PRESSURE  RECOVERED .     ',10X,'DPVREC',E14.6/
00574             4       ' ',5X,'MIN V PRESSURE            ',10X,'PVMIN ',E14.6/
00574             5       ' ',5X,'V PRESSURE CONDENSER      ',10X,'PVAP  ',E14.6/
00574             6       ' ',5X,'                          ',10X,'      ',E14.6/
00574             7       ' ',5X,'DP V EVAPORATOR           ',10X,'DPVE  ',E14.6/
00574             8       ' ',5X,'DP V MOMENTUM             ',10X,'DPVMOM',E14.6/
00574             9       ' ',5X,'HP RADIUS EVAPORATOR      ',10X,'RTE   ',E14.6/
00574             A       ' ',5X,'PRESSURE RECOVERED        ',10X,'DPVREE',E14.6)
00575          905 FORMAT (' ',5X,'TOTAL HEAT TRANSFERRED    ',10X,'QIN   ',E14.6/
00575             1       ' ',5X,'MASS FLOWRATE             ',10X,'MDOT  ',E14.6/
00575             2       ' ',5X,'                          ',10X,'AW    ',E14.6/
00575             3       ' ',5X,'                          ',10X,'TS    ',E14.6/
00575             4       ' ',5X,'CRITICAL HEAT FLUX        ',10X,'QACRIT',E14.6/
00575             4       ' ',5X,'ACTUAL HEAT FLUX          ',10X,'QA    ',E14.6/
00575             6       ' ',5X,'ENTRAINMENT LIMIT         ',10X,'QENTR ',E14.6)
00575        C
00575        C
00576              FUNCTION  FF(REVAP)
00601              IF(REVAP.GT.2000) GO TO 520
00603              FF=16./REVAP
00604              GO TO 521
00605          520 FF=0.0146/(REVAP)**0.048
00606          521 RETURN
00607              END

      END OF COMPILATION:          2 DIAGNOSTICS.
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```
@MAP,IS  HP,HP
MAP 23-D  06/23/73  18:44:10  (,0)  HP

    1.      IN  HPD

    2.      IN HOPIPE

    3.      IN SEARCB

    4.      IN ENTP


ADDRESS LIMITS     001000 020414      040000 047142
STARTING ADDRESS   014242

WORDS DECIMAL        7949 IBANK         3683 DBANK
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                SEGMENT MAIN                 001000 020414       040000 047142

NSWTCS/FOR                  1    001000 001021
NRBLKS/FOR                  1    001022 001044
NRWNDS/FOR                  1    001045 001126         2    040000 040011
NWEFS/FOR                   1    001127 001312         2    040012 040031
NFTCHS/FOR                  1    001313 001627         2    040032 040057
NINPTS/FOR                  1    001630 002514         2    040060 040103
NCLOSS/FOR                  1    002515 002705         2    040104 040134
NWBLKS/FOR                  1    002706 003017
NBSBLS/FOR                  1    003020 003060
NUPDAS/FOR                  1    003061 003116
NBF00S/FOR                                             2    040135 042336
NFTVS/FOR                   1    003117 003141
NBDCVS/FOR                  1    003142 003267         2    042337 042401
NCNVTS/FOR                  1    003270 003511         2    042402 042476
NININS/FOR                  1    003512 003702         2    042477 042502
NOTINS/FOR                  1    003703 004205         2    042503 042514
UTINFV (COMMON BLOCK)                                       042515 042517
NFCHKS/FOR                  1    004206 005174         2    042520 042673
                            3    UTINFV                4    042674 042745
NIOERS/FOR                  1    005175 005413         2    042746 043116
NOUTS/FOR                   1    005414 006472         2    043117 043152
NFMTS/FOR                   1    006473 007350         2    043153 043227
NTABS/FOR                                              2    043230 043404
ERUS
NLOUTS/FOR                  1    007351 010432         2    043405 043442
NLINPS/FOR                  1    010433 012236         2    043443 043627
NINTRS/FOR-JPL              1    012237 012461         2    043630 043714
NOBUFS/FOR                  1    012462 012523         2    043715 043715
SQRTS/FOR-JPL               1    012524 012562         2    043716 043722
EXPS/FOR                    1    012563 012652         2    043723 043743
ALOGS/FOR                   1    012653 012772         2    043744 044004
NEXP6S/FOR                  1    012773 013167         2    044005 044056
NERRS/FOR                   1    013170 013565         2    044057 044257
NIERS/FOR                   1    013566 013737         2    044260 044377
NOSYMS/FOR                  1    013740 014201         2    044400 044404
NSTOPS/FOR                  1    014202 014241         2    044405 044420
BLANKSCOMMON (COMMON BLOCK)                                 044421 044445
HPD                         1    014242 015547         0    044446 045412
                                                       2    BLANKSCOMMON
HOPIPE                      1    015550 017635         0    045413 047053
                                                       2    BLANKSCOMMON
SEARCB                      1    017636 020075         0    047054 047075
                                                       2    BLANKSCOMMON
ENTP                        1    020076 020414         0    047076 047142
                                                       2    BLANKSCOMMON


SYS$*RLIB$. LEVEL 68  02
END OF COLLECTION - TIME 1.450 SECONDS


@XQT  HP


$INPP
IHPT    =              +1
NSCL    =              +2
MESH    =     .10000000E+03
FDE     =     .10000000E+01
FCE     =     .10000000E+01

$END


PUMPING SUFFICIENT.  RTC MAINTAINED.
       TOTAL PRESURE DROP IN PIPE                DPTOT     .220647+00
       TOTAL AVAILABLE PRESSURE                  DPST      .276854+00
                                                 RTCU      .000000
                                                 RTCL      .000000
                                                 RSCICC    .434263+00
       V PRESSURE DROP CONDENSER                 DPVC      .141929-01
       FRICTION FACTOR                                F    .994367-02
       REYNOLDS NUMBER VAPOR                      REVAP    .298626+04
       VELOCITY VAPOR                            VVAP      .159531+04
       VAPOR DENSITY                             DENV      .352173-03
       LIQUID PRESSURE DROP CONDE                DPLC      .162729+00
       LIQUID DENSITY                            DENSL     .671531+00
       CONDENSER LENGTH                          LC        .138312+03
       AVG REJECTION TEMPERATURE                 TREJ      .997994+03
       DT CONDENSER WALL                         DTWC      .914876-01
       DT CONDENSER FILM                         DTFC      .000000
       DT CONDENSER SCREEN                       DISC      .224434+00
       VAPOR TEMP CONDENSER                      TVAPC     .998310+03
                                                 TVM       .994765+03
                                                 TVMIN     .994765+03
       PRESSURE IN CONSENSER                     PVAPC     .749792+01
       TOT L PRESSURE DROP COND                  DPLCT     .162729+00
       TOT V PRESSURE DROP                       DPV       .106193-01
       CONTRACT PRESSURE DROP                    DPLCON    .000000
       AREA RATIO                                AR        .100000+01
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| | | |
|---|---|---|
| LIQUID VELOCITY | VLE | .718693+01 |
| AREA L FLOW COND | ALC | .689699-01 |
| AREA L FLOW EVAP | ALE | .689699-01 |
| PRESSURE DROP EXPA N | DPVEX | .000000 |
| V PRESSURE DROP ADIABATIC | DPVA | .000000 |
| PRESSURE IN ADIABATIC SEC | PVAPA | .750323+01 |
| L PRESS DROP ADIAB | DPLA | .000000 |
| | RIC | .500000+00 |
| PRESSURE RECOVERED | DPVREC | .723838+01 |
| MIN V PRESSURE | PVMIN | .751524+01 |
| V PRESSURE CONDENSER | PVAP | .352932-01 |
| | | .307212-02 |
| DP V EVAPORATOR | DPVE | .893411-02 |
| DP V MOMENTUM | DPVMOM | .500000+00 |
| HP RADIUS EVAPORATOR | RTE | .357364-02 |
| PRESSURE RECOVERED | DPVREE | |
| TOTAL HEAT TRANSFERRED | QIN | .700000+03 |
| MASS FLOWRATE | MDOT | .332857+00 |
| | AW | .131368+00 |
| | TS | .457371-01 |
| CRITICAL HEAT FLUX | QACRIT | .191457+05 |
| ACTUAL HEAT FLUX | QA | .118152+04 |
| ENTRAINMENT LIMIT | QENTR | .823268+04 |

PUMPING SUFFICIENT. RTC MAINTAINED.

| | | |
|---|---|---|
| TOTAL PRESURE DROP IN PIPE | DPTOT | .147678+00 |
| TOTAL AVAILABLE PRESSURE | DPST | .276768+00 |
| | RTCU | .000000 |
| | RTCL | .000000 |
| | RSCICC | .534263+00 |
| V PRESSURE DROP CONDENSER | DPVC | .421640-02 |
| FRICTION FACTOR | F | .100433-01 |
| REYNOLDS NUMBER VAPOR | REVAP | .242640+04 |
| VELOCITY VAPOR | VVAP | .105022+04 |
| VAPOR DENSITY | DENV | .353446-03 |
| LIQUID PRESSURE DROP CONDE | DPLC | .111071+00 |
| LIQUID DENSITY | DENSL | .671430+00 |
| CONDENSER LENGTH | LC | .115071+03 |
| AVG REJECTION TEMPERATURE | TREJ | .998403+03 |
| DT CONDENSER WALL | DTWC | .913152-01 |
| DT CONDENSER FILM | DTFC | .000000 |
| DT CONDENSER SCREEN | DISC | .221263+00 |
| VAPOR TEMP CONDENSER | TVAPC | .998716+03 |
| | TVM | .995031+03 |
| | TVMIN | .995031+03 |
| PRESSURE IN CONSENSER | PVAPC | .752808+01 |
| TOT L PRESSURE DROP COND | DPLCT | .111071+00 |
| TOT V PRESSURE DROP | DPV | .265892-02 |
| CONTRACT PRESSURE DROP | DPLCON | .000000 |
| AREA RATIO | AR | .100000+01 |
| LIQUID VELOCITY | VLE | .594867+01 |
| AREA L FLOW COND | ALC | .833386-01 |
| AREA L FLOW EVAP | ALE | .833386-01 |
| PRESSURE DROP EXPA N | DPVEX | .000000 |
| V PRESSURE DROP ADIABATIC | DPVA | .000000 |
| PRESSURE IN ADIABATIC SEC | PVAPA | .752941+01 |
| L PRESS DROP ADIAB | DPLA | .000000 |
| | RIC | .600000+00 |
| PRESSURE RECOVERED | DPVREC | .725764+01 |
| MIN V PRESSURE | PVMIN | .753440+01 |
| V PRESSURE CONDENSER | PVAP | .289563-01 |
| | | .109842-02 |
| DP V EVAPORATOR | DPVE | .389368-02 |
| DP V MOMENTUM | DPVMOM | .600000+00 |
| HP RADIUS EVAPORATOR | RTE | .155747-02 |
| PRESSURE RECOVERED | DPVREE | |
| TOTAL HEAT TRANSFERRED | QIN | .700000+03 |
| MASS FLOWRATE | MDOT | .332862+00 |
| | AW | .160105+00 |
| | TS | .457371-01 |
| CRITICAL HEAT FLUX | QACRIT | .191918+05 |
| ACTUAL HEAT FLUX | QA | .780617+03 |
| ENTRAINMENT LIMIT | QENTR | .824417+04 |

PUMPING SUFFICIENT. RTC MAINTAINED.

| | | |
|---|---|---|
| TOTAL PRESURE DROP IN PIPE | DPTOT | .108369+00 |
| TOTAL AVAILABLE PRESSURE | DPST | .276716+00 |
| | RTCU | .000000 |
| | RTCL | .000000 |
| | RSCICC | .634263+00 |
| V PRESSURE DROP CONDENSER | DPVC | .154076-02 |
| FRICTION FACTOR | F | .101264-01 |
| REYNOLDS NUMBER VAPOR | REVAP | .204342+04 |
| VELOCITY VAPOR | VVAP | .743669+03 |
| VAPOR DENSITY | DENV | .354161-03 |
| LIQUID PRESSURE DROP CONDE | DPLC | .806363-01 |
| LIQUID DENSITY | DENSL | .671373+00 |
| CONDENSER LENGTH | LC | .985418+02 |
| AVG REJECTION TEMPERATURE | TREJ | .998633+03 |
| DT CONDENSER WALL | DTWC | .911780-01 |
| DT CONDENSER FILM | DTFC | .000000 |
| DT CONDENSER SCREEN | DISC | .219028+00 |
| VAPOR TEMP CONDENSER | TVAPC | .998943+03 |
| | TVM | .995217+03 |
| | TVMIN | .995217+03 |

| | | |
|---|---|---|
| PRESSURE IN CONSENSER | PVAPC | .754503+01 |
| TOT L PRESSURE DROP COND | DPLCT | .806363-01 |
| TOT V PRESSURE DROP | DPV | .757738-03 |
| CONTRACT PRESSURE DROP | DPLCON | .000000 |
| AREA RATIO | AR | .100000+01 |
| LIQUID VELOCITY | VLE | .507432+01 |
| AREA L FLOW COND | ALC | .977073-01 |
| AREA L FLOW EVAP | ALE | .977073-01 |
| PRESSURE DROP EXPA N | DPVEX | .000000 |
| V PRESSURE DROP ADIABATIC | DPVA | .000000 |
| PRESSURE IN ADIABATIC SEC | PVAPA | .754541+01 |
| L PRESS DROP ADIAB | DPLA | .000000 |
| | RIC | .700000+00 |
| PRESSURE RECOVERED | DPVREC | .727112+01 |
| MIN V PRESSURE | PVMIN | .754783+01 |
| V PRESSURE CONDENSER | PVAP | .245486-01 |
| | | .468914-03 |
| DP V EVAPORATOR | DPVE | .195757-02 |
| DP V MOMENTUM | DPVMOM | .700000+00 |
| HP RADIUS EVAPORATOR | RTE | .783026-03 |
| PRESSURE RECOVERED | DPVREE | |
| TOTAL HEAT TRANSFERRED | QIN | .700000+03 |
| MASS FLOWRATE | MDOT | .332865+00 |
| | AW | .188843+00 |
| | TS | .457371-01 |
| CRITICAL HEAT FLUX | QACRIT | .192240+05 |
| ACTUAL HEAT FLUX | QA | .553872+03 |
| ENTRAINMENT LIMIT | QENTR | .825117+04 |

| | | | |
|---|---|---|---|
| RTE | 5.000-01 | 6.000-01 | 7.000-01 |
| LE | 3.000+01 | 0.000 | 0.000 |
| NC | 1.000+00 | 0.000 | 0.000 |
| QIN | 7.000+02 | 0.000 | 0.000 |
| TL | 0.000 | 0.000 | 0.000 |
| TW | 2.000-02 | 0.000 | 0.000 |
| LA | 1.000-01 | 0.000 | 0.000 |
| TEVAP | 1.000+03 | 0.000 | 0.000 |
| RPST | 5.339-03 | 0.000 | 0.000 |
| NC | 1.000+00 | 0.000 | 0.000 |
| LC | 1.383+02 | 1.151+02 | 9.854+01 |
| RTC | 5.000-01 | 6.000-01 | 7.000-01 |
| TVAP | 9.985+02 | 9.988+02 | 9.990+02 |
| TVAPA | 9.984+02 | 9.987+02 | 9.989+02 |
| TVAPC | 9.983+02 | 9.987+02 | 9.989+02 |
| TVMIN | 9.948+02 | 9.950+02 | 9.952+02 |
| TREJ | 9.980+02 | 9.984+02 | 9.986+02 |
| DPVE | 3.072-03 | 1.098-03 | 4.689-04 |
| DPVMOM | 8.934-03 | 3.894-03 | 1.958-03 |
| DPVA | 0.000 | 0.000 | 0.000 |
| DPVC | 1.419-02 | 4.216-03 | 1.541-03 |
| DPVEX | 0.000 | 0.000 | 0.000 |
| DPLE | 3.529-02 | 2.896-02 | 2.455-02 |
| DPLA | 0.000 | 0.000 | 0.000 |
| DPLC | 1.627-01 | 1.111-01 | 8.064-02 |
| DPLCON | 0.000 | 0.000 | 0.000 |
| DPVT | 2.263-02 | 7.651-03 | 3.184-03 |
| DPLT | 1.980-01 | 1.400-01 | 1.052-01 |
| DPTOT | 2.206-01 | 1.477-01 | 1.084-01 |
| DPST | 2.769-01 | 2.768-01 | 2.767-01 |
| CON | 0.000 | 0.000 | 0.000 |


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