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USER'S MANUAL FOR THE TRW GASPIPE 2 PROGRAM

(A VAPOR–GAS FRONT ANALYSIS PROGRAM FOR HEAT PIPES CONTAINING NON-CONDENSIBLE GAS)

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This manual is a revision of an April 1971 report "User's Manual for the TRW Gaspipe Program". The Gaspipe 2 Program includes a number of changes in logic and operating options which provide it with expanded capability. The program revision was performed under NASA Contract No. NAS2-5503, "Design, Fabrication, and Testing of a Variable Conductance Constant Temperature Heat Pipe.

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1.0 INTRODUCTION

This report describes a digital computer program useful in the design and analysis of heat pipes which contain non-condensible gases; either for temperature control or to aid in start-up from the frozen state. Because the program includes the effects of axial conduction and mass diffusion on the performance of such heat pipes, it represents a significant advance in steady-state design technology over the "flat-front" theory previously found in the literature [1, 2]. It allows one to:

- Calculate the wall temperature profile along a gas-loaded heat pipe.
- Calculate the amount of gas loading necessary to obtain a desired evaporator temperature at a desired heat load.
- Calculate the heat load versus the evaporator temperature for a fixed amount of gas in the pipe.
- Calculate the heat and mass transfer along the pipe, including the vapor-gas front region.
- Calculate the heat leak when the condenser is filled with gas.
- Calculate whether or not freezing occurs in the condenser and, if so, at what rate.
- Determine the information required to size the gas reservoir of gas-controlled heat pipes.

The program contains numerous reservoir options which allow it to be used for hot or cold reservoir passive control as well as heated reservoir active control heat pipes. Additional input options permit its use for parametric studies and off-design performance predictions as well as heat pipe design.

Provision is also made in the nrogram for two condenser sections and an adiabatic section.

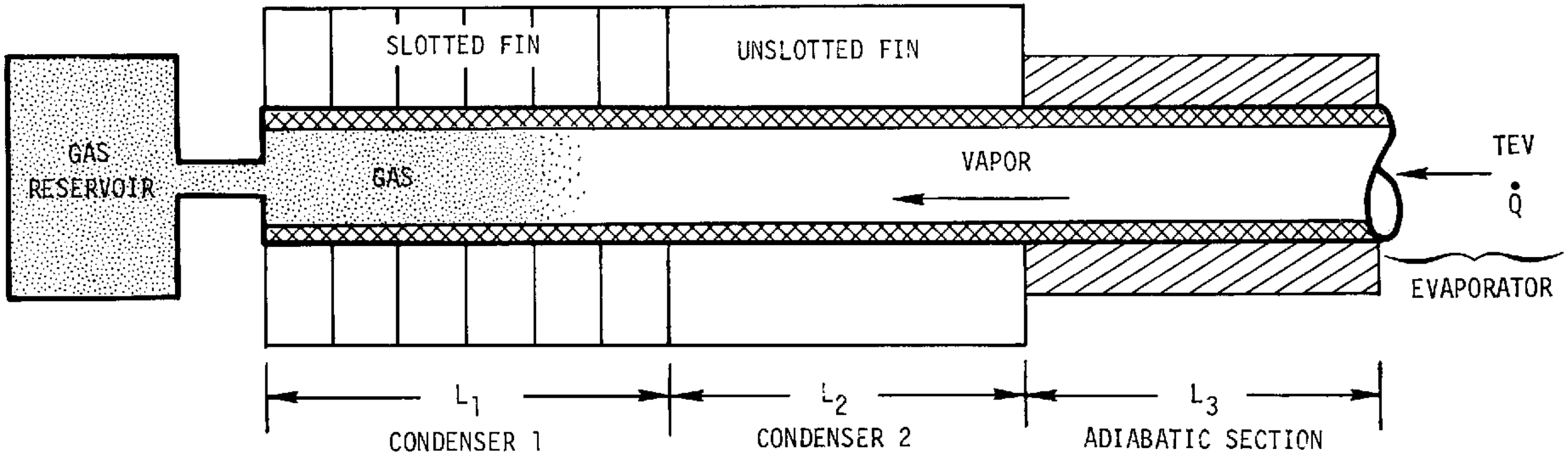
The analysis and formulation of the equations used in the program are presented in Section 2. Basically, a one-dimensional steady state analysis has been used and the equations written assuming small wick resistance and negligible vapor pressure drop along the pipe. The analytical model used is shown in Figs. 1-1 and 1-2. However, the program is not limited to the geometry shown. Non-circular and non-axisymmetric configurations can also be studied by calculating equivalent diameters, thicknesses, etc. consistent with the formulation of the equations.

The numerical technique used to solve the equations is also discussed in Section 2. It involves a fourth-order Runge-Kutta routine to solve two simultaneous equations for (1) a parameter fixing the mole fraction of the non-condensible gas, and (2) the condensible vapor velocity.

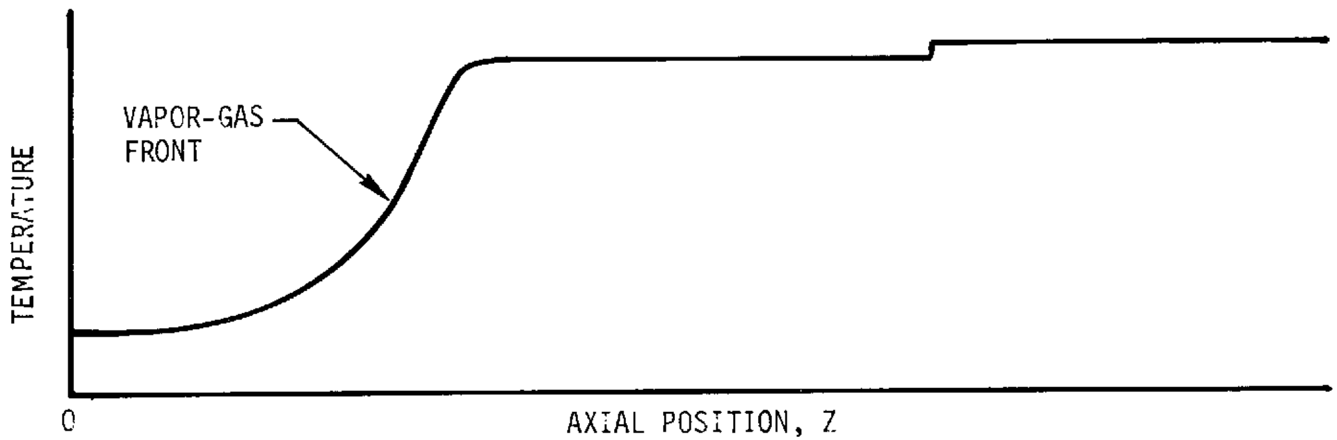
Section 3 discusses the potential uses of the program for research, heat pipe design and performance predictions. The program input requirements are described in Section 4, and the output discussed in Section 5.

Flow diagrams, program listings and sample problems are presented in the appendices.

This manual assumes that the user has a prior understanding of the principles involved in gas-loaded heat pipes. References [2 - 4] can aid in this respect.



a. Schematic Diagram of a Gas-Loaded Heat Pipe



b. Temperature Distribution

FIGURE . Vapor-Gas Front Analytical Model for a Gas Loaded Heat Pipe

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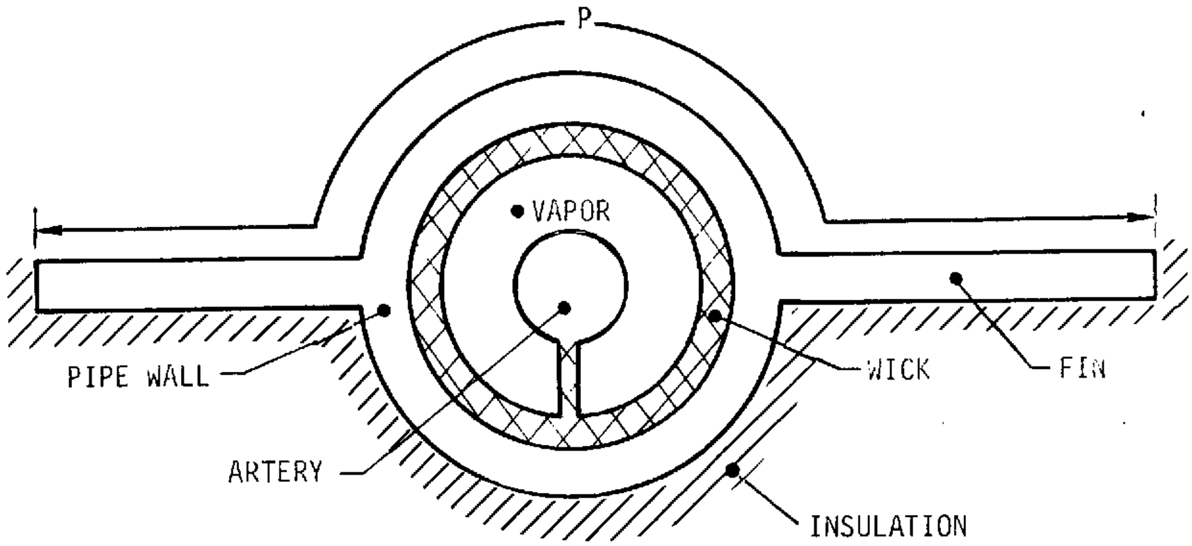


FIGURE 1-2. Cross-section of Condenser

2.0 ANALYSIS

2.1 Formulation

The condensing section of the pipe is assumed to reject heat by radiation and convection from a fin of perimeter P with an effectiveness η as shown in Figure 1-2. The net heat loss from a length of condenser dz is thus taken to be

$$d\dot{Q} = \left[\varepsilon\sigma T_w^{\ 4} + h(T_w - T_f) - q_{abs}\right]\eta P dz \qquad (2\text{-}1)$$

where ε is total hemispherical emittance, σ the Stefan-Boltzman constant, T_w the wall temperature, h the convective heat transfer coefficient, if any, T_f the external fluid temperature, and q_{abs} is the power absorbed per unit area from the surrounds, αH in the case of irradiation H onto the condenser surface of absorptance α. For simplicity all parameters are taken to be constants, but a step change is allowed between sections of condenser.

In the usual heat pipe application the difference between the wick-vapor interface temperature T_i and the condenser wall temperature T_w is small compared to absolute temperature level. For this reason Eq. (2-1) is written in a linearized form

$$d\dot{Q} = S dz\ (T_w - T_c) \qquad (2\text{-}2)$$

where

$$S(z) = \left[4\varepsilon\sigma T_i^{\ 3} + h\right]\eta P \qquad (2\text{-}3)$$

and

$$T_c(z) = \frac{3\varepsilon\sigma T_i^{\ 4} + q_{abs} + hT_f}{4\varepsilon\sigma T_i^{\ 3} + h} \qquad (2\text{-}4)$$

We adopt the unusual sign convention that the power $\dot{Q}$ is measured in the <u>negative</u> z direction. Then Fourier's law is written without the usual negative sign. Heat flows into an element of pipe dz long at z+dz and out at z by axial conduction. Heat also flows across the wick by conduction at the rate

$$\frac{2\pi k_e dz}{\ln \frac{D_i+2\delta}{D_i}} (T_i-T_w) = Kdz\ (T_i-T_w) \tag{2-5}$$

where k_e is the equivalent thermal conductivity of the liquid-filled wick, D_i the inside diameter of the wick, and δ the wick thickness. Eq. (2-5) defines K. The heat balance on an element of condenser is then

$$C\frac{d^2T_w}{dz^2} + K(T_i-T_w) - S(T_w-T_c) = 0 \tag{2-6}$$

where C is the axial conductivity-area product for the condenser cross section,

$$C = \sum_{n=1}^{N} k_n A_{c,n} \tag{2-7}$$

In Eq. (2-7) k_n is the effective axial conductivity, allowing for slots or other anisotropies, and $A_{c,n}$ the cross-sectional area of the nth element in the pipe. These elements include the pipe wall, the wick and the fin wall, as shown in Fig. 1-2. When an artery is present, even if it is not in intimate thermal contact with the condenser wall, its axial conductance should also be included in Eq. (2-7), because the temperature gradient in it tends to follow dT_i/dz which in turn tends to follow dT_w/dz, when K is large compared to S, (See Sec. 4.4).

The wick interface temperature T_i is the saturation temperature for the partial pressure of the vapor above the interface, since the net condensation rate is far from the absolute rate of condensation. Other simplifying assumptions introduced, which are reasonable for most applications, are negligible vapor side pressure loss and a simple vapor pressure law derived from the Clausius-Clapeyron relation. The mole fraction of the non-condensible at the interface x_i and the interface temperature T_i are then related in the following way

$$x_i = 1 - \exp\left[-(h_{fg}/RT_{ev})(T_{ev}/T_i - 1)\right] \qquad (2\text{-}8a)$$

$$T_i = \frac{T_{ev}}{1 + \frac{RT_{ev}}{h_{fg}} \ln \frac{1}{1-x_i}} = \frac{T_{ev}}{1 + \frac{T_{ev}}{T_o} \ln \frac{1}{1-x_i}} \qquad (2\text{-}8b)$$

Conservation of non-condensible gas requires that the diffusion plus convection in the tube sum to zero [5],

$$-c\mathcal{D}\frac{dx_s}{dz} - cVx_b = 0 \qquad (2\text{-}9)$$

where c is the molar concentration, $\mathcal{D}$ the diffusion coefficient for the non-condensible diffusing in the vapor, x_s the spatial or area-weighted average mole fraction, V the mole average velocity, and x_b the bulk (area-velocity weighted) average. At least in the region of the condenser which is gas-controlled, the radial velocity rates will be sufficiently low so that the bulk, spatial, and wall values of mole fraction of non-condensible will be nearly the same. This assumption is made for the entire condenser so that the subscripts i, s, and b on x will be dropped in what follows.

To obtain an equation having the grouping $\dot{m} = cVA_cM$, the condensible flow rate, Eq. (2-9) is multiplied by A_cM, where M is the molecular weight of the condensible working fluid. In addition, the dependent variable is transformed from mole fraction x to ϕ by introducing

$$\phi = \ln \frac{1}{x}, \quad x = e^{-\phi} \qquad (2\text{-}10)$$

Equation (2-9) then becomes

$$\dot{m} = A_cMc\mathcal{D}\frac{d\phi}{dz} \qquad (2\text{-}11)$$

Conservation of mass shows that increase in mass flow rate with distance from the end of the condenser is equal to the condensation rate which in turn is equal to the product of wick conductance and temperature difference across the wick divided by the latent heat of vaporization or sublimation.

$$\frac{d\dot{m}}{dz} = K(T_i - T_w)/h_{fg} \tag{2-12}$$

Equations (2-6, 2-11 and 2-12) form a set of three simultaneous differential equations in three unknowns: T_w, ϕ, and $\dot{m}$. The temperature T_i is related to ϕ through the highly non-linear relations, Eqs. (2-10) and (2-8). The coefficient S defined by Eq. (2-3) is also nonlinear. An explicit energy equation for the liquid or vapor is not written, because subcooling of liquid in the wick and superheating of the vapor in the pipe are not considered to be key physical phenomena and are neglected in the present treatment. Equations (2-12) and (2-6) will give an entirely correct energy balance when x_i, x_s and X_b are identical, the wick resistance small, and no freezing occurs.

A boundary condition on (2-6), (2-11) and (2-12) is taken to be

$$\dot{m} = 0 \text{ at } z = 0 \tag{2-13}$$

In addition, either one of two conditions may be prescribed: a total heat rate rejected

$$\dot{Q} = \int_0^L S(T_w - T_c)\,dz \tag{2-14a}$$

or a total number of moles of non-condensible present

$$\mathcal{M} = A_c \int_0^L \left[P_i(T_i(z))/R_u T_i\right] dz \tag{2-14b}$$

In computing $\mathcal{M}$ a more accurate vapor pressure law than Eq. (2-8) must be used. An exponential of a polynomial in the reciprocal of T_i is used.

Strictly speaking, since Eq. (2-6) is second order, two more conditions must be specified, such as a zero CdT_w/dz at $z = 0$ and $z = L$. However, an approximation is made that the first and second derivatives of T_w with respect to z are equal to those of T_i. As is shown in Section 2.2, this approximation reduces the set of equations to two first order ones so that Eqs. (2-13) and (2-14) are sufficient. The condition on CdT_w/dz is met at $z = 0$, and at $z = L$ it is met in practical effect when the evaporator is purged of gas. The approximation regarding the derivatives of T_w and T_i is, of course, exact when the wick resistance is zero.

A review of the features of the analysis and assumptions made are as follows:

1. Radiation and convection from a finned pipe are considered. Absorbed radiation from the surrounds is included. Provision for a step change in condenser properties and ambient conditions is made.
2. The condenser wall temperature T_w is assumed close to the wick interface temperature T_i. The first and second derivatives of T_w and T_i with respect to z are assumed equal, respectively. In essence high wick conductance is assumed.
3. Axial conduction of heat in the pipe wall and fin and one-dimensional axial diffusion of the condensible species, which carries latent heat, are accounted for.
4. Vapor pressure drop in the pipe is neglected. In calculating the shape of the wall temperature and wick temperature distributions, an approximate vapor pressure law derived from Clausius-Clapeyron is used. But in calculating the pressure in the pipe and the amount of non-condensible present a more accurate expression is used.
5. The condition of zero wall temperature gradient is met at $z = 0$. Either the total number of moles of non-condensible present in the pipe or the total heat rejected by the pipe is specified.

2.2 Dimensionless Governing Equations

The mass flow rate, mass diffusivity, temperatures, and other parameters were made dimensionless so that orders of magnitudes could be assessed and for convenient numerical solution. The dimensionless quantities are

$$z^* = z/D_e$$

$$V^* = \dot{m}h_{fg}/\dot{Q}_{nominal}$$

$$\mathcal{D}^* = M(c_{ev}\mathcal{D}_{ev}/D_e)A_c h_{fg}/\dot{Q}_{nominal}$$

$$T_i^* = T_i/T_{ev}$$

$$T_w^* = T_w/T_{ev}$$

$$T_0^* = T_0/T_{ev}$$

$$T_c^* = T_c/T_{ev}$$

$$T_R^* = T_R/T_{ev}$$

$$Q_e^* = \frac{dQ^*}{dz^*} = S^*(T_w^* - T_c^*)$$

$$S^* = F^*(4\varepsilon\sigma T_i^{*3} + H^*)$$

$$F^* = \eta P D_e \sigma T_{ev}^4/\dot{Q}_{nominal}$$

$$H^* = h/\sigma T_{ev}^3$$

$$C^* = CT_{ev}/D_e\dot{Q}_{nominal}$$

where T_{ev} is the evaporator temperature which sets the total pressure in the system, and D_e is an equivalent diameter allowing for the presence of arteries within the pipe,

$$D_e = (4A_c/\pi)^{1/2} ,$$

where A_c is the cross sectional area available for vapor flow. An exponent E is an empirical factor to account for the temperature variation of the mass diffusivity defined by

$$c\mathscr{L} = c_{ev}\mathscr{L}_{ev}(T_i/T_{ev})^E$$

Eqs. (2-6), (2-11), (2-12), and (2-8) written in dimensionless form become

$$C^* \frac{d^2T_w^*}{dz^{*2}} + K^*(T_i^* - T_w^*) - S^*(T_w^* - T_c^*) = 0 \qquad (2\text{-}16)$$

$$\frac{d\phi}{dz^*} = \frac{V^*}{\mathscr{L}^* T_i^{*E}} \qquad (2\text{-}17)$$

$$\frac{dV^*}{dz^*} = K^*(T_i^* - T_w^*) \qquad (2\text{-}18)$$

$$1 - e^{-\phi} = e^{-T_0^*(1/T_i^*-1)} \qquad (2\text{-}19)$$

Under approximation 2 Eq. (2-16) is approximated as

$$C^* \frac{d^2T_i^*}{dz^{*2}} + K^*(T_i^*-T_w^*) - S^*(T_w^*-T_c^*) = 0 \qquad (2\text{-}16a)$$

The simplifying feature of this approximation is that the second derivative in Eq. (2-16a) can now be eliminated. Eq. (2-19) is differentiated with respect to z^*, and Eq. (2-17) is used to eliminate $d\phi/dz^*$. The result multiplied by C^* is

$$C^* \frac{dT_i^*}{dz^*} = C^* \frac{e^{-\phi}}{1-e^{-\phi}} \frac{T_i^{*2-E}}{\mathscr{L}^* T_0^*} V^* \qquad (2\text{-}21)$$

Eq. (2-21) is differentiated again with respect to z^*, Eq. (2-17) is used again to eliminate $d\phi/dz^*$, and Eq. (2-21) itself is used to eliminate dT_i^*/dz^*.

$$C^* \frac{d^2T_i^*}{dz^{*2}} = \Phi_1 \frac{dV^*}{dz^*} - \Phi_1 \Phi_2 \Phi_3 \tag{2-22}$$

where the functions Φ_1, Φ_2, Φ_3 are

$$\Phi_1(\phi) = C^* \frac{e^{-\phi}}{(1-e^{-\phi})} \frac{T_i^{*2-E}}{\sigma^* T_0^*} \tag{2-23}$$

$$\Phi_2(\phi) = 1 - (2-E)(T_i^*/T_0^*)e^{-\phi} \tag{2-24}$$

$$\Phi_3(\phi, V^*) = V^{*2} / (1-e^{-\phi})\sigma^* T_i^{*E} \tag{2-25}$$

Equation (2-16a) together with Eqs. (2-18) and (2-22) now can be written

$$\frac{dV^*}{dz^*} = Q_e^* - \Phi_1 \Phi_4 \tag{2-26}$$

where

$$\Phi_4(\phi, V^*) = \frac{Q_e^*(\phi) - \Phi_2(\phi)\Phi_3(\phi, V^*)}{1 + \Phi_1(\phi)} \tag{2-27}$$

The program accounts for a step change in axial conduction between sections 1 and 2 of the condenser, Fig. 1-1, by assuming continuity in the mole fraction, x and ϕ. Because the analysis is one dimensional, this assumption leads to a step change in the vapor velocity, V, when the front forms across the discontinuity. Thus, for a discontinuity in condenser parameters, the mole average velocity, V, is calculated as follows:

$$V_2^* = V_1^* \frac{1 + \dfrac{C_1^*}{V_1^*} \left(\dfrac{dT_i^*}{dz^*}\right)_{z^*=z_1^*-}}{1 + \dfrac{C_2^*}{V_2^*} \left(\dfrac{dT_i^*}{dz^*}\right)_{z^*=z_1^*+}} \tag{2-28}$$

where $\dfrac{C^*}{V^*} \dfrac{dT_i^*}{dz^*}$ is given by Eq. (2-21).

Eqs. (2-17) and (2-26) together with (2-19) and the definitions of Φ_j in Eqs. (2-23, 2-24, 2-25 and 2-27) form a set of two simultaneous nonlinear first order ordinary differential equations which can be numerically solved by, say, a fourth-order Runge-Kutta routine. The initial conditions are $V^* = 0$ and $\phi = \phi_0$ at $z = 0$. Values of $\mathcal{M}$ and $\dot{Q}$ for a length of pipe L can be obtained versus ϕ_0 for a given set of parameters and an evaporator temperature T_{ev}. An iterative routine can be used to find ϕ_0 for a prescribed value of either $\mathcal{M}$ or $\dot{Q}$.

2.3 Numerical Solution

Section 2.2 shows how Eqs. (2-6), (2-11) and (2-12) are reduced by virtue of assumption 2 (high wick conductance) to Eqs. (2-17) and (2-26), a set of two simultaneous first order differential equations in ϕ and V^* (a dimensionless velocity or mass flow rate).

In the numerical solution of these equations, an initial value of T_i slightly in excess of the sink temperature is used to fix $\phi(0)$, and a fourth order Runge-Kutta routine is used to solve for $\phi(z)$ and $V^*(z)$. Either the amount of gas in the pipe or the total heat rejection is then compared with the input value. Depending on the sign of the deviation, the program then either (1) operates in the "long mode" and slides the front up the pipe a certain distance or (2) operates in the "short mode" and increases $\phi(0)$ a prescribed amount, and the integration is repeated. This iteration scheme is repeated until the calculated value of $\mathcal{M}$ or $\dot{Q}$ (depending on the option used) agrees within the numerical integration accuracy with the specified value.

3.0 PROGRAM APPLICATION

The program has been found useful in the following areas:

- Research
- Design
- Performance prediction

As a research tool it can be used to study the nature of the vapor-gas interface in gas-loaded heat pipes [Ref. 4]. Using the program for parametric analysis, one can study the relative effects of various boundary conditions, fluid properties, material properties, operating temperatures, etc., on heat and mass transfer. Useful program outputs for purposes of comparison are the temperature, heat transfer and mass transfer profiles, and the diffusion freezeout rates.

Although the computer program is not a design program, per se, it can be extremely useful in this respect. By running the program for minimum and maximum design conditions (evaporator temperature, power and sink conditions) one establishes the variation in condenser gas inventory and uses this information to size the gas reservoir. Also, through variation of design parameters, one can optimize the condenser and radiator design for the desired power and evaporator temperature control range.

Given a particular heat pipe configuration, the program can be used to predict performance at various operating conditions, i.e., run a performance map of $\dot{Q}$ versus T_{ev} for a fixed set of parameters. This is particularly useful in studying heat pipe performance under off-design conditions.

3.1 Minimum Power and Freezeout Rates

It is possible to obtain the heat leakage when the gas completely blocks the condenser by simply reading the value of QSUM at the beginning of an adiabatic section. This heat transfer represents, for example, the heat leak associated with a variable conductance heat pipe in the "full-off" position. Each component of heat transfer can be calculated separately by multiplying the mass flow at a point (for example, TI = 0.986) by the latent heat of vaporization of the working fluid and subtracting from QFLOW. In the example given in Appendix C the total heat transfer across the front is 2.01 Btu/hr, with 0.37 Btu/hr due to diffusion and 1.64 Btu/hr due to conduction.

If the temperature of the gas-blocked portion of the condenser falls below the freezing point of the working fluid, then vapor which diffuses through the gas and freezes on the walls does not return to the evaporator. Given sufficient time, this will deplete the evaporator of fluid and result in heat pipe failure. The rate of fluid loss (diffusion freezeout rate) is given by the mass flow past the point at which the wick falls to the freezing point of the fluid.

3.2 Design

For design applications one most commonly uses the heat input option (MODEQM = 0) and prescribes the required heat input, $\dot{Q}$. An example of how the program might be used to size the reservoir of gas-controlled heat pipes is outlined below.

For a given condenser/fin geometry the following conditions determine the amount of gas in the pipe for the "full-on"* and "full-off"* cases.

(1) Condenser Full-on (Maximum Power):

Heat Input
Evaporator Temperature
Sink Conditions

(2) Condenser Full-Off (Minimum Power):

Heat Input
Evaporator Temperature
Sink Conditions

*Note that if the condenser were truly full-on then there would be no gas in the pipe. In reality, however, it is not possible to achieve this condition in a gas loaded pipe because of diffusion, nor is it desirable from a control point of view--especially in passive systems. Similarly, there is always a minimum power (heat leak) in the full-off position.

A run is made for each of these two cases with the reservoir volume set equal to zero (VRES = 0) to yield the number of moles of non-condensible gas, $\mathcal{M}_{max}$ and $\mathcal{M}_{min}$, in the pipe. These are the final values of MPIPE printed at $z = L_1 + L_2 + L_3$ in each case. Summing the total number of moles--constant for a closed system--yields two simultaneous equations, which may be solved for the required reservoir volume and gas inventory:

$$\begin{aligned} \mathcal{M} &= V_R \left(\frac{P_{gr}}{R_u T_R}\right)_{max} + \mathcal{M}_{max} \\ \mathcal{M} &= V_R \left(\frac{P_{gr}}{R_u T_R}\right)_{min} + \mathcal{M}_{min} \end{aligned} \qquad (3\text{-}1)$$

where P_{gR} is the partial pressure of non-condensible gas in the reservoir, which may be found by reading the vapor pressure curve at the evaporator and reservoir temperatures ($P_{gR} = P_{ev} - P_{vR}$).

Solving for the reservoir volume:

$$V_R = \frac{R_u \left(\mathcal{M}_{min} - \mathcal{M}_{max}\right)}{\left(\frac{P_{gR}}{T_R}\right)_{max} - \left(\frac{P_{gR}}{T_R}\right)_{min}} \qquad (3\text{-}2)$$

This equation may be expressed in terms of the computer output variables as follows:

$$V_R = \frac{\mathcal{M}_{min} - \mathcal{M}_{max}}{\left[x_R\, c_{ev}\left(\frac{T_{ev}}{T_R}\right)\right]_{max} - \left[x_R\, c_{ev}\left(\frac{T_{ev}}{T_R}\right)\right]_{min}} \qquad (3\text{-}3)$$

where

$c_{ev} = \dfrac{P_{ev}}{R_u T_{ev}}$, lb-mole/ft^3

T_{ev} = evaporator temperature, °R

P_{ev} = vapor pressure corresponding to evaporator temperature, psf

x_R = mole fraction of non-condensible gas in the control reservoir, (P_{gR}/P_{ev}) = XSR

CEV and TEV are direct outputs of the program, but some discretion must be used in defining the reservoir properties, x_R and T_R. Although the reservoir volume was set equal to zero, much information about the reservoir properties may be obtained from the output. The temperature at the end of the condenser (z=0) where the reservoir feedtube is attached, for instance, defines the reservoir temperature and the mole fraction in certain cases, Ref. [1]. The temperature at the end of the pipe depends on the length and shape of the front; and the reservoir properties are usually quite sensitive to this temperature. These considerations are summarized in Table 3-I for the usual applications.

Table 3-I

Gas Reservoir Characteristics (Design)

Type of Control	Type of Reservoir	T_R	X_R
Passive	Non-Wicked (Hot)	TEV*	XS @ Z=0
Active	Wicked (Heated)	Independent Variables (determined external to program).	
Passive	Wicked (Insulated)	TWICK @ Z=0**	XS @ Z=0

*Assuming the reservoir temperature is coupled to the evaporator temperature.
**Assuming the reservoir well coupled, thermally, to the end of the condenser and insulated from the surrounds.

It must be emphasized that the preceding is not a fixed design procedure, and the approach may be altered to accommodate other possibilities, such as variable volume reservoirs, or passive wicked reservoirs which are thermally de-coupled from the condenser.

3.3 Performance Prediction

For a given application, the amount of inert gas in the pipe is a known quantity. Thus, in order to predict the performance at various design or off-design conditions, the amount of gas is prescribed and MODEQM is set equal to one. Note that under this option the gas inventory may be specified in either of two ways:

(1) ZGAS - the length of condenser filled with gas if a sharp front is assumed (flat-front theory).

(2) AGAS - the amount of gas in lb-moles, m.

The former might be used in parametric analyses to establish similar vapor-gas interface locations for varying conditions without tedious calculation of appropriate molar inventories. It might also be used for specifying the amount of gas in a heat pipe to aid start-up from the frozen state. For example, one might specify that the entire condenser be gas-blocked at an evaporator temperature a few degrees above the freezing point of the working fluid.

But, for performance estimation purposes, the AGAS option is used and the amount of gas is put in directly, in lb-moles. If there is a separate reservoir volume, it is necessary to enter the appropriate control integer (NRES) and reservoir temperature (TRES) in the input. Table 3-II is a summary of the appropriate input values for typical applications. It should be pointed out that the program does not account for heat leakage from an actively heated reservoir into the condenser.

Again, the preceding is not a fixed procedure, but may be modified for other possibilities. The heat load might be more accurately known than the molar inventory, for example, in a certain performance test. In this case one would use the heat input option (MODEQM = 0) rather than specifying the amount of gas. Table 3-II is applicable in either case.

Table 3-II

Gas Reservoir Characteristics (Performance)

Type of Control	Type of Reservoir	NRES	TRES
Passive	Non-wicked (Hot)	0	TEV*
Active	Wicked (Heated)	1	Desired Temp
Passive	Wicked (Insulated)	2	Arbitrary**

*Assuming the reservoir temperature coupled to the evaporator temperature.
**The program assumes that the reservoir is insulated and takes the temperature at the end of the condenser as the reservoir temperature in this case. Thus, the input value is arbitrary (non-zero).

3.4 Adiabatic Section

In many heat pipe applications an unfinned, insulated section exists between the evaporator and condenser. The heat loss from this section may be negligible. It can then be treated as adiabatic. The computer program has the capability of dealing with such a section in addition to two condenser sections farther from the evaporator.

If an "adiabatic section" is not truly adiabatic but loses heat so that it is not satisfactory to model it so, the program can still be used, but care must be exercised. The way to treat a not-quite adiabatic section with the existing program is to treat that section as a condenser, Section 2. There then remains only one other condenser Section 1 which must model the active condenser of the actual pipe. The program adiabatic section capability is then not made use of, and a value of XLONGA = 0.0 is accordingly input.

4.0 INPUT DESCRIPTION

An input form for the program is reproduced in Fig. 4-1. Each line corresponds to a data card, and the input format is given in the second column. Also shown are the input parameters which cannot be set equal to zero without causing numerical difficulties in operation of the program. The following defines each input variable and gives some of the restrictions and limitations imposed on these variables.

Cards 1 & 2 (72H)

These are title cards which are used to identify the run. Any desired information, such as project, name, date, etc. may be typed on these cards. The only restriction is that column one is used for carriage control. Thus, a "1" is usually punched in the first column of card one to start printout at the top of the page, and the first column of card two is left blank.

4.1 Fluid Characteristics

Card 3 (3F 12.5)

A11, B11, C11: vapor pressure parameters in the least squares fit,

$$\ln P = A11 - \frac{B11}{T} - \frac{C11}{T^2}$$

where the pressure, P, is in psia and the temperature, T, is in ^{o}R. See Table 4-I.

Card 4 (5 F 12.5)

XMC: molecular weight of the condensible. See Table 4-I.

DIF: mass diffusivity for the vapor-gas pair at one atmosphere and 460^{o}R (ft^2/hr). See Table 4-I.

CARD	FORMAT	DESCRIPTION					
1	72H	1					
2	72H						
		PARAMETERS					
3	3F12.5	A11	B11	C11			
		$\neq 0$	$\neq 0$	$\neq 0$			
4	4F12.5	XMC	DIF	E	HFG		
		$\neq 0$	$\neq 0$		$\neq 0$		
5	6F12.5	PF1	AF1	CF1	EF1	EMIS1	HF1
		$\neq 0$			$\neq 0$	NOT BOTH	
6	6F12.5	PF2	AF2	CF2	EF2	EMIS2	HF2
						NOT BOTH	
7	6F12.5	DOUTA	THKWA	CWA	DELA	CWKA	XLONGA
		$\neq 0$					
8	3F12.5	DOUT	THKW	CW			
		$\neq 0$					
9	3F12.5	DEL	CONWK	DART			
		$\neq 0$	$\neq 0$				
10	3F12.5	TF1	POW1	XLONG1			
			$\neq 0$	$\neq 0$			
11	3F12.5	TF2	POW2	XLONG2			
			$\neq 0$				
12	3F12.5, E12.5	TEV	Q	ZGAS	AGAS	TTRAP	
		$\neq 0$	$\neq 0$	NOT BOTH			
13	2F12.5, 2I4, F12.5, I4	VRES	TRES	NRES	MODEQM	ZPRINT	NRUN
			$\neq 0$			$\neq 0$	

FIGURE 4-1. Program Input Form Showing Parameters Which Cannot be Set Equal to Zero

E: exponent used in the following equation to convert mass diffusivity at standard conditions to the value at operating pressure and temperature. See Table 4-I.

$$\mathcal{D}_{ev} = DIF \left(\frac{1}{P_{ev}}\right) \left(\frac{T_{ev}}{460}\right)^{1 + E}$$

where T_{ev} = evaporator temperature (^{o}R)

P_{ev} = vapor pressure of condensible corresponding to evaporator temperature (atmos).

HFG: latent heat of vaporization of the condensible evaluated at the evaporator temperature (Btu/lb_m). If a freeze-out rate is the primary quantity desired, the latent heat of vaporization plus the latent heat of fusion (the heat of sublimation) at the freezing point should be used.

Table 4-I

Fluid Characteristics

Fluid	A11	B11	C11	XMC	DIF*	E
Ammonia (NH_3)	13.13	3821.04	296548.2	17.0	0.763	0.81
Methanol (CH_3OH)	14.48	6262.17	557386.2	32.0	0.442	0.81
Water (H_2O)	14.20	6526.73	810130.7	18.0	0.892	0.81

*Typical values for diffusion in air.

4.2 Condenser Parameters, Section 1, Farthest from Evaporator

Card 5 (6F 12.5)

PF1: fin perimeter perpendicular to the pipe over which heat transfer occurs (inches). Note that if there is no fin (e.g. a tube rejecting heat from its outer diameter) PF1 equals πD_{out}. See Fig. 1-2.

AF1: fin cross-sectional area perpendicular to the pipe (in.^{2}). When there is no fin AF1 is set equal to zero. AF1 can even have a negative value to account for a reduction in pipe wall thickness with respect to the input value THKW.

CF1: effective thermal conductivity of fin for conduction in the axial direction (Btu/hr-ft-°F). For a plain fin, the effective conductivity is simply the conductivity of the fin material. However, in many cases the fin might be segmented (slotted) to lower axial conductance. In that case CF1 should reflect the contribution of the segmented fin to overall axial conductance. An approximate approach to this case is as follows:

The total axial resistance is given by:

$$R_T = R_{fin} + R_{gap} \tag{4-1}$$

But,

$$R_T = \frac{N}{\frac{1}{R_{wick}} + \frac{1}{R_{wall}} + \frac{1}{R_{fin}}} + \frac{N-1}{\frac{1}{R_{wick}} + \frac{1}{R_{wall}}} \tag{4-2}$$

Defining the relation for k'_{fin}, the effective conductivity:

$$R_T = \frac{L}{(kA)_{wick} + (kA)_{wall} + k'_{fin}(A_c)_{fin}}$$

$$= \frac{NL_f}{(kA)_{wick} + (kA)_{wall} + (kA)_{fin}}$$

$$+ \frac{(N-1)\ L_g}{(kA)_{wick} + (kA)_{wall}} \qquad (4\text{-}3)$$

where R_T = overall axial thermal resistance of the condenser section

R_{FIN} = thermal resistance in the region where the fins are attached

R_{GAP} = thermal resistance of the gaps between the fins

R_{wick} = axial thermal resistance of the wick

R_{wall} = axial thermal resistance of the pipe wall

R_{fin} = axial thermal resistance of a single fin

L = XLONG = overall length of condenser section

L_f = length of a single fin in axial direction

L_g = gap width

N = number of fin segments

kA = axial conductivity - area product

k'_{fin} = CF1 - effective thermal conductivity of the slotted fin

$(A_c)_{fin}$ = AF1 - fin cross-sectional area

Equation 4-3 may be solved in detail for k'_{fin} (CF1), but for most applications the conductance of the wick and the first term on the right hand side of Eq. 4-3 are negligible relative to the other terms. Thus, in most cases the effective conductivity may be calculated from the following:

$$k'_{fin} = \frac{(kA)_{wall}}{(A_c)_{fin}} \left[\frac{L}{(N-1)\, L_g} - 1 \right] \qquad (4\text{-}4)$$

EF1: effectiveness of condenser fin, η (dimensionless)

EMIS1: fin total hemispherical emissivity, ε (dimensionless) Must be consistent with POW1, section 4.6, and must be zero when convection only.

HF1: fin external convective heat transfer coefficient, h_{f_1} (Btu/hr-ft^2-°F)

Must be set equal to zero when radiation only.

Note that EF1 and HF1 cannot both be set equal to zero.

4.3 Condenser Parameters, Section 2, Nearest to Evaporator

Card 6 (6F 12.5)

The input variables for card 6 are the same as defined above for condenser section number 1. If there is only one condenser section, then set everything on card 6 identical to card 5. If section number 2 is an adiabatic section, then PF2 is set equal to zero (Paragraph 3.4).

4.4 Adiabatic Section Parameters

Card 7 (6F 12.5)

DOUTA = outside diameter of adiabatic section pipe (inches)

THKWA = wall thickness of adiabatic section (inches)

CWA = thermal conductivity of adiabatic section wall (Btu/hr.ft.°F)

DELA = wick thickness in the adiabatic section (inches)

CWKA = wick thermal conductivity of the wick in the adiabatic section (Btu/hr.ft.°F.)

XLONGA = length of adiabatic section (feet)

4.5 Wall Characteristics

Card 8 (3F 12.5)

DOUT: outside diameter of heat pipe (inches)

THKW: heat pipe wall thickness (inches)

CW: pipe wall thermal conductivity (Btu/hr-ft-°F)

If an artery is present, multiply CW by the ratio

$$[(kA)_{artery} + (kA)_{wall}] / (kA)_{wall}.$$

4.6 Wick Characteristics

Card 9 (3F 12.5)

DEL: heat pipe wick thickness, δ (inches)

CONWK: effective thermal conductivity of saturated wick (Btu/hr-ft-°F)

DART: effective diameter of arteries in pipe (inches)

$$DART = (4A_c/\pi)^{1/2} \qquad (4\text{-}5)$$

where A_c is the total cross-sectional area of arteries in the pipe. See Fig. 1-2.

4.7 Environmental Parameters and Lengths

Card 10 (3F 12.5)

TF1: condenser, section number 1, external fluid or sink temperature for convective heat transfer, T_{f_1}, (^{o}R). May be set equal to zero if only heat transfer mode is radiation.

POW1: The absorbed power per unit area of the outer fin surface (perimeter times length). The power is both from the back (internal power) and the front (solar absorption, etc.), but the area is the front area only (Btu/hr-ft^2). For the case where the front is surrounded by an effectively black enclosure at a known temperature T_1 and there is no internal heat transfer, POW1 is calculated as follows:

$$\mathrm{POW1} = \alpha_1 \sigma T_1^{\,4} \tag{4-6}$$

where α is the external* total hemispherical absorptivity for source temperature T_1 and surface temperature T_{ev}.* If T_1 is close to T_{ev} both α and ε would be the same internal total hemispherical emissivity.

POW1 may be set equal to zero for convection heat transfer only. In other applications POW1 or POW2 may be a very small number, e.g. 0.01, but not zero.

XLONG1: length of condenser, section 1, L_1 (feet).

*See the Journal of Heat Transfer, 91, p. 2, Feb. 1969.

Card 11 (3F 12.5)

The input variables for card 10 are the same as defined above for condenser section number 1. If there is only one condenser section, then set TF2 and POW2 equal to TF1 and POW1, respectively and make the sum of the lengths, XLONG1 + XLONG2 equal to the total length of the condenser. If section 2 is an adiabatic section, then TF2 and POW2 should be input identical to section 1, but XLONG2 is the adiabatic length (see Section 3.4).

4.8 Operating Conditions

Card 12 (3F 12.5, E12.5)

TEV: evaporator temperature, T_{ev} (^{o}R)

Q: heat pipe power, $\dot{Q}$ (Btu/hr).
When using the heat input option, MODEQM = 0, $\dot{Q}$ is the prescribed heat pipe heat load. If the amount of gas is input, MODEQM = 1, the program calculates the heat pipe power, but it is necessary to put in a nominal value for $\dot{Q}$, since it is used to non-dimensionalize certain variables. The value of $\dot{Q}$ in this case is arbitrary; it need be correct only within half an order of magnitude. See Table 4-II.

The value of $\dot{Q}$ cannot exceed the heat rejection of an isothermal condenser at T_{ev}, as given by Eq. (4-7); otherwise an error message will print "heat flux too high or pipe too short."

$$\dot{Q} < \eta_1 P_1 L_1 [\epsilon_1 \sigma T_{ev}^4 + h_{f_1} (T_{ev} - T_{f_1}) - POW_1]$$

$$+ \eta_2 P_2 L_2 [\epsilon_2 \sigma T_{ev}^4 + h_{f_2} (T_{ev} - T_{f_2}) - POW_2] \qquad (4-7)$$

ZGAS: length of condenser filled with gas if a sharp temperature front is assumed (feet). ZGAS is a means of specifying the non-condensible gas inventory when using the gas input option, MODEQM = 1. It is convenient for making parametric runs or estimating the performance of a pipe with gas in it to aid in start-up from the frozen state.

Since ZGAS and AGAS cannot both be zero, ZGAS is set equal to a nominal value when the heat input option is used. See Table 4-II.

AGAS: Amount of non-condensible gas in heat pipe and reservoir. $\mathcal{M}$ (lb-moles). See Table 4-II.

TTRAP: Temperature of the wick at the entrance to a non-wicked reservoir if different from the temperature of the end of Condenser 1 farthest from the evaporator. If the same as the temperature of the end of the condenser, enter 0.0.

Table 4-II

Operating Conditions

MODEQM	$\dot{Q}$	ZGAS	AGAS	REMARKS
0	Actual	Nominal*	0	Heat input option
1	Nominal**	0	Actual	Amount of gas input in terms of lb-moles
1	Nominal**	Actual	0	Amount of gas input in terms of gas length

*Not used in calculations, but must be input since ZGAS and AGAS cannot both be zero.

**Used to non-dimensionalize certain variables. Put in a low estimate.

4.9 Reservoir Characteristics

Card 13 (2F 12.5, 2I12, F 12.5, I 12)

VRES: gas reservoir volume, V_R (in.^{3}). Set equal to zero when a reservoir is not desired.

TRES: gas reservoir temperature, T_R (°R). When VRES = 0 an arbitrary non-zero value must be put in for TRES. Use TEV. When NRES = 2 the reservoir temperature is determined internally to the program. Thus, an arbitrary non-zero value (e.g., TEV) must also be input for TRES in this case. See Tables 3-I and 3-II.

NRES: control constant for type of reservoir (0, 1, 2). Refer to Table 3-II.

4.10 Program Control Options

The following variables are included on card 12 although not related to the reservoir characteristics.

MODEQM: refers to a prescribed heat input (0) or a prescribed amount of gas (1). Refer to paragraphs 3.2, 3.3 and Table 4-II.

ZPRINT: Indicates the length of condenser in inches between printed output points. This distance should exceed one-quarter of a pipe diameter.

NRUN: equals 1 if another set of data follows; otherwise leave blank.

5.0 OUTPUT DESCRIPTION

5.1 Input

The input is printed out to document the input parameters and to permit the user to verify that they were read in correctly. The first two lines are the descriptive words used to describe the run.

5.1.1 Vapor Pressure and Fluid Properties

The first two lines of numerical printout are the input vapor pressure parameters and the fluid properties read in on input cards 3 and 4 See Section 4.1.

5.1.2 Fin Properties

The next two lines of numerical printout are the fin properties read in on input cards 5 and 6, Section 4.2.

5.1.3 Adiabatic Section and Pipe Properties

The adiabatic section parameters read in on input card 7 is then printed, followed by the data on input card 8.

5.1.4 Condenser Environments

The condenser environments are next printed out, corresponding to input cards 10 and 11.

5.1.5 Wick, Artery and Reservoir

Input data on card 9 having to do with the wick and artery, and data on input card 13 having to do with the reservoir are next printed in the output.

5.1.6 Operating Conditions

Finally, the remaining data on input cards 12 and 13 are printed out. The quantities XGAS and AMT are computed quantities corresponding to input ZGAS or AGAS which fix the gas in the reservoir. The dimensionless quantity GAS is the amount of gas divided by the normalizing factor COEF, which is also printed.

5.2 Dimensionless Parameters

A number of dimensionless parameters used in the program are printed. These printouts are of no great import, but the user may be interested in some of them. For example, the dimensionless sink temperatures TS1 and TS2 give the fraction of the evaporator absolute temperature which would be achieved under completely gas-blocked conditions with no axial conduction acting.

5.2.1 Dimensionless Temperatures

The quantities TZ, TS1, TS2, TR, and TTRP are as follows:

TZ	To* in Eq. (2-19)
TS1	T_w in Eq. (2-1) when $d\dot{Q} = 0$, Condenser I
TS2	As above, Condenser 2
TR	T_{res}/T_{ev}, dimensionless reservoir temperature
TTRP	Dimensionless cold trap temperature

5.2.2 Dimensionless Condenser Parameters

For each of the two condenser sections the following quantities are printed:

EMIS	Emissivity
C	C* in Eq. (2-16)
F	F* defined in Section 2.2, radiation parameter
H	H* defined in Section 2.2, convection parameter
XL	L* length L divided by D_e
XS	x_s, mole fraction of gas corresponding to temperature T_w in Eq. (2-1) when $d\dot{Q} = 0$.

5.2.3 Dimensionless Adiabatic Section Parameters

Quantities are printed as follows:

C3	C* in Eq. (2-16) for the adiabatic third section
RA	Dimensionless wick resistance, adiabatic section
DIADI	Inside diameter normalized by the condensing section inside diameter D_e
R	Dimensionless wick resistance, condensing section
XL3	Length normalized by D_e

5.3 Debug Information

A number of printed statements give the user clues as to whether or not the program is functioning with the input data given it.

5.3.1 Exits from INPT

In subroutine INPT certain errors in the input data will result in the printing of one or more of the following error messages:

CONDENSER SECTION NO. 1 INPUT WRONG
CONDENSER SECTION NO. 2 INPUT WRONG
INPUT ERROR, ZGAS = 0.0 AGAS = 0.0
PIPE EXCEEDS 250 DIAMETERS

The first two above result when, for the condenser section in question, the effectiveness, perimeter, or the sum of the emissivity and convective heat transfer coefficient is zero.

The "input error" message results when both the length of gas-blocked condenser and the amount of gas specified are zero. The program is designed to treat heat pipes containing enough non-condensible gas to affect at least a portion of one of the condensers.

If the combined lengths of the three sections exceeds 250 inside diameters D_e, the internally specified incremental length DZ = 0.25 will result in over 1000 integration steps along the pipe. This number will then exceed the number of storage locations specified within the program. For heat pipes which exceed 250 diameters in length, it is necessary to increase DZ within the Fortran source program or increase the number of storage locations.

5.3.2 Exits from FIRST

A check is made in subroutine FIRST to determine whether the mole fraction in gas blocked condenser 1 exceeds 0.999999. If it does, a warning message is printed

INPUT ERROR, CONDENSER 1 ENVIRONMENT TOO COLD

Next a check is made to establish whether the sink conditions for Condenser 1 are colder than those for Condenser 2. If they are not, a message is printed as follows:

INPUT ERROR, CONDENSER 1 ENVIRONMENT HOTTER THAN
THAT FOR CONDENSER 2

Also in subroutine FIRST, depending upon whether MODEQM equals 0 or 1, that is, depending upon whether the heat flux or the amount of gas is meant to be specified, a check is made to see whether the specification is compatible with the other specified parameters, such as evaporator temperature, condenser parameters, and reservoir size. IF they are not compatible the program prints one of the following two messages:

INPUT ERROR, HEAT FLUX TOO HIGH OR CONDENSERS TOO SHORT
INPUT ERROR, TOO MUCH GAS FOR PIPE

The gas inventory estimate is made using elementary flat-front theory so that it is remotely possible that the user can input too large a gas inventory and still pass the screening test.

5.3.3 Convergence

The program prints messages indicating the subroutines used in the search for an answer satisfying the convergence criterion. One normal message is:

ITERATING IN PATCH

Subroutine PATCH calls BACK once and then FORWRD and CROSS repeatedly to establish the gas-blocked temperature profile in the first condenser section, based upon the assumption that the second condenser is sufficiently long to achieve a uniform gas-blocked temperature in the region remote from the first. If the quantity DELTEE is not large enough, or if the axial conduction is quite strong, difficulty may be experienced resulting in the prints:

1000 STEPS IN BACK
1000 STEPS IN FORWARD

Trouble in CROSS may result in the following messages:

1000 STEPS IN CROSS
ZERO J2 IN CROSS

With none of these troubles the next normal print is:

ITER=0 TSTART = Z1 = XL1 =

This printing is normally repeated with ITER increasing sequentially. Convergence in PATCH occurs when Z1 is within DZ of XL1. Failure to achieve this situation is signalled with the message:

FAILED TO CONVERGE IN PATCH

After the completion of subroutine PATCH, subroutine LONG calls subroutine START which utilizes PIPE. Trouble in PIPE may be signalled by:

TOO MANY STEPS IN PIPE, J = 1001

In the normal situation the next print, after successful completion of the iterating in PATCH, will be:

ITERATING IN LONG
ITER=0 JSTART = 1 GAS = QSUM = JEND = MOREJ =

If the program continues iterating in LONG, additional lines with ITER = 1, 2, etc. will appear. Successful convergence is signalled by MOREJ = 0 and may be verified by QSUM $\doteq$ 1.0 for prescribed power or GAS nearly equalling the value printed under the previous heading AMOUNT OF NONCONDENSIBLE GAS. Failure to achieve this condition results in the message:

FAILED TO CONVERGE IN LONG

Under some conditions subroutine LONG may call upon subroutine START2. In this case the message:

ITERATING IN START2

may appear followed by prints of:

I = TSTART = XSUM = QSUM = JEND = MOREJ =

Convergence is again indicated by MOREJ = 0 and an appropriate value of QSUM or XSUM.

Under other conditions, following the print ITER = 0 from subroutine LONG, the print:

ITERATING IN SHORT

ITER = TSTART = XSUM = QSUM =

appears. Convergence is indicated by an appropriate value of XSUM or QSUM. Lack of convergence is indicated by:

FAILED TO CONVERGE IN SHORT

5.4 Calculated Reservoir Conditions

After completion of the iteration searching process the reservoir conditions are printed:

TRES	Reservoir Temperature in °R
XSR	Mole fraction of noncondensible in reservoir
RESGAS	Amount of gas in lb.-moles in reservoir

If the volume of the reservoir is input as Zero, this line of output will not appear.

5.5 Profiles

Profiles of temperature, mass flow, mole fraction and cumulative sums of power lost and gas contained in the reservoir and pipe are printed versus length along the pipe. These profiles are as follows:

J	Integration step
ZIN	Distance from end of condenser farthest from the evaporator in inches
Z	Dimensionless distance
V	Dimensionless mass flow V* in Eq. (2-17)
P	Dimensionless gas quantity ϕ in Eq. (2-10)
TI	Dimensionless wick - vapor interface temperatures
XSUM	Dimensionless running sum of gas contained
QSUM	Dimensionless running sum of power lost
MASS FLOW	Vapor flow in the pipe, lb./hr.
QFLOW	Cumulative power lost, BTU/hr.
XS	Mole fraction
TWICK	Wick-vapor interface temperature, °R
TWALL	Wall temperature, °R
MGAS	Cumulative sum of gas contained in the reservoir and the pipe, lb.-moles

Missing values of J have been skipped because of the ZPRINT criterion.

5.6 Total Gas and Heat Flow

The final four print statements are as follows:

GAS IN ONE DZ STEP OF GAS-BLOCKED CONDENSER 1 = LB-MOLES.
POWER LOST BY ONE DZ STEP OF FULL-ON CONDENSER 1 = BTU/HR.
TOTAL GAS IN PIPE AND RESERVOIR = LB-MOLES.
TOTAL POWER LOST BY CONDENSERS = BTU/HR.

The first line is the gas contained in a length of Condenser 1 equal to the step size used in the integration. The second line likewise equals the power radiated in an incremental length of full-on condenser. Of the final two lines, one should agree, within the integration precision, with the input value, and the other constitutes an answer of interest to the heat pipe analyst or designer. If ZGAS or AGAS had been input, the gas inventory should agree with that value within the precision indicated, and the power is the answer sought. If Q had been input, the power should agree with that value within the indicated precision, and the gas inventory is the answer sought.

6.0 NOMENCLATURE

A_c	-	Cross sectional area
C	-	Axial conductivity-area product
D	-	Diameter
$\mathcal{D}$	-	Diffusion coefficient for noncondensible in condensible
E	-	Empirical constant for temperature dependence of $\mathcal{D}$
F*	-	Nondimensional quantity defined in Paragraph 2.2
H	-	Irradiation onto condenser surface
K	-	Radial wick conductance
L	-	Length of condenser
M	-	Molecular weight of condensible
$\mathcal{M}$	-	Molar inventory of noncondensible
P	-	Heat transfer perimeter of fin
P_i	-	Partial pressure of noncondensible at temperature T_i
$\dot{Q}$	-	Heat transfer rate
Q_e^*	-	Nondimensional quantity defined in Paragraph 2.2
R	-	Gas constant for condensible
R_u	-	Universal gas constant (1545.4, ft-lb_f/°R-lbmole)
S	-	Radial conductance from condenser
T	-	Temperature
T_o	-	Characteristic temperature of fluid defined by Eq. (2-8b)
V	-	Mole average velocity
c	-	Molar concentration
h	-	Coefficient of heat transfer
h_{fg}	-	Latent heat of vaporization
k	-	Thermal conductivity
$\dot{m}$	-	Mass flow rate
q	-	Heat flux
v	-	Void volume
x	-	Mole fraction of noncondensible
z	-	Axial position

α - Absorptance of condenser surface

δ - Wick thickness

ε - Total hemispherical emittance of condenser surface

ϕ - Dimensional variable defined by Eq. (2-10)

$\Phi_1, \Phi_2, \Phi_3, \Phi_4$ - Dimensionless groupings defined in Paragraph 2.2

η - Effectiveness of condenser fin

σ - Stefan-Boltzmann constant

Subscripts:

abs - Absorbed from surrounds

b - Bulk average (area-velocity weighted) value

c - Effective sink conditions

e - Equivalent value

ev - Evaporator conditions

f - External fluid conditions

i - Wick surface conditions

min,max - Minimum, maximum

nominal - Initialized value for numerical solution

n - Cross-sectional element of pipe

Res, R - Reservoir conditions

s - Spatial (area weighted) average

w - Condenser wall conditions

1,2 - Condenser section number 1 and 2, respectively

* - Superscript denotes nondimensional variable

7.0 REFERENCES

1. B.D. Marcus and G.L. Fleischman, "Steady-State and Transient Performance of Hot Reservoir Gas-Controlled Heat Pipes," A.S.M.E. Paper No. 70-HT/SpT-11.

2. W. Bienert, "Heat Pipes for Temperature Control," Proc: Fourth Intersociety Energy Conversion Engineering Conference, Washington D.C. (1969).

3. B. D. Marcus, Theory and Design of Variable Conductance Heat Pipes, NASA Contractor Report NASA Cr-2018, April 1972.

4. D. K. Edwards and B. D. Marcus, "Heat and Mass Transfer in the Vicinity of the Vapor - Gas Front in a Gas-Loaded Heat Pipe", J. Heat Transfer, 94, 155-162, 1972.

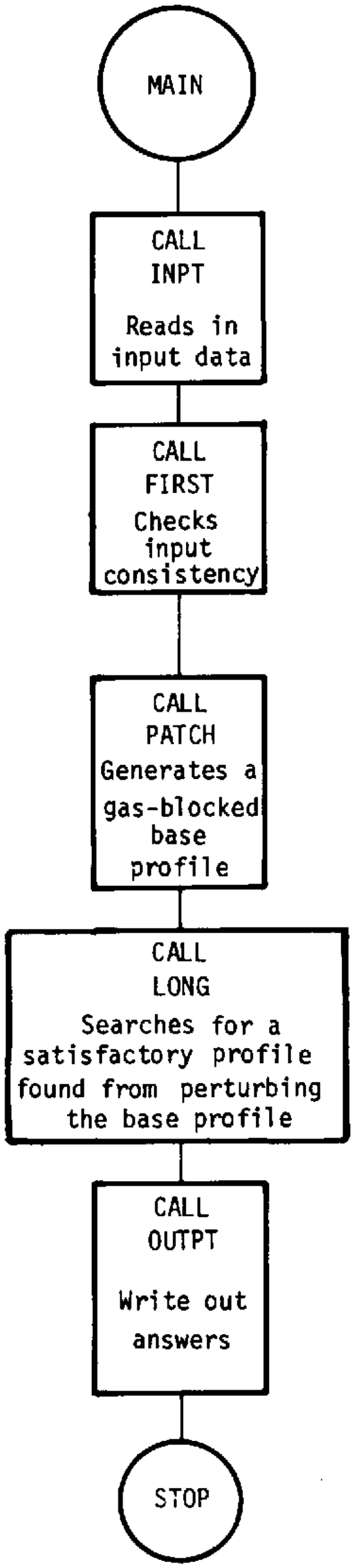
5. D. K. Edwards, V. E. Denny, and A. F. Mills, Transfer Processes, Holt, Rinehart and Winston, New York, 1973, Ch. 3.

APPENDIX A

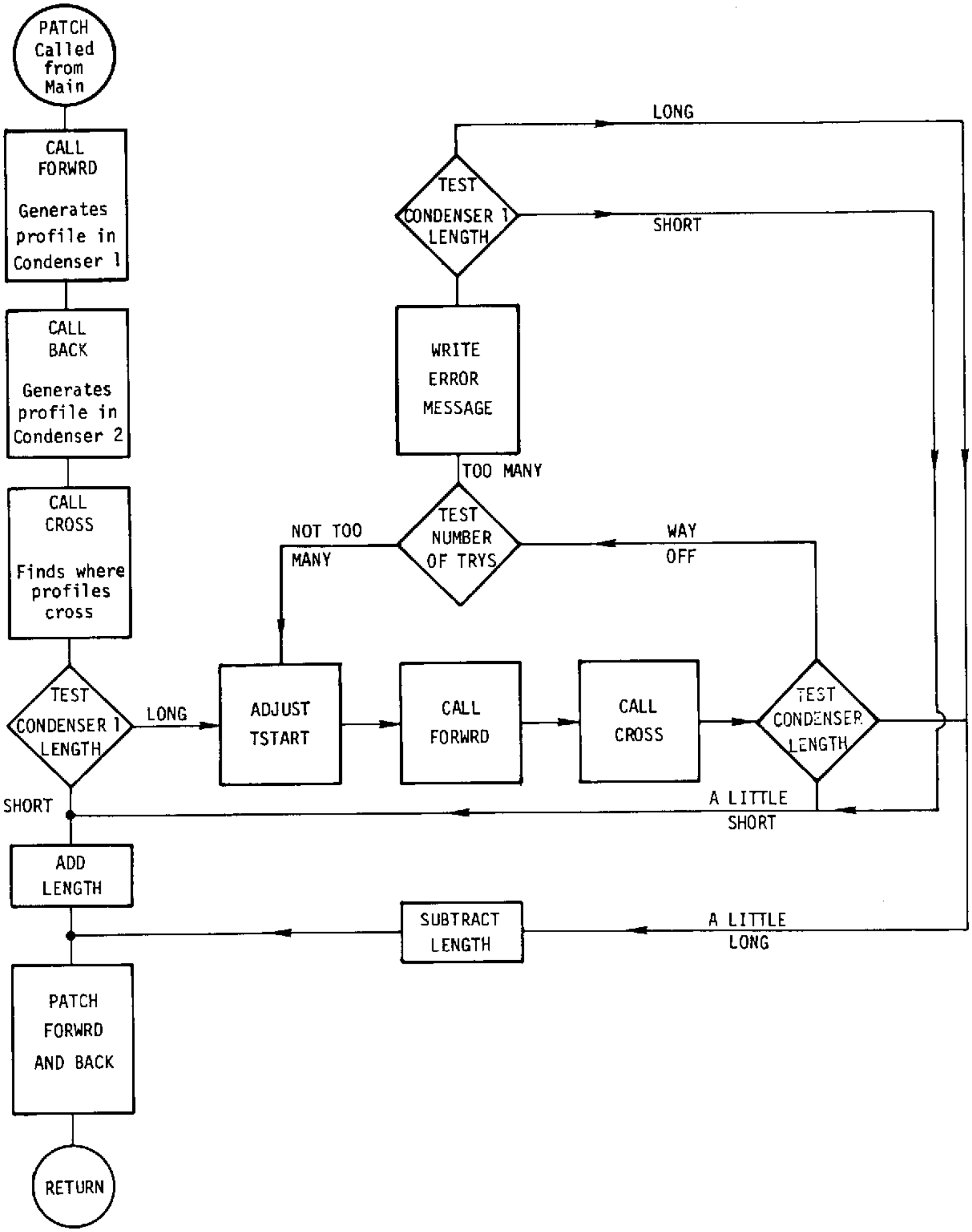
FLOW DIAGRAM (TRW-GASPIPE)

The flow diagrams presented in the following pages are included as an aid to understanding the overall program logic.

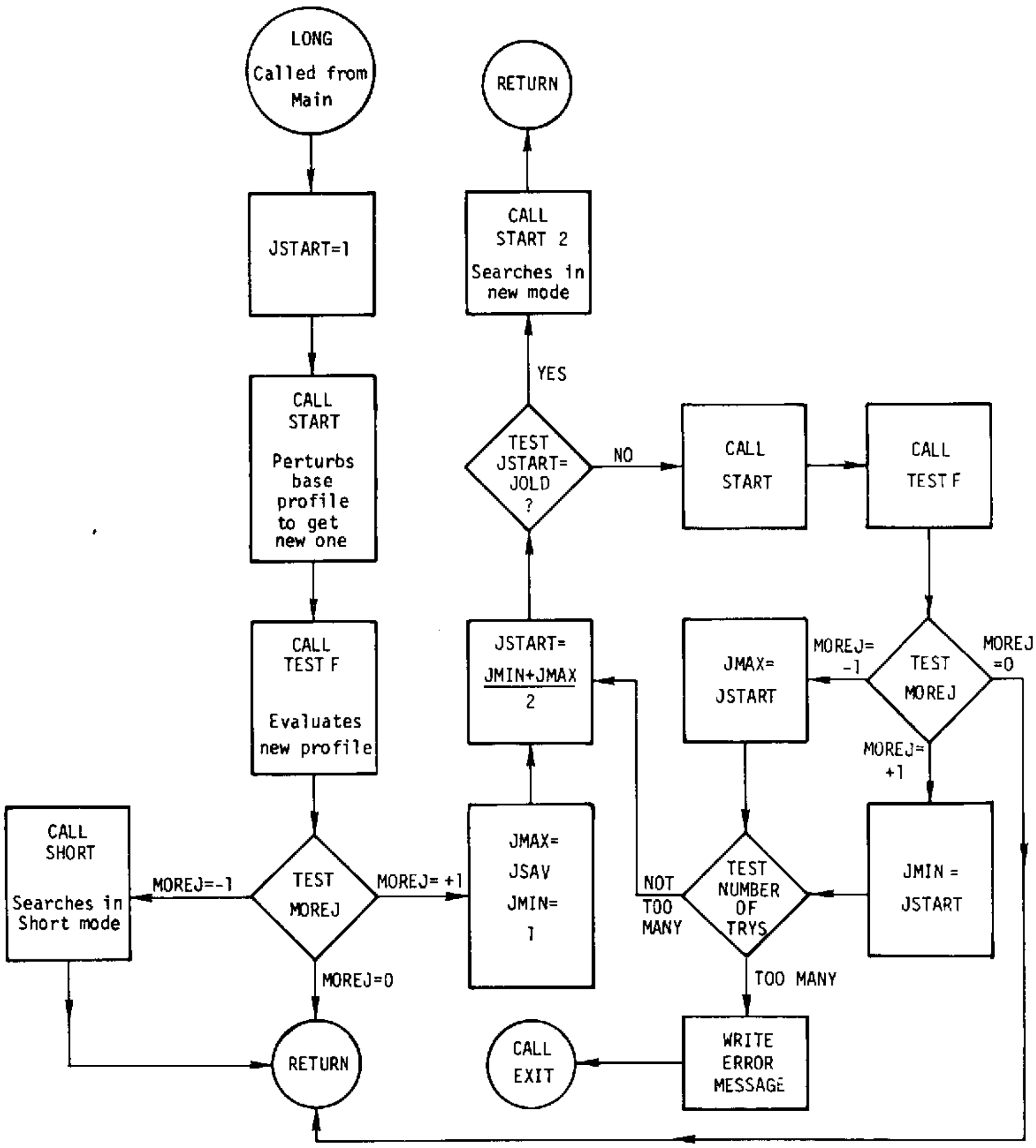
FLOWCHART OF MAIN PROGRAM



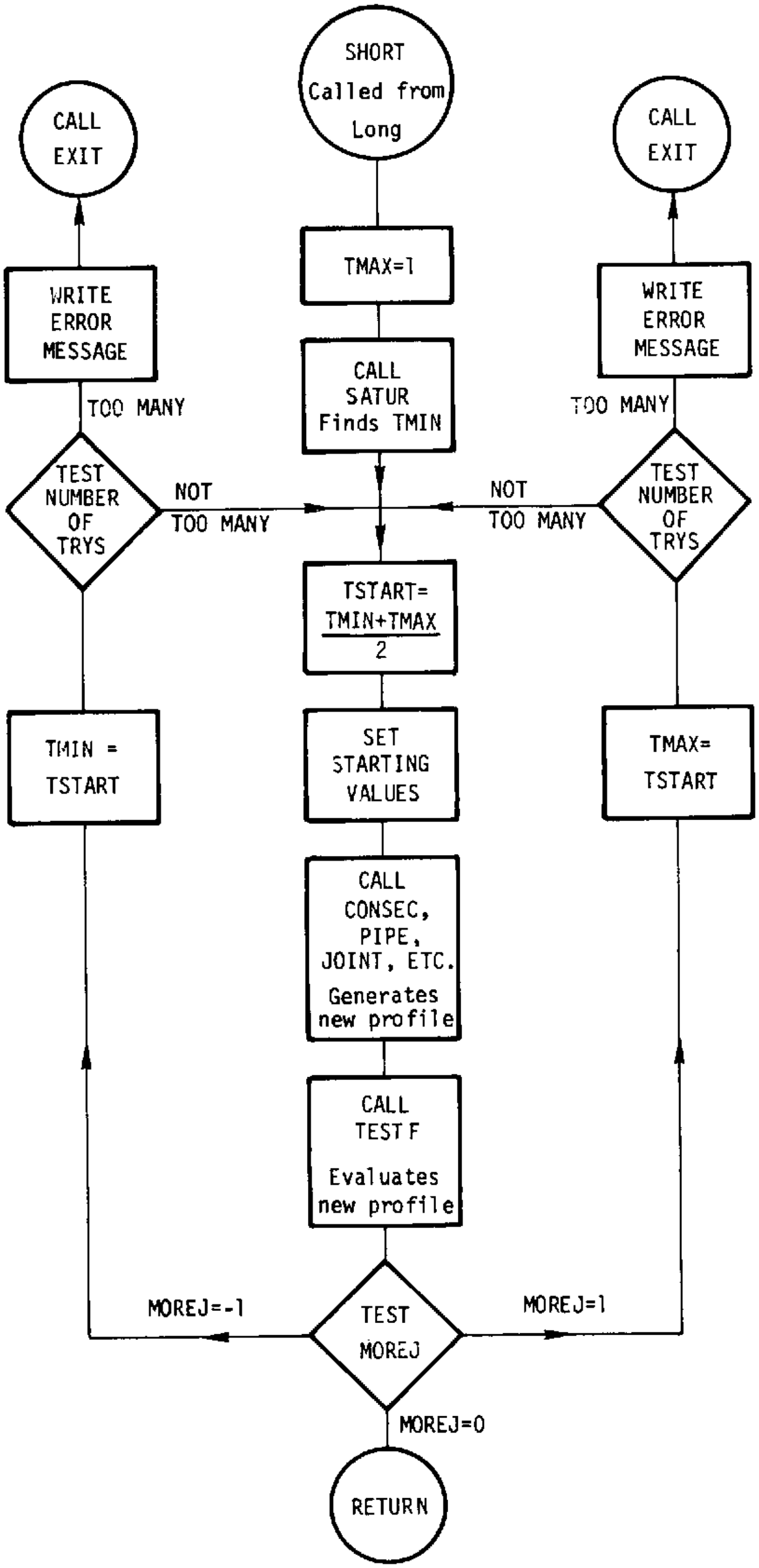
FLOWCHART OF SUBROUTINE PATCH



FLOWCHART OF SUBROUTINE LONG



FLOWCHART OF SUBROUTINE SHORT



APPENDIX B

LISTING (TRW - GASPIPE)

The program listing which is reproduced in the following pages was compiled on a CDC-6500 computer. The program is general and may be used on the IBM 360 or Univac 1108 simply by changing the asterisks in the output format statements to an apostrophe. In addition, the first card of the main program, which defines the input and output tapes, is not required with the IBM and Univac versions.

Storage requirements are on the order of 50,000 words (octal); approximately 15 seconds are required for compilation and from 10 to 60 seconds computation time per run.

```
              PROGRAM GASCON (INPUT=201,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
        C        MODIFICATION OF GASPIPE TO TREAT TWO GAS-BLOCKED
        C        CONDENSERS AND AN ADIABATIC SECTION
000004        COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000004        COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000004        COMMON /ADIAB/ XL3,C3,RA,DIADI
000004        COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000004        COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000004       1               VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000004       2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000004        COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000004        COMMON /PIPDTA/ TCV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000004        COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
000004        COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000004        COMMON /PIPOUT/ XSUM, QSUM, PSUM, XSR, ZFRONT, JEND, PREQ, PREG
000004        COMMON /LNG/ JSTART, JSAV, XL12, XL123
000004        COMMON /CRSS/ Z1,Z2,V1,V2,X1,X2,PCROSS,QCROSS,J1,J1M,J2,J2M,JBAK
000004        REWIND 5
000006        REWIND 6
        C
000010      1 NERROR=0
000011    500 CALL INPT
000012        IF (NERROR.EQ.0) GO TO 2
000013        IF (NRUN.EQ.1) GO TO 1
000015    600 CALL EXIT
000015      2 CONTINUE
000016        TMIN=TS1
000020        DELTEE=0.25
000022        CALL FIRST
        C        FIRST CHECKS CONSISTENCY OF INPUT Q AND GAS
000023        CALL PATCH
        C        PATCH PATCHES TOGETHER THE TEMP. PROFILES AT THE
        C        CONDENSER JOINT.
000024        CALL LONG
        C        LONG SEARCHES FOR A VALUE OF JSTART FOR WHICH
        C        XSUM EQUALS GAS
000025        CALL OUTPT
```

MAIN

```
        C        OUTPUT WRITES OUT THE VPZXQ VARIABLES AND CONVERTS
        C        SOME OF THEM TO DIMENSIONAL QUANTITIES
        C
000026        IF (NRUN.EQ.1)  GO TO 1
        C
000030        STOP
000032        END
```

MAIN

13111-6054-R0-00

```
RUNX COMPILER (VER.26)                  10/02/73. 15.05.14.          BACK

000060            PM=(P1+P)/2.0
000063            CALL SATUR (PM,TM)
000065            CALL MOLE (TM,XM)
000067            XSUM=XSUM+XM*DZ/TM
000073            CALL SURF (TM,S,TC)
000076            QI=S*(TM-TC)/(1.0+S*P)
000104            QSUM=QSUM+QI*DZ
000107            PB(J)=P
000112            VB(J)=V
000115            XB(J)=XSUM
000120            QB(J)=QSUM
000123            ZB(J)=Z
000126            IF (ABS(DV).LT.0.015625  .AND.  ABS(DZ).LT.0.25) DZ=2.0*DZ
000143            CALL SATUR (P,TI)
000145            IF (TI.LE.TS1) GO TO 150
000150      100   CONTINUE
          C
000152            WRITE (6,10)
000156      10    FORMAT (/2X,*1000 STEPS IN BACK*)
000156            CALL EXIT
          C
000157      150   CONTINUE
000157            DZ=+0.25
000161            JBAK=J
000163            RETURN
000164            END
```

BACK

B-4

13111-6054-RO-00

```
RUNX COMPILER (VER.26)              10/02/73. 15.05.14.

                    SUBROUTINE BACK
              C
000002              COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002              COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002              COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002             1               VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002             2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002              COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002              COMMON /PIPDTA/ TEV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002              COMMON /WORK/ DUMMY(6), THIN, ZF
000002              COMMON /CRSS/ Z1,Z2,V1,V2,X1,X2,PCROSS,QCROSS,J1,J1M,J2,J2M,JBAK
              C
000002              CALL CONSEC (2)
000004              TSTART=TS2-DELTEE/TEV
000007              PZERO=PHI(TSTART)
000012              DZ=-0.25
000014              V=1.0E-8
000016              P=PZERO
000020              CALL SATUR (P,TI)
000022              CALL MOLE (TI,XS)
              C
000024              J=0
000025              XSUM=0.0
000026              QSUM=0.0
000027              Z=0.0
000030              DO 100 I=1,1000
000032              CALL RUNGE (V,P,DV,DP)
000035              IF (ABS(DV).GT.0.0625) GO TO 200
000042              GO TO 400
000043        200   DZ=DZ/2.0
000045              GO TO 100
000046        400   CONTINUE
000046              J=J+1
000050              Z=Z+DZ
000052              P1=P
000054              P=P+DP
000056              V=V+DV
```

BACK

13111-6054-R0-00

```
              SUBROUTINE CONSEC (NSEC)
       C
000003        COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000003        COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000003        COMMON /ADIAB/ XL3,C3,RA,DIADI
000003        COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
       C
000003        IF (NSEC.NE.1) GO TO 100
000005        XL=XL1
000007        TS=TS1
000011        C=C1
000013        F=F1
000015        H=H1
000017        EMIS=EMIS1
000021        RETURN
       C
000022   100  CONTINUE
000022        IF(NSEC.NE.2) GO TO 200
000024        XL=XL1+XL2
000026        TS=TS2
000030        C=C2
000032        F=F2
000034        H=H2
000036        EMIS=EMIS2
000040        RETURN
000041   200  CONTINUE
000041        XL=XL1+XL2+XL3
000044        TS=TS2
000046        C=C3
000050        F=0.0
000051        H=1.0
000053        EMIS=0.0
000054        RETURN
000055        END
```

CONSEC

```
                     SUBROUTINE CROSS
               C
000002               COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002               COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002               COMMON /ADIAB/ XL3,C3,RA,DIADI
000002               COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002              1              VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002              2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002               COMMON /PIPDTA/ TEV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002               COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002               COMMON /LNG/ JSTART, JSAV, XL12, XL123
000002               COMMON /CRSS/ Z1,Z2,V1,V2,X1,X2,PCROSS,QCROSS,J1,J1M,J2,J2M,JBAK
               C
000002               XL123=XL1+XL2+XL3
000005               XL12=XL1+XL2
000007               J2=JBAK
000011               J1=0
               C
000012               P2=PB(J2)
000015               Q2=QB(J2)
000020               DO 100 I=1,1000
000022               J1=J1+1
000024               P1=PP(J1)
000027               Q1=QQ(J1)
000032               IF(P1.LT.P2) GO TO 100
000035          99   J2=J2-1
000037               IF (J2.EQ.0) GO TO 101
000040               P2=PB(J2)
000043               Q2=QB(J2)
000046               IF (P2.LT.P1) GO TO 99
000051               IF (Q2.LT.Q1) GO TO 102
000054         100   CONTINUE
               C
000056               WRITE (6,30)
000062          30   FORMAT (/* 1000 STEPS IN CROSS*)
000062               CALL EXIT
               C
```

CROSS

13111-6054-R0-00

```
000063     101  WRITE (6,40)
000067      40  FORMAT (/* ZERO J2 IN CROSS*)
              C
000067     102  CONTINUE
000067          J2M=J2+1
000071          Q2M=QB(J2M)
000074          P2M=PB(J2M)
000077          J1M=J1-1
000101          Q1M=QQ(J1M)
000104          P1M=PP(J1M)
000107          TERM1=(P1-P1M)*(Q2-Q2M)
000113          TERM2=(Q1-Q1M)*(P2M-P2)
000117          DENOM=TERM1+TERM2
000121          TERM3=(Q1-Q1M)*P1M-(P1-P1M)*Q1M
000130          TERM4=(Q2-Q2M)*P2M+(P2M-P2)*Q2M
000135          XNUM=TERM3*(P2M-P2)+TERM4*(P1-P1M)
000144          PCROSS=XNUM/DENOM
000146          XNUM=(Q1-Q1M)*TERM4-(Q2-Q2M)*TERM3
000154          QCROSS=XNUM/DENOM
000156          IF(P1.NE.P1M) FRAC1=(PCROSS-P1M)/(P1-P1M)
000164          IF(P2.NE.P2M) FRAC2=(PCROSS-P2M)/(P2-P2M)
000172          IF(Q1.NE.Q1M)  FRAC1=(QCROSS-Q1M)/(Q1-Q1M)
000200          IF(Q2.NE.Q2M)  FRAC2=(QCROSS-Q2M)/(Q2-Q2M)
000206          Z1=ZZ(J1M)+FRAC1*(ZZ(J1)-ZZ(J1M))
000214          Z2=ZB(J2M)+FRAC2*(ZB(J2)-ZB(J2M))
000222          V1=VV(J1M)+FRAC1*(VV(J1)-VV(J1M))
000230          X1=XX(J1M)+FRAC1*(XX(J1)-XX(J1M))
000236          V2=VB(J2M)+FRAC2*(VB(J2)-VB(J2M))
000244          X2=XB(J2M)+FRAC2*(XB(J2)-XB(J2M))
000252          RETURN
000253          END
```

CROSS

```
                 SUBROUTINE DELTA(V,P,DV,DP)
000007           COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000007           COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000007           COMMON /PIPDTA/ TEV, DFT, Q, GAS, TP, VR, VRES, DZ, R, COEF,TTRP
000007           CALL SATUR(P,T)
000014           TEE = T**E
000020           XC=FEX(P)
000025           CALL SURF(T,S,TC)
000033           X=EXP(-P)
000041           QI = S*(T-TC)/(1.0+S*R)
000047           TERM1 = C*(X/XC)*(T**2/TEE)/(D*TZ)
000057           DP = DZ*V/(D*TEE)
000062           TERM2 = 1.0-(2.0-E)*(T/TZ)*X
000070           TERM3 = V**2/(D*TEE*XC)
000074           DV=DZ*TERM1*TERM2*TERM3/(1.+TERM1)
000102           IF (QI.EQ.0.) RETURN
000104           DV=(DZ*QI/(1.0+TERM1))*(1.0+TERM1*TERM2*TERM3/QI)
000115           RETURN
000116           END
```

RUNX COMPILER (VER.26)   10/02/73. 15.05.14.

```
                    FUNCTION FEX(X)
000003              IF(X.LT.0.1) GO TO 100
000006              FEX=1.0
000010              IF (X.GT.30.) RETURN
000014              FEX=1.0-EXP(-X)
000022              RETURN
000024          100 XXX = X
000025              FEX = X
000026              XN = 1.0
000030              F = 1.0
000032              SIGN = 1.0
000034              DO 101 I = 1,7
000036              XN = XN+1.0
000040              SIGN = -SIGN
000041              F = F*XN
000043              XXX = X*XXX
000045              FEX = FEX+SIGN*XXX/F
000051          101 CONTINUE
000053              RETURN
000055              END
```

FEX

```
               SUBROUTINE FIRST
         C        FIRST CHECKS Q AND GAS
000002         COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002         COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002         COMMON /ADIAB/ XL3,C3,RA,DIADI
000002         COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000002         COMMON /GASDTA/ TZ, Q, E, A11, B11, C11, DELTEF, HFG
000002         COMMON /PIPDTA/ TEV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002         COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
000002         COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000002         COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
         C
000002         TEST=1.0-XS1
000004         IF(TEST.LT.1.0E-6) WRITE(6,10)
000012      10 FORMAT(/,* INPUT ERROR, CONDENSER 1 ENVIRONMENT TOO COLD*)
000012         IF(TS2.LT.TS1) WRITE(6,11)
000020      11 FORMAT(/,* INPUT ERROR, CONDENSER 1 ENVIRONMENT HOTTER*,
000020        1   * THAN THAT FOR CONDENSER 2*)
000020         DZ=0.25
000022         PREG=DZ*XS1/TS1
000025         TI=1.0
000027         CALL CONSEC(1)
000031         CALL SURF(TI,S1,TC1)
000034         QI1 = S1*(TI-TC1)/(1.0+S1*R)
000042         PREQ=DZ*QI1
000044         IF(MODEQM.NE.0) GO TO 98
         C        CHECK FOR Q CONSISTENCY
000045         CALL CONSEC(2)
000047         CALL SURF(TI,S2,TC2)
000052         QI2 = S2*(TI-TC2)/(1.0+S2*R)
000060         VZ = QI1*XL1+QI2*XL2
000064         IF(VZ.GT.1.0) RETURN
000067         WRITE(6,12)
000073      12 FORMAT(/,* INPUT ERROR, HEAT FLUX TOO HIGH OR CONDENSERS*,
000073        1   * TOO SHORT*)
000073         WRITE(6,60) S1,TC1,QI1,XL1,S2,TC2,QI2,XL2,VZ
000121      60 FORMAT(1X,9E12.4)
```

FIRST

```
000121          GO TO 999
          C
          C        CHECK FOR GAS CONSISTENCY
          C
000122       98 CONTINUE
000122          TR1=TS1
000124          IF(NRES.EQ.1) TR1=TR
000130          IF(NRES.EQ.2) TR=TR1
000134          IF(NRES.EQ.0.AND.TTRP.NE.0.0) TR1=TTRP
000144          CALL MOLE (TR1,XSR)
000146          RSUM=VR*XSR/TR
000151          GASMAX=RSUM+XS1*XL1/TS1+XS2*(XL2+XL3)/TS2
000162          IF(GASMAX.GT.GAS) RETURN
000165          WRITE(6,13)  GAS, GASMAX
000175       13 FORMAT(/,2X,*INPUT ERROR, TOO MUCH GAS FOR PIPE*,4X,
000175        1    *GAS =*,E12.4,4X,*GASMAX =*,E12.4)
000175      999 CALL EXIT
000176          RETURN
000177          END
```

```
                SUBROUTINE FORWPD(TSTART)
         C
000003          COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000003          COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000003          COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000003         1               VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000003         2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000003          COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000003          COMMON /PIPDTA/ TEV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000003          COMMON /WORK/ DUMMY(6), TMIN, ZF
         C
000003          TMIN=TSTART
000004          PZERO=PHI(TSTART)
000007          TR1=TSTART
000010          IF(NRES.EQ.1) TR1=TR
000014          IF(NRES.EQ.2) TR=TR1
000020          IF(NRES.EQ.0.AND.TTRP.NE.0.0) TR1=TTRP
000030          CALL MOLE (TR1,XSR)
000033          RSUM=VR*XSR/TR
000036          CALL MOLE (TSTART,XSTART)
000041          Z=0.
000042          V=0.
000043          P=PZERO
000045          XSUM=RSUM
000047          QSUM=0.
000050          J=0
000051          DZ=0.25
000053          CALL CONSEC (1)
000056          DO 100 I=1,1000
000060          CALL RUNGE (V,P,DV,DP)
000064          IF(ABS(DV).GT.0.0525) GO TO 200
000071          GO TO 400
000072     200  DZ=DZ/2.
000074          GO TO 100
000075     400  CONTINUE
000075          J=J+1
000077          Z=Z+DZ
```

```
000101           P1=P
000103           P=P+DP
000105           V=V+DV
000107           PM=(P1+P)/2.
000112           CALL SATUR (PM,TM)
000115           CALL MOLE (TM,XM)
000120           XSUM=XSUM+XM*DZ/TM
000124           CALL SURF(TM,S,TC)
000130           QI=S*(TM-TC)/(1.+S*R)
000136           QSUM=QSUM+QI*DZ
000141           VV(J)=V
000144           PP(J)=P
000147           ZZ(J)=Z
000152           XX(J)=XSUM
000155           QQ(J)=QSUM
000160           IF(ABS(DV).LT.0.015625.AND.ABS(DZ).LT.0.25)  DZ=2.*DZ
000173           CALL SATUR (P,TI)
000176           IF(TI.GE.TS2) GO TO 150
000201       100 CONTINUE
000203           WRITE(5,10)
000210        10 FORMAT(/2X,*1000 STEPS IN FORWRD*)
000210           CALL EXIT
000212       150 CONTINUE
000212           TMIN=TS1
000214           DZ=0.25
000216           RETURN
000217           END
```

```
                 SUBROUTINE INPT
000002           COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002           COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002           COMMON /ADIAB/ XL3,C3,RA,DIADI
000002           COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000002           COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002           COMMON /PIPDTA/ TEV, DET, Q, GAS, TP, VR, VRES, DZ, R, COEF,TTRP
000002           COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
000002           COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000002           COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002           READ (5,5)
000006         5 FORMAT (72H
000006          $                    /72H
000006          $                                 )
000006           WRITE (6,5)
           C
           C     FLUID CHARACTERISTICS
           C1
000012           READ (5,10) A11,B11,C11
000024        10 FORMAT (3F12.5)
           C     A11,B11 AND C11 ARE VAPOR PRESSURE PARAMETERS IN THE LEAST SQUARES
           C     FIT, P=EXP(A11-B11/T-C11/(T**2)), PSIA,T IN DEG-R.
           C2
000024           READ(5,11) XMC,DIF,E,HFG
000040        11 FORMAT(4F12.5)
           C     XMC IS MOLECULAR WEIGHT OF THE CONDENSIBLE
           C     DIF IS THE MASS DIFFUSIVITY AT ONE ATMOS AND 460R, FT**2/HR
           C     E IS THE TEMPERATURE EXPONENT FOR DIFFUSIVITY MINUS ONE
           C     HFG IS THE LATENT HEAT (BTU/LB) ( AT TEV )
000040           WRITE(6,12)
000044        12 FORMAT(/,26H VAPOR PRESSURE PARAMETERS)
000044           WRITE (6,13) A11,B11,C11
000056        13 FORMAT (/, 6H  A11=1PE12.5,7H   B11=1PE12.5,7H   C11=1PE12.5)
000056           WRITE(6,14)
000062        14 FORMAT(//,17H FLUID PROPERTIES)
000062           WRITE(6,15) HFG,DIF,XMC,E
000076        15 FORMAT(/,6H  HFG=F9.4,14H BTU/LB   DIF=F9.4,15H FTFT/HR   XMC=F9.4
```

INPT

```
000076          $          ,10H   CD EXP=F9.4)
           C
           C       CONDENSER PARAMETERS, SECTION 1, FARTHEST FROM EVAPORATOR
           C3
000076             READ(5,16) PF1,AF1,CF1,EF1,EMIS1,HF1
000115          16 FORMAT(6F12.5)
           C       PF1 IS FIN PERIMETER PERPENDICULAR TO PIPE (INCHES)
           C       AF1 IS FIN CROSS-SECTIONAL AREA (SQ. INCHES)
           C       CF1 IS EFFECTIVE THERMAL CONDUCTIVITY OF FIN, ALLOWS FOR SLOTS
           C       EF1 IS FIN EFFECTIVENESS (DIMENSIONLESS)
           C       EMIS1 IS FIN TOTAL HEMISPHERICAL EMISSIVITY (DIMENSIONLESS)
           C       HF1 IS FIN CONVECTIVE HEAT TRANSFER COEFFICIENT (BTU/HR-FT2-R)
000116             WRITE(6,17)
000122          17 FORMAT(//,* FIN PROPERTIES, CONDENSER SECTION NUMBER 1*)
000122             WRITE(6,18) PF1,AF1,CF1,EF1,EMIS1,HF1
000142          18 FORMAT(/,2X,*PF=*,F8.4,* IN*,2X,*AF=*,F8.4,* SQ IN*,2X,
000142           1   *CF=*,F8.4,* BTU/HRFTR*,2X,*EF=*,F6.4,2X,*EMIS=*,F6.4,2X,
000142           2   *HF=*,F9.4,* BTU/HRFT2R*)
000142             TEST=EF1*PF1*(EMIS1+HF1)
000146             IF (TEST.NE.0.) GO TO 996
000147             NERROR=1
000150             WRITE(6,19)
000154          19 FORMAT(/,35H CONDENSER SECTION NO. 1 INPUT WRONG)
000154         996 CONTINUE
           C
           C       CONDENSER PARAMETERS, SECTION 2, NEAREST TO EVAPORATOR
           C4
000154             READ(5,16) PF2,AF2,CF2,EF2,EMIS2,HF2
000174             WRITE(6,20)
000200          20 FORMAT(//,* FIN PROPERTIES, CONDENSER SECTION NUMBER 2*)
000200             WRITE(6,18) PF2,AF2,CF2,EF2,EMIS2,HF2
000220             TEST=EMIS2+HF2
000222             IF (TEST.NE.0.) GO TO 997
000223             NERROR=1
000224             WRITE(6,21)
000230          21 FORMAT(/,35H CONDENSER SECTION NO. 2 INPUT WRONG)
000230         997 CONTINUE
           C
```

```
              C       ADIABATIC SECTION CHARACTERISTICS
              C5
000230                READ (5,22) DOUTA,THKWA,CWA,DELA,CWKA,XLONGA
000250             22 FORMAT(6F12.5)
              C       DOUTA IS OUTSIDE DIAMETER (INCHES)
              C       THKWA IS WALL THICKNESS (INCHES)
              C       CWA IS WALL THERMAL CONDUCTIVITY (BTU/HR-FT-R)
              C       DELA IS THE WICK THICKNESS IN ADIABATIC SECTION (INCHES)
              C       CWKA IS EFFECTIVE CONDUCTIVITY OF WICK (BTU/HR-FT-R)
              C       XLONGA IS THE LENGTH OF THE ADIABATIC SECTION (FT)
000250                WRITE (6,23)
000254             23 FORMAT(//,29H ADIABATIC SECTION PROPERTIES    )
000254                WRITE (6,24) DOUTA,THKWA,CWA,DELA,CWKA,XLONGA
000274             24 FORMAT(/8H  DOUTA=F9.4,11H IN.  THKWA=F9.4,4H IN. /
000274              1  6H  CWA=   F9.4,17H BTU/HRFTR  DELA=F9.4,
000274              2   6H CWKA=    F9.4,19H BTU/HRFTR  XLONGA=F9.4,3H FT )
              C
              C       WALL CHARACTERISTICS
              C5
000274                READ(5,25) DOUT,THKW,CW
000306             25 FORMAT(3F12.5)
              C       DOUT IS OUTSIDE DIAMETER OF HEAT PIPE (INCHES)
              C       THKW IS WALL THICKNESS (INCHES)
              C       CW IS WALL THERMAL CONDUCTIVITY (BTU/HR-FT-R)
000306                WRITE(6,26)
000312             26 FORMAT(//,16H PIPE PROPERTIES)
000312                WRITE(6,27) DOUT,THKW,CW
000324             27 FORMAT(/,7H  DOUT=F9.4,15H IN   WALL THK=F9.4,16H IN   WALL COND=
000324              $         F9.4,10H BTU/HRFTR)
              C
              C       WICK CHARACTERISTICS
              C7
000324                READ(5,28) DEL,CONWK,DART
000336             28 FORMAT(3F12.5)
              C       DEL IS THE HEAT PIPE WICK THICKNESS (INCHES)
              C       CONWK IS THE EFFECTIVE THERMAL CONDUCTIVETY OF FILLED WICK
              C       DART IS THE EFFECTIVE DIAMETER OF ARTERIES IN PIPE (INCHES)
              C
```

```
          C      ENVIRONMENTAL PARAMETERS AND LENGTHS
          C8
000336           READ(5,29) TF1,POW1,XLONG1
000350        29 FORMAT(3F12.5)
          C      TF1 IS THE FLUID TEMPERATURE (DEGREES-R)
          C      POW1 IS THE ABSORBED POWER PER UNIT AREA OF THE OUTER FIN SURFACE
          C      (PERIMITER TIMES LENGTH)  THE POWER IS BOTH INSIDE (INTERNAL
          C      POWER) AND OUTSIDE (SOLAR ABSORPTION, ETC.) BUT THE AREA IS THE
          C      OUTSIDE AREA ONLY (BTU/HR-FT2)
          C      XLONG1 IS THE LENGTH OF CONDENSER SECTION NUMBER 1 (FEET)
          C9
000350           READ(5,29) TF2,POW2,XLONG2
          C      XLONG2 IS THE LENGTH OF CONDENSER SECTION NUMBER 2 (FEET)
000362           WRITE(6,30)
000366        30 FORMAT(//,* CONDENSER ENVIRONMENT, SECTION NUMBER 1*)
000365           WRITE(6,31) TF1,POW1,XLONG1
000400        31 FORMAT(/,* TF=*,0PE12.4,* R    POW=*,0PE12.4,* BTU/HRFTFT    XLONG=*
000400          *         ,0PF12.4,* FT*)
000400           WRITE(6,32)
000404        32 FORMAT(//,* CONDENSER ENVIRONMENT, SECTION NUMBER 2*)
000404           WRITE(6,31) TF2,POW2,XLONG2
          C
          C      OPERATING CONDITIONS
          C10
000416           READ(5,33) TEV,Q,ZGAS,AGAS,TTRAP
000434        33 FORMAT(5F12.5)
          C      TEV IS THE EVAPORATOR TEMPERATURE (DEGREES-R)
          C      Q IS THE HEAT PIPE POWER (BTU/HR)
          C      ZGAS IS THE LENGTH OF CONDENSER FILLED WITH GAS IF SHARP FRONT, FT
          C      AGAS IS THE AMOUNT OF GAS IN LB-MOLES
          C      ONE, BUT NOT BOTH, OF ZGAS AND AGAS MUST BE EQUAL TO ZERO
          C      TTRAP IS THE COLD TRAP TEMPERATURE (R).  IF THERE IS NO
          C      ACTIVE COLD TRAP, USE ZERO FOR THE INPUT VALUE.
000434           IF(ZGAS.EQ.0.0.AND.AGAS.EQ.0.0) GO TO 998
000442           IF(ZGAS.EQ.0.0.OR.AGAS.EQ.0.0) GO TO 200
000450       998 CONTINUE
000450           NERROR=1
000451           WRITE(6,34) ZGAS,AGAS
```

```
000461       34 FORMAT(/,* INPUT WRONG, ZGAS=*,0PE12.5,* AGAS=*,0PE12.5)
000461          CALL EXIT
000462      200 CONTINUE
          C
          C     RESERVOIR CHARACTERISTICS
          C11
000462          READ (5,35) VRES,TRES,NRES,MODEQM,ZPRINT,NRUN
000502       35 FORMAT(2F12.5,2I12,F12.5,I12)
          C     VRES IS THE RESERVOIR VOLUME IN CUBIC INCHES
          C     TRES IS THE RESERVOIR TEMPERATURE IN DEGREES R
          C     NRES REFERS TO A NON-WICKED (0), AN ACTIVE-WICKED (1) OR A
          C     PASSIVE-WICKED (2) RESERVOIR.
          C     MODEQM REFERS TO A PRESCRIBED Q (0) OR PRESCRIBED MOLES OF GAS (1).
          C     IN THE LATTER CASE Q IS SIMPLY A GUESS, HOPEFULLY LOW BUT CORRECT
          C     IN ORDER OF MAGNITUDE.  IN THE FORMER CASE AGAS IS SET EQUAL TO
          C     ZERO AND ZGAS IS A NOMINAL GUESS.
          C     NPRINT INDICATES THE NUMBER OF LINES TO BE SKIPPED IN OUTPUT.
          C     NRUN EQUALS 1 IF ANOTHER SET OF DATA FOLLOWS.  OTHERWISE 0.
000502          WRITE(6,36)
000506       36 FORMAT(//,* WICK PROPERTIES AND RESERVOIR CONDITIONS*)
000506          WRITE(6,37) DEL,CONWK,DART,VRES,TRES,NRES
000526       37 FORMAT(/,2X,*WCK THK=*,F6.4,* IN*,2X,*WCK CON=*,F8.4,
000526        1  * BTU/HRFTR*,2X,*D-ART=*,F7.4,* IN*,2X,*VRES=*,F8.4,* CU IN*,
000526        2  2X,  *TRES=*,F6.1,* R*,2X,*NRES=*,I2)
000526          SIGMA = 0.1714E-8
000530          RU = 1544.0
000532          PI = 3.1415927
000534          IF(EMIS1.EQ.0.0.AND.HF1.EQ.0.0) GO TO 999
000542          GO TO 100
000543      999 CONTINUE
000543          NERROR=1
000544          RETURN
          C
          C     CALCULATION OF DIMENSIONLESS PARAMETERS
          C
000545      100 CONTINUE
000545          IF (NERROR.EQ.1) GO TO 999
000547          CALL SINK(EMIS1,POW1,HF1,TF1,TS1)
```

```
000553           TS2=TS1
000555           IF(PF2.NE.0.) CALL SINK(EMIS2,POW2,HF2,TF2,TS2)
000562           TS1 = TS1/TEV
000564           TS2 = TS2/TEV
000566           B11 = B11/TEV
000570           C11 = C11/TEV**2
000572           CALL MOLE(TS1,XS1)
000574           CALL MOLE (TS2,XS2)
000576           TR = TRES/TEV
000600           TTRP=TTRAP/TEV
000602           PEV=(EXP(A11-B11-C11))*144.0
000611           CEV = PEV/(RU*TEV)
000614           TZ=B11+C11*(1.0+1.0/TS1)
000621           PATMOS = PEV/(144.0*14.7)
000623           DEV=(DIF/PATMOS)*((TEV/460.0)**(E+1.0))
000634           CMDH = XMC*DEV*CEV*HFG
000640           DIN = DOUT-2.0*THKW
000643           DI = DIN-2.0*DEL
000646           FINKA1 = CF1*AF1/144.0
000651           FINKA2 = CF2*AF2/144.0
000654           WALKA = (PI/576.0)*(DOUT**2-DIN**2)*CW
000662           WICKA = (PI/576.0)*(DIN**2-DI**2)*CONWK
000670           SUMKA1 = FINKA1+WALKA+WICKA
000673           SUMKA2 = FINKA2+WALKA+WICKA
000676           DINA=DOUTA-2.*THKWA
000701           DINWA=DINA-2.*DELA
000704           AWA=(PI/4.)*(DOUTA**2-DINA**2)
000711           AWKA=(PI/4.)*(DINA**2-DINWA**2)
000716           SUMKA3=(CWA*AWA+CWKA*AWKA)/144.
000723           IF(DI.GE.DART) GO TO 300
000726           WRITE(6,39) DI,DART
000736        39 FORMAT(/,* DART TOO BIG.   DI=*,0PE12.4,*   DART=*,0PE12.4)
000736           NERROR=1
000737           RETURN
000740       300 DFT = SQRT(DI**2-DART**2)/12.0
000747           VR = VRES/((PI/4.0)*1728.0*DFT**3)
000754           XL1 = XLONG1/DFT
000756           XL2 = XLONG2/DFT
```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000760          XL3 = XLONGA/DFT
000762          XLTOT=XL1+XL2
000764          IF(XLTOT.LT.250.) GO TO 600
000767          WRITE(6,40)
000773       40 FORMAT(//,27H PIPE EXCEEDS 250 DIAMETERS)
000773          CALL EXIT
000774      600 CONTINUE
000774          C1 = SUMKA1*TEV/(Q*DFT)
001000          C2 = SUMKA2*TEV/(Q*DFT)
001004          C3 = SUMKA3*TEV/(Q*DFT)
001010          XKA=2.*PI*CWKA*DFT*TEV/(Q*ALOG(DINA/DINWA))
001023          RA=1./XKA
001025          DIADI=DINA/DI
001027          XK = 2.0*PI*CONWK*DFT*TEV/(Q*ALOG(DIN/DI))
001042          R = 1.0/XK
001044          D = (PI/4.0)*DFT*CMDH/Q
001051          F1 = EF1*(PF1/12.0)*DFT*SIGMA*TEV**4/Q
001060          F2 = EF2*(PF2/12.0)*DFT*SIGMA*TEV**4/Q
001067          H1 = HF1*TEV/(SIGMA*TEV**4)
001073          H2 = HF2*TEV/(SIGMA*TEV**4)
001077          COEF = 3.1415927*CEV*DFT**3/4.0
001103          GAS = AGAS/COEF
001105          TR1=TS1
001107          IF(NRES.EQ.1) TR1=TR
001113          IF(NRES.EQ.2) TR=TR1
001117          IF(NRES.EQ.0.AND.TTRP.NE.0.0) TR1=TTRP
001127          CALL MOLE(TR1,XR)
001131          RSUM=XR*VR/TR
001134          IF(ZGAS.EQ.0.0) GO TO 400
001135          GAS = (ZGAS*XS1/(TS1*DFT))+RSUM
001142          IF(ZGAS.LE.XLONG1) GO TO 400
001145          GAS=RSUM+XL1*XS1/TS1+(ZGAS-XLONG1)*XS2/(TS2*DFT)
001157      400 AMT = COEF*GAS
001161          XGAS = DFT*(GAS-RSUM)*TS1/XS1
001166          IF(XGAS.LE.XLONG1) GO TO 500
001171          GAS1=XL1*XS1/TS1
001174          GAS2=(GAS-RSUM)-GAS1
001177          XGAS=DFT*(XL1+(GAS2*TS2/XS2))
```

```
001204       500 CONTINUE
001204           WRITE(6,41)
001210        41 FORMAT(//,21H OPERATING CONDITIONS)
001210           WRITE(6,42) TEV,Q,MODEQM,CEV,TTRAP
001226        42 FORMAT(/,*   TEV=*,0PE12.4,* R   Q=*,0PE12.4,* BTU/HR   MODEQM=*,
001226          $I2,     *   CEV=*,0PE12.4,* LBMOLE/FT3   TTRAP=*,0PE12.4,* R*)
001226           WRITE(6,43)
001232        43 FORMAT(//,29H AMOUNT OF NONCONDENSIBLE GAS)
001232           WRITE(6,44) GAS,ZGAS,AGAS,COEF,AMT,XGAS
001252        44 FORMAT(/,5H GAS=0PE12.4,9H   ZGAS=0PE12.4,11H FT   AGAS=0PE12.4,
001252          $         15H LBMOLE   COEF=0PE12.4,9H   LBMOLE/,5H AMT=0PE12.4,
001252          $         14H LBMOLE  XGAS=0PE12.4,3H FT)
001252           WRITE(6,45)
001256        45 FORMAT(//,* DIMENSIONLESS TEMPERATURES*)
001256           WRITE(6,46) TZ,TS1,TS2,TR,TTRP
001274        46 FORMAT(/,* TZ=*,0PE12.4,* TS1=*,0PE12.4,* TS2=*,0PE12.4,* TR=*,
001274          $         0PE12.4,*  TTRP=*,0PE12.4)
001274           WRITE(6,47)
001300        47 FORMAT(//,* DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 1*)
001300           WRITE(6,48) EMIS1,C1,F1,H1,XL1,XS1
001320        48 FORMAT(/,* EMIS=*,0PE12.4,* C=*,0PE12.4,* F=*,0PE12.4,* H=*,
001320          $         0PE12.4,* XL=*,0PE12.4,* XS=*,0PE12.4)
001320           WRITE(6,49)
001324        49 FORMAT(//,* DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 2*)
001324           WRITE(6,48) EMIS2,C2,F2,H2,XL2,XS2
001344           WRITE(6,50)
001350        50 FORMAT(//,* DIMENSIONLESS ADIABATIC SECTION PARAMETERS*)
001350           WRITE(6,51) C3,RA,DIADI,R,XL3
001366        51 FORMAT(/,4H C3=E12.5,5H  RA=E12.5,
001366          1  8H  DIADI=E12.5,4H  R=E12.5,6H  XL3= E12.5)
001366           WRITE(6,52)
001372        52 FORMAT(///)
001372           RETURN
001373           END
```

```
                 SUBROUTINE JOINT (NSEC,P,V,VNEW)
        C
000007           COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000007           COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000007           COMMON /ADIAB/ XL3,C3,PA,DIADI
000007           COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
        C
000007           CALL SATUP (P,TI)
000014           DTEE=D*TI**E
000021           TERM=(TI**2/DTEE)*EXP(-P)/(FEX(P)*TZ)
000041           IF(NSEC.EQ.2) GO TO 100
000043           VNEW=V*((1.0+C1*TERM)/(1.0+C2*TERM))
000052           RETURN
000053       100 CONTINUE
000053           VNEW=V*((1.+C2*TERM)/(1.+C3*TERM))
000062           RETURN
000063           END
```

JOINT

```
                SUBROUTINE LONG
           C       LONG CALLS START REPEATEDLY TO SEARCH FOR A VALUE
           C       OF JSTART FOR WHICH XSU = GAS OR QSUM = 0
000002          COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002          COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002          COMMON /ADIAB/ XL3,C3,PA,DIADI
000002          COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000002          COMMON /PIPDTA/ TEV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002          COMMON /INTC/  NRES, MODEQM, ZPRINT, NPUN, NERROR
000002          COMMON /LNG/ JSTART, JSAV, XL12, XL123
000002          COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002          JSAV=JEND
000004          JSTART=1
000005          CALL START
000006          CALL TESTF(MOREJ)
000010          WRITE(6,30)
000014       30 FORMAT(/,2X,*ITERATING IN LONG*)
000014          I=0
000015          WRITE(6,20)  I,JSTART,XSUM,QSUM,JEND,MOREJ
000035          IF(MOREJ.EQ.0) RETURN
000037          IF(MOREJ.EQ.1)  GO TO 99
000041          CALL SHORT
           C
000042          RETURN
000043       99 CONTINUE
000043          JMAX=JSAV
000045          JMIN=1
           C
000046          DO 100 I=1,30
000050          JOLD=JSTART
000052          JSTART=(JMAX+JMIN)/2
000055          IF(JSTART.NE.JOLD)  GO TO 101
000057          IF(MOREJ.EQ.1)   JSTART=JSTART+1
000063          CALL START2
000064          TMIN=TS1
000065          RETURN
000067      101 CONTINUE
```

LONG

```
000067          CALL START
000070          CALL TESTF(MOREJ)
000072          WRITE(6,20) I, JSTART, XSUM, QSUM, JEND, MOREJ
          C
000112       20 FORMAT(2X,*ITER=*,I4,2X,*JSTART=*,I4,2X,
000112         1  *XSUM=*,E12.5,2X,*QSUM=*,E12.5,
000112         2  2X,*JEND=*,I4,2X,*MOREJ=*,I4)
000112          IF(MOREJ.EQ.0) RETURN
000114          IF(MOREJ.EQ.1) GO TO 200
000116          JMAX=JSTART
000120          GO TO 100
          C
000121     200  CONTINUE
000121          JMIN=JSTART
000123     100  CONTINUE
          C
000125          WRITE (6,10)
000131      10  FORMAT (/* FAILED TO CONVERGE IN LONG*)
000131          CALL EXIT
          C
000132          RETURN
000133          END
```

LONG

```
                 SUBROUTINE MOLE (TI,XS)
000005           COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEF, HFG
000005           TERM1 = B11*(1.0/TI-1.0)
000010           TERM2 = C11*(1.0/TI**2-1.0)
000014           ARG = TERM1+TERM2
000015           XS = FEX(ARG)
000022           RETURN
000023           END
```

MOLE

```
                  SUBROUTINE OUTPT
000002            COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000002            COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002          1                VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002          2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002            COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002            COMMON /PIPDTA/ TEV, DET, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002            COMMON /PIPOUT/ XSUM, QSUM, PSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002            COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
            C
000002            V=0.0
000003            Z=0.0
000004            RESGAS=COEF*PSUM
000006            TRES=TEV*TR
000010            IF(VRES.EQ.0.0) GO TO 98
000011            WRITE(5,10) TRES,XSR,RESGAS
000023         10 FORMAT(/,2X,*TRES =*,E12.4,* DEG R*,4X,*XSR =*,E12.4,10X,
000023          1    *RESGAS =*,E12.4,* LB-MOLES*)
000023         98 CONTINUE
000023            NSEC=1
000024            CALL CONSEC(NSEC)
000026            IPRINT=1
            C
000027            DO 100 J=1,JEND
000031            V1=V
000033            Z1=Z
000035            Z=ZZ(J)
000040            ZFT=Z*DET
000042            ZIN=12.*ZFT
000044            IF(J.EQ.1.OR.J.EQ.JEND) GO TO 102
000054            IF(Z.LE.XL) GO TO 99
000057            IF (NSEC.EQ.1) GO TO 101
000061            IF (NSEC.EQ.2) GO TO 103
000063            IF (NSEC.EQ.3) GO TO 200
000065         99 JPRINT=ZIN/ZPRINT
000070            IF(JPRINT.LT.IPRINT) GO TO 100
000073            IPRINT=JPRINT+1
```

OUTPT

```
000075       102 CONTINUE
000075           V=VV(J)
000100           P=PP(J)
000103           XSUM=XX(J)
000106           QSUM=QQ(J)
000111           QFLOW=Q*QSUM
000113           CALL SATUP(P,TI)
000115           CALL MOLE(TI,XS)
000117           CALL SURF(TI,S,TC)
000122           TW=(TI+S*R*TC)/(1.0+S*R)
000132           TWICK=TEV*TI
000134           TWALL=TEV*TW
000136           XMDOT=V*Q/HFG
000141           AMT=COEF*XSUM
000143           DTEE=D*(TI**E)
000150           DVDZ=(V-V1)/(Z-Z1)
000154           ASTN=DVDZ/(15.0*DTEE)
000157           WRITE (6,11) J,ZIN,Z
000171        11 FORMAT (/* J =*,I4,6X,*ZIN =*,E12.4,* INCHES*,8X,*Z =*,E12.4)
000171           WRITE (6,12) V,P,TI
000203        12 FORMAT (16X,*V =*,E12.4,15X,*P =*,E12.4,14X,*TI =*,E12.4)
000203           WRITE (6,13) XSUM,QSUM,XMDOT
000215        13 FORMAT (13X,*XSUM =*,E12.4,12X,*QSUM =*,E12.4,8X,*MASSFLOW =*,
000215          1    E12.4,* LB/HR*)
000215           WRITE (6,14) QFLOW,XS,TWICK
000227        14 FORMAT (12X,*QFLOW =*,E12.4,* BTU/HR*,7X,*XS =*,E12.4,
000227          1    11X,*TWICK =*,E12.4,* DEG R*)
000227           WRITE (6,15) TWALL,AMT
000237        15 FORMAT (12X,*TWALL =*,E12.4,* DEG R*,5X,* MGAS =*,E12.4,
000237          1    * LB-MOLES*)
000237           GO TO 100
000240       101 CONTINUE
000240           NSEC=2
000241           CALL CONSEC(NSEC)
000243           GO TO 102
000244       103 CONTINUE
000244           NSEC=3
000245           CALL CONSEC(NSEC)
```

```
000247          GO TO 102
000250      100 CONTINUE
000253      200 CONTINUE
          C
000253          DQ=Q*PREQ
000255          DG=COEF*PREG
000257          WRITE(6,23) DG
000265       23 FORMAT(/,* GAS IN ONE DZ STEP OF GAS-BLOCKED CONDENSER 1*,
000265        1    4X,*=*,E12.5,* LB-MOLES*)
000265          WRITE(6,24) DQ
000273       24 FORMAT(/,* POWER LOST BY ONE DZ STEP OF FULL-ON*,
000273        1    * CONDENSER 1 =*,F12.5,* BTU/HR*)
000273          WRITE (6,25) AMT
000301       25 FORMAT (/* TOTAL GAS IN PIPE AND RESERVOIR =*,E12.5,
000301        1    * LB-MOLES*)
000301          WRITE(6,26) QFLOW
000307          RETURN
000310       26 FORMAT(/,* TOTAL POWER LOST BY CONDENSERS  =*,E12.5,
000310        1    * BTU/HR*)
000310          END
```

OUTPT

```
                 SUBROUTINE PATCH
          C
000002           COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002           COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002           COMMON /ADIAB/ XL3,C3,RA,DIADI
000002           COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002          1             VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002          2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002           COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002           COMMON /PIPDTA/ TEV, DFT, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002           COMMON /PIPOUT/ XSUM, QSUM, PSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002           COMMON /LNG/ JSTART, JSAV, XL12, XL123
000002           COMMON /CRSS/ Z1,Z2,V1,V2,X1,X2,PCROSS,QCROSS,J1,J1M,J2,J2M,JBAK
          C
000002           WRITE(6,10)
000006        10 FORMAT(/,2X,*ITERATING IN PATCH*)
          C
000006           TDIF=DELTEE/TEV
000010           TSTART=TS1+TDIF
000012           TMIN=TSTART
000014           TMAX=TS2
000016           CALL FORWRD(TSTART)
000020           CALL BACK
000021           CALL CROSS
000022           I=0
000023           WRITE(6,11) I,TSTART,Z1,XL1
000037        11 FORMAT(2X,*ITER=*,I4,2X,*TSTART=*,F10.5,2X,*Z1=*,
000037          1    F10.5,2X,*XL1=*,F10.5)
000037           IF(Z1.LE.XL1) GO TO 200
000042           DO 100 I=1,30
000044           TSTART=(TMIN+TMAX)/2.
000047           CALL FORWRD(TSTART)
000051           CALL CROSS
000052           WRITE(6,11) I,TSTART,Z1,XL1
000066           TEST=ABS(Z1-XL1)
000071           IF (TEST.LT.DZ)  GO TO 101
000074           IF (Z1.GT.XL1) TMIN=TSTART
```

```
000100          IF(Z1.LT.XL1) TMAX=TSTART
000104      100 CONTINUE
000106          WRITE(5,12)
000112       12 FORMAT(/,2X,*FAILED TO CONVERGE IN PATCH*)
000112      101 CONTINUE
000112          IF (Z1.LE.XL1)  GO TO 200
000115          II=J1
000117          DO 103 I=1,J1
000121          II=II-1
000123          TEST=Z1-ZZ(II)
000126          IF(TEST.GT.XL1) GO TO 104
000132      103 CONTINUE
000135      104 CONTINUE
000135          P=PP(II)
000140          II=II+1
000142          ZDIFF=Z1-XL1
000144          CALL CONSEC(1)
000146          CALL SATUR(P,TI)
000150          CALL MOLE(TI,XS)
000152          CALL SURF(TI,S,TC)
000155          XDIFF=XX(II)+XS*(ZZ(II)-ZDIFF)/TI-XX(1)+XS1*ZZ(1)/TS1
000167          QDIFF=QQ(II)-(ZZ(II)-ZDIFF)*S*(TI-TC)/(1.+S*R)
000202          JJ=0
000203          DO 105 I=II,J1M
000205          JJ=JJ+1
000207          V=VV(I)
000212          VV(JJ)=V
000215          VSAV(JJ)=V
000220          P=PP(I)
000223          PP(JJ)=P
000226          PSAV(JJ)=P
000231          Z=ZZ(I)-ZDIFF
000234          ZZ(JJ)=Z
000237          ZSAV(JJ)=Z
000242          XSUM=XX(I)-XDIFF
000245          XX(JJ)=XSUM
000250          XSAV(JJ)=XSUM
000253          QSUM    =QQ(I)-QDIFF
```

```
000256          QQ(JJ)=QSUM
000261          QSAV(JJ)=QSUM
000264     105  CONTINUE
000267          GO TO 300
000270     200  CONTINUE
000270          ZDIFF=XL1-Z1
000272          STEP=ZDIFF/DZ
000274          I1=STEP
000276          STEP=I1
000300          ZDIFF=DZ*STEP
000302          RSUM=XX(1)-ZZ(1)*XS1/TS1
000306          Z=XL1-Z1-ZDIFF
000311          XSUM=RSUM+Z*XS1/TS1
000315          P=PHI(TS1)
000320          IF(I1.LE.0) GO TO 202
000322          DO 201 I=1,I1
000324          Z=Z+DZ
000326          XSUM=XSUM+DZ*XS1/TS1
000332          VSAV(I)=0.
000334          PSAV(I)=P
000337          ZSAV(I)=Z
000342          XSAV(I)=XSUM
000345          QSAV(I)=0.
000347     201  CONTINUE
000352     202  CONTINUE
000352          DO 203 I=1,J1M
000354          JJ=I1+I
000356          VSAV(JJ)=VV(I)
000362          PSAV(JJ)=PP(I)
000366          ZSAV(JJ)=ZZ(I)
000372          XSAV(JJ)=XX(I)+(XSUM-RSUM)
000400          QSAV(JJ)=QQ(I)
000404     203  CONTINUE
000407          DO 204 I=1,JJ
000411          VV(I)=VSAV(I)
000414          PP(I)=PSAV(I)
000417          ZZ(I)=ZSAV(I)
000422          XX(I)=XSAV(I)
```

```
000425          QQ(I)=QSAV(I)
000430      204 CONTINUE
000433      300 CONTINUE
000433          ZDIFF=XL1-ZZ(JJ)
000436          JJ=JJ+1
000440          Z=XL1
000442          CALL SATUP(PCROSS,TCROSS)
000444          CALL MOLE(TCROSS,XSC)
000446          P=PCROSS
000450          V=V1
000452          XSUM=XX(JJ)+ZDIFF*XSC/TCROSS
000457          QSUM=QCROSS
000461          VV(JJ)=V
000464          VSAV(JJ)=V
000467          PP(JJ)=P
000472          PSAV(JJ)=P
000475          ZZ(JJ)=Z
000500          ZSAV(JJ)=Z
000503          XX(JJ)=XSUM
000506          XSAV(JJ)=XSUM
000511          QQ(JJ)=QSUM
000514          QSAV(JJ)=QSUM
000517          XSUMC=XSUM
000521          II=J2
000523          JJJ=J2-1
000525          DO 301 I=1,JJJ
000527          II=II-1
000531          ZDIFF=ZB(II)-Z2
000534          XDIFF=XB(II)-X2
000537          JJ=JJ+1
000541          V=VB(II)
000544          VV(JJ)=V
000547          VSAV(JJ)=V
000552          P=PB(II)
000555          PP(JJ)=P
000560          PSAV(JJ)=P
000563          Z=XL1+ZDIFF
000565          ZZ(JJ)=Z
```

```
000571          ZSAV(JJ)=Z
000573          XSUM=XSUMC+XDIFF
000575          XX(JJ)=XSUM
000600          XSAV(JJ)=XSUM
000603          QSUM=QB(II)
000606          QQ(JJ)=QSUM
000611          QSAV(JJ)=QSUM
000614          ZDIFF=ZB(II)-Z2
000617          XDIFF=XX(II)-X2
000622          JEND=JJ
000624          IF(Z.GE.XL123) RETURN
000630      301 CONTINUE
000633          ZDIFF=XL123-Z
000635          STEP=ZDIFF/DZ
000637          NSTEP=STEP
000641          NSTEP=NSTEP+1
000643          STEP=NSTEP
000645          DZ=ZDIFF/STEP
000647          V=0.
000650          P=PHI(TS2)
000653          QSUM=0.
000654          XSUM=XX(JJ)
000657          DO 302 I=1,NSTEP
000661          JJ=JJ+1
000663          Z=Z+DZ
000665          XSUM=XSUM+DZ*XS2/TS2
000671          VV(JJ)=V
000674          VSAV(JJ)=V
000677          PP(JJ)=P
000702          PSAV(JJ)=P
000705          ZZ(JJ)=Z
000710          ZSAV(JJ)=Z
000713          XX(JJ)=XSUM
000716          XSAV(JJ)=XSUM
000721          QQ(JJ)=QSUM
000724          QSAV(JJ)=QSUM
000727      302 CONTINUE
000732          JEND=JJ
```

```
000734          DZ=0.25
000736          RETURN
000737          END
```

PATCH

```
                  SUBROUTINE PIPE
              C
000002            COMMON /WORK/  XL, TS, G, F, H, EMIS, TMIN, ZF
000002            COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002           1               VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002           2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002            COMMON /PIPDTA/ TEV, DET, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002            COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000002            COMMON /PIPOUT/ XSUM, QSUM, PSUM, XSR, ZFRONT, JEND, PREQ, PREG
              C
000002            V=VZERO
000004            P=PZERO
000006            Z=ZZERO
000010            J=JZERO
000012            XSUM=XZERO
000014            QSUM=QZERO
000016            DZ=0.25
              C
000020            DO 100 I=1,2000
000022            CALL RUNGE (V,P,DV,DP)
000025            IF (ABS(DV).GT.0.1250) GO TO 200
000032            GO TO 400
000033      200   DZ=DZ/2.0
000035            GO TO 100
000036      400   CONTINUE
000036            J=J+1
000040            IF(J.GT.1000) GO TO 102
000044            Z=Z+DZ
000046            IF (Z.GT.XL) GO TO 150
000052            P1=P
000054            P=P+DP
000056            V=V+DV
000060            PM=(P1+P)/2.0
000063            CALL SATUR (PM,TM)
000065            CALL MOLE (TM,XM)
000067            XSUM=XSUM+XM*DZ/TM
000073            CALL SURF (TM,S,TC)
```

PIPE

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```
000076         QI=S*(TM-TC)/(1.0+S*P)
000104         QSUM=QSUM+QI*DZ
000107         PP(J)=P
000112         VV(J)=V
000115         ZZ(J)=Z
000120         XX(J)=XSUM
000123         QQ(J)=QSUM
000126         IF (ABS(DV).LT.0.04     .AND. DZ.LT.0.25) DZ=2.0*DZ
000141     100 CONTINUE
000143      102 CONTINUE
000143         WRITE (6,10)  J
000151      10 FORMAT (/,* TOO MANY STEPS IN PIPE, J =*,I5)
          C
000151     150 DZ1=Z-XL
000153         ZZ(J)=XL
000156         FRAC=(DZ-DZ1)/DZ
000161         TEST=Z
000163         Z=XL
000165         P1=P
000167         P=P+DP*FRAC
000172         PP(J)=P
000175         V=V+DV*FRAC
000200         VV(J)=V
000203         PM=(P1+P)/2.0
000206         CALL SATUP (PM,TM)
000210         CALL MOLE (TM,XM)
000212         XSUM=XSUM+XM*DZ*FRAC/TM
000217         XX(J)=XSUM
000222         CALL SURF (TM,S,TC)
000225         QI=S*(TM-TC)/(1.0+S*P)
000233         QSUM=QSUM+QI*DZ*FRAC
000237         QQ(J)=QSUM
000242         JEND=J
000244         JZERO=J
000246         PZERO=P
000250         VZERO=V
000252         ZZERO=Z
000254         XZERO=XSUM
```

RUNX COMPILER (VER.26)   10/02/73. 15.05.14.   PIPE

```
000256          QZERO=QSUM
      C
000260          RETURN
000261          END
```

PIPE

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RUNX COMPILER (VER.26)   10/02/73. 15.05.14.

```
              SUBROUTINE RUNGE(V,P,DV,DP)
        C
000007        CALL DELTA(V,P,DV1,DP1)
000014        V1 = V+DV1/2.0
000017        P1 = P+DP1/2.0
000022        CALL DELTA(V1,P1,DV2,DP2)
000030        V1 = V+DV2/2.0
000033        P1 = P+DP2/2.0
000036        CALL DELTA(V1,P1,DV3,DP3)
000044        V1 = V+DV3
000046        P1 = P+DP3
000050        CALL DELTA(V1,P1,DV4,DP4)
000056        DV = (DV1+2.0*DV2+2.0*DV3+DV4)/6.0
000064        DP = (DP1+2.0*DP2+2.0*DP3+DP4)/6.0
000072        RETURN
000073        END
```

RUNGE

```
              SUBROUTINE SATUP(P,TI)
000005        COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000005        COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
          C   FLAT RADIAL PROFILE
000005        IF(P.GT.30.0) GO TO 100
000011        IF(P.LE.0.0) GO TO 101
000013        TI = 1.0/(1.0+(1.0/TZ)*ALOG(1.0/FEX(P)))
000026        IF (TI.LT.TMIN) TI=TMIN
000032        GO TO 102
000033    100 TI = 1.0
000034        GO TO 102
000035    101 TI=TMIN
000036    102 RETURN
000037        END
```

SATUP

```
              SUBROUTINE SHORT
000002        COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002        COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002        COMMON /ADIAB/ XL3,C3,PA,DIADI
000002        COMMON /WORK/  XL, TS, C, F, H, EMIS, DUMM, ZF
000002        COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002       1               VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002       2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002        COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002        COMMON /PIPDTA/ TEV, DET, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002        COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
000002        COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000002        COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002        COMMON /LNG/ JSTART, JSAV, XL12, XL123
000002        WRITE(6,10)
000006     10 FORMAT(/,2X,*ITERATING IN SHORT*)
000006        TMAX=1.
000010        CALL SATUR(PSAV(1),TMIN)
000012        DO 100 I=1,30
000014        TSTART=(TMIN+TMAX)/2.
000017        DUMM=TSTART
000021        JZERO=0
000022        PZERO=PHI(TSTART)
000025        VZERO=0.
000026        ZZERO=0.
000027        TR1=TSTART
000031        IF(NRES.EQ.1) TR1=TR
000035        IF(NRES.EQ.2) TR=TR1
000041        IF(NRES.EQ.0.AND.TTRP.NE.0.0) TR1=TTRP
000051        CALL MOLE(TR1,YSP)
000053        RSUM=VR*XSR/TR
000056        XZERO=RSUM
000060        QZERO=0.
000061        CALL CONSEC(1)
000063        CALL PIPE
000064        CALL JOINT(1,PZERO,VZERO,VZERO)
000067        CALL CONSEC(2)
```

```
000071          CALL PIPE
000072          CALL JOINT(2,PZERO,VZERO,VZERO)
000075          CALL CONSEC(3)
000077          CALL PIPE
000100          CALL TESTF(MOREJ)
000102          IF(MOREJ.EQ.1) GO TO 200
000104          TMIN=TSTART
000106          WRITE(6,11) I,TSTART,XSUM,OSUM
000122          IF(MOREJ.EQ.0) RETURN
          C
000124          GO TO 100
000125      200 CONTINUE
000125          TMAX=TSTART
000127          WRITE(6,11) I,TSTART,XSUM,OSUM
000143       11 FORMAT(2X,*ITER=*,I4,2X,*TSTART=*,F10.5,2X,
000143        1   *XSUM=*,E12.5,2X,*OSUM=*,E12.5)
000143      100 CONTINUE
000145          WRITE(6,12)
000151       12 FORMAT(/,2X,*FAILED TO CONVERGE IN SHORT*)
000151          CALL EXIT
000152          END
```

```
             SUBROUTINE SINK(EMIS,POW,HF,TF,TS)
000010       SIGMA = 0.1714E-8
000012       TS = TF
000013       IF(EMIS.EQ.0.0) GO TO 102
000014       TS = SQRT(SQRT(POW/(EMIS*SIGMA)))
000031       IF(HF.EQ.0.0) GO TO 102
000032       IF(TS.EQ.TF) GO TO 102
000034       TM = (TF+TS)/2.0
000037       DO 101 I = 1,10
000041       HR = 4.0*EMIS*SIGMA*TM**3
000045       TS2 = (POW+HF*TF+3.0*EMIS*SIGMA*TM**4)/(HF+HR)
000057       TS = (TS+TS2)/2.0
000062       TM = TS
000063   101 CONTINUE
000065   102 RETURN
000066       END
```

SINK

```
RUNX COMPILER (VER.26)                    10/02/73. 15.05.14.

                        SUBROUTINE START
000002                  COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002                  COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002                  COMMON /ADIAB/ XL3,C3,PA,DIADI
000002                  COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000002                  COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002                1                VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002                2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002                  COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002                  COMMON /PIPDTA/ TEV, DET, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002                  COMMON /INTC/  NRES, MODEQM, ZPPINT, NRUN, NERROR
000002                  COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000002                  COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002                  COMMON /LNG/ JSTART, JSAV, XL12, XL123
               C
000002                  DO 100 I=1,JSTART
000004                  VV(I)=VSAV(I)
000007                  PP(I)=PSAV(I)
000012                  ZZ(I)=ZSAV(I)
000015                  XX(I)=XSAV(I)
000020                  QQ(I)=QSAV(I)
000023           100    CONTINUE
000026                  JZERO=JSTART
000030                  VZERO=(VSAV(JSTART)+1.0E-4)*1.001
000034                  ZZERO=ZSAV(JSTART)
000037                  XZERO=XSAV(JSTART)
000042                  QZERO=QSAV(JSTART)
000045                  P=PSAV(JSTART)
000050                  CALL SATUR(P,TI)
000052                  TSTART=TI+DELTEE/TEV
000055                  TMIN=TSTART
000057                  PZERO=PHI(TSTART)
000062                  IF(ZZERO.EQ.XL1) CALL JOINT(1,PZERO,VZERO,VZERO)
000067                  IF(ZZERO.GE.XL1) GO TO 200
000072                  CALL CONSEC(1)
000074                  CALL PIPE
000075                  CALL JOINT(1,PZERO,VZERO,VZERO)
```

START

TRW SYSTEMS

RUNX COMPILER (VER.26)   10/02/73. 15.05.14.   START

```
000100      200 CONTINUE
000100          IF(ZZERO.EQ.XL12) CALL JOINT(2,PZERO,VZERO,VZERO)
000105          IF(ZZERO.GE.XL12) GO TO 300
000110          CALL CONSEC(2)
000112          CALL PIPE
000113          CALL JOINT(2,PZERO,VZERO,VZERO)
000116      300 CALL CONSEC(3)
000120          CALL PIPE
000121          TMIN=TS1
000123          RETURN
000124          END
```

START

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RUNX COMPILER (VER.26)   10/02/73. 15.05.14.

```
                SUBROUTINE START2
000002          COMMON /COND1/ XL1, TS1, C1, F1, H1, EMIS1, XS1
000002          COMMON /COND2/ XL2, TS2, C2, F2, H2, EMIS2, XS2
000002          COMMON /ADIAB/ XL3,C3,RA,DIADI
000002          COMMON /HOPK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000002          COMMON /VPZXQ/ VV(1000), PP(1000), ZZ(1000), XX(1000), QQ(1000),
000002         1               VB(1000), PB(1000), ZB(1000), XB(1000), QB(1000),
000002         2   VSAV(1000), PSAV(1000), ZSAV(1000), XSAV(1000), QSAV(1000)
000002          COMMON /GASDTA/ TZ, D, E, A11, B11, C11, DELTEE, HFG
000002          COMMON /PIPDTA/ TEV, DET, Q, GAS, TR, VR, VRES, DZ, R, COEF,TTRP
000002          COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
000002          COMMON /PIPIN/ ZZERO, VZERO, PZERO, XZERO, QZERO, JZERO, XTEST
000002          COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000002          COMMON /LNG/ JSTART, JSAV, XL12, XL123
            C
000002          WRITE(5,10)
000005       10 FORMAT(/,2X,*ITERATING IN START2*)
000006          IB=0
000007          MOREJ=-1
000010          DO 100 I=1,JSTART
000012          VV(I)=VSAV(I)
000015          PP(I)=PSAV(I)
000020          ZZ(I)=ZSAV(I)
000023          XX(I)=XSAV(I)
000026          QQ(I)=QSAV(I)
000031      100 CONTINUE
000034          VSTART=VSAV(JSTART)
000037          ZSTART=ZSAV(JSTART)
000042          XSTART=XSAV(JSTART)
000045          QSTART=QSAV(JSTART)
000050          P=PSAV(JSTART)
000053          CALL SATUP(P,TSTART)
000055          TDIFF=DELTEE/(2.*TEV)
000060          DO 101 J=1,30
000062          IF(IB.EQ.0) TDIFF=2.*TDIFF
000065          IF(IB.EQ.1) TDIFF=TDIFF/2.
000071          SIGN=-MOREJ
```

START 2

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```
000073         TSTART=TSTART+SIGN*TDIFF
000076         TMIN=TSTART
000100         VZERO=VSTART
000102         PZERO=PHI(TSTART)
000105         ZZERO=ZSTART
000107         XZERO=XSTART
000111         QZERO=QSTART
000113         JZERO=JSTART
000115         IF(ZZERO.EQ.XL1) CALL JOINT(1,PZERO,VZERO,VZERO)
000122         IF(ZZERO.GE.XL1) GO TO 200
000125         CALL CONSEC(1)
000127         CALL PIPE
000130         CALL JOINT(1,PZERO,VZERO,VZERO)
000133     200 CONTINUE
000133         IF(ZZERO.EQ.XL12) CALL JOINT(2,PZERO,VZERO,VZERO)
000140         IF(ZZERO.GE.XL12) GO TO 300
000143         CALL CONSEC(2)
000145         CALL PIPE
000146         CALL JOINT(2,PZERO,VZERO,VZERO)
000151     300 CONTINUE
000151         CALL CONSEC(3)
000153         CALL PIPE
000154         CALL TESTF(MOREJ)
000155         WRITE(6,15) I,TSTART,XSUM,QSUM,JEND,MOREJ
000176      15 FORMAT(/,5X,*I=*,I4,2X,*TSTART=*,F10.5,2X,
000176       1   *GAS,I.E.,XSUM,=*,E12.5,2X,*QSUM=*E12.5,
000176       2   2X,*JEND=*,I4,2X,*MOREJ=*,I4)
000176         IF(MOREJ.EQ.0) RETURN
000200         IF(MOREJ.GT.0) IR=1
000203     101 CONTINUE
000205         WRITE(6,20)
000211      20 FORMAT(/,2X,*FAILED TO CONVERGE IN START2*)
000211         CALL EXIT
000212         END
```

START 2

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C-2

N74-13663
(NASA-CR-114672) USER'S MANUAL FOR THE TRW GASPIPE 2 PROGRAM: A VAPOR-GAS FRONT ANALYSIS PROGRAM FOR HEAT PIPES CONTAINING NON-CONDENSIBLE GAS D.K. Edwards, et al (TRW Systems Group) Oct. 1973 128 p CSCL 20M G3 33
Unclas

```
RUNX COMPILER (VER.26)                    10/02/73. 15.05.14.

              SUBROUTINE SURF(TI,S,TC)
000006        COMMON /WORK/  XL, TS, C, F, H, EMIS, TMIN, ZF
000006        DENOM = 4.0*EMIS*TI**3+H
000012        S = F*DENOM
000014        TC = (EMIS*TS**4+H*TS+3.0*EMIS*TI**4)/DENOM
000025        RETURN
000026        END
```

SURF

13111-6054-R0-00

RUNX COMPILER (VER.26)   10/02/73. 15.05.14.

```
              SUBROUTINE TESTF(MOREJ)
         C       TESTF TESTS TO FIND WHETHER QSUM OR XSUM
         C       IS ALL RIGHT OR NEEDS MORE OR LESS GAS CONTROL
000003        COMMON /PIPDTA/ TEV, DET, Q, GAS, TR, VR, VRES, DZ, P, COEF,TTRP
000003        COMMON /INTC/  NRES, MODEQM, ZPRINT, NRUN, NERROR
000003        COMMON /PIPOUT/ XSUM, QSUM, RSUM, XSR, ZFRONT, JEND, PREQ, PREG
000003        IF(MODEQM.EQ.1) GO TO 100
         C      PRESCRIBED Q HERE
000005        TEST=QSUM-Q
000007        MOREJ=0
000010        IF(ABS(TEST).LT.PREQ) RETURN
000014        MOREJ=1
000015        IF(TEST.GT.0.) RETURN
000017        MOREJ=-1
000020        RETURN
000021    100 CONTINUE
         C      PRESCRIBED GAS HERE
000021        TEST=XSUM-GAS
000023        MOREJ=0
000024        IF(ABS(TEST).LT.PREG) RETURN
000030        MOREJ=1
000031        IF(TEST.LT.0.) RETURN
000033        MOREJ=-1
000034        RETURN
000035        END
```

TESTF

APPENDIX C

SAMPLE PROBLEM

One sample problem consists of a performance run for a variable conductance heat pipe for temperature control of NASA's Lunar Surface Magnetometer (LSM). The function of the LSM heat pipe, illustrated in Figure C-1, is to supplement heat rejection during the lunar day while shutting down during the night. It is a passive, gas controlled heat pipe utilizing a cold, wicked gas reservoir. The design details are summarized in Table C-1.

At the "full-on" condition the boundary conditions were stated as follows:

Heat Rejection	> 4 Btu/hr
Evaporator Temperature	$\leq 530°R$
Effective Sink Temperature	$= 495°R$

The gas front will form in the cold trap region of the radiator at the end of the condenser, and may extend into the main radiator. Thus, Section 1 of the condenser (cards 5 and 10) consists of the cold trap region, and the main radiator will comprise Section 2 (cards 6 and 11). Note that, in terms of the model, the condenser is visualized as a straight tube with no bends; i.e., the radiator is considered one-half its actual width and twice the actual length. There is some error in this approach if the front extends into the main radiator, in that the bend section offers additional resistance to axial conduction, but the results will be conservative. There is negligible error in not using the actual condenser length, for the control gas occupies only a small portion of the entire length.

An input form for the sample run is shown in Figure C-2. The fluid properties were obtained from Table 4-1. Note that the fin width (PF1) is slightly less than the actual radiator width in the cold trap region to account for the reduced area due to gaps between the fin segments. Using the approximation discussed in Section 4-3 (Eq. 4-4) the effective axial conductivity of the cold trap is calculated as follows:*

*This approach neglects the axial conductance due to the axial metal felt wick inside the heat pipe.

$$(A_c)_{fin} = AF1 = (3.18)\ (0.016) = 0.0509\ in^2$$

$$A_{wall} = \frac{\pi}{4}\ (0.25^2 - 0.21^2) = 0.0145\ in^2$$

$$CF1 = \frac{9.3\ (0.0145)}{0.0509} \left[\frac{4.5}{8\ (0.2)} - 1\right] = 4.80\ \frac{Btu}{hr\text{-}ft\text{-}°F}$$

The effective conductivity of the main radiator is simply the thermal conductivity of aluminum since there are no fin segments. Also,

$$AF2 = (3.5)\ (0.016) = 0.056\ in^2$$

Because the circumferential grooves offer negligible radial heat transfer resistance, a wick thickness of 0.001 in. was input, which roughly corresponds to the average groove depth. For this reason the wick conductivity was assumed to be the conductivity of the working fluid. The axial wick was treated as an artery.

$$(A_c)_{wick} = (0.02)\ (0.21) = 0.0042\ in^2$$

$$DART = \left(\frac{4\ (0.0042)}{\pi}\right)^{1/2}$$

$$= 0.073\ in.$$

The effective sink temperature was input as follows:

$$POW1 = POW2 = (0.1712 \times 10^{-8})\ (0.85)\ (495)^4$$

$$= 87.5\ Btu/hr\text{-}ft^2$$

Finally, the nominal value for the heat input was estimated using Eq. (4-7).

$$\dot{Q} < \frac{(0.959)(3.18)(4.5)}{144}\ [(0.85)(0.1712 \times 10^{-8})(530)^4 - 87.5]$$

$$+ \frac{(0.959)(3.5)(7.5)}{144}\ [(0.85)(0.1712 \times 10^{-8})(530)^4 - 87.5]$$

$$\dot{Q} < 7.44\ Btu/hr$$

TABLE C-I
HEAT PIPE DESIGN DETAILS

Pipe:

Material:		321 stainless steel
Outside Diameter	=	0.250 in.
Wall Thickness	=	0.020 in.
Evaporator Length	=	2.0 in.
Condenser Length	=	13.5 in.
Adiabatic Length	=	3.5 in.

Radiator:

Material: 6061 aluminum sheet (0.016 in. thick)

Cold Trap:	N	=	9 fin segments
	L	=	4.5 in.
	L_f	=	0.30 in.
	L_g	=	0.2 in.

Wick Structure:

Material: Stainless steel
Description: Metal felt axial wick (0.21 in. X 0.02 in.) with circumferential grooves in the tube wall.

Reservoir:

Type: Cold, wicked
Volume: 0.79 in.

Working Fluid: Methanol

Control Gas: Nitrogen (1.26×10^{-7} lb-moles)

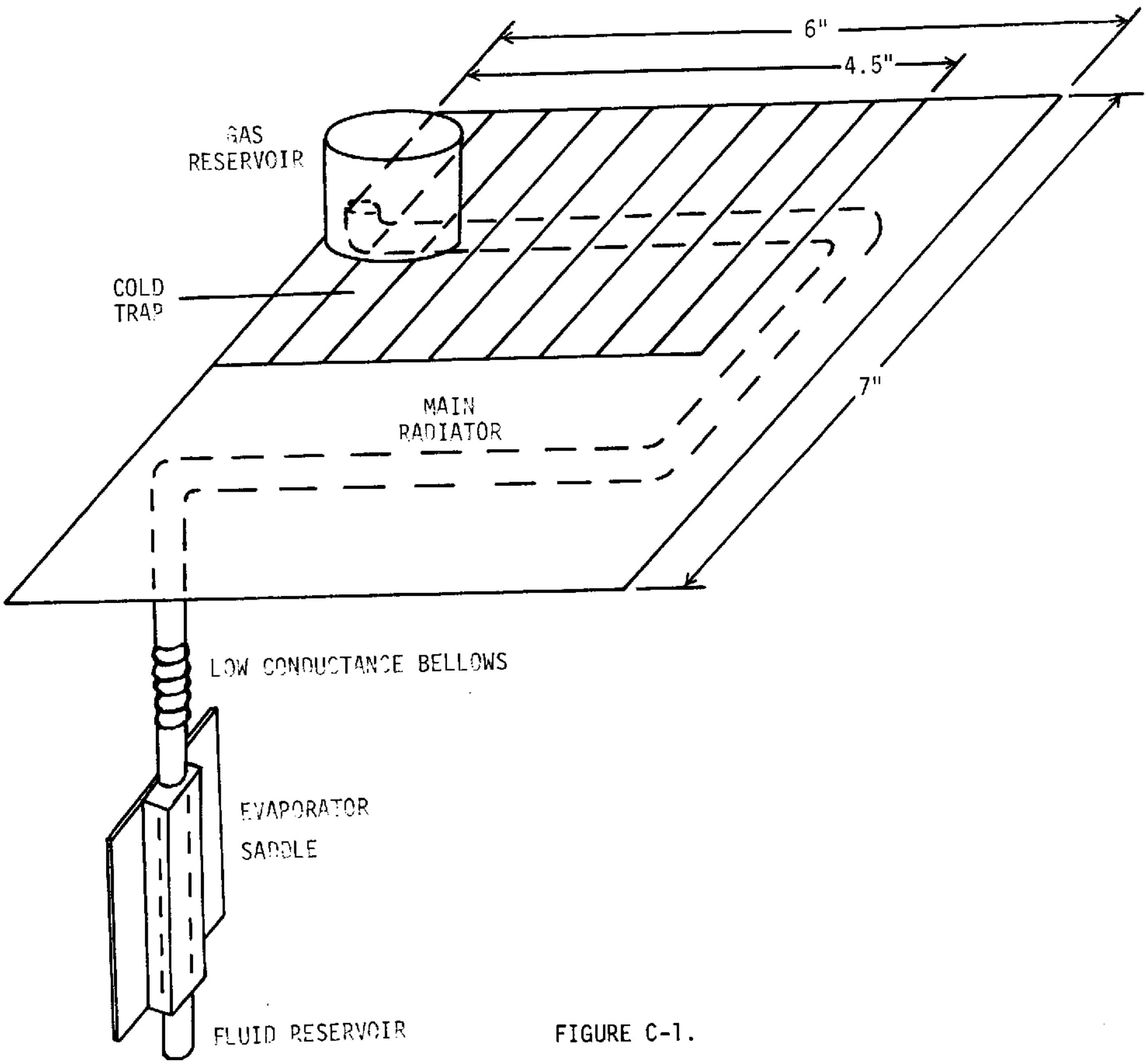

FIGURE C-1.

LUNAR SURFACE MAGNETOMETER HEAT PIPE

CARD	FORMAT	DESCRIPTION					
1	72H	1 SAMPLE PROBLEM 1					
2	72H	A SHORT HEAT PIPE					
		PARAMETERS					
3	3F12.5	A11	B11	C11			
		14.48	6262.17	557386.2			
4	4F12.5	XMC	DIF	E	HFG		
		32.0	0.442	0.81	501.0		
5	6F12.5	PF1	AF1	CF1	EF1	EMIS1	HF1
		3.18	0.051	4.8	0.96	0.85	0.0
6	6F12.5	PF2	AF2	CF2	EF2	EMIS2	HF2
		3.50	0.056	104.0	0.96	0.85	
7	6F12.5	DOUTA	THKWA	CWA	DELA	CWKA	XLINGA
		0.250	0.020	9.30	0.0010	0.120	0.500
8	3F12.5	DOUT	THKW	CW			
		0.25	0.02	9.3			
9	3F12.5	DEL	CONWK	DART			
		0.001	0.12	0.073			
10	3F12.5	TF1	POW1	XLONG1			
		0.	87.5	0.375			
11	3F12.5,	TF2	POW2	XLONG2			
		0.	87.5	0.625			
12	3F12.5 E12.5	TEV	Q	ZGAS	AGAS		
		530.	5.0	0.	1.26E-07		
13	2F12.5, 2I4, F12.5, I4	VRES	TRES	NRES	MODEQM	PRINT	NRUN
		0.79	495.0	2	1	0.50	

FIGURE C-2. Sample Input, LSM Heat Pipe

The second sample problem consists of a prediction for the AHPE (Ames Heat Pipe Experiment). The pipe, illustrated in Figure C-3, flew on board OAO-C (Orbiting Astronomical Observatory, Configuration C) launched in August 1972. The pipe provides temperature control for the spacecraft's OBP (On Board Processor) platform, keeping it at 60 $\pm$ 5°F despite large variations in environmental conditions and power dissipation loads. It utilizes a hot, nonwicked reservoir containing helium to control the heat rejection by the methanol working fluid. Axial conductivity was minimized by slots in the radiator fins as shown in the figure.

Figure C-4 shows the input data for the sample run, and the output follows.

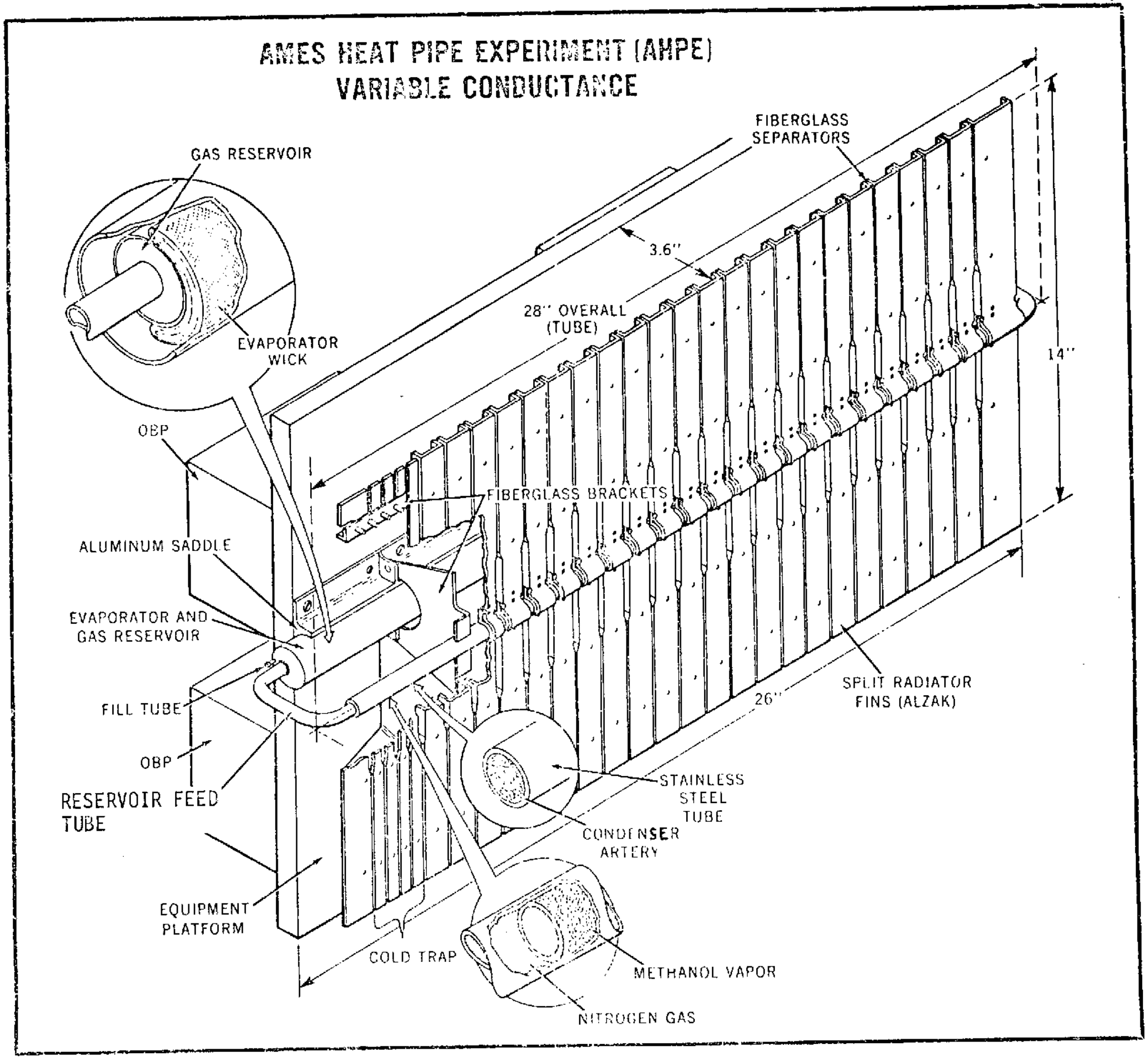

Figure C-3

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CARD	FORMAT	DECRIPTION					
1	72H	1 SAMPLE PROBLEM 2					
2	72H	A LONG HEAT PIPE					
3	3F12.5	A11	B11	C11			
		14.48	6262.17	557386.2			
4	4F12.5	XMC	DIF	E	HFG		
		32.0	1.77	.91	501.		
5	6F12.5	PF1	AF1	CF1	EF1	EMIS1	HF1
		14.3	0.458	0.545	0.85	0.75	
6	6F12.5	PF2	AF2	CF2	EF2	EMIS2	HF2
		14.3	0.458	1.1	0.89	0.75	0.48
7	6F12.5	DOUTA	THKWA	CWA	DELA	CWKA	XLONGA
		0.437	0.035	6.51	0.0052	0.09	0.30
8	3F12.5	DOUT	THKW	CW			
		0.437	0.035	6.51			
9	3F12.5	DEL	CONWK	DART			
		0.0052	0.09	0.205			
10	3F12.5	TF1	POW1	XLONG1			
		0.0	42.3	0.25			
11	3F12.5	TF2	POW2	XLONG2			
		544.0	42.3	1.960			
12	3F12.5 E12.5	TEV	Q	ZGAS			
		539.0	5.0	1.0			
13	2F12.5, 2I4, F12.5, I4	VRES	TRES	NRES	MODEQM	ZPRINT	NRUN
		13.2	539.0	0	1	0.500	

FIGURE C-4. Sample Input, AHPE Heat Pipe

SAMPLE PROBLEM 1
A SHORT HEAT PIPE

VAPOR PRESSURE PARAMETERS

A11=14.48000E+00 B11=62.52170E+02 C11=55.73862E+04

FLUID PROPERTIES

HFG= 501.0000 BTU/LB DTF= .4420 FTFT/HR XMC= 32.0000 CO EXP= .8100

FIN PROPERTIES, CONDENSER SECTION NUMBER 1

PF= 3.1800 IN AF= .0510 SQ IN CF= 4.8000 BTU/HRFTR EF= .9600 EMIS= .8500 HF= -0.0000 BTU/HRFT2R

FIN PROPERTIES, CONDENSER SECTION NUMBER 2

PF= 3.5000 IN AF= .0560 SQ IN CF=104.0000 BTU/HRFTR EF= .9600 EMIS= .8500 HF= -0.0000 BTU/HRFT2R

ADIABATIC SECTION PROPERTIES

DOUTA= .2500 IN. THKWA= .0200 IN.
CWA= 9.3000 BTU/HRFTR DELA= .0010 CWKA= .1200 BTU/HRFTR XLONGA= .5000 FT

PIPE PROPERTIES

DOUT= .2500 IN WALL THK= .0200 IN WALL COND= 9.3000 BTU/HRFTR

CONDENSER ENVIRONMENT, SECTION NUMBER 1

TF= 0. R POW= 4.3700E+01 BTU/HRFTFT XLONG= 3.7500E-01 FT

CONDENSER ENVIRONMENT, SECTION NUMBER 2

TF= 0. R POW= 8.7500E+01 BTU/HRFTFT XLONG= 6.2500E-01 FT

EXAMPLE 1

WICK PROPERTIES AND RESERVOIR CONDITIONS

```
WCK THK= .0019 IN   WCK CON=   .1200 BTU/HRFTR   D-ART=  .0730 IN   VRES=   .7900 CU IN   TRES= 495.0 R   NRES= 2
```

OPERATING CONDITIONS

```
TEV=  5.3000E+02 R    Q=  5.0000E+00 BTU/HR    MODEQM= 1    CEV=  3.4745E-04 LBMOLE/FT3    TTRAP= -0.          R
```

AMOUNT OF NONCONDENSIBLE GAS

```
GAS=  1.7216E+02    ZGAS=  1.0000E-02 FT    AGAS= -0.          LBMOLE    COEF=  1.1568E-09    LBMOLE
AMT=  2.0088E-07 LBMOLE   XGAS=  1.0000E-02 FT
```

DIMENSIONLESS TEMPERATURES

```
TZ=  1.6327E+01 TS1=  7.8521E-01 TS2=  9.3405E-01 TP=  7.8521E-01  TTRP=  0.
```

DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 1

```
EMIS=  8.5000E-01 C=  1.7201E+01 F=  1.1169E-01 H=  0.          XL=  2.3104E+01 XS=  9.8851E-01
```

DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 2

```
EMIS=  8.5000E-01 C=  2.7023E+02 F=  1.2293E-01 H=  0.          XL=  3.8507E+01 XS=  6.7515E-01
```

DIMENSIONLESS ADIABATIC SECTION PARAMETERS

```
C3= 6.09888E+00  PA= 7.37702E-03  DIADI= 1.00962E+00  R= 7.37702E-03  XL3= 3.08057E+01
```

ITERATING IN PATCH

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```
ITER=   0   TSTART=      .78568   Z1=   59.93265   XL1=   23.10428
ITER=   1   TSTART=      .85987   Z1=   10.13391   XL1=   23.10428
ITER=   2   TSTART=      .82277   Z1=   17.25290   XL1=   23.10428
ITER=   3   TSTART=      .80423   Z1=   24.00287   XL1=   23.10428
ITER=   4   TSTART=      .81350   Z1=   20.08438   XL1=   23.10428
ITER=   5   TSTART=      .80887   Z1=   21.85655   XL1=   23.10428
ITER=   6   TSTART=      .80655   Z1=   22.87404   XL1=   23.10428

ITERATING IN LONG
ITER=   0   JSTART=    1   XSUM= 1.88245E+02   QSUM= 1.59621E+00   JEND= 374   MOREJ=  -1

ITERATING IN SHORT
ITER=   1   TSTART=      .90328   XSUM= 1.30764E+02   QSUM= 2.07965E+00
ITER=   2   TSTART=      .85492   XSUM= 1.63010E+02   QSUM= 1.79534E+00
ITER=   3   TSTART=      .83074   XSUM= 1.77305E+02   QSUM= 1.55440E+00
ITER=   4   TSTART=      .84283   XSUM= 1.70100E+02   QSUM= 1.68818E+00
ITER=   5   TSTART=      .83678   XSUM= 1.73666E+02   QSUM= 1.62534E+00
ITER=   6   TSTART=      .83980   XSUM= 1.71877E+02   QSUM= 1.65767E+00

TRES =   4.4510E+02 DEG R     XCR =   9.5418E-01           RESGAS =   1.8048E-07 LB-MOLES

J =   1        ZIN =   4.8692E-02 INCHES           Z =   2.5000E-01
                 V =   9.0850E-06                  P =   4.5442E-02           TI =   8.3982E-01
              XSUM =   1.5496E+02               QSUM =   2.7790E-03     MASSFLOW =   9.0668E-08 LB/HR
             QFLOW =   1.3895E-02 BTU/HR          XS =   9.5416E-01        TWICK =   4.4511E+02 DEG R
             TWALL =   4.4506E+02 DEG R         MGAS =   1.8081E-07 LB-MOLES

J =  11        ZIN =   5.3562E-01 INCHES           Z =   2.7500E+00
                 V =   1.0734E-04                  P =   4.8133E-02           TI =   8.4226E-01
              XSUM =   1.5789E+02               QSUM =   3.1069E-02     MASSFLOW =   1.0713E-06 LB/HR
             QFLOW =   1.5535E-01 BTU/HR          XS =   9.5148E-01        TWICK =   4.4640E+02 DEG R
             TWALL =   4.4635E+02 DEG R         MGAS =   1.8412E-07 LB-MOLES

J =  21        ZIN =   1.0225E+00 INCHES           Z =   5.2500E+00
                 V =   2.4882E-04                  P =   5.6301E-02           TI =   8.4894E-01
              XSUM =   1.6060E+02               QSUM =   6.1935E-02     MASSFLOW =   2.4833E-06 LB/HR
             QFLOW =   3.0967E-01 BTU/HR          XS =   9.4338E-01        TWICK =   4.4994E+02 DEG R
             TWALL =   4.4989E+02 DEG R         MGAS =   1.8739E-07 LB-MOLES

J =  31        ZIN =   1.5095E+00 INCHES           Z =   7.7500E+00
                 V =   5.0925E-04                  P =   7.3405E-02           TI =   8.6044E-01
              XSUM =   1.6334E+02               QSUM =   9.8056E-02     MASSFLOW =   5.0823E-06 LB/HR
```

```
                                                                  TWICK =   4.5603E+02 DEG R
          QFLOW =  4.9028E-01 BTU/HR        XS =  9.2664E-01
          TWALL =  4.5597E+02 DEG R       MGAS =  1.9059E-07 LB-MOLES

J =  42     ZIN =  2.0451E+00 INCHES         Z =  1.0500E+01
              V =  1.1795E-03                P =  1.1368E-01               TI =   8.7980E-01
           XSUM =  1.6622E+02             QSUM =  1.4796E-01         MASSFLOW =   1.1772E-05 LB/HR
          QFLOW =  7.3981E-01 BTU/HR        XS =  8.8848E-01            TWICK =   4.6629E+02 DEG R
          TWALL =  4.6621E+02 DEG R       MGAS =  1.9394E-07 LB-MOLES

J =  52     ZIN =  2.5320E+00 INCHES         Z =  1.3000E+01
              V =  2.9169E-03                P =  1.9938E-01               TI =   9.0516E-01
           XSUM =  1.6862E+02             QSUM =  2.0780E-01         MASSFLOW =   2.9111E-05 LB/HR
          QFLOW =  1.0390E+00 BTU/HR        XS =  8.1279E-01            TWICK =   4.7974E+02 DEG R
          TWALL =  4.7963E+02 DEG R       MGAS =  1.9674E-07 LB-MOLES

J =  62     ZIN =  3.0189E+00 INCHES         Z =  1.5500E+01
              V =  9.4322E-03                P =  4.3650E-01               TI =   9.4015E-01
           XSUM =  1.7062E+02             QSUM =  2.8888E-01         MASSFLOW =   9.4134E-05 LB/HR
          QFLOW =  1.4444E+00 BTU/HR        XS =  6.3679E-01            TWICK =   4.9828E+02 DEG R
          TWALL =  4.9813E+02 DEG R       MGAS =  1.9908E-07 LB-MOLES

J =  72     ZIN =  3.5058E+00 INCHES         Z =  1.8000E+01
              V =  7.3376E-02                P =  1.5747E+00               TI =   9.8599E-01
           XSUM =  1.7179E+02             QSUM =  4.0226E-01         MASSFLOW =   7.3230E-04 LB/HR
          QFLOW =  2.0113E+00 BTU/HR        XS =  2.0125E-01            TWICK =   5.2257E+02 DEG R
          TWALL =  5.2236E+02 DEG R       MGAS =  2.0045E-07 LB-MOLES

J =  83     ZIN =  4.0415E+00 INCHES         Z =  2.0750E+01
              V =  5.6119E-01                P =  1.9487E+01               TI =   1.0000E+00
           XSUM =  1.7189E+02             QSUM =  5.6150E-01         MASSFLOW =   5.6006E-03 LB/HR
          QFLOW =  2.8075E+00 BTU/HR        XS =  3.3408E-09            TWICK =   5.3000E+02 DEG R
          TWALL =  5.2977E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J =  94     ZIN =  4.5487E+00 INCHES         Z =  2.3354E+01
              V =  7.0555E-01                P =  4.6968E+01               TI =   1.0000E+00
           XSUM =  1.7188E+02             QSUM =  7.0587E-01         MASSFLOW =   7.0414E-03 LB/HR
          QFLOW =  3.5293E+00 BTU/HR        XS =  0.                    TWICK =   5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J =  95     ZIN =  4.5974E+00 INCHES         Z =  2.3604E+01
              V =  7.1177E-01                P =  4.9902E+01               TI =   1.0000E+00
           XSUM =  1.7188E+02             QSUM =  7.1209E-01         MASSFLOW =   7.1035E-03 LB/HR
```

```
        QFLOW =  3.5604E+00 BTU/HR        XS =  0.                        TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 104   ZIN =  5.0356E+00 INCHES         Z =  2.5854E+01
            V =  7.6775E-01                P =  7.7463E+01                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  7.6807E-01           MASSFLOW =  7.6621E-03 LB/HR
        QFLOW =  3.8403E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 114   ZIN =  5.5225E+00 INCHES         Z =  2.8354E+01
            V =  8.2994E-01                P =  1.1053E+02                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  8.3026E-01           MASSFLOW =  8.2829E-03 LB/HR
        QFLOW =  4.1513E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 124   ZIN =  6.0095E+00 INCHES         Z =  3.0854E+01
            V =  8.9214E-01                P =  1.4618E+02                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  8.9246E-01           MASSFLOW =  8.9036E-03 LB/HR
        QFLOW =  4.4623E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 135   ZIN =  6.5451E+00 INCHES         Z =  3.3604E+01
            V =  9.6056E-01                P =  1.8836E+02                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  9.6088E-01           MASSFLOW =  9.5864E-03 LB/HR
        QFLOW =  4.8044E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 145   ZIN =  7.0320E+00 INCHES         Z =  3.6104E+01
            V =  1.0228E+00                P =  2.2941E+02                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  1.0231E+00           MASSFLOW =  1.0207E-02 LB/HR
        QFLOW =  5.1154E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 155   ZIN =  7.5189E+00 INCHES         Z =  3.8604E+01
            V =  1.0850E+00                P =  2.7304E+02                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  1.0853E+00           MASSFLOW =  1.0828E-02 LB/HR
        QFLOW =  5.4264E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
        TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 165   ZIN =  8.0058E+00 INCHES         Z =  4.1104E+01
            V =  1.1472E+00                P =  3.1924E+02                 TI =  1.0000E+00
         XSUM =  1.7188E+02             QSUM =  1.1475E+00           MASSFLOW =  1.1449E-02 LB/HR
```

```
          QFLOW =  5.7374E+00 BTU/HR        XS =  0.                          TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 176     ZIN =  8.5415E+00 INCHES         Z =  4.3854E+01
              V =  1.2156E+00                P =  3.7303E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.2159E+00           MASSFLOW =  1.2131E-02 LB/HR
          QFLOW =  6.0794E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 186     ZIN =  9.0284E+00 INCHES         Z =  4.6354E+01
              V =  1.2778E+00                P =  4.2464E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.2781E+00           MASSFLOW =  1.2752E-02 LB/HR
          QFLOW =  6.3904E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 196     ZIN =  9.5153E+00 INCHES         Z =  4.8854E+01
              V =  1.3400E+00                P =  4.7883E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.3403E+00           MASSFLOW =  1.3373E-02 LB/HR
          QFLOW =  6.7014E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 206     ZIN =  1.0002E+01 INCHES         Z =  5.1354E+01
              V =  1.4022E+00                P =  5.3558E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.4025E+00           MASSFLOW =  1.3994E-02 LB/HR
          QFLOW =  7.0124E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 217     ZIN =  1.0538E+01 INCHES         Z =  5.4104E+01
              V =  1.4706E+00                P =  6.0099E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.4709E+00           MASSFLOW =  1.4676E-02 LB/HR
          QFLOW =  7.3545E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 227     ZIN =  1.1025E+01 INCHES         Z =  5.6604E+01
              V =  1.5328E+00                P =  6.6315E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.5331E+00           MASSFLOW =  1.5297E-02 LB/HR
          QFLOW =  7.6655E+00 BTU/HR        XS =  0.                      TWICK =  5.3000E+02 DEG R
          TWALL =  5.2990E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 237     ZIN =  1.1512E+01 INCHES         Z =  5.9104E+01
              V =  1.5950E+00                P =  7.2789E+02                 TI =  1.0000E+00
           XSUM =  1.7188E+02             QSUM =  1.5953E+00           MASSFLOW =  1.5918E-02 LB/HR
```

```
         QFLOW =  7.9765E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.2990E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 249    ZIN =  1.2049E+01 INCHES          Z =  6.1961E+01
             V =  1.6574E+00                 P =  8.0227E+02                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
         QFLOW =  8.2883E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.3000E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 250    ZIN =  1.2097E+01 INCHES          Z =  6.2111E+01
             V =  1.6574E+00                 P =  8.0913E+02                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
         QFLOW =  8.2883E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.3000E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 259    ZIN =  1.2536E+01 INCHES          Z =  6.4361E+01
             V =  1.6574E+00                 P =  8.7087E+02                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
         QFLOW =  8.2883E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.3000E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 269    ZIN =  1.3023E+01 INCHES          Z =  6.6861E+01
             V =  1.6574E+00                 P =  9.3948E+02                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
         QFLOW =  8.2883E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.3000E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 279    ZIN =  1.3509E+01 INCHES          Z =  6.9361E+01
             V =  1.6574E+00                 P =  1.0081E+03                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
         QFLOW =  8.2883E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.3000E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 290    ZIN =  1.4045E+01 INCHES          Z =  7.2111E+01
             V =  1.6574E+00                 P =  1.0836E+03                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
         QFLOW =  8.2883E+00 BTU/HR         XS =  0.                       TWICK =  5.3000E+02 DEG R
         TWALL =  5.3000E+02 DEG R        MGAS =  2.0055E-07 LB-MOLES

J = 300    ZIN =  1.4532E+01 INCHES          Z =  7.4611E+01
             V =  1.6574E+00                 P =  1.1522E+03                  TI =  1.0000E+00
          XSUM =  1.7188E+02              QSUM =  1.6577E+00            MASSFLOW =  1.6540E-02 LB/HR
```

```
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 310     ZIN =   1.5019E+01 INCHES         Z =  7.7111E+01
              V =   1.6574E+00                P =  1.2208E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 320     ZIN =   1.5506E+01 INCHES         Z =  7.9611E+01
              V =   1.6574E+00                P =  1.2894E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 331     ZIN =   1.6041E+01 INCHES         Z =  8.2361E+01
              V =   1.6574E+00                P =  1.3649E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 341     ZIN =   1.6528E+01 INCHES         Z =  8.4861E+01
              V =   1.6574E+00                P =  1.4335E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 351     ZIN =   1.7015E+01 INCHES         Z =  8.7361E+01
              V =   1.6574E+00                P =  1.5021E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 361     ZIN =   1.7502E+01 INCHES         Z =  8.9861E+01
              V =   1.6574E+00                P =  1.5707E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
          QFLOW =   8.2883E+00 BTU/HR        XS =  0.                     TWICK =   5.3000E+02 DEG R
          TWALL =   5.3000E+02 DEG R       MGAS =  2.0055E-07 LB-MOLES

J = 372     ZIN =   1.8000E+01 INCHES         Z =  9.2417E+01
              V =   1.6574E+00                P =  1.6408E+03                TI =   1.0000E+00
           XSUM =   1.7188E+02             QSUM =  1.6577E+00          MASSFLOW =   1.6540E-02 LB/HR
```

```
                    QFLOW =   8.2883E+00 BTU/HR        XS =  0.                           TWICK =  5.3000E+02 DEG R
                    TWALL =   5.3000E+02 DEG R      MGAS =   2.0055E-07 LB-MOLES

GAS IN ONE DZ STEP OF GAS-BLOCKED CONDENSER 1     = 3.67221E-10 LB-MOLES

POWER LOST BY ONE DZ STEP OF FULL-ON CONDENSER 1 = 7.33508E-02 BTU/HR

TOTAL GAS IN PIPE AND RESERVOIR = 2.005455-07 LB-MOLES

TOTAL POWER LOST BY CONDENSERS  = 8.28835E+00 BTU/HR
```

SAMPLE PROBLEM 2
A LONG HEAT PIPE

VAPOR PRESSURE PARAMETERS

A11=14.48000E+00   B11=62.62170E+02   C11=55.73862E+04

FLUID PROPERTIES

HFG= 501.0000 BTU/LB   DIF=   1.7700 FTFT/HR   XMC= 32.0000   CD EXP=   .9100

FIN PROPERTIES, CONDENSER SECTION NUMBER 1

PF= 14.3000 IN AF=   .4580 SQ IN CF=   .5450 BTU/HRFTR EF= .8500 EMIS= .7500 HF= -0.0000 BTU/HRFT2R

FIN PROPERTIES, CONDENSER SECTION NUMBER 2

PF= 14.3000 IN AF=   .4580 SQ IN CF= 1.1000 BTU/HRFTR EF= .8900 EMIS= .7500 HF=   .4800 BTU/HRFT2R

ADIABATIC SECTION PROPERTIES

DOUTA=   .4370 IN. THKHA=   .0350 IN.
CWA=   6.5100 BTU/HRFTR DFLA=   .0052 CWKA=   .0900 BTU/HRFTR XLONGA=   .3000 FT

PIPE PROPERTIES

DOUT=   .4370 IN   WALL THK=   .0350 IN   WALL COND=   6.5100 BTU/HRFTR

CONDENSER ENVIRONMENT, SECTION NUMBER 1

TF= 0.   R   POW= 4.2300E+01 BTU/HRFTFT   XLONG= 2.5000E-01 FT

CONDENSER ENVIRONMENT, SECTION NUMBER 2

TF= 5.4400E+02 R   POW= 4.2300E+01 BTU/HRFTFT   XLONG= 1.9600E+00 FT

EXAMPLE 2

```
WICK PROPERTIES AND RESERVOIR CONDITIONS

WCK THK= .0052 IN  WCK CON=   .0900 BTU/HRFTR  D-ART=  .2050 IN  VRES= 13.2000 CU IN  TRES= 539.0 R  NRES= 0

OPERATING CONDITIONS

  TEV=  5.3900E+02 R   Q=  5.0000E+00 BTU/HR   MODEQM= 1   CEV=  4.4442E-04 LBMOLE/FT3   TTRAP= -0.          R

AMOUNT OF NONCONDENSIBLE GAS

GAS=  7.0804E+02   ZGAS=  1.0000E+00 FT   AGAS= -0.          LBMOLE   COEF=  5.0180E-09   LBMOLE
AMT=  3.5530E-06 LBMOLE  XGAS=  1.0000E+00 FT

DIMENSIONLESS TEMPERATURES

TZ=  1.5965E+01 TS1=  7.9018E-01 TS2=  8.9883E-01 TP=  1.0000E+00  TTRP=  0.

DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 1

EMIS=  7.5000E-01 C=  1.6561E+01 F=  7.1261E-01 H=  0.          XL=  1.0282E+01 XS=  9.8558E-01

DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 2

EMIS=  7.5000E-01 C=  2.4386E+01 F=  7.4614E-01 H=  1.7884E+00 XL=  8.0607E+01 XS=  8.2861E-01

DIMENSIONLESS ADIABATIC SECTION PARAMETERS

C3= 8.87568E+00  RA= 1.93942E-02  DIADI= 1.02916E+00  R= 1.93942E-02  XL3= 1.23378E+01

ITERATING IN PATCH
```

```
ITER=    0  TSTART=      .79065  Z1=  22.87307  XL1=  10.28154
ITER=    1  TSTART=      .84474  Z1=   3.48817  XL1=  10.28154
ITER=    2  TSTART=      .81769  Z1=   6.38581  XL1=  10.28154
ITER=    3  TSTART=      .80417  Z1=   9.15265  XL1=  10.28154
ITER=    4  TSTART=      .79741  Z1=  11.84004  XL1=  10.28154
ITER=    5  TSTART=      .80079  Z1=  10.28317  XL1=  10.28154

ITERATING IN LONG
ITER=    0  JSTART=   1  XSUM= 6.79337E+02  QSUM= 2.39200E+01  JEND= 423  MOREJ=   1
ITER=    1  JSTART= 207  XSUM= 7.29072E+02  QSUM= 7.54485E+00  JEND= 422  MOREJ=  -1
ITER=    2  JSTART= 104  XSUM= 7.05382E+02  QSUM= 1.54601E+01  JEND= 422  MOREJ=   1
ITER=    3  JSTART= 155  XSUM= 7.17112E+02  QSUM= 1.15409E+01  JEND= 422  MOREJ=  -1
ITER=    4  JSTART= 129  XSUM= 7.11132E+02  QSUM= 1.35389E+01  JEND= 422  MOREJ=  -1
ITER=    5  JSTART= 116  XSUM= 7.08142E+02  QSUM= 1.45379E+01  JEND= 422  MOREJ=   0

TRES =  5.3900E+02 DEG R     XSR =   9.8558E-01          RESGAS =   3.3459E-06 LB-MOLES

J =    1       ZIN =  7.2470E-02 INCHES          Z =  2.4837E-01
                 V =  2.4409E-05                 P =  1.9035E-02            TI =  8.0081E-01
              XSUM =  6.6337E+02              QSUM =  9.1593E-15      MASSFLOW =  2.4360E-07 LB/HR
             QFLOW =  4.5797E-15 BTU/HR         XS =  9.8099E-01         THICK =  4.3164E+02 DEG R
             TWALL =  4.3152E+02 DEG R        MGAS =  3.3288E-06 LB-MOLES

J =    7       ZIN =  5.1015E-01 INCHES          Z =  1.7484E+00
                 V =  1.8074E-04                 P =  1.9529E-02            TI =  8.0183E-01
              XSUM =  6.6521E+02              QSUM =  1.7418E-02      MASSFLOW =  1.8038E-06 LB/HR
             QFLOW =  8.7089E-02 BTU/HR         XS =  9.8049E-01         THICK =  4.3219E+02 DEG R
             TWALL =  4.3206E+02 DEG R        MGAS =  3.3380E-06 LB-MOLES

J =   14       ZIN =  1.0208E+00 INCHES          Z =  3.4984E+00
                 V =  4.3048E-04                 P =  2.1224E-02            TI =  8.0516E-01
              XSUM =  6.6734E+02              QSUM =  4.1702E-02      MASSFLOW =  4.2962E-06 LB/HR
             QFLOW =  2.0851E-01 BTU/HR         XS =  9.7877E-01         THICK =  4.3398E+02 DEG R
             TWALL =  4.3382E+02 DEG R        MGAS =  3.3487E-06 LB-MOLES

J =   21       ZIN =  1.5314E+00 INCHES          Z =  5.2484E+00
                 V =  8.7251E-04                 P =  2.4794E-02            TI =  8.1145E-01
              XSUM =  6.6946E+02              QSUM =  7.5051E-02      MASSFLOW =  8.7077E-06 LB/HR
             QFLOW =  3.7526E-01 BTU/HR         XS =  9.7515E-01         THICK =  4.3737E+02 DEG R
             TWALL =  4.3713E+02 DEG R        MGAS =  3.3594E-06 LB-MOLES

J =   28       ZIN =  2.0420E+00 INCHES          Z =  6.9984E+00
```

```
                 V =  1.8187E-03                P =  3.2009E-02              TI =  8.2197E-01
              XSUM =  6.7154E+02             QSUM =  1.2462E-01        MASSFLOW =  1.8151E-05 LB/HR
             QFLOW =  6.2309E-01 BTU/HR        XS =  9.6785E-01           TWICK =  4.4304E+02 DEG R
             TWALL =  4.4268E+02 DEG R       MGAS =  3.3698E-06 LB-MOLES

J =  35        ZIN =  2.5526E+00 INCHES         Z =  8.7484E+00
                 V =  4.2618E-03                P =  4.7729E-02              TI =  8.3889E-01
              XSUM =  6.7357E+02             QSUM =  2.0179E-01        MASSFLOW =  4.2533E-05 LB/HR
             QFLOW =  1.0085E+00 BTU/HR        XS =  9.5211E-01           TWICK =  4.5216E+02 DEG R
             TWALL =  4.5159E+02 DEG R       MGAS =  3.3800E-06 LB-MOLES

J =  42        ZIN =  3.1023E+00 INCHES         Z =  1.0632E+01
                 V =  7.0463E-03                P =  8.7844E-02              TI =  8.6574E-01
              XSUM =  6.7653E+02             QSUM =  2.7560E-01        MASSFLOW =  7.0322E-05 LB/HR
             QFLOW =  1.3780E+00 BTU/HR        XS =  9.1309E-01           TWICK =  4.6663E+02 DEG R
             TWALL =  4.6758E+02 DEG R       MGAS =  3.3948E-06 LB-MOLES

J =  43        ZIN =  3.1753E+00 INCHES         Z =  1.0882E+01
                 V =  6.8701E-03                P =  9.3154E-02              TI =  8.6839E-01
              XSUM =  6.7679E+02             QSUM =  2.5394E-01        MASSFLOW =  6.8564E-05 LB/HR
             QFLOW =  1.2697E+00 BTU/HR        XS =  9.0806E-01           TWICK =  4.6806E+02 DEG R
             TWALL =  4.6893E+02 DEG R       MGAS =  3.3961E-06 LB-MOLES

J =  48        ZIN =  3.5400E+00 INCHES         Z =  1.2132E+01
                 V =  5.6842E-03                P =  1.1705E-01              TI =  8.7873E-01
              XSUM =  6.7807E+02             QSUM =  1.6852E-01        MASSFLOW =  5.5728E-05 LB/HR
             QFLOW =  8.4258E-01 BTU/HR        XS =  8.8575E-01           TWICK =  4.7364E+02 DEG R
             TWALL =  4.7422E+02 DEG R       MGAS =  3.4026E-06 LB-MOLES

J =  55        ZIN =  4.0506E+00 INCHES         Z =  1.3882E+01
                 V =  3.8565E-03                P =  1.4201E-01              TI =  8.8758E-01
              XSUM =  6.7980E+02             QSUM =  9.4749E-02        MASSFLOW =  3.8488E-05 LB/HR
             QFLOW =  4.7374E-01 BTU/HR        XS =  8.6307E-01           TWICK =  4.7841E+02 DEG R
             TWALL =  4.7873E+02 DEG R       MGAS =  3.4113E-06 LB-MOLES

J =  62        ZIN =  4.5612E+00 INCHES         Z =  1.5632E+01
                 V =  2.4044E-03                P =  1.5812E-01              TI =  8.9253E-01
              XSUM =  6.8148E+02             QSUM =  5.3191E-02        MASSFLOW =  2.3996E-05 LB/HR
             QFLOW =  2.6595E-01 BTU/HR        XS =  8.4876E-01           TWICK =  4.8107E+02 DEG R
             TWALL =  4.8125E+02 DEG R       MGAS =  3.4197E-06 LB-MOLES

J =  69        ZIN =  5.0719E+00 INCHES         Z =  1.7382E+01
```

```
          V =  1.4278E-03              P =  1.6789E-01             TI =  8.9529E-01
       XSUM =  6.8314E+02           QSUM =  2.9786E-02       MASSFLOW =  1.4250E-05 LB/HR
      QFLOW =  1.4893E-01 BTU/HR      XS =  8.4021E-01          TWICK =  4.8256E+02 DEG R
      TWALL =  4.8265E+02 DEG R     MGAS =  3.4280E-06 LB-MOLES

J =  75   ZIN =  5.5095E+00 INCHES     Z =  1.8882E+01
          V =  8.8983E-04              P =  1.7295E-01             TI =  8.9666E-01
       XSUM =  6.8454E+02           QSUM =  1.8030E-02       MASSFLOW =  8.8806E-06 LB/HR
      QFLOW =  9.0150E-02 BTU/HR      XS =  8.3581E-01          TWICK =  4.8330E+02 DEG R
      TWALL =  4.8336E+02 DEG R     MGAS =  3.4350E-06 LB-MOLES

J =  82   ZIN =  6.0202E+00 INCHES     Z =  2.0632E+01
          V =  4.9651E-04              P =  1.7645E-01             TI =  8.9758E-01
       XSUM =  6.8616E+02           QSUM =  9.8642E-03       MASSFLOW =  4.9552E-06 LB/HR
      QFLOW =  4.9321E-02 BTU/HR      XS =  8.3279E-01          TWICK =  4.8380E+02 DEG R
      TWALL =  4.8383E+02 DEG R     MGAS =  3.4432E-06 LB-MOLES

J =  89   ZIN =  6.5308E+00 INCHES     Z =  2.2382E+01
          V =  2.5825E-04              P =  1.7835E-01             TI =  8.9808E-01
       XSUM =  6.8779E+02           QSUM =  5.0767E-03       MASSFLOW =  2.5773E-06 LB/HR
      QFLOW =  2.5384E-02 BTU/HR      XS =  8.3115E-01          TWICK =  4.8406E+02 DEG R
      TWALL =  4.8409E+02 DEG R     MGAS =  3.4513E-06 LB-MOLES

J =  96   ZIN =  7.0414E+00 INCHES     Z =  2.4132E+01
          V =  1.0370E-04              P =  1.7927E-01             TI =  8.9831E-01
       XSUM =  6.8940E+02           QSUM =  2.0284E-03       MASSFLOW =  1.0350E-06 LB/HR
      QFLOW =  1.0142E-02 BTU/HR      XS =  8.3036E-01          TWICK =  4.8419E+02 DEG R
      TWALL =  4.8421E+02 DEG R     MGAS =  3.4594E-06 LB-MOLES

J = 103   ZIN =  7.5517E+00 INCHES     Z =  2.5881E+01
          V =  0.                      P =  1.8130E-01             TI =  8.9883E-01
       XSUM =  6.9102E+02           QSUM =  0.                   MASSFLOW =  0.         LB/HR
      QFLOW =  0.         BTU/HR      XS =  8.2861E-01          TWICK =  4.8447E+02 DEG R
      TWALL =  4.8447E+02 DEG R     MGAS =  3.4675E-06 LB-MOLES

J = 110   ZIN =  8.0613E+00 INCHES     Z =  2.7628E+01
          V =  0.                      P =  1.8130E-01             TI =  8.9883E-01
       XSUM =  6.9263E+02           QSUM =  0.                   MASSFLOW =  0.         LB/HR
      QFLOW =  0.         BTU/HR      XS =  8.2861E-01          TWICK =  4.8447E+02 DEG R
      TWALL =  4.8447E+02 DEG R     MGAS =  3.4756E-06 LB-MOLES

J = 117   ZIN =  8.5711E+00 INCHES     Z =  2.9375E+01
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                V =  1.1747E-04                P =  1.8322E-01             TI =  8.9932E-01
             XSUM =  6.9424E+02             QSUM =  3.3179E-04       MASSFLOW =  1.1724E-06 LB/HR
            QFLOW =  1.6589E-03 BTU/HR        XS =  8.2697E-01          TWICK =  4.8473E+02 DEG R
            TWALL =  4.8472E+02 DEG R       MGAS =  3.4837E-06 LB-MOLES

J = 123       ZIN =  9.0088E+00 INCHES         Z =  3.0875E+01
                V =  2.4382E-04                P =  1.8400E-01             TI =  8.9952E-01
             XSUM =  6.9562E+02             QSUM =  2.7314E-03       MASSFLOW =  2.4334E-06 LB/HR
            QFLOW =  1.3657E-02 BTU/HR        XS =  8.2630E-01          TWICK =  4.8484E+02 DEG R
            TWALL =  4.8482E+02 DEG R       MGAS =  3.4906E-06 LB-MOLES

J = 130       ZIN =  9.5194E+00 INCHES         Z =  3.2625E+01
                V =  4.7522E-04                P =  1.8580E-01             TI =  8.9997E-01
             XSUM =  6.9722E+02             QSUM =  7.0565E-03       MASSFLOW =  4.7427E-06 LB/HR
            QFLOW =  3.5283E-02 BTU/HR        XS =  8.2476E-01          TWICK =  4.8508E+02 DEG R
            TWALL =  4.8505E+02 DEG R       MGAS =  3.4987E-06 LB-MOLES

J = 137       ZIN =  1.0030E+01 INCHES         Z =  3.4375E+01
                V =  8.8284E-04                P =  1.8920E-01             TI =  9.0080E-01
             XSUM =  6.9883E+02             QSUM =  1.4459E-02       MASSFLOW =  8.8108E-06 LB/HR
            QFLOW =  7.2295E-02 BTU/HR        XS =  8.2186E-01          TWICK =  4.8553E+02 DEG R
            TWALL =  4.8548E+02 DEG R       MGAS =  3.5067E-06 LB-MOLES

J = 144       ZIN =  1.0541E+01 INCHES         Z =  3.6125E+01
                V =  1.6367E-03                P =  1.9549E-01             TI =  9.0231E-01
             XSUM =  7.0042E+02             QSUM =  2.7480E-02       MASSFLOW =  1.6334E-05 LB/HR
            QFLOW =  1.3740E-01 BTU/HR        XS =  8.1653E-01          TWICK =  4.8635E+02 DEG R
            TWALL =  4.8624E+02 DEG R       MGAS =  3.5147E-06 LB-MOLES

J = 151       ZIN =  1.1051E+01 INCHES         Z =  3.7875E+01
                V =  3.0969E-03                P =  2.0724E-01             TI =  9.0501E-01
             XSUM =  7.0199E+02             QSUM =  5.0592E-02       MASSFLOW =  3.0907E-05 LB/HR
            QFLOW =  2.5296E-01 BTU/HR        XS =  8.0668E-01          TWICK =  4.8780E+02 DEG R
            TWALL =  4.8762E+02 DEG R       MGAS =  3.5226E-06 LB-MOLES

J = 158       ZIN =  1.1562E+01 INCHES         Z =  3.9625E+01
                V =  6.1223E-03                P =  2.2987E-01             TI =  9.0979E-01
             XSUM =  7.0353E+02             QSUM =  9.1749E-02       MASSFLOW =  6.1100E-05 LB/HR
            QFLOW =  4.5875E-01 BTU/HR        XS =  7.9803E-01          TWICK =  4.9038E+02 DEG R
            TWALL =  4.9005E+02 DEG R       MGAS =  3.5303E-06 LB-MOLES

J = 165       ZIN =  1.2073E+01 INCHES         Z =  4.1375E+01
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                 V =  1.3115E-02                 P =  2.7617E-01                  TI =  9.1823E-01
              XSUM =  7.0501E+02              QSUM =  1.5513E-01            MASSFLOW =  1.3089E-04 LB/HR
             QFLOW =  8.2564E-01 BTU/HR         XS =  7.5129E-01               TWICK =  4.9493E+02 DEG R
             TWALL =  4.9435E+02 DEG R        MGAS =  3.5377E-06 LB-MOLES

J = 171        ZIN =  1.2519E+01 INCHES          Z =  4.2875E+01
                 V =  2.8176E-02                 P =  3.6026E-01                  TI =  9.3032E-01
              XSUM =  7.0618E+02              QSUM =  2.7231E-01            MASSFLOW =  2.8120E-04 LB/HR
             QFLOW =  1.3616E+00 BTU/HR         XS =  6.8909E-01               TWICK =  5.0144E+02 DEG R
             TWALL =  5.0050E+02 DEG R        MGAS =  3.5436E-06 LB-MOLES

J = 178        ZIN =  1.3021E+01 INCHES          Z =  4.4625E+01
                 V =  8.6856E-02                 P =  6.1122E-01                  TI =  9.5328E-01
              XSUM =  7.0734E+02              QSUM =  4.8596E-01            MASSFLOW =  8.6682E-04 LB/HR
             QFLOW =  2.4298E+00 BTU/HR         XS =  5.3328E-01               TWICK =  5.1382E+02 DEG R
             TWALL =  5.1215E+02 DEG R        MGAS =  3.5494E-06 LB-MOLES

J = 185        ZIN =  1.3531E+01 INCHES          Z =  4.6375E+01
                 V =  4.1771E-01                 P =  1.5823E+00                  TI =  9.8580E-01
              XSUM =  7.0803E+02              QSUM =  8.5246E-01            MASSFLOW =  4.1688E-03 LB/HR
             QFLOW =  4.2623E+00 BTU/HR         XS =  1.9996E-01               TWICK =  5.3134E+02 DEG R
             TWALL =  5.2861E+02 DEG R        MGAS =  3.5529E-06 LB-MOLES

J = 197        ZIN =  1.4006E+01 INCHES          Z =  4.8000E+01
                 V =  1.3047E+00                 P =  5.4091E+00                  TI =  9.9972E-01
              XSUM =  7.0814E+02              QSUM =  1.3283E+00            MASSFLOW =  1.3021E-02 LB/HR
             QFLOW =  6.6413E+00 BTU/HR         XS =  4.3333E-03               TWICK =  5.3885E+02 DEG R
             TWALL =  5.3564E+02 DEG R        MGAS =  3.5535E-06 LB-MOLES

J = 207        ZIN =  1.4516E+01 INCHES          Z =  4.9750E+01
                 V =  1.8675E+00                 P =  1.2886E+01                  TI =  1.0000E+00
              XSUM =  7.0814E+02              QSUM =  1.8670E+00            MASSFLOW =  1.8637E-02 LB/HR
             QFLOW =  9.3350E+00 BTU/HR         XS =  2.4535E-06               TWICK =  5.3900E+02 DEG R
             TWALL =  5.3578E+02 DEG R        MGAS =  3.5535E-06 LB-MOLES

J = 214        ZIN =  1.5027E+01 INCHES          Z =  5.1500E+01
                 V =  2.4065E+00                 P =  2.2908E+01                  TI =  1.0000E+00
              XSUM =  7.0814E+02              QSUM =  2.4060E+00            MASSFLOW =  2.4017E-02 LB/HR
             QFLOW =  1.2030E+01 BTU/HR         XS =  1.0894E-10               TWICK =  5.3900E+02 DEG R
             TWALL =  5.3579E+02 DEG R        MGAS =  3.5535E-06 LB-MOLES

J = 221        ZIN =  1.5537E+01 INCHES          Z =  5.3250E+01
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             V =  2.9455E+00               P =  3.5459E+01            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  2.9450E+00      MASSFLOW =  2.9396E-02 LB/HR
         QFLOW =  1.4725E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 228    ZIN =  1.6048E+01 INCHES        Z =  5.5000E+01
             V =  3.4845E+00               P =  5.0536E+01            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  3.4840E+00      MASSFLOW =  3.4775E-02 LB/HR
         QFLOW =  1.7420E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 235    ZIN =  1.6559E+01 INCHES        Z =  5.6750E+01
             V =  4.0235E+00               P =  6.8142E+01            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  4.0230E+00      MASSFLOW =  4.0155E-02 LB/HR
         QFLOW =  2.0115E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 242    ZIN =  1.7069E+01 INCHES        Z =  5.8500E+01
             V =  4.5625E+00               P =  8.8276E+01            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  4.5620E+00      MASSFLOW =  4.5534E-02 LB/HR
         QFLOW =  2.2810E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 248    ZIN =  1.7507E+01 INCHES        Z =  6.0000E+01
             V =  5.0245E+00               P =  1.0755E+02            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  5.0240E+00      MASSFLOW =  5.0145E-02 LB/HR
         QFLOW =  2.5120E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 255    ZIN =  1.8018E+01 INCHES        Z =  6.1750E+01
             V =  5.5635E+00               P =  1.3237E+02            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  5.5630E+00      MASSFLOW =  5.5524E-02 LB/HR
         QFLOW =  2.7815E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 262    ZIN =  1.8528E+01 INCHES        Z =  6.3500E+01
             V =  6.1025E+00               P =  1.5973E+02            TI =  1.0000E+00
          XSUM =  7.0814E+02            QSUM =  6.1020E+00      MASSFLOW =  6.0903E-02 LB/HR
         QFLOW =  3.0510E+01 BTU/HR       XS =  0.                 TWICK =  5.3900E+02 DEG R
         TWALL =  5.3578E+02 DEG R      MGAS =  3.5535E-06 LB-MOLES

J = 269    ZIN =  1.9039E+01 INCHES        Z =  6.5250E+01
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               V =  6.6415E+00                P =  1.8961E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  6.6410E+00       MASSFLOW =  6.6282E-02 LB/HR
           QFLOW =  3.3205E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 276      ZIN =  1.9550E+01 INCHES         Z =  6.7000E+01
               V =  7.1805E+00                P =  2.2283E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  7.1800E+00       MASSFLOW =  7.1662E-02 LB/HR
           QFLOW =  3.5900E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 283      ZIN =  2.0060E+01 INCHES         Z =  6.8750E+01
               V =  7.7195E+00                P =  2.5697E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  7.7190E+00       MASSFLOW =  7.7041E-02 LB/HR
           QFLOW =  3.8595E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 290      ZIN =  2.0571E+01 INCHES         Z =  7.0500E+01
               V =  8.2585E+00                P =  2.9443E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  8.2580E+00       MASSFLOW =  8.2420E-02 LB/HR
           QFLOW =  4.1290E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 296      ZIN =  2.1008E+01 INCHES         Z =  7.2000E+01
               V =  8.7205E+00                P =  3.2856E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  8.7200E+00       MASSFLOW =  8.7031E-02 LB/HR
           QFLOW =  4.3600E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 303      ZIN =  2.1519E+01 INCHES         Z =  7.3750E+01
               V =  9.2595E+00                P =  3.7072E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  9.2590E+00       MASSFLOW =  9.2410E-02 LB/HR
           QFLOW =  4.6295E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 310      ZIN =  2.2030E+01 INCHES         Z =  7.5500E+01
               V =  9.7985E+00                P =  4.1541E+02             TI =  1.0000E+00
            XSUM =  7.0814E+02             QSUM =  9.7980E+00       MASSFLOW =  9.7790E-02 LB/HR
           QFLOW =  4.8990E+01 BTU/HR        XS =  0.                  TWICK =  5.3900E+02 DEG R
           TWALL =  5.3578E+02 DEG R       MGAS =  3.5535E-06 LB-MOLES

J = 317      ZIN =  2.2540E+01 INCHES         Z =  7.7250E+01
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        V =  1.0338E+01                     P =  4.6263E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.0337E+01        MASSFLOW =  1.0317E-01 LB/HR
    QFLOW =  5.1685E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 324  ZIN =  2.3051E+01 INCHES           Z =  7.9000E+01
        V =  1.0877E+01                     P =  5.1238E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.0876E+01        MASSFLOW =  1.0855E-01 LB/HR
    QFLOW =  5.4380E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 331  ZIN =  2.3562E+01 INCHES           Z =  8.0750E+01
        V =  1.1416E+01                     P =  5.6465E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.1415E+01        MASSFLOW =  1.1393E-01 LB/HR
    QFLOW =  5.7075E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 338  ZIN =  2.4072E+01 INCHES           Z =  8.2500E+01
        V =  1.1955E+01                     P =  6.1945E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.1954E+01        MASSFLOW =  1.1931E-01 LB/HR
    QFLOW =  5.9770E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 344  ZIN =  2.4510E+01 INCHES           Z =  8.4000E+01
        V =  1.2417E+01                     P =  6.6844E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.2416E+01        MASSFLOW =  1.2392E-01 LB/HR
    QFLOW =  6.2080E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 351  ZIN =  2.5020E+01 INCHES           Z =  8.5750E+01
        V =  1.2956E+01                     P =  7.2793E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.2955E+01        MASSFLOW =  1.2930E-01 LB/HR
    QFLOW =  6.4775E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 358  ZIN =  2.5531E+01 INCHES           Z =  8.7500E+01
        V =  1.3495E+01                     P =  7.8996E+02              TI =  1.0000E+00
     XSUM =  7.0814E+02                  QSUM =  1.3494E+01        MASSFLOW =  1.3468E-01 LB/HR
    QFLOW =  6.7470E+01 BTU/HR             XS =  0.                   TWICK =  5.3900E+02 DEG R
    TWALL =  5.3578E+02 DEG R            MGAS =  3.5535E-06 LB-MOLES

J = 365  ZIN =  2.6042E+01 INCHES           Z =  8.9250E+01
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	V =	1.4034E+01	P =	8.5451E+02	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4033E+01	MASSFLOW =	1.4006E-01 LB/HR
	QFLOW =	7.0165E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3578E+02 DEG R	MGAS =	3.5535E-06 LB-MOLES		
J = 372	ZIN =	2.6520E+01 INCHES	Z =	9.0889E+01		
	V =	1.4538E+01	P =	9.1727E+02	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4538E+01	MASSFLOW =	1.4509E-01 LB/HR
	QFLOW =	7.2690E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3578E+02 DEG R	MGAS =	3.5535E-06 LB-MOLES		
J = 373	ZIN =	2.6593E+01 INCHES	Z =	9.1139E+01		
	V =	1.4538E+01	P =	9.2701E+02	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4538E+01	MASSFLOW =	1.4509E-01 LB/HR
	QFLOW =	7.2690E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3900E+02 DEG R	MGAS =	3.5535E-06 LB-MOLES		
J = 379	ZIN =	2.7031E+01 INCHES	Z =	9.2639E+01		
	V =	1.4538E+01	P =	9.8545E+02	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4538E+01	MASSFLOW =	1.4509E-01 LB/HR
	QFLOW =	7.2690E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3900E+02 DEG R	MGAS =	3.5535E-06 LB-MOLES		
J = 386	ZIN =	2.7541E+01 INCHES	Z =	9.4389E+01		
	V =	1.4538E+01	P =	1.0536E+03	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4538E+01	MASSFLOW =	1.4509E-01 LB/HR
	QFLOW =	7.2690E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3900E+02 DEG R	MGAS =	3.5535E-06 LB-MOLES		
J = 393	ZIN =	2.8052E+01 INCHES	Z =	9.6139E+01		
	V =	1.4538E+01	P =	1.1218E+03	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4538E+01	MASSFLOW =	1.4509E-01 LB/HR
	QFLOW =	7.2690E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3900E+02 DEG R	MGAS =	3.5535E-05 LB-MOLES		
J = 400	ZIN =	2.8562E+01 INCHES	Z =	9.7889E+01		
	V =	1.4538E+01	P =	1.1900E+03	TI =	1.0000E+00
	XSUM =	7.0814E+02	QSUM =	1.4538E+01	MASSFLOW =	1.4509E-01 LB/HR
	QFLOW =	7.2690E+01 BTU/HR	XS =	0.	TWICK =	5.3900E+02 DEG R
	TWALL =	5.3900E+02 DEG R	MGAS =	3.5535E-06 LB-MOLES		
J = 406	ZIN =	2.9000E+01 INCHES	Z =	9.9389E+01		

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                 V =  1.4538E+01            P =  1.2484E+03            TI =  1.0000E+00
              XSUM =  7.0814E+02         QSUM =  1.4538E+01      MASSFLOW =  1.4509E-01 LB/HR
             QFLOW =  7.2690E+01 BTU/HR    XS =  0.                 TWICK =  5.3900E+02 DEG R
             TWALL =  5.3900E+02 DEG R   MGAS =  3.5535E-06 LB-MOLES

J = 413        ZIN =  2.9511E+01 INCHES     Z =  1.0114E+02
                 V =  1.4538E+01            P =  1.3166E+03            TI =  1.0000E+00
              XSUM =  7.0814E+02         QSUM =  1.4538E+01      MASSFLOW =  1.4509E-01 LB/HR
             QFLOW =  7.2690E+01 BTU/HR    XS =  0.                 TWICK =  5.3900E+02 DEG R
             TWALL =  5.3900E+02 DEG R   MGAS =  3.5535E-06 LB-MOLES

J = 420        ZIN =  3.0021E+01 INCHES     Z =  1.0289E+02
                 V =  1.4538E+01            P =  1.3848E+03            TI =  1.0000E+00
              XSUM =  7.0814E+02         QSUM =  1.4538E+01      MASSFLOW =  1.4509E-01 LB/HR
             QFLOW =  7.2690E+01 BTU/HR    XS =  0.                 TWICK =  5.3900E+02 DEG R
             TWALL =  5.3900E+02 DEG R   MGAS =  3.5535E-06 LB-MOLES

J = 422        ZIN =  3.0120E+01 INCHES     Z =  1.0323E+02
                 V =  1.4538E+01            P =  1.3980E+03            TI =  1.0000E+00
              XSUM =  7.0814E+02         QSUM =  1.4538E+01      MASSFLOW =  1.4509E-01 LB/HR
             QFLOW =  7.2690E+01 BTU/HR    XS =  0.                 TWICK =  5.3900E+02 DEG R
             TWALL =  5.3900E+02 DEG R   MGAS =  3.5535E-06 LB-MOLES

GAS IN ONE DZ STEP OF GAS-BLOCKED CONDENSER 1    = 1.56471E-09 LB-MOLES

POWER LOST BY ONE DZ STEP OF FULL-ON CONDENSER 1 = 3.91387E-01 BTU/HR

TOTAL GAS IN PIPE AND RESERVOIR = 3.55346E-06 LB-MOLES

TOTAL POWER LOST BY CONDENSERS  = 7.26895E+01 BTU/HR
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