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USER'S MANUAL FOR THE TRW GASPIPE PROGRAM

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

APRIL 1971

TRW DOCUMENT NO 13111-6022-RO-00

PREPARED BY
D K EDWARDS
G L FLEISCHMAN
B D MARCUS

CONTRACT NO NAS 2-5503

PREPARED FOR
NASA - AMES RESEARCH CENTER
MOFFET FIELD, CALIFORNIA 93405

MATERIALS SCIENCE STAFF
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FOREWORD

The work described in this report was performed under NASA contract NAS2-5503, "Design, Fabrication, and Testing of a Variable Conductance Constant Temperature Heat Pipe". The contract is administered by Ames Research Center, Moffett Field, California, with Mr. J. P. Kirkpatrick serving as Technical Monitor.

The program is being conducted by TRW Systems Group of TRW, Inc., Redondo Beach, California, with Dr. Bruce D. Marcus serving as Program Manager and Principal Investigator. Major contributers to the effort include Mr. G. L. Fleischman and Prof. D. K. Edwards.

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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 program for two condenser sections with a step change in the condenser/fin properties. Thus, the program can accommodate cold traps or adiabatic sections in addition to the primary condenser.

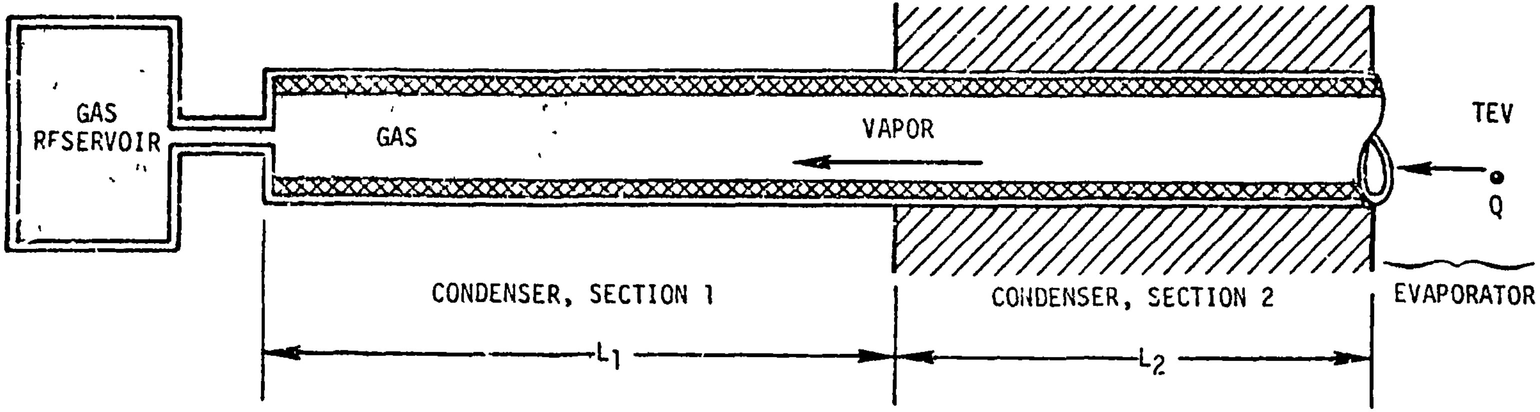
The analysis and formulation of the equations used in the program are presented in Section 2. Basically, a one-dimensional steady state analysis has been used and the equations written assuming small wick resistance and negligible vapor pressure drop along the pipe. The analytical model used is shown 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.

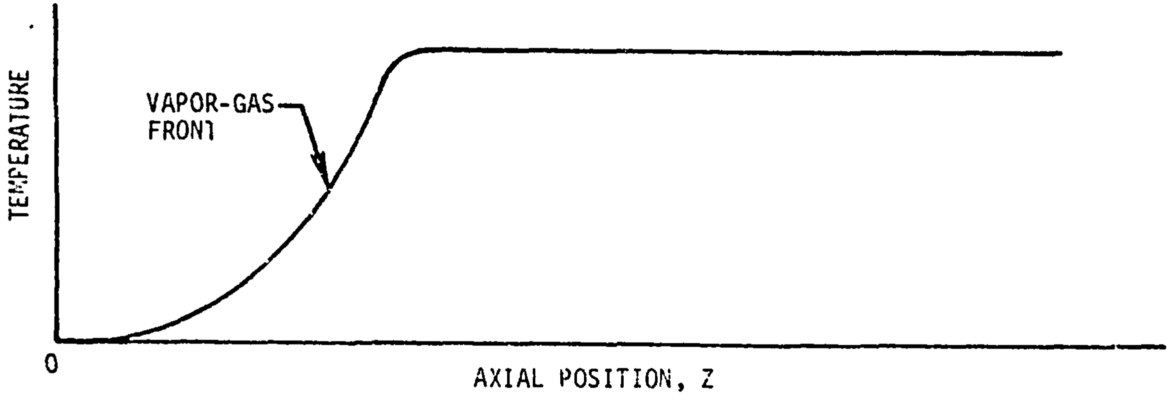
Section 3 discusses the potential uses of the program for research, heat pipe design and performance predictions. The program input requirements are described in Section 4, and the output discussed in Section 5.

Flow diagrams, program listings and a sample problem 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] and [3] can aid in this respect.



a. Schematic Diagram of a Gas-Loaded Heat Pipe



b. Temperature Distribution

FIGURE 1-1. Vapor-Gas Front Analytical Model for a Gas Loaded Heat Pipe

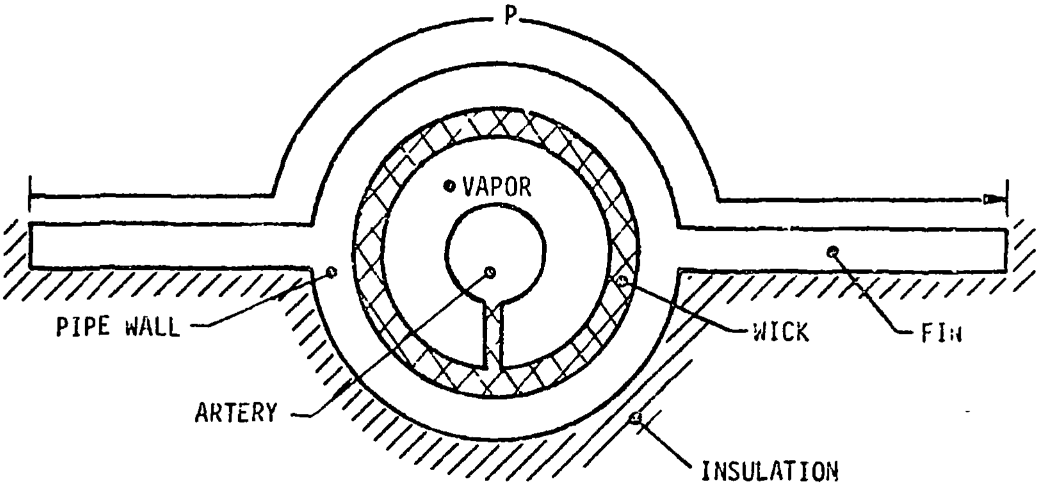


FIGURE 1-2. Cross-section of Condenser

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

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

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

$$dQ = S dz\,(T_w - T_c) \tag{2-2}$$

where

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

and

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

We adopt the unusual sign convention that the power 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

$$\frac{2\pi k_e dz}{\ln \frac{D_1+2\delta}{D_1}} (T_1 - T_w) = K dz\,(T_i - T_w) \qquad (2\text{-}5)$$

where k_e is the equivalent thermal conductivity of the liquid-filled wick, D_1 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

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

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

$$C = \sum_{n=1}^{N} k_n A_{c,n} \qquad (2\text{-}7)$$

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_1/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

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

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

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

$$-c\mathcal{D}\frac{dx_s}{dz} - cVx_b = 0 \tag{2-9}$$

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 $m = cVA_cM$, 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 ξ by introducing

$$\xi = \ln\frac{1}{x}, \quad x = e^{-\xi} \tag{2-10}$$

Equation (2-9) then becomes

$$A_c M \mathcal{D}\frac{d\xi}{dz} + m = 0 \tag{2-11}$$

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.

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

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

$$\dot{m} = 0 \text{ at } z = 0 \qquad (2\text{-}13)$$

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

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

or a total number of moles of non-condensible present

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

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 is 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, is 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

$$Z^* = z/D_e$$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$c\rho = c_{ev}\rho_{ev}(T_i/T_{ev})^E$$

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

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

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

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

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

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

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

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^*.

$$C^* \frac{d^2T_i^*}{dz^{*2}} = \phi_1 \frac{dV^*}{dz^*} - \phi_1 \phi_2 \phi_3 \qquad (2\text{-}22)$$

where the functions ϕ_1, ϕ_2, ϕ_3 are

$$\phi_1(\phi) = C^* \frac{e^{-\phi}}{(1-e^{-\phi})} \frac{T_1^{*2-E}}{\sigma^* T_0^*} \qquad (2\text{-}23)$$

$$\phi_2(\phi) = 1 - (2-E)(T_i^*/T_0^*)e^{-\phi} \qquad (2\text{-}24)$$

$$\phi_3(\phi, V^*) = V^{*2}/ (1-e^{-\phi})\sigma^* T_i^{*E} \qquad (2\text{-}25)$$

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

$$\frac{dV^*}{dz^*} = Q_e^* - \phi_1 \phi_4 \qquad (2\text{-}26)$$

where

$$\phi_4(\phi, V^*) = \frac{Q_e^*(\phi) - \phi_2(\phi)\phi_3(\phi, V^*)}{1 + \phi_1(\phi)} \qquad (2\text{-}27)$$

The program accounts for a step change in axial conduction between section 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:

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

where $C^* \frac{dT_i^*}{dz^*}$ 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 one-tenth of one percent 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. 3]. 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 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 = 0.999) by the latent heat of vaporization of the working fluid and subtracting from QSUM. In the example given in Appendix C the total heat transfer across the front is 2.09 Btu/hr, with 0.51 Btu/hr due to diffusion and 1.58 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 $z = L_1 + L_2$, 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:

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

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:

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

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

$c_{ev} = \frac{P_{ev}}{R_u\,T_{ev}}$, 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, $(P\,/P\;)$

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 Variable (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 Sections

In many heat pipe applications an insulated section exists between the evaporator and condenser. Although the radial heat transfer through the insulation to ambient may be negligible, there may still be a significant rate of condensation in the "adiabatic" section due to axial conduction along the pipe wall. The program is set up to handle this situation, but some care must be taken in the input.

First, condenser section number 1, Fig. 1-1, cannot be an adiabatic section, since PF1 and EF1 cannot be set equal to zero. Second, although the program will work when PF2 and EF2 are zero in condenser section 2, the axial conduction effect will not be properly calculated unless some realistic values are put in for PF, EF and EMIS or HF to account for the radial heat loss through the insulation; that is, in practical situations, no section is truly adiabatic. In the event that a hypothetical truly adiabatic section is to be investigated, it is only necessary to input PF2=0. The values of HF2, TF2, etc., should be input identical to section 1.

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 °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°R (ft^2/hr) See Table 4-I.

HEAT PIPE VII INPUT DATA

CARD	FORMAT	DESCRIPTION					
1	72H						
2	72H						
		PARAMETERS					
3	3F12.5	A11	B11	C11			
		≠0	≠0	≠0			
4	4F12.5	XMC	DIF	E	HFG		
		≠0	≠0		≠0		
5	6F12.5	FF1	AF1	CF1	EF1	EMIS1	HF1
		≠0			≠0	NOT BOTH	
6	6F12.5	FF2	AF2	CF2	EF2	EMIS2	HF2
						NOT BOTH	
7	3F12.5	DOUT	THKW	CW			
		≠0					
8	3F12.5	DEL	CONWK	DART			
		≠0	≠0				
9	3F12.5	TF1	POW1	XLONG1			
			≠0	≠0			
10	3F12.5	TF2	POW2	XLONG2			
			≠0				
11	3F12.5, E12.5	TEV	Q	ZGAS	AGAS		
		≠0	≠0	NOT BOTH			
12	2F12.5, 4I12	VRES	TRES	NRES	MODEQN	NPRINT	NRUN
			≠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.

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

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_4O)	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:

$$R_T = R_{fin} + R_{gap} \qquad (4-1)$$

But,

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

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 Wall Characteristics

Card 7 (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

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

4.5 Wick Characteristics

Card 8 (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)

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

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

4.6 Environmental Parameters and Lengths

Card 9 (3F 12.5)

TF1: condenser, section number 1, external fluid or sink temperature for convective heat transfer, T_{f_1}, (°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:

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

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).

Card 10 (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).

4.7 Operating Conditions

Card 11 (3F 12.5, E12.5)

TEV: evaporator temperature, T_{ev} (°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."

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

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

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. (lb-moles). See Table 4-II.

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.

4.8 Reservoir Characteristics

Card 12 (2F 12.5, 4I12)

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.

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.

NPRINT: indicates the number of lines to be skipped in the output to limit the number of pages of printout. The first and last lines ($z = 0$ and $z = L_1 + L_2$) of output are always printed.

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

5.0 OUTPUT DESCRIPTION

5.1 Input and Dimensionless Parameters

Cards 1 and 2 of the data deck are printed first. These are title cards which are used to identify the run as defined in Section 4.0. The program then simply prints out the input parameters as a matter of record and a check on the input.

Parameters which are printed in addition to the input variables are listed below. Refer also to the nomenclature or paragraph 2.2 for their definitions.

5.1.1 Operating Conditions

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

Molar concentration, Reference Eq. (3.3).

5.1.2 Dimensionless Temperatures

TZ: T_o^*
TS: T_c^*
TR: T_R^*

5.1.3 Dimensionless Condenser Parameters

C: C^*
F: F^*
H: H^*
XL: L/D_e Dimensionless condenser length.

5.1.4 Amount of Non-condensible Gas:

GAS: AMT/COEF

Dimensionless amount of non-condensible gas. The value is meaningless when MODEQM = 0.

COEF: $\pi/4c_{ev}\, D_e^3$ (1/lb-moles)

AMT: m (lb-moles)

Amount of non-condensible gas in the pipe. The value is meaningless when MODEQM = 0.

XGAS: Length of condenser filled with gas if a sharp front exists (feet). The value should agree with ZGAS if ZGAS is input, but is meaningless if MODEQM = 0.

5.2 Debug Information

The program next prints out the number of iterations required for convergence and whether the program is operating in the short or long mode. If more than 16 iterations are required in the long mode (ITER = 16) or 48 iterations (ITER = 48) in the short mode, then the program writes "did not converge" or "16 steps in long mode", calls output and then exits. Note that the output may not be correct in this case but is useful for debugging purposes.

JEND gives the number of steps required for numerical integration along the total length of the pipe. If NPRINT equals zero, then the program will print each of the JEND steps. If JEND equals 1000 steps, then an error message will result. Note that under the heat input option (MODEQM = 0), QSUM approaches 1.0 for convergence.

The 1000 step limit currently constrains the pipe length to somewhat less than 250 diameters. Should the need arise for analyzing longer heat pipes, this restriction can be circumvented by increasing DZ from its current value of 0.25 within the program logic.

5.3 Gas Reservoir Properties (Not printed when VRES = 0)

When a gas reservoir is included in the analysis (VRES ≠ 0), the following reservoir properties are printed.

NRES, VRES: input values

TRES: if NRES = 2, then TRES corresponds to the temperature at the end of the condenser at z = 0. Otherwise TRES is an input value, T_R (°R).

XR: mole fraction of non-condensible gas in the reservoir, x_R.

MRES: amount of non-condensible gas in the reservoir, $\mathcal{M}_R$ (lb-moles)

5.4 Profiles

The primary output consists of various profiles versus z. In addition, the missing value of $\mathcal{M}$ for the heat input option (MODEQM = 0) and a correct value of $\dot{Q}(L)$ when MODEQM = 1 is obtained. These values are printed in the last line of output. The variables which are printed in each line of output are defined below:

J: step number in numerical integration along the pipe. Final J is equal to JEND+1. The missing values of J indicate which lines have been skipped when NPRINT is not set equal to zero.

Z: $Z^* = z/D_e$

Dimensionless axial position.

ZIN: axial position, z (inches)

V: V^*

Dimensionless vapor flow rate.

P: $\emptyset = \ln \frac{1}{x}$

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

Dimensionless vapor liquid interface (wick) temperature.

XSUM: $\int \frac{X_n}{T_i^*} \, dz^*$

Dimensionless amount of non-condensible gas in the pipe.

ASTN: $\frac{dV^*}{dz^*} = \frac{1}{160^* \; T_f{}^{*E}}$

Dimensionless condensation rate.

MASS FLOW: mass flow rate of vapor, $\dot{m}$ (lb/hr)

QSUM: summation of heat transport due to vapor mass flow and axial conduction at each step along the pipe. The final value printed at $z = L_1 + L_2$, J = JEND+1, is the total heat rejection from the condenser, $\dot{Q}(L)$, (Btu/hr).

XS: x_s

Spatial (area weighted) average of mole fraction of the non-condensible at each step along the pipe.

TWICK: wick temperature (°R)

TWALL: wall temperature (°R)

MPIPE: summation of the non-condensible gas inventory at each step along the pipe. The final value printed at $z = L_1 + L_2$, J = JEND+1, is the total amount of gas in the pipe only; i.e., not including the reservoir, $\mathcal{M}$ (lb-moles).

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)

Φ_1, Φ_2, Φ_3, Φ_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).

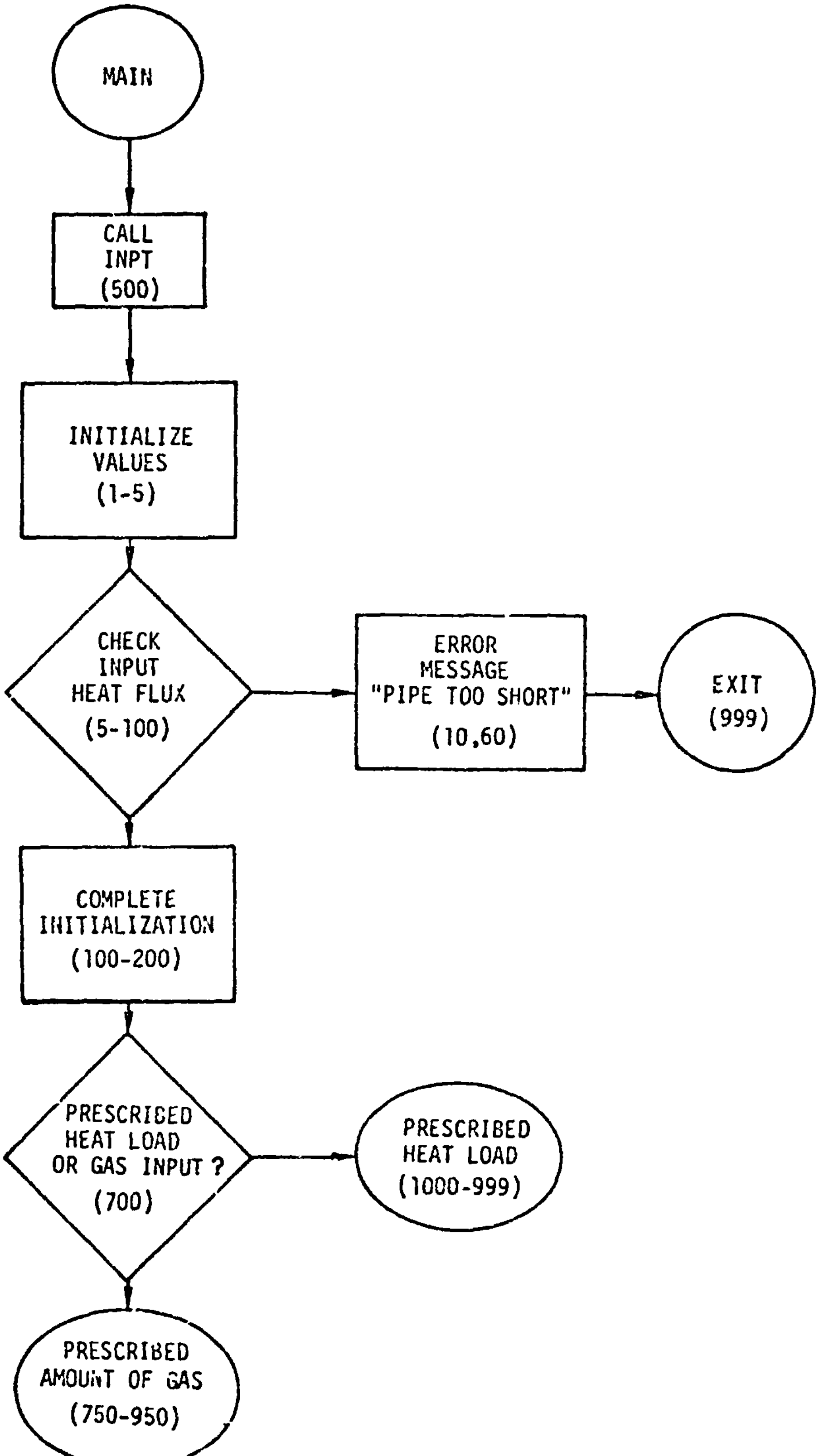
3. D.K. Edwards and B.D. Marcus, "Heat and Mass Transfer in the Vicinity of the Vapor-Gas Front in a Gas Loaded Heat Pipe," To be published.

APPENDIX A

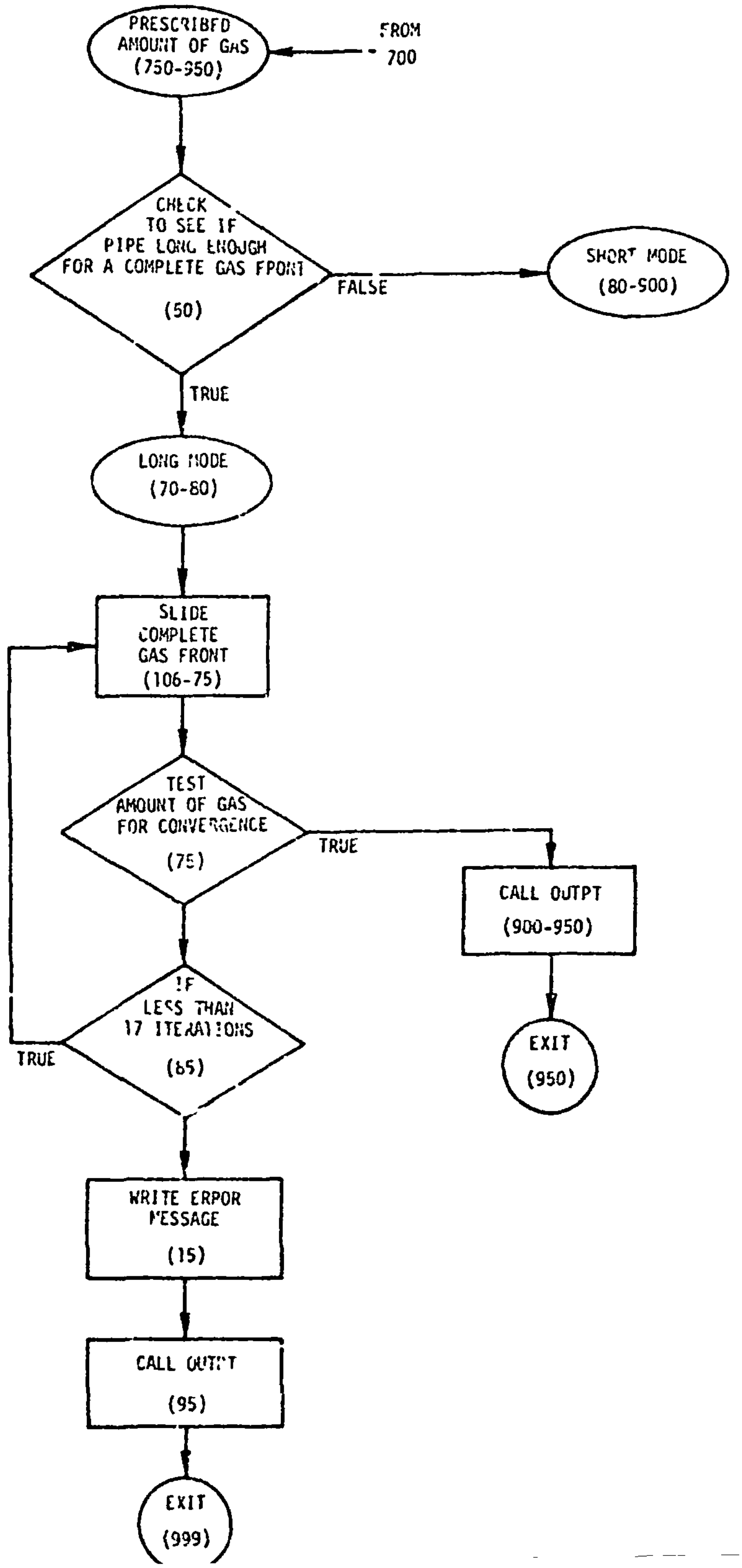
FLOW DIAGRAM (TRW-GASPIPE)

The flow diagram presented in the following pages is included as an aid in the overall program logic. Statement numbers are indicated for debugging purposes. These statement numbers are referenced to the main program, which is listed in Appendix B. Note that the numbers are not in consecutive order, but refer to the relative location in the listing.

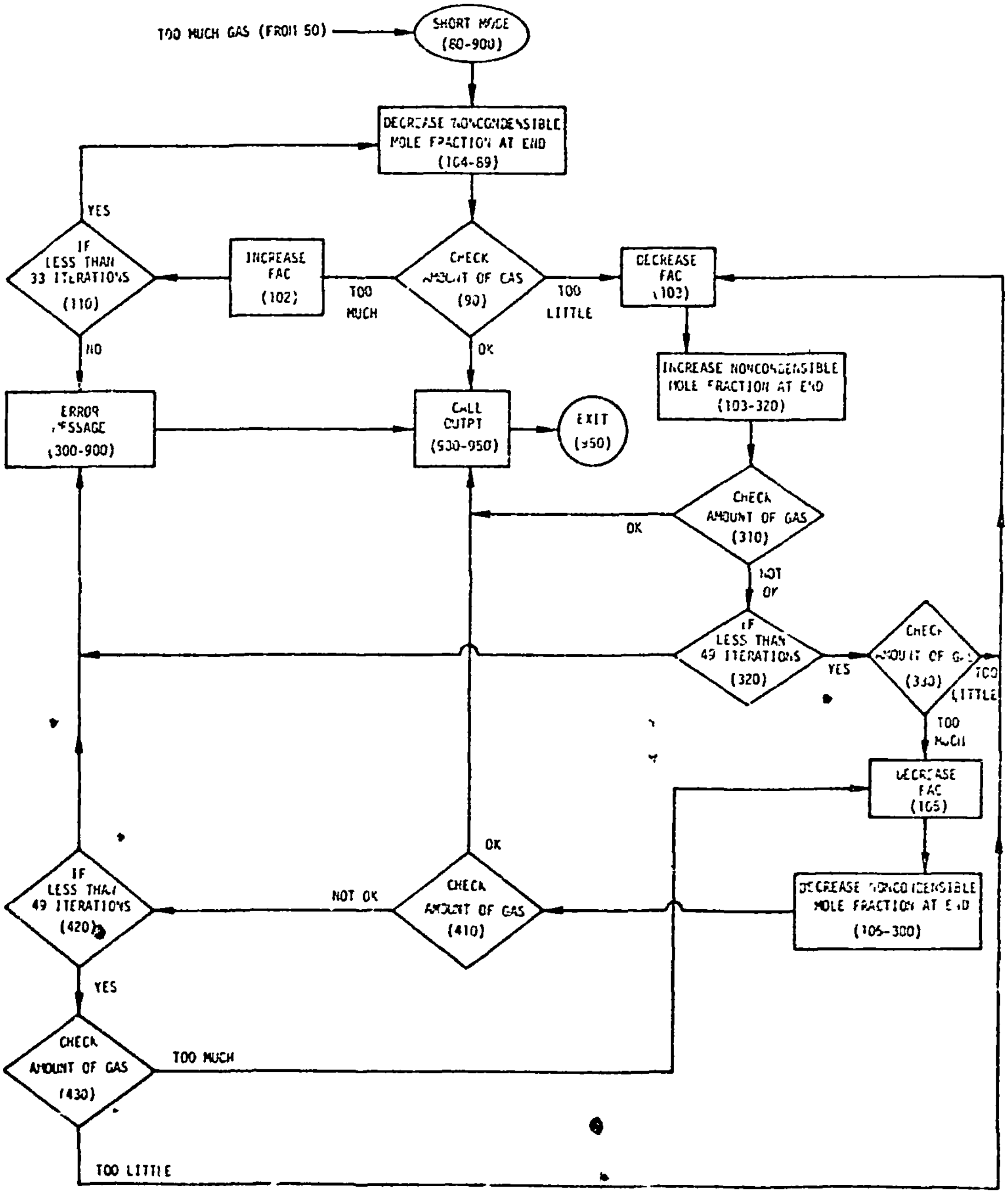
FLOWCHART TO FIRST MAJOR BRANCHING



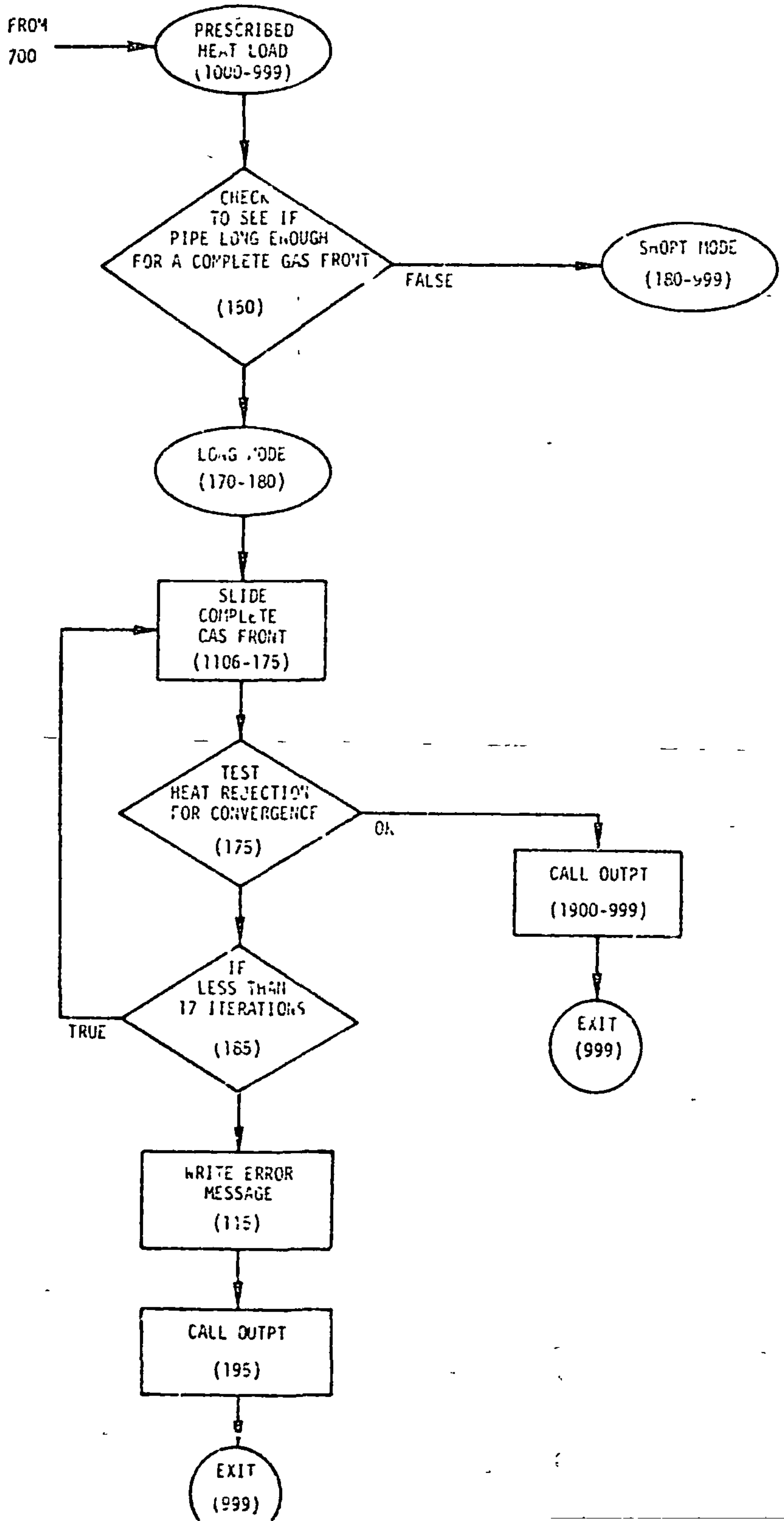
PRESCRIBED AMOUNT OF GAS, LONG MODE



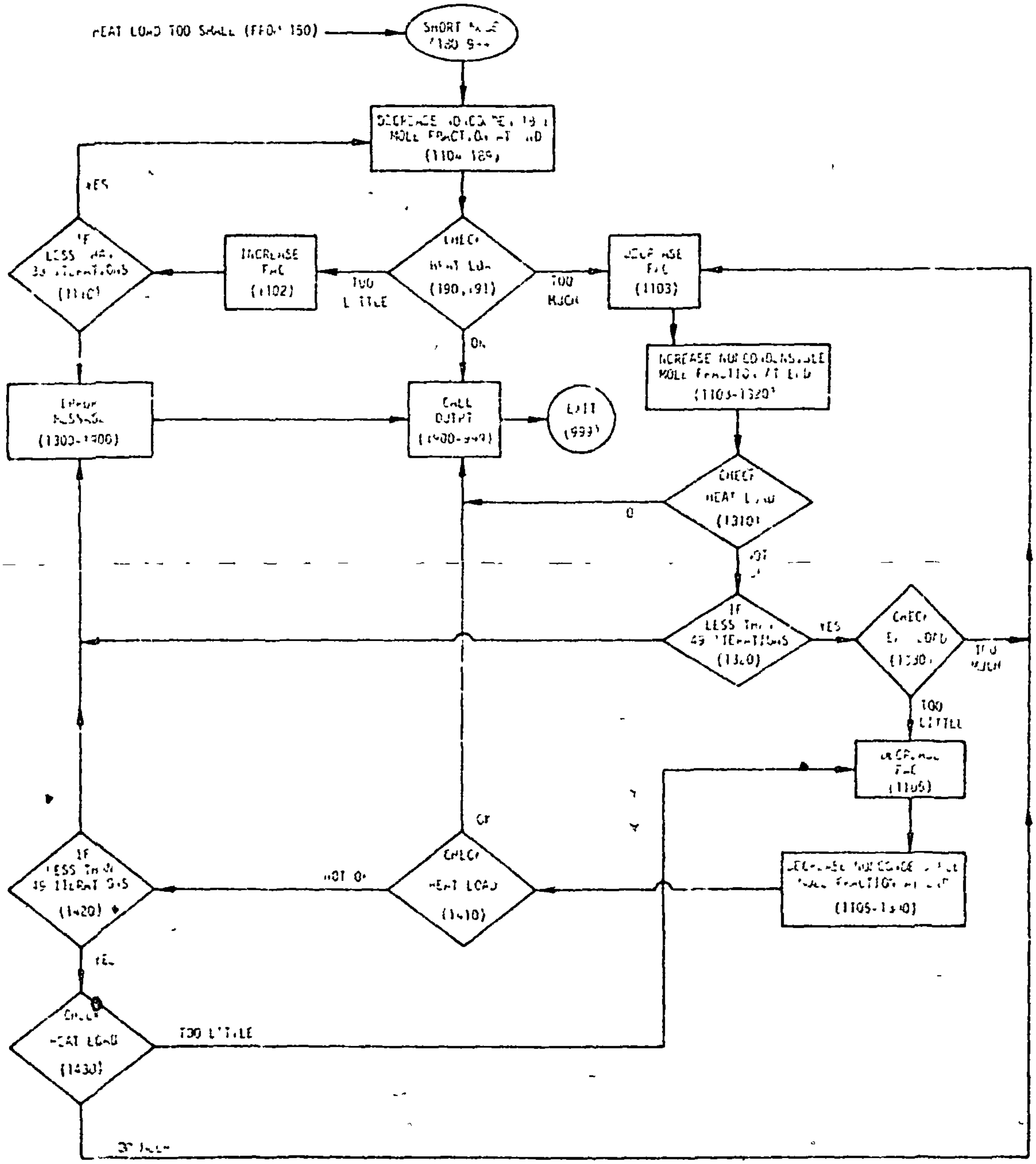
PRESCRIBED AMOUNT OF GAS, SHORT MODE



PRESCRIBED HEAT LOAD, LONG MODE



PRESCRIBED HEAT LOAD SHORT MODE



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.

```
RUN 2.3J  06/07/71.

                       PROGRAM GASPIPE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
              C        * * * * * * * * * *    HEAT PIPE VII    * * * * * * * * * *
              C        AXIAL CONDUCTION, STEP CHANGE IN FIN PARAMETERS
 000003                COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
 000003                COMMON /DATA/ GAS,[illegible]
             $                      ,F TS1,XL1,TS[illegible],EMIS,HFG
             $                      ,A[illegible],NERROR,DELTEE
             $                      ,V-ES
 000003              1 NERROR=C
 000004            500 CALL INPT
 000005                IF (NERROR.EQ.0) GO TO 2
 000006                IF (NPUN.EQ.1) GO TO 1
 000010            600 CALL EXIT
 000011              2 TI = 1.C
 000012                EMIS = EMIS1
 000014                H = H1
 000015                F = F1
 000017                TS = TS1
 000021                CALL SURF(TI,S1,TC1)
 000023                QI1 = S1*(TI-TC1)/(1.0+S1**[illegible])
 000031                EMIS = EMIS2
 000032                H = H2
 000034                F = F2
 000035                TS = TS2
 000037                CALL SURF(TI,S2,TC2)
 000042              5 CONTINUE
 000042                QI2 = S2*(TI-TC2)/(1.0+S2**[illegible])
 000050                VZ = QI1*XL1+QI2*XL2
 000053                IF(VZ.GT.[illegible]
 000057                WRITE(6,10)
 000062             10 FORMAT([illegible] SPHERE)
 000062                WRITE(6,60) S1,TC1,[illegible],S2,TC2,QI2,XL2,VZ
 000110             60 FORMAT(1X,[illegible])
 000110                GO TO [illegible]
 [illegible]       1[illegible] CONTI[illegible]
 000111                [illegible] = [illegible]
 000112                CALL [illegible]
```

```
RUN 2.3J  06/27/71.          [illegible]

000114           DELTF=0.1
000115           TSTART=TS1+DELTF/TF
000120           ARG=TZ*(1.0/TSTA-T-1.0)
000123           SMAL=EXP(-ARG)
000125           PHIZ=ALOG(1.0/FEX(ARG))
000133           IF(SMAL  T.0.0001) PHIZ=SMAL*(1.+SMAL/4.+SMAL*SMAL/3.)
000143           FAC=PHIZ
000144           ZGAS = 0.0
000145           DUMMY = XLI
000147           ITER = 0
000150           CALL SATUR(PHIZ,TS1)
000152           IF (PRES.EQ.0.) TS1=T-
000156           IF (PRES.EQ.0) T =TS1
000162           CALL MOLE(T-1,XSR)
000164           RSUM=VR*XSR/TR
000167       200 CONTINUE
000167       700 IF (MODE.NE.0.0) GO TO 1000
000170       750 CALL PIPE(PHIZ,X   ,XSUM,JE,1)
000173           WRITE(6,40) ITER,PHIZ,XSUM,QSUM,JE
000211        40 FORMAT(/,6H ITE =I3,7H PHIZ=0PE12.4,7H  XSUM=0PE12.4,7H  QSUM=
                $          0PE12.4,7H  JE =I-)
000211        41 FORMAT(/,5H ITER=I4,7H  ZGAS=0PE12.4,7H  XSUM=0PE12.4,7H  QSUM=
                $          0PE12.4,7H  JE =I-)
000211           ITER = ITER+1
000213           XSUM = XSUM+DSUM+-SUM
000216           XX1=PHIZ
000217           YY1=XSUM-GAS
000222        50 IF(XSUM.GT.GAS) GO TO 105
000226        70 CONTINUE
000226           WRITE(6,33)
000232        33 FORMAT(/,* THE PROGRAM IS OPERATING IN LONG MODE*)
000232       105 DZGAS = (GAS-XSUM)*TS1/XS1
000235           TEST=XLI/2.0
000237           IF(DZGAS.GT.TEST) DZGAS = TEST
000244           ZGAS = ZGAS+DZGAS
000246           XLI = DUMMY-ZGAS
000250           DSUM = ZGAS*XS1/TS1
000253           CALL PIPE(PHIZ,XSUM, [illegible])
```

```
RUN 2.3J  [illegible]/07/7[illegible]          [illegible]

000256          XSUM = [illegible]
000261          WRITE([illegible]) [illegible] GAS,XSUM,DSUM,J[illegible]
000277          TEST = (XSUM-GAS)/GAS
000302       75 IF(ABS(TEST).LT.[illegible]) GO TO [illegible]
000306          ITER = ITER+1
000307       35 IF(ITER.[illegible]) GO TO [illegible]
000312          WRITE(6,15)
000313       15 FORMAT(/,= [illegible] STEPS [illegible])
000315       55 CALL OUTPT(PHIZ,[illegible],JEND)
000320          GO TO 999
000321       80 CONTINUE
000321      104 PHIZ = PHIZ+A
000323          WRITE (6,25)
000327       25 FORMAT(/,= THE PROGRAM IS OPERATING IN SHORT MODE=)
000327          IF (NES.EQ.1) GO TO 27
000331          CALL SATUR(PHIZ,TI)
000333          CALL MOLE (TI,XS)
000335          IF (NES.EQ.2) T=TI
000341          XSUM=VR*XS/T[illegible]
000344       29 CALL DIFF(PHIZ,XSUM,DSUM,JEND)
000347          XSUM = XSUM+DSUM+SUM
000352          WRITE(6,40) ITER,PHIZ,XSUM,DSUM,JEND
000370          ITER = ITER+1
000372       89 TEST = XSUM-GAS
000374          XX2=PHIZ
000375          YY2=TEST
000377       90 IF(TEST) 103,[illegible],102
000401      102 FAC=(XX2-XX1)*YY2/(YY1-YY2)
000406          XX1=XX2
000410          YY1=YY2
000412      110 IF(ITER.[illegible]) GO TO [illegible]
000415          GO TO 104
000415      103 FAC = FAC/2.0
000417          PHIZ = PHIZ-FAC
000420          IF (NES.EQ.1) GO TO 1[illegible]
000423          CALL SATUR(PHIZ,TI)
000425          CALL MOLE (TI,XS)
000427          IF (NES.EQ.2) T=TI
```

```
RUN 2.3J  05/07/71.          GASPIPE

000433            RSUM=VR*XS/TR
000435        104 CALL PIPE(PHIZ,XSUM,DSUM,JEND)
000441            XSUM = XSUM+DSUM+XSUM
000444            WRITE(6,40) ITER,PHIZ,XSUM,DSUM,JEND
000462            ITER = ITER+1
000464            TEST = (XSUM-GAS)/GAS
000467        310 IF(ABS(TEST).LE.0.001) GO TO 900
000473        320 IF(ITER.GE.40) GO TO 300
000476        330 IF(TEST) 103,900,105
000500        105 FAC = 0.55*FAC
000502            PHIZ = PHIZ+FAC
000503            IF (NRES.EQ.1) GO TO 117
000506            CALL SATUR (PHIZ,TI)
000510            CALL MULF (TI,XS)
000512            IF (NRES.EQ.2) TR=TI
000516            RSUM=VR*XS/TR
000521        117 CALL PIPE(PHIZ,XSUM,DSUM,JEND)
000524            XSUM = XSUM+DSUM+XSUM
000527            WRITE(6,40) ITER,PHIZ,XSUM,DSUM,JEND
000545            ITER = ITER+1
000547            TEST = (XSUM-GAS)/GAS
000552        410 IF(ABS(TEST).LE.0.001) GO TO 900
000556        420 IF(ITER.GE.40) GO TO 300
000561        430 IF(TEST) 103,900,105
000563        300 CONTINUE
000563            WRITE(6,20)
000567         20 FORMAT(/,* DID NOT CONVERGE*)
000567        900 CONTINUE
000567            ZGAS = DUMMY-XL1
000571            CALL OUTPT(PHIZ,ZGAS,JEND)
000574        950 IF (NRUN.EQ.1) GO TO 1
000576            CALL EXIT
000577       1000 CALL PIPE(PHIZ,XSUM,DSUM,JEND)
000602            XX1=PHIZ
000603            YY1=1.0-DSUM
000605            WRITE(6,40) ITER,PHIZ,XSUM,DSUM,JEND
000623            ITER=ITER+1
000625        150 IF ( SU .LT... ) GO TO 1[illegible]
```

```
RUN 2.3J  06/07/73.          GASPIPE

000626       170 CONTINUE
000630           WRITE (6,40)
           C     LONG MODE OPERATION
000634      1106 DZGAS=(QSUM-1.0)/Q11
000637           TEST=ZGAS+DZGAS
000640           QI=Q11
000642           IF (TEST.GT.DUMMY) QI=Q12
000646           DZGAS=(QSUM-1.0)/QI
000651           ZGAS=ZGAS+DZGAS
000652           XL1=DUMMY-ZGAS
000654           IF (XL1.GT.0.0) GO TO 1200
000657           XL1=0.
000657           DUMMY2=XL2
000660           XL2=DUMMY2-ZGAS
000662      1200 CONTINUE
000662           CALL PIPE(PHIZ,XSUM,QSUM,JEND)
000665           WRITE(6,41) ITER,ZGAS,XSUM,QSUM,JEND
000703           TEST=QSUM-1.0
000705       175 IF (ABS(TEST).LE.0.001) GO TO 1900
000711           ITER=ITER+1
000712       165 IF (ITER.LE.15) GO TO 1106
000715       115 WRITE (6,15)
000721       195 CALL OUTPT (PHIZ,ZGAS,JEND)
000724           GO TO 999
000725       180 CONTINUE
000725      1104 PHIZ=PHIZ+.50
000727           WRITE (6,25)
           C     SHORT MODE OPERATION
000733           CALL PIPE(PHIZ,XSUM,QSUM,JEND)
000736           XX2=PHIZ
000737           YY2=1.0-QSUM
000742           WRITE(6,42) ITER,PHIZ,XSUM,QSUM,JEND
000757           ITER=ITER+1
000761       189 TEST=QSUM-1.0
000763       190 IF (ABS(TEST).LE.0.001) GO TO 1900
000767       191 IF (QSUM.LT.1.0) GO TO 11
000773      1102 FAC=(XX2-XX1)*YY2/(YY1-YY2)
001000           XX1=XX2
```

```
RUN 2.3J  06/07/71.            GASPIPE

001002             YY1=YY2
001004       1110 IF (ITER.GE.32) GO TO 1300
001007             GO TO 1104
001007       1103 FAC=FAC/2.0
001011             PHIZ=PHIZ-FAC
001013             CALL  SATUR(PHIZ,TI)
001015             CALL  PIPE(PHIZ,XSUM,QSUM,JEND)
001020             WRITE(6,40) ITER,PHIZ,XSUM,QSUM,JEND
001036             ITER=ITER+1
001040             TEST=QSUM-1.0
001042       1310 IF (ABS(TEST).LE.0.001) GO TO 1900
001046       1320 IF (ITER.GT.48) GO TO 1300
001052       1330 IF (QSUM.GT.1.0) GO TO 1105
001056       1105 FAC=0.55*FAC
001060             PHIZ=PHIZ+FAC
001062             CALL  SATUR(PHIZ,TI)
001064             CALL  PIPE(PHIZ,XSUM,QSUM,JEND)
001067             WRITE(6,41) ITER,PHIZ,XSUM,QSUM,JEND
001105             ITER=ITER+1
001107             TEST=QSUM-1.0
001111       1410 IF (ABS(TEST).LE.0.001) GO TO 1900
001115       1420 IF (ITER.GT.48) GO TO 1300
001121       1430 IF (QSUM.GT.1.0) GO TO 1103
001125             GO TO 1105
001125       1300 CONTINUE
001125             WRITE (6,70)
001131       1900 CONTINUE
001131             ZGAS=DUMMY-XL1
001133             CALL OUTPT(PHIZ,ZGAS,JEND)
001136        999 IF (NRUN.EQ.1) GO TO 1
001140             CALL EXIT
001141             END
```

```
RUN 2.3J  06/07/71.

                SUBROUTINE INPT
000002          COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
000002          COMMON /DATA/ GAS,DZ,TEV,DFT,W,CTV,TZ,D,L,K,TI,VS,TS1,C1,F1,H1
               $              ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
               $              ,A11,B11,C11,[illegible],NPRINT,NRUN,NERROR,DELTEE
               $              ,VELS
000002          READ (5,5)
000006        5 FORMAT (72H
               $                    /72H
               $                                        )
000006          WRITE (6,5)
          C
          C     FLUID CHARACTERISTICS
          C
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.
000024          READ(5,15) XMC,DIF,E,HFG
000040       15 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(6,20)
000044       20 FORMAT(/,26H VAPOR PRESSURE PARAMETERS)
000044          WRITE (6,21) A11,B11,C11
000056       21 FORMAT (/, 5H  A11=1PE12.5,7H   B11=1PE12.5,7H   C11=1PE12.5)
000056          WRITE(6,22)
000062       22 FORMAT(//,17H FLUID PROPERTIES)
000062          WRITE(6,23) HFG,DIF,XMC,E
000076       23 FORMAT(/,5H  HFG=F8.4,14H BTU/LB    DIF=F8.4,15H FT**2/HR   XMC=F8.4
               $         ,10H   DIF EXP=F8.4)
          C
          C     CONDENSER PARAMETERS, SECTION 1, EARLIEST FROM EVAPORATOR
          C
000076          READ(5,11) [illegible],F1,[illegible],[illegible],EMIS1,HF1
```

```
RUN 2.3J  06/07/71.          IPPT

000116        11 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(6,24)
000122        24 FORMAT(//,* FIN PROPERTIES, CONDENSER SECTION NUMBER 1*)
000122           WRITE(6,25) PF1,AF1,CF1,EF1,EMIS1,HF1
000142        25 FORMAT(/,5H  PF=F9.4,9H IN   AF=F9.4,12H SQ IN   CF=F9.4,
              $        10H BTU/HRFTR    EF=F9.4,6H   EMIS=F9.4,6H   HF=F9.4,
              $        12H BTU/HRFT2R)
000142           TEST=EF1*PF1*(EMIS1+HF1)
000145           IF (TEST.NE.0.) GO TO 996
000147           NERROR=1
000150           WRITE(6,96)
000155        96 FORMAT(/,30H CONDENSER SECTION NO. 1 INPUT WRONG)
000153       996 CONTINUE
           C
           C     CONDENSER PARAMETERS, SECTION 2, NEAREST TO EVAPORATOR
           C
000153           READ(5,11) PF2,AF2,CF2,EF2,EMIS2,HF2
000173           WRITE(6,54)
000177        54 FORMAT(/ ,* FIN PROPERTIES, CONDENSER SECTION NUMBER 2*)
000177           WRITE(6,25) PF2,AF2,CF2,EF2,EMIS2,HF2
000217           TEST=EMIS2+HF2
000221           IF (TEST.NE.0.) GO TO 997
000222           NERROR=1
000223           WRITE(6,97)
000227        97 FORMAT(/,30H CONDENSER SECTION NO. 2 INPUT WRONG)
000227       997 CONTINUE
           C
           C     WALL CHARACTERISTICS
           C
000227           READ(5,12) DOUT,THKW,CW
000241        12 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)
000241           WRITE(6,26)
000245        26 FORMAT(//,16H PIPE PROPERTIES)
000245           WRITE(6,27) DOUT,THKW,CW
000257        27 FORMAT(/,7H  DOUT=F9.4,17H IN    WALL THK=F9.4,16H IN    WALL COND=
                $        F9.4,10H BTU/HRFTR)
          C
          C      WICK CHARACTERISTICS
          C
000257           READ(5,13) DEL,CONWK,DART
000271        13 FORMAT(3F12.5)
          C      DEL IS THE HEAT PIPE WICK THICKNESS (INCHES)
          C      CONWK IS THE EFFECTIVE THERMAL CONDUCTIVITY OF FILLED WICK
          C      DART IS THE EFFECTIVE DIAMETER OF ARTERIES IN PIPE (INCHES)
          C
          C      ENVIRONMENTAL PARAMETERS AND LENGTHS
          C
000271           READ(5,14) TF1,POW1,XLONG1
000303        14 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)
000303           READ(5,14) TF2,POW2,XLONG2
          C      XLONG2 IS THE LENGTH OF CONDENSER SECTION NUMBER 2 (FEET)
000315           WRITE(6,32)
000321        32 FORMAT(//,* CONDENSER ENVIRONMENT, SECTION NUMBER 1*)
000321           WRITE(6,33) TF1,POW1,XLONG1
000333        33 FORMAT(/,* TF=*,1PE12.4,* R    POW=*,1PE12.4,* BTU/HRFTFT    XLONG=*
                $        ,1PE12.4,* FT*)
000333           WRITE(6,34)
000337        34 FORMAT(//,* CONDENSER ENVIRONMENT, SECTION NUMBER 2*)
000337           WRITE(6,33) TF2,POW2,XLONG2
          C
          C      OPERATING CONDITIONS
```

```
          C
 000351         READ(5,16) TEV,Q,ZGAS,AGAS
 000365      16 FORMAT(4E12.5)
          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
 000355         IF(ZGAS.EQ.0.0.AND.AGAS.EQ.0.0) GO TO 998
 000373         IF(ZGAS.EQ.0.0.OR.AGAS.EQ.0.0) GO TO 200
 000401     998 CONTINUE
 000401         NERROR=1
 000402         WRITE(6,98) ZGAS,AGAS
 000412      98 FORMAT(/,* INPUT ERROR, ZGAS=*,0PE12.5,* AGAS=*,1PE12.5)
 000412         CALL EXIT
 000413     200 CONTINUE
          C
          C     RESERVOIR CHARACTERISTICS
          C
 000413         READ (5,17) VRES,TRES,NRES,MODEQM,NPRINT,NRUN
 000433      17 FORMAT(2F12.5,4I12)
          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.
 000433         WRITE(6,28)
 000437      28 FORMAT(//,* WICK PROPERTIES AND RESERVOIR CONDITIONS*)
 000437         WRITE(6,29) DEL,[illegible],DART,VRES,TRES,NRES
 000457      29 FORMAT(/,* WICK THK=*,F6.3,* IN  WICK COND=*,F5.3,* BTU/HRFTR  *,
               $* D-A  [illegible],F[illegible],* IN  V[illegible]S=*,F[illegible],* CU IN  TRES=*,F7.4,* R  NRES=*
               $,I2)
 000457         SIGMA = 0.1714E-
```

```
RUN 2.3J  06/07/71.           INPT

000460        RU = 1544.0
000462        PI = 3.1415927
000463        IF(EMIS1.EQ.0.0.AND.HF1.EQ.0.0) GO TO 999
000472        GO TO 100
000472    999 CONTINUE
000472        NERROR=1
000473        WRITE(6,99)
000477     99 FORMAT(/,12H INPUT ERROR)
000477        RETURN
       C
       C      CALCULATION OF DIMENSIONLESS PARAMETERS
       C
000500    100 CONTINUE
000500        IF (NERROR.EQ.1) GO TO [illegible]
000502        CALL SINK(EMIS1,POW1,HF1,TF1,TS1)
000506        TS2=TS1
000507        IF(HF2.NE.0.) CALL SINK(EMIS2,POW2,HF2,TF2,TS2)
000514        TS1 = TS1/TEV
000516        TS2 = TS2/TEV
000520        TP = TRES/TEV
000522        B11 = B11/TEV
000524        C11 = C11/TEV**2
000526        PEV=(EXP(A11-B11-C11))*144.0
000534        CEV = PEV/(RU*TEV)
000537        TZ=B11+C11*(1.0+1.0/TS1)
000544        PATMOS = PEV/(144.*14.7)
000546        DEV=(DIF/PATMOS)*((TEV/460.0)**(E+1.0))
000556        CMOH = XMC*DEV*CEV [illegible]
000562        DIN = DOUT-2.0*THKW
000565        DI = DIN-2.0*[illegible]
000570        FINKA1 = [illegible]
000573        FINKA2 = [illegible]
000575        WALKA = (PI/360. [illegible]
000602        WICKA = (PI/360. [illegible]
000607        SUMKA1 = FINKA1+WALKA+WICKA
000612        SUMKA2 = FINKA2+WALKA+WICKA
000615        IF(DI.[illegible]) GO TO [illegible]
000620        WRITE( ,2 ) DI,[illegible]
```

```
RUN 2.3J  06/07/71.            INPT

000630      18 FORMAT(/,* CAPI T[illegible]       [illegible]     [illegible]=*,E[illegible]12.[illegible])
000630         NERROR=1
000631         RETURN
000632     300 DFT = SQRT(DI**2-DAPT**2)/12.0
000640         VR = VRES/((PI/4.0)*1728.0*DFT**3)
000645         XL1 = XLONG1/DFT
000647         XL2 = XLONG2/DFT
000651         XLTOT=XL1+XL2
000653         IF(XLTOT.LT.250.) GO TO 600
000656         WRITE(6,60)
000662      60 FORMAT(//,27H PIPE EXCEEDS 250 DIAMETERS)
000662         CALL EXIT
000663     600 CONTINUE
000663         C1 = SUMKA1*TEV/(G*DFT)
000666         C2 = SUMKA2*TEV/(G*DFT)
000672         XK = 2.0*PI*CONKK*DFT*TEV/(G*ALOG(DIN/DI))
000704         R = 1.0/XK
000706         D = (PI/4.0)*DFT-[illegible]/[illegible]
000713         F1 = EF1*(PF1/12.0)*DFT*SIGMA*TEV**4/2
000722         F2 = EF2*(PF2/12.0)*DFT*SIGMA*TEV**4/2
000731         H1 = HF1*TEV/(SIGMA*TEV**4)
000735         H2 = HF2*TEV/(SIGMA*TEV**4)
000741         COEF = 3.14159*27*CEV*DFT**3/4.0
000745         GAS = AGAS/COEF
000746         TS = TS1
000750         XS = 1.0-EXP(-TZ*(1.0/TS-1.0))
000757         RSUM = XS*VR/TR
000761         IF(ZGAS.EQ.0.0) GO TO 400
000762         GAS = (ZGAS*XS/(TS*DFT))+RSUM
000767     400 AMT = COEF*GAS
000771         XGAS = DFT*(GAS-[illegible])*TS/XS
000776         WRITE(6,30)
001001      30 FORMAT(//,21H OPERATING CONDITIONS)
001001         WRITE(6,31) TEV,[illegible],MODE,W,CEV
001015      31 FORMAT(/,*    TEV=*,F[illegible]12.[illegible],*  [illegible]    W=*,[illegible]12.[illegible],* LB/HR     MODEJ*=*,
              $I2,      *     CEV=*,[illegible].4,* [illegible]MOLE/FT3*)
001015         WRITE(6,[illegible])
001021      36 FORMAT(//,* [illegible] SS T[illegible] [illegible]S*)
```

```
RUN 2.3J  06/07/71.          IIPT

001021          WRITE(6,37) T2,TS1,TS2,TR
001035       37 FORMAT(/,* T2=*,0PE12.4,* TS1=*,0PE12.4,* TS2=*,0PE12.4,* TR=*,
               $           0PE12.4)
001035          WRITE(6,38)
001041       38 FORMAT(//,* DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 1*)
001041          WRITE(6,39) EMIS1,C1,F1,H1,XL1
001057       39 FORMAT(/,* EMIS=*,0PE12.4,* C=*,0PE12.4,* F=*,0PE12.4,* H=*,
               $           0PE12.4,* XL=*,0PE12.4)
001057          WRITE(6,40)
001063       40 FORMAT(//,* DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 2*)
001063          WRITE(6,39) EMIS2,C2,F2,H2,XL2
001101          WRITE(6,42)
001105       42 FORMAT(//,25H AMOUNT OF NONCONDENSIBLE GAS)
001105          WRITE(6,43) GAS,ZGAS,AGAS,COEF,AMT,XGAS
001125       43 FORMAT(/,5H GAS=0PE12.4,8H   ZGAS=0PE12.4,11H FT   ACAS=0PE12.4,
               $           15H LBMOLE   COEF=0PE12.4,5H 1/LBMOLE/,5H AMT=0PE12.4,
               $           14H LBMOLE  XGAS=0PE12.4,3H FT)
001125          WRITE(6,44)
001131       44 FORMAT(///)
001131          RETURN
001132          END
```

```
RUN 2.3J  06/07/71.

                   SUBROUTINE SI[illegible](EMIS,POW,HF,TF,TS)
000010             SIGMA = 0.1714E-8
000011             TS = TF
000012             IF(EMIS.EQ.0.0) GO TO 102
000013             TS = SQRT(SQRT(POW/(EMIS*SIGMA)))
000027             IF(HF.EQ.0.0) GO TO 102
000030             IF(TS.EQ.TF) GO TO 102
000032             TM = (TF+TS)/2.0
000034             DO 101 I = 1,10
000036             HR = 4.0*EMIS*SIGMA*TM**3
000042             TS2 = (POW+HF*TF+3.0*EMIS*SIGMA*TM**4)/(HF+HR)
000053             TS = (TS+TS2)/2.0
000055             TM = TS
000056         101 CONTINUE
000061         102 RETURN
000062             END
```

RUN 2.3J 06/07/71.

```
                SUBROUTINE SURF(TI,S,TC)
000006          COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
000006          COMMON /DATA/ GAS,DZ,TEV,DFT,Q,CEV,TZ,D,E,R,TR,VR,TS1,C1,F1,H1
               $              ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
               $              ,A11,B11,C11,NFES,MODEOM,NPRINT,NRUN,NERROR,DELTEE
               $              ,VFES
000006          DENOM = 4.0*EMIS*TI**3+H
000012          S = F*DENOM
000013          TC = (EMIS*TS**4+H*TS+3.0*EMIS*TI**4)/DENOM
000024          RETURN
000024          END
```

RUN 2.3J 06/07/71.

```
                  SUBROUTINE PIPE (PHIZ,XSUM,QSUM,JEND)
 000007           COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
 000007           COMMON /DATA/ GAS,DZ,TFV,DFT,Q,CEV,TZ,U,E,R,TK,VF,TS1,C1,F1,H1
                 $             ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
                 $             ,A11,B11,C11,NR=S,MODE,M,NPRINT,NRUN,NERROR,DELTEE
                 $             ,VRES
 000007        99 CONTINUE
 000007           DZ=0.25
 000010           V=0.0
 000011           P=PHIZ
 000013           CALL SATUR(P,TI)
 000015           CALL MOLE(TI,XS)
 000017           Z=0.0
 000020           J=0
 000020           XSUM=0.0
 000024           QSUM=0.0
 000024           XL=XL1
 000025           TS=TS1
 000027           C=C1
 000030           F=F1
 000032           H=H1
 000033           EMIS=EMIS1
 000035           DO 100 I=1,1000
 000037           CALL RUNGE(V,P,DV,DP)
 000042           IF (DV.LT.0.0) DV=0.0
 000047           IF (DP.LT.0.0) DP=0.0
 000052           IF (DV.LE.0.0.AND.DP.LE.0.0) GO TO 200
 000062           IF (DV.GT.0.0625) GO TO 200
 000065           GO TO 400
 000065       200 DZ=DZ/2.0
 000067           GO TO 99
 000067       400 CONTINUE
 000067           J=J+1
 000071           Z=Z+DZ
 000073           IF (Z.GT.XL) GO TO 150
 000077           ZZ(J)=Z
 000101           P1=P
```

```
RUN 2.3J  06/07/71.          PIPE

000102          P=P+DP
000104          PP(J)=P
000107          V=V+DV
000111          VV(J)=V
000114          PM=(P1+P)/2.0
000120          CALL  SATUR(PM,TM)
000122          CALL  MOLE(TM,XM)
000124          XSUM=XSUM+XM*DZ/TM
000132          XX(J)=XSUM
000135          CALL  SURF(TM,S,TC)
000137          QI=S*(TM-TC)/(1.0+S*R)
000145          QSUM=QSUM+QI*DZ
000152          QQ(J)=QSUM
000154          IF(DV.LT.0.015625) DZ=2.0*DZ
000161          IF (DZ.GT.0.25) DZ=0.25
000165          GO TO 100
000166      150 DZ1=Z-XL
000170          ZZ(J)=XL
000172          FRAC=(DZ-DZ1)/DZ
000175          TESTZ=Z
000177          Z=XL
000200          P1=P
000202          P=P+DP*FRAC
000205          PP(J)=P
000210          V=V+DV*FRAC
000213          VV(J)=V
000216          PM=(P1+P)/2.0
000221          CALL  SATUR(PM,TM)
000223          CALL  MOLE(TM,XM)
000225          XSUM=XSUM+XM*DZ*FRAC/TM
000234          XX(J)=XSUM
000237          CALL  SURF(TM,S,TC)
000241          QI=S*(TM-TC)/(1.0+S*R)
000247          QSUM=QSUM+QI*DZ*FRAC
000255          QQ(J)=QSUM
000260          CALL  SATUR(P,TI)
000262          DTCR=D*TI**C
000266          TERM=(TI**./DTCR)*EXP(-R)/(EX(2)**/)
```

```
RUN 2.3J  06/07/71.           PIPE

000300          V=V*((1.0+C*TERM)/(1.0+C2*TERM))
000306          XL=XL1+XL2
000310          IF(TESTZ.GE.XL)GO TO 101
000316          TS=TS2
000317          C=C2
000320          F=F2
000322          H=H2
000323          EMIS=EMIS2
000325       98 CONTINUE
000325      100 CONTINUE
000327          WRITE(6,10) DELTEE,DV,DP,DZ,TI,TS1,TC
000351       10 FORMAT(/,26H 1000 STEPS IN PIPE, DELTEE=F10.4,5H  DV=E12.4,
               $         5H  DP=E12.4,5H  DZ=E12.4,/5H  TI=E12.4,6H  TS1=E12.4,
               $         5H  TC=E12.4)
000351          DELTEE=4.0*DELTEE
000353          TSTART=TS1+DELTEE/TEV
000355          IF (TSTART.GT.1.0) GO TO 101
000364          ARG=TZ*(1.0/TSTART-1.0)
000366          SMAL=EXP(-ARG)
000371          PHIZ=ALOG(1.0/FEX(ARG))
000407          IF (SMAL.LT.0.0001) PHIZ=SMAL*(1.+SMAL/2.+SMAL*SMAL/3.)
000417          GO TO 99
000420      101 CONTINUE
000420          JEND=J
000421          RETURN
000422          END
```

RUN 2.3J 06/07/71.

```
                      SUBROUTINE RUNGE(V,P,DV,DP)
000007                COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),WW(1000)
000007                COMMON /DATA/ GAS,DZ,TEV,DFT,W,CEV,TZ,D,E,R,TR,VK,TS1,C1,F1,H1
                     $              ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
                     $              ,A11,B11,C11,NRES,MODENM,NPRINT,NRUN,NERROR,DELTEE
                     $              ,VRES
000007                CALL DELTA(V,P,DV1,DP1)
000011                V1 = V+DV1/2.0
000016                P1 = P+DP1/2.0
000022                CALL DELTA(V1,P1,DV2,DP2)
000025                V1 = V+DV2/2.0
000032                P1 = P+DP2/2.0
000036                CALL DELTA(V1,P1,DV3,DP3)
000041                V1 = V+DV3
000045                P1 = P+DP3
000050                CALL DELTA(V1,P1,DV4,DP4)
000053                DV = (DV1+2.0*DV2+2.0*DV3+DV4)/6.0
000063                DP = (DP1+2.0*DP2+2.0*DP3+DP4)/6.0
000072                RETURN
000072                END
```

```
RUN 2.3J  06/07/71.

                  SUBROUTINE DELTA(V,P,DV,DP)
 000007           COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
 000007           COMMON /DATA/ GAS,DZ,TEV,DFT,Q,CEV,TZ,D,E,R,TR,VR,TS1,C1,F1,H1
                 $              ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
                 $              ,A11,B11,C11,NRES,MODEQ4,NPRINT,NRUN,NERPCK,DELTFE
                 $              ,VRES
 000007           CALL SATUR(P,T)
 000011           TEE = T**F
 000015           XC=FEX(P)
 000024           CALL SURF(T,S,TC)
 000027           X=EXP(-P)
 000037           QI = S*(T-TC)/(1.0+S*K)
 000045           TERM1 = C*(X/XC)*(T**2/TEE)/(D*TZ)
 000054           DP = DZ*V/(D*TEE)
 000060           TERM2 = 1.0-(2.0-E)*(T/TZ)*X
 000065           TERM3 = V**2/(D*TEE*XC)
 000071           DV=DZ*TERM1*TERM2*TERM3/(1.+TERM1)
 000077           IF (QI.LE.0.) RETURN
 000102           DV=(DZ*QI/(1.0+TERM1))*(1.0+TERM1*TERM2*TERM3/QI)
 000113           RETURN
 000113           END
```

```
RUN 2.3J  06/07/71.

                    SUBROUTINE  SATUR(P,TI)
000005              COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
000005              COMMON /DATA/ GAS,DZ,TEV,DFT,U,CEV,TZ,D,E,R,TR,VR,TS1,C1,F1,H1
                   $              ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
                   $              ,A11,B11,C11,NRES,MODECM,NPRINT,NRUN,NERROR,DELTFE
                   $              ,VPES
               C    FLAT RADIAL PROFILE
000005              TMIN=TS+DELTEE/TEV
000007              IF(P.GT.30.0) GO TO 100
000013              IF(P.LE.0.0) GO TO 101
000014              TI = 1.0/(1.0+(1.0/TZ)*ALOG(1.0/FIX(P)))
000027              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
```

```
RUN 2.3J  06/07/71.

                  SUBROUTINE MOLT (TI,XS)
000005            COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),QQ(1000)
000005            COMMON /DATA/ GAS,DZ,TEV,DFT,Q,CEV,TZ,D,E,R,TK,VP,TS1,C1,F1,H1
                $               ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
                $               ,A11,B11,C11,NRES,MODCOM,NPRINT,NRUN,NERROR,DELTLI
                $               ,VRES
000005            TERM1 = B11*(1.0/TI-1.0)
000007            TERM2 = C11*(1.0/TI**2-1.0)
000012            ARG = TERM1+TERM2
000014            XS = FEX(ARG)
000020            RETURN
000020            END
```

```
RUN 2.3J  06/07/71.

              SUBROUTINE OUTPT(PHIZ,ZGAS,JEND)
000006        COMMON VV(1000),PP(1000),ZZ(1000),XX(1000),UU(1000)
000006        COMMON /DATA/ GAS,GZ,TEV,DFT,W,CEV,TZ,D,E,I,TR,VF,TS1,C1,F1,H1
             $              ,EMIS1,XL1,TS2,C2,F2,H2,EMIS2,XL2,TS,C,F,H,EMIS,HFG
             $              ,A11,B11,C11,NRES,MODEQN,NPRINT,NRUN,IERROR,DELTFF
             $              ,VRES
000006        COEF=3.1415927*CEV*DFT**2/4.0
000011        M=JEND+1
000013        NPRINT=NPRINT+1
000015        NP=0
000016        J=0
000017        Z=0.0
000020        P=PHIZ
000022        CALL SATUR(P,TI)
000024        CALL MOLI(TI,XS)
000026        DTEE=D*TI**E
000032        XL=XL1
000034        EMIS=EMIS1
000035        H=H1
000037        F=F1
000040        TS=TS1
000042        C=C1
000044        CALL SURF(TI,S,TC)
000046        TW=(TI+S*H*TC)/(1. +S*H)
000055        IF (NRES.EQ.1) TW=TI
000063        CALL MOLE(TW,XW)
000065        IF (NRES.EQ.1) XW=XS
000072        RSUM=VR*XW/TW
000075        CALL MOLE(TS1,XS1)
000077        USUM=ZGAS-XS1/TS1
000103        XSUM=RSUM
000104        ASUM=0.0
000105        V=0.0
000106        GSUM=0.0
000107        TWICK=TEV*TI
000111        TWALL=TEV*TW
000112        TFS=TEV*TS
```

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```
RUN 2.3J  06/07/71.          OUTPT

000115          ZFT=Z*DFT
000117          ZIN=12.*ZFT
000121          AMT=COEF*RSUM
000123          XMDOT=V*Q/HFG
000126          IF (VR.EQ.0.) GO TO 20
000127          WRITE(6,10) NRES,VRES,TRES,XR,AMT
000145       10 FORMAT(///,6H NRES=I2,8H    VRES=0PE12.4,12H IN3    TRES=0PE12.4,
               $               3H R    XR=0PE12.4,8H    MRES=0PE12.4,9H LB-MOLES///)
000145          AMT=0.
000146       20 WRITE(6,11) J,Z,ZIN,V,P,TI,XSUM,ASTN,XMDOT
000174       11 FORMAT(/,3H J=I4,4H  Z=0PE12.4,6H  ZIN=0PE12.4,3H IN/,11H
                1V=0PE12.4,4H  P=0PE12.4,5H  TI=0PE12.4,7H  XSUM=0PE12.4,7H  ASTN=0
                2PE12.4,11H  MASSFLOW=0PE12.4,6H LB/HR)
000174          WRITE(6,21) QSUM,XS,TWICK,TWALL,AMT
000212       21 FORMAT(14H          QSUM=0PE12.4,12H BTU/HR  XS=0PE12.4,8H  TWICK=E
                112.4,10H R  TWALL=0PE12.4,10H R  MPIPE=0PE12.4,8H LBMOLES)
000212          Z=ZGAS
000215          CALL MOLF(TS1,XS1)
000217          DSUM=ZGAS*XS1/TS1
000223          XSUM=DSUM
000224          AMT=COEF*XSUM
000227          DO 100 I=1,M
000230          J=J+1
000232          NP=NP+1
000234          IF(M-I)12,15,12
000236       12 IF (NPRINT-NP) 30,15,30
000240       15 WRITE(6,11) J,Z,ZIN,V,P,TI,XSUM,ASTN,XMDOT
000266          WRITE(6,21) QSUM,XS,TWICK,TWALL,AMT
000304          IF(I.EQ.M) GO TO 101
000310          NP=0
000311       30 Z1=Z
000312          Z=ZZ(I)+ZGAS
000315          ZZ(I)=Z
000320          V1=V
000321          P=PP(I)
000324          V=VV(I)
000326          XSUM=XX(I)+DSUM
000331          QSUM=QQ(I)*C
```

```
RUN 2.3J  06/07/71.          OUTPT

000335          CALL  SATUF(P,TI)
000337          CALL  MULE(TI,XS)
000341          DTEE=D*TI**E
000345          DVDZ=(V-V1)/(Z-Z1)
000352          CALL  SURF(TI,S,TC)
000354          TW=(TI+R*S*TC)/(1.0+P*S)
000363          ASTN=DVDZ/(10.0*DTEE)
000366          THICK=TEV*TI
000370          TWALL=TW*TEV
000372          ZFT=Z*DFT
000374          ZIN=ZFT*12.
000376          AMT=COEF*XSUM
000400          XMDOT=V*Q/HFG
000402          IF (Z.LT.XL) GO TO 100
000407          XL=XL1+XL2
000411          TS=TS2
000412          C=C2
000414          F=F2
000415          H=H2
000417          EMIS=EMIS2
000421      100 CONTINUE
000424      101 XSUM=XSUM+RSUM
000426          AMT=COEF*XSUM
000430          WRITE(6,25) AMT
000435       25 FORMAT(/,33H TOTAL GAS IN PIPE AND RESERVOIR=0PE12.5,9H LB-MOLES)
000435          RETURN
000436          END
```

```
RUN 2.3J  06/07/71.

                      FUNCTION FEX(X)
 000003               IF(X.LT.0.1) GO TO 100
 000005               FEX=1.0
 000006               IF (X.GT.30.) RETURN
 000013               FEX=1.0-EXP(-X)
 000021               RETURN
 000021           100 XXX = X
 000022               FEX = X
 000023               XN = 1.0
 000024               F = 1.0
 000026               SIGN = 1.0
 000030               DO 101 I = 1,7
 000031               XN = XN+1.0
 000033               SIGN = -SIGN
 000034               F = F*XN
 000036               XXX = X*XXX
 000040               FEX = FEX+SIGN*XXX/F
 000044           101 CONTINUE
 000046               RETURN
 000047               END
```

APPENDIX C

SAMPLE PROBLEM

The 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	≤ 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 9) consists of the cold trap region, and the main radiator will comprise Section 2 (cards 6 and 10). 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 = 10.5 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)

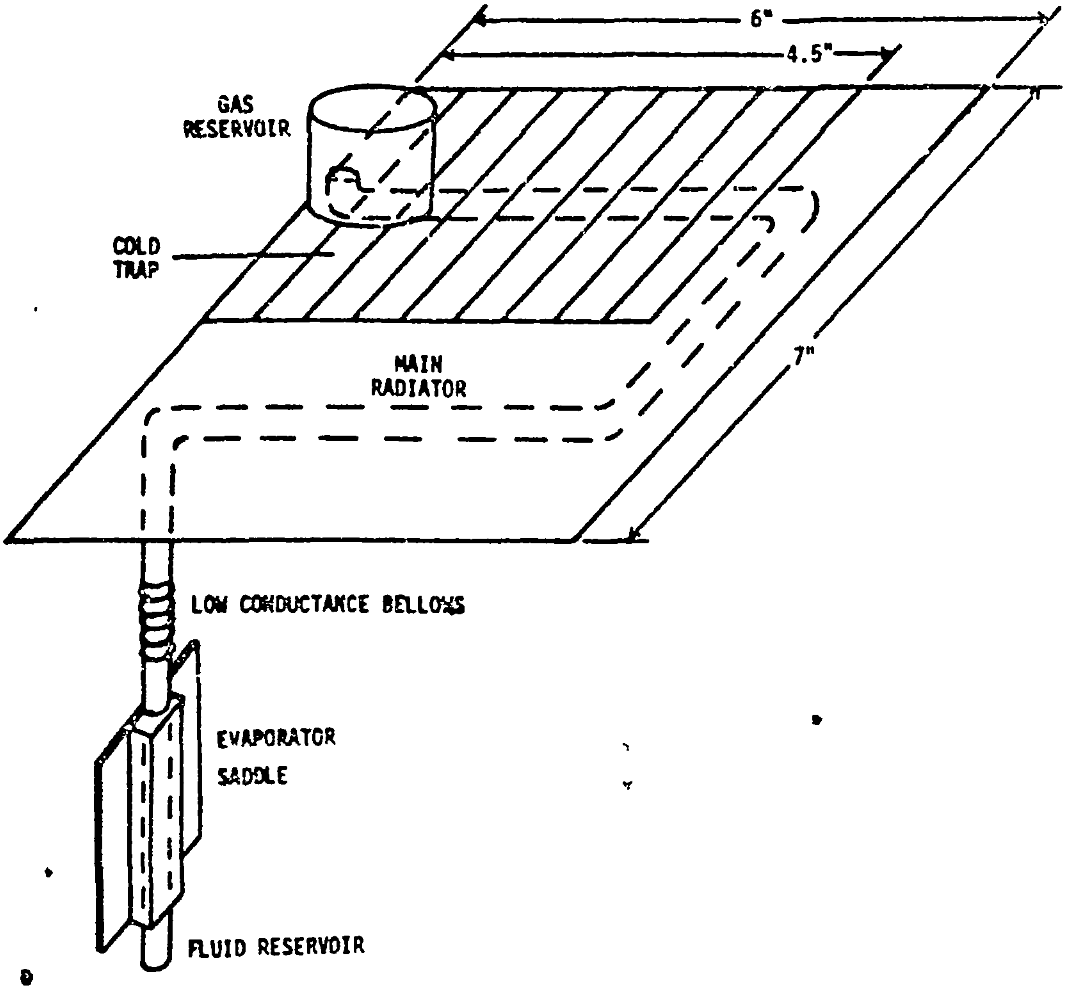

FIGURE C-1.

LUNAR SURFACE MAGNETOMETER HEAT PIPE

HEAT PIPE VII INPUT DATA

CARD	FORMAT	DESCRIPTION					
1	72H	1 LSM VARIABLE CONDUCTANCE HEAT PIPE					
2	72H	MAX Q, N=126E-07 LB MOLES, PERF, 1-8-71					
		PARAMETERS					
3	3F12.5	A11	B11	C11			
		1448	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	48	0.96	0.85	
6	6F12.5	PF2	AF2	CF2	EF2	EMIS2	HF2
		3.50	0 056	1040	0.96	0 85	
7	3F12.5	DOUT	THKW	CW			
		0.25	0.02	9.3			
8	3F12.5	DEL	CONWK	DART			
		0.001	0.12	0 073			
9	3F12.5	TF1	POW1	XLONG1			
		0	87.5	0 375			
10	3F12.5	TF2	POW2	XLONG2			
		0.	87.5	0.625			
11	3F12.5, E12.5	TEV	Q	ZGAS	AGAS		
		530.	5.0	0.	1.26E-07		
12	2F12.5, 4I12	VRES	TRES	NRES	MODEQM	NPRINT	NRUN
		0.79	495.0	2	1	2	

FIGURE C-2. Sample Input Form

```
  LSM VARIABLE CONDUCTANCE HEAT PIPE
  MAX Q, N=1.26E-07 LB-MOLES, PERF, 1-8-71

VAPOR PRESSURE PARAMETERS

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

FLUID PROPERTIES

 HFG= 501.0000 BTU/LB   DIF=    .4420 FTFT/HR   RMC=  32.0000   CD 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

PIPE PROPERTIES

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

CONDENSER ENVIRONMENT, SECTION NUMBER 1

 TF=  0.           R   POW=  8.7500E+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

WICK PROPERTIES AND RESERVOIR CONDITIONS

 WICK THK=    .0010 IN   WICK COND=    .1200 BTU/HRFTR   D-ART=    .0730 IN   VRES=    .7900 CU IN   TRES= 495.0000 R   NRES= 2
```

```
OPERATING CONDITIONS

  TEV=  5.300OE+02 R    Q=  5.0000E+00 BTU/HR    MODEQM= 1    CEV=  3.4745E-04 LBMOLE/FT3

DIMENSIONLESS TEMPERATURES

TZ=  1.5924E+01 TS1=  9.3405E-01 TS2=  9.3405E-01 TR=  9.3396E-01

DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 1

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

DIMENSIONLESS CONDENSER PARAMETERS, SECTION NO. 2

EMIS=  8.5000E-01 C=  2.7023E+02 F=  1.2293E-01 H=  0.         XL=  3.0507E+01

AMOUNT OF NONCONDENSIBLE GAS

GAS=  1.0799E+02   ZGAS=  0.          FT   AGAS=  1.2600E-07 LBMOLE   COEF=  1.1668E-09 1/LBMOLE
AMI=  1.2600E-07 LBMOLE  XGAS=  2.1501E-01 FT


ITER=  0  PHIZ=  3.9448E-01  XSUM=  4.3560E+01  QSUM=  4.5023E-02  JEND= 248

THE PROGRAM IS OPERATING IN SHORT MODE

ITER=  1  PHIZ=  7.8895E-01  XSUM=  6.7810E+01  QSUM=  1.3776E+00  JEND= 249

ITER=  2  PHIZ=  5.9172E-01  XSUM=  8.5579E+01  QSUM=  1.2958E+00  JEND= 248

ITER=  3  PHIZ=  4.[illegible]31CE-01  XSUM=  [illegible]E+01  QSUM=  1.1987E+00  JEND= 24[illegible]

ITER=  4  PHIZ=  4.437[illegible]  XSUM=  1.[illegible]E+02  QSUM=  1.0693E+00  JEND= 251
```

```
ITER=  5  PHIZ=  4.1913E-01  XSUM=  1.2049E+02  QSUM=  7.3304E-01  JEND= 256
ITER=  6  PHIZ=  4.3269E-01  XSUM=  1.1160E+02  QSUM=  9.6464E-01  JEND= 256
ITER=  7  PHIZ=  4.4015E-01  XSUM=  1.0825E+02  QSUM=  1.0414E+00  JEND= 251
ITER=  8  PHIZ=  4.4475E-01  XSUM=  1.0678E+02  QSUM=  1.0724E+00  JEND= 251
ITER=  9  PHIZ=  4.4270E-01  XSUM=  1.0749E+02  QSUM=  1.0578E+00  JEND= 252
ITER= 10  PHIZ=  4.4118E-01  XSUM=  1.0786E+02  QSUM=  1.0499E+00  JEND= 252
ITER= 11  PHIZ=  4.4066E-01  XSUM=  1.0806E+02  QSUM=  1.0457E+00  JEND= 252

NRES= 2   VRES=  7.9000E-01 IN3   TPES=  4.9775E+02 R   XR=  6.4334E-01   MRES=  1.0861E-07 LB-MOLES

J=   0  Z=  0.              ZIN=  0.          IN
        V=  0.              P=  4.4006E-01  TI=  9.3915E-01  XSUM=  0.          ASTN=  0.          MASSFLOW=  0.          LB/HR
        QSUM=  0.             BTU/HR  XS=  6.4334E-01  TWICK=  4.9775E+02 R  TWALL=  4.9774E+02 R  MPIPE=  0.          LBMOLES
J=   3  Z=  5.0000E-01  ZIN=  9.7385E-02 IN
        V=  2.5675E-05  P=  4.4077E-01  TI=  9.3916E-01  XSUM=  3.4250E-01  ASTN=  5.5958E-05  MASSFLOW=  2.5624E-07 LB/HR
        QSUM=  3.9759E-03 BTU/HR  XS=  6.4327E-01  TWICK=  4.9776E+02 R  TWALL=  4.9775E+02 R  MPIPE=  3.9962E-10 LBMOLES
J=   6  Z=  1.2500E+00  ZIN=  2.4346E-01 IN
        V=  6.4535E-05  P=  4.4136E-01  TI=  9.3922E-01  XSUM=  8.5605E-01  ASTN=  5.6732E-05  MASSFLOW=  6.4406E-07 LB/HR
        QSUM=  9.9781E-03 BTU/HR  XS=  6.4289E-01  TWICK=  4.9779E+02 R  TWALL=  4.9778E+02 R  MPIPE=  9.9984E-10 LBMOLES
J=   9  Z=  2.0000E+00  ZIN=  3.8954E-01 IN
        V=  1.0429E-04  P=  4.4246E-01  TI=  9.3933E-01  XSUM=  1.3691E+00  ASTN=  5.8300E-05  MASSFLOW=  1.0408E-06 LB/HR
        QSUM=  1.6080E-02 BTU/HR  XS=  6.4217E-01  TWICK=  4.9785E+02 R  TWALL=  4.9784E+02 R  MPIPE=  1.5975E-09 LBMOLES
J=  12  Z=  2.7500E+00  ZIN=  5.3562E-01 IN
        V=  1.4551E-04  P=  4.4409E-01  TI=  9.3949E-01  XSUM=  1.8814E+00  ASTN=  5.0697E-05  MASSFLOW=  1.4522E-06 LB/HR
        QSUM=  2.2341E-02 BTU/HR  XS=  6.4112E-01  TWICK=  4.9793E+02 R  TWALL=  4.9793E+02 R  MPIPE=  2.1952E-09 LBMOLES
J=  15  Z=  3.5000E+00  ZIN=  6.8169E-01 IN
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         V=  1.8880E-04   P=  4.4628E-01   TI=   9.3971E-01   XSUM=  2.3926E+00   ASTN=  6.3983E-05   MASSFLOW=  1.8842E-06 LB/HR
         QSUM=  2.8825E-02 BTU/HR  XS=  6.3971E-01   TWICK=  4.9805E+02 R   TWALL=  4.9804E+02 R   MPIPE=  2.7917E-09 LBMOLES

J=  18   Z=  4.2500E+00   ZIN=  8.2777E-01 IN
         V=  2.3480E-04   P=  4.4904E-01   TI=   9.3998E-01   XSUM=  2.9024E+00   ASTN=  6.8239E-05   MASSFLOW=  2.3433E-06 LB/HR
         QSUM=  3.5595E-02 BTU/HR  XS=  6.3793E-01   TWICK=  4.9819E+02 R   TWALL=  4.9818E+02 R   MPIPE=  3.3666E-09 LBMOLES

J=  21   Z=  5.0000E+00   ZIN=  9.7385E-01 IN
         V=  2.8424E-04   P=  4.5242E-01   TI=   9.4031E-01   XSUM=  3.4105E+00   ASTN=  7.3575E-05   MASSFLOW=  2.8367E-06 LB/HR
         QSUM=  4.2720E-02 BTU/HR  XS=  6.3576E-01   TWICK=  4.9836E+02 R   TWALL=  4.9836E+02 R   MPIPE=  3.9794E-09 LBMOLES

J=  24   Z=  5.7500E+00   ZIN=  1.1199E+00 IN
         V=  3.3792E-04   P=  4.5640E-01   TI=   9.4070E-01   XSUM=  3.9165E+00   ASTN=  8.0132E-05   MASSFLOW=  3.3725E-06 LB/HR
         QSUM=  5.0271E-02 BTU/HR  XS=  6.3316E-01   TWICK=  4.9857E+02 R   TWALL=  4.9856E+02 R   MPIPE=  4.5697E-09 LBMOLES

J=  27   Z=  6.5000E+00   ZIN=  1.2660E+00 IN
         V=  3.9679E-04   P=  4.6126E-01   TI=   9.4116E-01   XSUM=  4.4200E+00   ASTN=  8.6090E-05   MASSFLOW=  3.9599E-06 LB/HR
         QSUM=  5.8323E-02 BTU/HR  XS=  6.3012E-01   TWICK=  4.9881E+02 R   TWALL=  4.9881E+02 R   MPIPE=  5.1572E-09 LBMOLES

J=  30   Z=  7.2500E+00   ZIN=  1.4121E+00 IN
         V=  4.6191E-04   P=  4.6686E-01   TI=   9.4169E-01   XSUM=  4.9206E+00   ASTN=  9.7681E-05   MASSFLOW=  4.6098E-06 LB/HR
         QSUM=  6.6957E-02 BTU/HR  XS=  6.2657E-01   TWICK=  4.9909E+02 R   TWALL=  4.9908E+02 R   MPIPE=  5.7413E-09 LBMOLES

J=  33   Z=  8.0000E+00   ZIN=  1.5582E+00 IN
         V=  5.3455E-04   P=  4.7334E-01   TI=   9.4229E-01   XSUM=  5.4179E+00   ASTN=  1.0920E-04   MASSFLOW=  5.3348E-06 LB/HR
         QSUM=  7.6261E-02 BTU/HR  XS=  6.2249E-01   TWICK=  4.9941E+02 R   TWALL=  4.9940E+02 R   MPIPE=  6.3216E-09 LBMOLES

J=  36   Z=  8.7500E+00   ZIN=  1.7042E+00 IN
         V=  6.1623E-04   P=  4.8083E-01   TI=   9.4297E-01   XSUM=  5.9113E+00   ASTN=  1.2301E-04   MASSFLOW=  6.1500E-06 LB/HR
         QSUM=  8.6328E-02 BTU/HR  XS=  6.1781E-01   TWICK=  4.9977E+02 R   TWALL=  4.9976E+02 R   MPIPE=  6.8973E-09 LBMOLES

J=  39   Z=  9.5000E+00   ZIN=  1.8503E+00 IN
         V=  7.0876E-04   P=  4.8944E-01   TI=   9.4374E-01   XSUM=  6.4004E+00   ASTN=  1.3960E-04   MASSFLOW=  7.0735E-06 LB/HR
         QSUM=  9.7261E-02 BTU/HR  XS=  6.1247E-01   TWICK=  5.0018E+02 R   TWALL=  5.0017E+02 R   MPIPE=  7.4680E-09 LBMOLES

J=  42   Z=  1.0250E+01   ZIN=  1.9964E+00 IN
         V=  8.1436E-04   P=  4.9933E-01   TI=   9.4461E-01   XSUM=  6.0846E+00   ASTN=  1.5958E-04   MASSFLOW=  8.1274E-06 LB/HR
         QSUM=  1.0917E-01 BTU/HR  XS=  6.0639E-01   TWICK=  5.0064E+02 R   TWALL=  5.0053E+02 R   MPIPE=  8.0329E-09 LBMOLES

J=  45   Z=  1.1000E+01   ZIN=  2.1425E+00 IN
         V=  9.3576E-04   P=  5.1069E-01   TI=   9.4558E-01   XSUM=  7.3631E+00   ASTN=  1.8373E-04   MASSFLOW=  9.3390E-06 LB/HR
         QSUM=  1.2218E-01 BTU/HR  XS=  5.9949E-01   TWICK=  5.0116E+02 R   TWALL=  5.0114E+02 R   MPIPE=  8.5913E-09 LBMOLES
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J=  48  Z=  1.1750E+01  ZIN=  2.2885E+00 IN
        V=  1.0764E-03  P=  5.2373E-01  TI=  9.4666E-01  XSUM=  7.8353E+00  ASTN=  2.1310E-04  MASSFLOW=  1.0742E-05 LB/HR
        QSUM=  1.3642E-01 BTU/HR  XS=  5.9165E-01  TWICK=  5.0173E+02 R  TWALL=  5.0171E+02 R  MPIPE=  9.1422E-09 LBMOLES

J=  51  Z=  1.2500E+01  ZIN=  2.4346E+00 IN
        V=  1.2404E-03  P=  5.3874E-01  TI=  9.4787E-01  XSUM=  8.3003E+00  ASTN=  2.4907E-04  MASSFLOW=  1.2380E-05 LB/HR
        QSUM=  1.5204E-01 BTU/HR  XS=  5.8277E-01  TWICK=  5.0237E+02 R  TWALL=  5.0235E+02 R  MPIPE=  9.6847E-09 LBMOLES

J=  54  Z=  1.3250E+01  ZIN=  2.5907E+00 IN
        V=  1.4335E-03  P=  5.5503E-01  TI=  9.4921E-01  XSUM=  8.7572E+00  ASTN=  2.9347E-04  MASSFLOW=  1.4306E-05 LB/HR
        QSUM=  1.6919E-01 BTU/HR  XS=  5.7270E-01  TWICK=  5.0308E+02 R  TWALL=  5.0306E+02 R  MPIPE=  1.0218E-08 LBMOLES

J=  57  Z=  1.4000E+01  ZIN=  2.7268E+00 IN
        V=  1.6526E-03  P=  5.7603E-01  TI=  9.5070E-01  XSUM=  9.2049E+00  ASTN=  3.4682E-04  MASSFLOW=  1.6592E-05 LB/HR
        QSUM=  1.8807E-01 BTU/HR  XS=  5.6124E-01  TWICK=  5.0387E+02 R  TWALL=  5.0385E+02 R  MPIPE=  1.0740E-08 LBMOLES

J=  60  Z=  1.4750E+01  ZIN=  2.8728E+00 IN
        V=  1.9370E-03  P=  5.9924E-01  TI=  9.5235E-01  XSUM=  9.6423E+00  ASTN=  4.1858E-04  MASSFLOW=  1.9331E-05 LB/HR
        QSUM=  2.0886E-01 BTU/HR  XS=  5.4850E-01  TWICK=  5.0474E+02 F  TWALL=  5.0472E+02 R  MPIPE=  1.1251E 08 LBMOLES

J=  63  Z=  1.5500E+01  ZIN=  3.0189E+00 IN
        V=  2.2691E-03  P=  6.2632E-01  TI=  9.5418E-01  XSUM=  1.0068E+01  ASTN=  5.0764E-04  MASSFLOW=  2.2646E-05 LB/HR
        QSUM=  2.3179E-01 BTU/HR  XS=  5.3395E-01  TWICK=  5.0571E+02 R  TWALL=  5.0569E+02 R  MPIPE=  1.1747E-08 LBMOLES

J=  66  Z=  1.6250E+01  ZIN=  3.1650E+00 IN
        V=  2.6758E-03  P=  6.5810E-01  TI=  9.5520E-01  XSUM=  1.0480E+01  ASTN=  6.0304E-04  MASSFLOW=  2.5705E-05 LB/HR
        QSUM=  2.5708E-01 BTU/HR  XS=  5.1675E-01  TWICK=  5.0678E+02 R  TWALL=  5.0676E+02 R  MPIPE-  1.2224E-08 LBMOLES

J=  69  Z=  1.7000E+01  ZIN=  3.3111E+00 IN
        V=  3.1805E-03  P=  6.9555E-01  TI=  9.5645E-01  XSUM=  1.0878E+01  ASTN=  7.7519E-04  MASSFLOW=  3.1742E-05 LB/HR
        QSUM=  2.8532E-01 BTU/HR  XS=  4.9757E-01  TWICK=  5.0797E+02 R  TWALL=  5.0794E+02 R  MPIPE=  1.2692E-08 LBMOLES

J=  72  Z=  1.7750E+01  ZIN=  3.4572E+00 IN
        V=  3.8169E-03  P=  7.4041E-01  TI=  9.6090E-01  XSUM=  1.1258E+01  ASTN=  9.7989E-04  MASSFLOW=  3.8089E-05 LB/HR
        QSUM=  3.1590E-01 BTU/HR  XS=  4.7565E-01  TWICK=  5.0926E+02 R  TWALL=  5.0924E+02 R  MPIPE=  1.3136E-08 LBMOLES

J=  75  Z=  1.8500E+01  ZIN=  3.6032E+00 IN
        V=  4.6324E-03  P=  7.9431E-01  TI=  9.6361E-01  XSUM=  1.1620E+01  ASTN=  1.2620E-03  MASSFLOW=  4.6231E-05 LB/HR
        QSUM=  3.5295E-01 BTU/HR  XS=  4.5054E-01  TWICK=  5.1072E+02 R  TWALL=  5.1068E+02 R  MPIPE=  1.3558E-08 LBMOLES

J=  78  Z=  1.9250E+01  ZIN=  3.7493E+00 IN
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         V=  5.7019E-03  P=  8.6023E-01  TI=  9.6660E-01  XSUM=  1.1959E+01  ASTN=  1.6623E-03  MASSFLOW=  5.6904E-05 LB/HR
         QSUM=  3.4781E-01 BTU/HR  XS=  4.2172E-01  TWICK=  5.1230E+02 R  TWALL=  5.1226E+02 R  MPIPE=  1.3953E-08 LBMOLES

J=  81  Z=  2.0000E+01  ZIN=  3.8954E+00 IN
         V=  7.1406E-03  P=  9.4141E-01  TI=  9.6989E-01  XSUM=  1.2273E+01  ASTN=  2.2506E-03  MASSFLOW=  7.1263E-05 LB/HR
         QSUM=  4.2961E-01 BTU/HR  XS=  3.8859E-01  TWICK=  5.1404E+02 R  TWALL=  5.1399E+02 R  MPIPE=  1.4320E-08 LBMOLES

J=  84  Z=  2.0750E+01  ZIN=  4.0415E+00 IN
         V=  9.1405E-03  P=  1.0441E+00  TI=  9.7348E-01  XSUM=  1.2558E+01  ASTN=  3.1548E-03  MASSFLOW=  9.1223E-05 LB/HR
         QSUM=  4.7585E-01 BTU/HR  XS=  3.5247E-01  TWICK=  5.1594E+02 R  TWALL=  5.1589E+02 R  MPIPE=  1.4653E-08 LBMOLES

J=  87  Z=  2.1500E+01  ZIN=  4.1875E+00 IN
         V=  1.2039E-02  P=  1.1771E+00  TI=  9.7739E-01  XSUM=  1.2811E+01  ASTN=  4.6247E-03  MASSFLOW=  1.2015E-04 LB/HR
         QSUM=  5.2702E-01 BTU/HR  XS=  3.3655E-01  TWICK=  5.1802E+02 R  TWALL=  5.1796E+02 R  MPIPE=  1.4948E-08 LBMOLES

J=  90  Z=  2.2250E+01  ZIN=  4.3336E+00 IN
         V=  1.6479E-02  P=  1.3551E+00  TI=  9.8161E-01  XSUM=  1.3027E+01  ASTN=  7.1958E-03  MASSFLOW=  1.6446E-04 LB/HR
         QSUM=  5.8358E-01 BTU/HR  XS=  2.5650E-01  TWICK=  5.2025E+02 R  TWALL=  5.2019E+02 R  MPIPE=  1.5200E-08 LBMOLES

J=  93  Z=  2.3000E+01  ZIN=  4.4797E+00 IN
         V=  2.3805E-02  P=  1.5043E+00  TI=  9.8610E-01  XSUM=  1.3201E+01  ASTN=  1.2143E-02  MASSFLOW=  2.3759E-04 LB/HR
         QSUM=  6.4601E-01 BTU/HR  XS=  1.9975E-01  TWICK=  5.2253E+02 R  TWALL=  5.2257E+02 R  MPIPE=  1.5403E-08 LBMOLES

J=  96  Z=  2.3604E+01  ZIN=  4.5974E+00 IN
         V=  2.1536E-03  P=  1.6661E+00  TI=  9.8702E-01  XSUM=  1.3318E+01  ASTN=  4.0367E-04  MASSFLOW=  2.1493E-05 LB/HR
         QSUM=  7.0399E-01 BTU/HR  XS=  1.9777E-01  TWICK=  5.2312E+02 R  TWALL=  5.2304E+02 R  MPIPE=  1.5534E-08 LBMOLES

J=  99  Z=  2.4354E+01  ZIN=  4.7435E+00 IN
         V=  2.4623E-03  P=  1.6950E+00  TI=  9.8742E-01  XSUM=  1.3458E+01  ASTN=  4.4475E-04  MASSFLOW=  2.4574E-05 LB/HR
         QSUM=  7.7770E-01 BTU/HR  XS=  1.8243E-01  TWICK=  5.2333E+02 R  TWALL=  5.2326E+02 R  MPIPE=  1.5703E-08 LBMOLES

J= 102  Z=  2.5104E+01  ZIN=  4.8895E+00 IN
         V=  2.8049E-03  P=  1.7280E+00  TI=  9.8787E-01  XSUM=  1.3595E+01  ASTN=  4.9515E-04  MASSFLOW=  2.7993E-05 LB/HR
         QSUM=  8.5206E-01 BTU/HR  XS=  1.7646E-01  TWICK=  5.2357E+02 R  TWALL=  5.2349E+02 R  MPIPE=  1.5862E-08 LBMOLES

J= 105  Z=  2.5854E+01  ZIN=  5.0356E+00 IN
         V=  3.1896E-03  P=  1.7656E+00  TI=  9.8835E-01  XSUM=  1.3726E+01  ASTN=  5.5735E-04  MASSFLOW=  3.1830E-05 LB/HR
         QSUM=  9.2711E-01 BTU/HR  XS=  1.6995E-01  TWICK=  5.2383E+02 R  TWALL=  5.2375E+02 R  MPIPE=  1.6016E-08 LBMOLES

J= 108  Z=  2.6604E+01  ZIN=  5.1817E+00 IN
         V=  3.6258E-03  P=  1.8082E+00  TI=  9.8888E-01  XSUM=  1.3853E+01  ASTN=  6.3482E-04  MASSFLOW=  3.6185E-05 LB/HR
         QSUM=  1.0029E+00 BTU/HR  XS=  1.6284E-01  TWICK=  5.2411E+02 R  TWALL=  5.2403E+02 R  MPIPE=  1.6163E-08 LBMOLES
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J= 111  Z=  2.7354E+01  ZIN=  5.3278E+00 IN
        V=  4.1273E-03  P=  1.8567E+00  TI=  9.8945E-01  XSUM=  1.3973E+01  ASTN=  7.3240E-04  MASSFLOW=  4.1191E-05 LB/HR
        QSUM=  1.0796E+00 BTU/HR  XS=  1.5511E-01  TWICK=  5.2441E+02 R  TWALL=  5.2433E+02 R  MPIPE=  1.6304E-08 LBMOLES

J= 114  Z=  2.8104E+01  ZIN=  5.4738E+00 IN
        V=  4.7118E-03  P=  1.9120E+00  TI=  9.9006E-01  XSUM=  1.4088E+01  ASTN=  8.5712E-04  MASSFLOW=  4.7024E-05 LB/HR
        QSUM=  1.1571E+00 BTU/HR  XS=  1.4676E-01  TWICK=  5.2473E+02 R  TWALL=  5.2465E+02 R  MPIPE=  1.6437E-08 LBMOLES

J= 117  Z=  2.8854E+01  ZIN=  5.6199E+00 IN
        V=  5.4036E-03  P=  1.9751E+00  TI=  9.9071E-01  XSUM=  1.4195E+01  ASTN=  1.0194E-03  MASSFLOW=  5.3928E-05 LB/HR
        QSUM=  1.2356E+00 BTU/HR  XS=  1.3776E-01  TWICK=  5.2507E+02 R  TWALL=  5.2499E+02 R  MPIPE=  1.6563E-08 LBMOLES

J= 120  Z=  2.9604E+01  ZIN=  5.7660E+00 IN
        V=  6.2371E-03  P=  2.0475E+00  TI=  9.9140E-01  XSUM=  1.4296E+01  ASTN=  1.2352E-03  MASSFLOW=  6.2247E-05 LB/HR
        QSUM=  1.3151E+00 BTU/HR  XS=  1.2839E-01  TWICK=  5.2544E+02 R  TWALL=  5.2536E+02 R  MPIPE=  1.6680E-08 LBMOLES

J= 123  Z=  3.0354E+01  ZIN=  5.9121E+00 IN
        V=  7.2627E-03  P=  2.1319E+00  TI=  9.9213E-01  XSUM=  1.4389E+01  ASTN=  1.5299E-03  MASSFLOW=  7.2482E-05 LB/HR
        QSUM=  1.3957E+00 BTU/HR  XS=  1.1774E-01  TWICK=  5.2580E+02 R  TWALL=  5.2575E+02 R  MPIPE=  1.6789E-08 LBMOLES

J= 126  Z=  3.1104E+01  ZIN=  6.0587E+00 IN
        V=  8.5568E-03  P=  2.2304E+00  TI=  9.9291E-01  XSUM=  1.4474E+01  ASTN=  1.9463E-03  MASSFLOW=  8.5397E-05 LB/HR
        QSUM=  1.4774E+00 BTU/HR  XS=  1.0669E-01  TWICK=  5.2624E+02 R  TWALL=  5.2616E+02 R  MPIPE=  1.6888E-08 LBMOLES

J= 129  Z=  3.1854E+01  ZIN=  6.2047E+00 IN
        V=  1.0241E-02  P=  2.3475E+00  TI=  9.9375E-01  XSUM=  1.4550E+01  ASTN=  2.5600E-03  MASSFLOW=  1.0221E-04 LB/HR
        QSUM=  1.5604E+00 BTU/HR  XS=  9.4893E-02  TWICK=  5.2668E+02 R  TWALL=  5.2659E+02 R  MPIPE=  1.6977E-08 LBMOLES

J= 132  Z=  3.2604E+01  ZIN=  6.3503E+00 IN
        V=  1.2523E-02  P=  2.4886E+00  TI=  9.9459E-01  XSUM=  1.4617E+01  ASTN=  3.5153E-03  MASSFLOW=  1.2498E-04 LB/HR
        QSUM=  1.6446E+00 BTU/HR  XS=  8.7384E-02  TWICK=  5.2718E+02 R  TWALL=  5.2704E+02 R  MPIPE=  1.7055E-08 LBMOLES

J= 135  Z=  3.3354E+01  ZIN=  6.4964E+00 IN
        V=  1.5784E-02  P=  2.6637E+00  TI=  9.9548E-01  XSUM=  1.4674E+01  ASTN=  5.1156E-03  MASSFLOW=  1.5752E-04 LB/HR
        QSUM=  1.7302E+00 BTU/HR  XS=  6.9135E-02  TWICK=  5.2761E+02 R  TWALL=  5.2752E+02 R  MPIPE=  1.7121E-08 LBMOLES

J= 138  Z=  3.4104E+01  ZIN=  6.6425E+00 IN
        V=  2.0803E-02  P=  2.6842E+00  TI=  9.9642E-01  XSUM=  1.4721E+01  ASTN=  6.0865E-03  MASSFLOW=  2.0762E-04 LB/HR
        QSUM=  1.8173E+00 BTU/HR  XS=  5.5170E-02  TWICK=  5.2810E+02 R  TWALL=  5.2801E+02 R  MPIPE=  1.7176E-08 LBMOLES

J= 141  Z=  3.4854E+01  ZIN=  6.7885E+00 IN
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         V=  2.5454E-02  P=  3.1966E+00  TI=  9.9738E-01  XSUM=  1.4757E+01  ASTN=  1.6511E-02  MASSFLOW=  2.9395E-04 LB/HR
         QSUM=  1.9057E+00 BTU/HR  XS=  4.0563E-02  TWICK=  5.2861E+02 R  TWALL=  5.2852E+02 R  MPIPE=  1.7218E-08 LBMOLES

J= 144   Z=  3.5604E+01  ZIN=  6.9346E+00 IN
         V=  4.7463E-02  P=  3.6592E+00  TI=  9.9836E-01  XSUM=  1.4781E+01  ASTN=  3.2335E-02  MASSFLOW=  4.7368E-04 LB/HR
         QSUM=  1.9957E+00 BTU/HR  XS=  2.5535E-02  TWICK=  5.2913E+02 R  TWALL=  5.2904E+02 R  MPIPE=  1.7247E-08 LBMOLES

J= 147   Z=  3.6354E+01  ZIN=  7.0807E+00 IN
         V=  1.0145E-01  P=  4.5119E+00  TI=  9.9931E-01  XSUM=  1.4795E+01  ASTN=  1.0974E-01  MASSFLOW=  1.0125E-03 LB/HR
         QSUM=  2.0873E+00 BTU/HR  XS=  1.0882E-02  TWICK=  5.2963E+02 R  TWALL=  5.2954E+02 R  MPIPE=  1.7263E-08 LBMOLES

J= 150   Z=  3.6854E+01  ZIN=  7.1781E+00 IN
         V=  2.3041E-01  P=  5.7851E+00  TI=  9.9981E-01  XSUM=  1.4798E+01  ASTN=  3.8981E-01  MASSFLOW=  2.2995E-03 LB/HR
         QSUM=  2.1490E+00 BTU/HR  XS=  3.0460E-03  TWICK=  5.2990E+02 R  TWALL=  5.2980E+02 R  MPIPE=  1.7266E-08 LBMOLES

J= 153   Z=  3.7229E+01  ZIN=  7.2511E+00 IN
         V=  3.9144E-01  P=  7.7413E+00  TI=  9.9997E-01  XSUM=  1.4799E+01  ASTN=  3.8125E-01      FLOW=  3.9066E-03 LB/HR
         QSUM=  2.1956E+00 BTU/HR  XS=  4.3069E-04  TWICK=  5.2999E+02 R  TWALL=  5.2989E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 156   Z=  3.7604E+01  ZIN=  7.3242E+00 IN
         V=  4.4472E-01  P=  1.0384E+01  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  7.1858E-02  MASSFLOW=  4.4383E-03 LB/HR
         QSUM=  2.2422E+00 BTU/HR  XS=  2.0639E-05  TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 159   Z=  3.8354E+01  ZIN=  7.4702E+00 IN
         V=  4.6724E-01  P=  1.6063E+01  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.6079E-02  MASSFLOW=  4.6631E-03 LB/HR
         QSUM=  2.3355E+00 BTU/HR  XS=  1.0476E-07  TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7257E-08 LBMOLES

J= 162   Z=  3.9104E+01  ZIN=  7.6163E+00 IN
         V=  4.8591E-01  P=  2.1981E+01  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5749E-02  MASSFLOW=  4.8494E-03 LB/HR
         QSUM=  2.4288E+00 BTU/HR  XS=  2.8161E-10  TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 165   Z=  3.9854E+01  ZIN=  7.7624E+00 IN
         V=  5.0457E-01  P=  2.8132E+01  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  5.0356E-03 LB/HR
         QSUM=  2.5221E+00 BTU/HR  XS=  5.6076E-13  TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 168   Z=  4.0604E+01  ZIN=  7.9085E+00 IN
         V=  5.2323E-01  P=  3.4514E+01  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  5.2219E-03 LB/HR
         QSUM=  2.6154E+00 BTU/HR  XS=  0.              TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 171   Z=  4.1354E+01  ZIN=  8.0545E+00 IN
         V=  5.4189E-01  P=  4.1128E+01  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  5.4081E-03 LB/HR
         QSUM=  2.7087E+00 BTU/HR  XS=  0.              TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES
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J= 174  Z=  4.2104E+01   ZIN=  8.2006E+00 IN
        V=  5.6055E-01   P=  4.7974E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  5.5943E-03 LB/HR
        QSUM=  2.8920E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 177  Z=  4.2854E+01   ZIN=  8.3467E+00 IN
        V=  5.7921E-01   P=  5.5051E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  5.7805E-03 LB/HR
        QSUM=  2.8953E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 180  Z=  4.3604E+01   ZIN=  8.4928E+00 IN
        V=  5.9787E-01   P=  6.2360E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  5.9657E-03 LB/HR
        QSUM=  2.9886E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 183  Z=  4.4354E+01   ZIN=  8.6389E+00 IN
        V=  6.1653E-01   P=  6.9901E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  6.1530E-03 LB/HR
        QSUM=  3.0819E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 186  Z=  4.5104E+01   ZIN=  8.7849E+00 IN
        V=  6.3519E-01   P=  7.7673E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  6.3392E-03 LB/HR
        QSUM=  3.1752E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 189  Z=  4.5854E+01   ZIN=  8.9310E+00 IN
        V=  6.5385E-01   P=  8.5678E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  6.5254E-03 LB/HR
        QSUM=  3.2685E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 192  Z=  4.6604E+01   ZIN=  9.0771E+00 IN
        V=  6.7251E-01   P=  9.3914E+01   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  6.7116E-03 LB/HR
        QSUM=  3.3618E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 195  Z=  4.7354E+01   ZIN=  9.2232E+00 IN
        V=  6.9116E-01   P=  1.0238E+02   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  6.8978E-03 LB/HR
        QSUM=  3.4551E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 198  Z=  4.8104E+01   ZIN=  9.3692E+00 IN
        V=  7.0982E-01   P=  1.1108E+02   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  7.0841E-03 LB/HR
        QSUM=  3.5484E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 201  Z=  4.8854E+01   ZIN=  9.5153E+00 IN
        V=  7.2848E-01   P=  1.2001E+02   TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  7.2703E-03 LB/HR
        QSUM=  3.6417E+00 BTU/HR  XS=  0.          TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 204  Z=  4.9604E+01   ZIN=  9.6614E+00 IN
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          V=  7.4714E-01   P=  1.2917E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  7.4565E-03 LB/HR
          QSUM=  3.7350E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 207  Z=  5.0354E+01  ZIN=  9.8075E+00 IN
          V=  7.6580E-01   P=  1.3857E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  7.6427E-03 LB/HR
          QSUM=  3.8283E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 210  Z=  5.1104E+01  ZIN=  9.9535E+00 IN
          V=  7.8446E-01   P=  1.4829E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  7.8289E-03 LB/HR
          QSUM=  3.9216E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 213  Z=  5.1854E+01  ZIN=  1.0100E+01 IN
          V=  8.0312E-01   P=  1.5805E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  8.0152E-03 LB/HR
          QSUM=  4.0149E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 216  Z=  5.2604E+01  ZIN=  1.0246E+01 IN
          V=  8.2178E-01   P=  1.6814E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  8.2014E-03 LB/HR
          QSUM=  4.1082E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 219  Z=  5.3354E+01  ZIN=  1.0392E+01 IN
          V=  8.4044E-01   P=  1.7847E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  8.3876E-03 LB/HR
          QSUM=  4.2015E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 222  Z=  5.4104E+01  ZIN=  1.0538E+01 IN
          V=  8.5910E-01   P=  1.8902E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  8.5738E-03 LB/HR
          QSUM=  4.2948E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 225  Z=  5.4854E+01  ZIN=  1.0684E+01 IN
          V=  8.7776E-01   P=  1.9980E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  8.7601E-03 LB/HR
          QSUM=  4.3881E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 228  Z=  5.5604E+01  ZIN=  1.0830E+01 IN
          V=  8.9642E-01   P=  2.1082E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  8.9463E-03 LB/HR
          QSUM=  4.4813E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 231  Z=  5.6354E+01  ZIN=  1.0976E+01 IN
          V=  9.1508E-01   P=  2.2207E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  9.1325E-03 LB/HR
          QSUM=  4.5746E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 234  Z=  5.7104E+01  ZIN=  1.1122E+01 IN
          V=  9.3374E-01   P=  2.3355E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  9.3187E-03 LB/HR
          QSUM=  4.6679E+00 BTU/HR  XS=  0.           TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES
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. . .

J= 237  Z=  5.7854E+01  ZIN=  1.1268E+01 IN
        V=  9.5239E-01  P=  2.4526E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  9.5049E-03 LB/HR
        QSUM=  4.7612E+00 BTU/HR  XS=  0.            TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 240  Z=  5.8604E+01  ZIN=  1.1414E+01 IN
        V=  9.7105E-01  P=  2.5721E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  9.6912E-03 LB/HR
        QSUM=  4.8[illegible]E+00 BTU/HR  XS=  0.            TWICK=  5.3000F+02 R  TWALL=  5.2990F+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 243  Z=  5.9354E+01  ZIN=  1.1560E+01 IN
        V=  9.8971E-01  P=  2.6938E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  9.8774E-03 LB/HR
        QSUM=  4.9478E+00 BTU/HR  XS=  0.            TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 246  Z=  6.0104E+01  ZIN=  1.1706F+01 IN
        V=  1.0084E+00  P=  2.8179F+02  TI=  1.0C0CF+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  1.0064E-02 LB/HR
        QSUM=  5.0411F+00 BTU/HR  XS=  0.            TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 249  Z=  6.0854E+01  ZIN=  1.1853E+01 IN
        V=  1.0270E+00  P=  2.9443E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  1.0250E-02 LB/HR
        QSUM=  5.1344F+00 BTU/HR  XS=  0.            TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 252  Z=  6.1604E+01  ZIN=  1.1999E+01 IN
        V=  1.0457E+00  P=  3.0730E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  1.0436E-02 LB/HR
        QSUM=  5.2277E+00 BTU/HR  XS=  0.            TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

J= 253  Z=  6.1611E+01  ZIN=  1.2000E+01 IN
        V=  1.0459E+00  P=  3.0742E+02  TI=  1.0000E+00  XSUM=  1.4799E+01  ASTN=  2.5748E-02  MASSFLOW=  1.0438E-02 LB/HR
        QSUM=  5.2286E+00 BTU/HR  XS=  0.            TWICK=  5.3000E+02 R  TWALL=  5.2990E+02 R  MPIPE=  1.7267E-08 LBMOLES

TOTAL GAS IN PIPE AND RESERVOIR= 1.26080E-07 LB-MOLES
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