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A Computer Simulation of Steady-State Performance of Air-to-Air Heat Pumps

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OAK RIDGE NATIONAL LABORATORY
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ABSTRACT

A computer model by which the performance of air-to-air heat pumps can be simulated is described. The intended use of the model is to evaluate analytically the improvements in performance that can be effected by various component improvements. The model is based on a trio of independent simulation programs originated at the Massachusetts Institute of Technology Heat Transfer Laboratory. The three programs have been combined so that user intervention and decision making between major steps of the simulation are unnecessary. The program was further modified by the authors by substituting a new compressor model and adding a capillary tube model, both of which are described. Performance predicted by the computer model is shown to be in reasonable agreement with performance data observed in our laboratory. Planned modifications by which the utility of the computer model can be enhanced in the future are described. User instructions and a FORTRAN listing of the program are included.

1. INTRODUCTION

Initial evaluation of possible improvements to a heat pump can be performed accurately and expeditiously by mathematical analysis. Such analysis should, for the sake of efficiency, precede the more expensive and time consuming laboratory testing of changes. Because a change in performance of any component of the system will affect the performance of all others, it is necessary to analyze the whole system under a variety of operating conditions in order to evaluate the worth of a single change of component or configuration. Obviously, a repetitious task of this magnitude should be undertaken with the aid of computers. Hiller and Glicksman[1] have provided an elegant trio of computer programs that comprise a sophisticated model of a heat pump. They have also provided a good bibliography of the literature relevant to heat pump modeling.

The study for which Hiller and Glicksman wrote their programs (the "MIT model") focused principally on variable-capacity heat pump systems and ultimately upon the compressor. Their compressor model is necessarily very detailed and calls for design parameters that may not be available to most investigators; reasonably enough, some other portions of their model are most suited to the specific heat pump in their laboratory. It is the intent of the present authors to provide a program that may be used more easily to analyze a variety of heat pump configurations.

Our model retains the structure of the MIT model and makes extensive use of its collection of very useful "service routines" for calculation of thermodynamic properties of refrigerants and air, forced convection heat transfer, and fluid flow pressure drops. The use of these routines dictates that we work in the units (English) employed therein.

This report of our preliminary version of a heat pump model presents a new compressor model which is based on loss parameters that can be evaluated in the laboratory. Also reported are variations of the calculation of refrigerant pressure and flow balance that allow modeling of refrigerant flow control devices other than thermal expansion valves. Refinement and generalization of these and other portions of the program will be presented in a later report; we believe, however, that this preliminary version is a useful tool in its present form.

2. DESCRIPTION OF THE MODEL

2.1 Organization and Calculational Procedure

Since the structure of the MIT program has been retained for the Oak Ridge National Laboratory (ORNL) model of an air-to-air heat pump, a brief review of the calculatonal procedures common to both models may be useful. Methods employed in portions of the MIT program that have been retained with little or no change will be described briefly; detailed descriptions of new routines are presented in later sections of this report. The model is organized in three sections, the first of which establishes compressor power consumption, mass-flow rates, pressure balances, and thermodynamic states for the refrigerant. The second and third sections are detailed models of the condenser and of the evaporator; they are used to predict performance by calculating energy balances at these heat exchangers.

Rather than start with indoor and outdoor air temperatures against which the heat pump is working, and then iterate over the entire thermodynamic cycle, the reverse procedure is used in order to promote calculational efficiency. The refrigerant mass-flow rate is established from assumed values for evaporating temperature, superheat of the refrigerant reaching the compressor, and the degree of subcooling of refrigerant leaving the condenser; dimensions of the interconnecting pipes and the metering device, and (for the MIT program) detailed design parameters of the compressor are also used. By iteration over the saturation temperature in the condenser until a pressure balance is achieved, thermodynamic states of the refrigerant at the condenser and evaporator are established.

The refrigerant states calculated for the condenser entry are used as input to the condenser model which calculates an energy balance between refrigerant and air to find the heat rejection rate of this heat exchanger and to predict the temperature of refrigerant leaving the condenser. This temperature is compared with the previously assumed subcooling of the refrigerant; iteration over the degree of subcooling is performed until agreement is reached. Finally, the evaporator model is used to calculate its heat absorption rate for several air temperatures. The saturation temperature and superheat of the refrigerant leaving the evaporator may then be compared with those used to calculate the refrigerant flow rate in order to determine which air temperature is appropriate for the assumed conditions. Both heat exchanger models require detailed dimensions of the tubing and fins as well as airflow rates and temperatures. Refrigerant states and mass-flow rates calculated in the refrigerant flow rate routines are the other inputs to these programs. Power consumption by air fans or blowers has not been calculated; the MIT program does not calculate a coefficient of performance.

2.2 Refrigerant Flow Balance Model

As previously mentioned, the refrigerant mass flow is established from an assumed evaporating temperature, the superheat of refrigerant leaving the evaporator, and the amount of subcooling of refrigerant in the condenser. An initial guess of the condensing temperature is provided along with diameters and equivalent lengths of the interconnecting pipe (including fittings), and a description of the refrigerant metering device. The ORNL model will accommodate a thermal expansion valve (as will the MIT) or capillary tubes. The parameters required for the ORNL compressor model are displacement, motor speed, and loss parameters, as described in Sect. 2.3.

The thermodynamic cycle being modeled is shown in Fig. 1, a somewhat distorted pressure vs enthalpy (p-h) diagram. Thermodynamic states of the refrigerant are calculated using subroutines from Kartsounes and Erth[2] as modified by Hiller and Glicksman.[1] Viscosity, thermal conductivity, and specific heat are obtained from subroutines that reproduce plots[3,4] of these properties (as functions of temperature) from curve fitting parameters. These routines, as well as the pressure-drop routines, are due to Hiller and Glicksman.[1] Single-phase pressure drops in the connecting pipes are calculated from the standard incompressible flow relation and the Moody friction factor; single- and two-phase pressure drops in the heat exchangers are calculated by the Lockhart-Martinelli[5] method.

Calculation of the refrigerant mass-flow rate and the pressure drops begins in both the MIT and ORNL models by calling the compressor subroutine.

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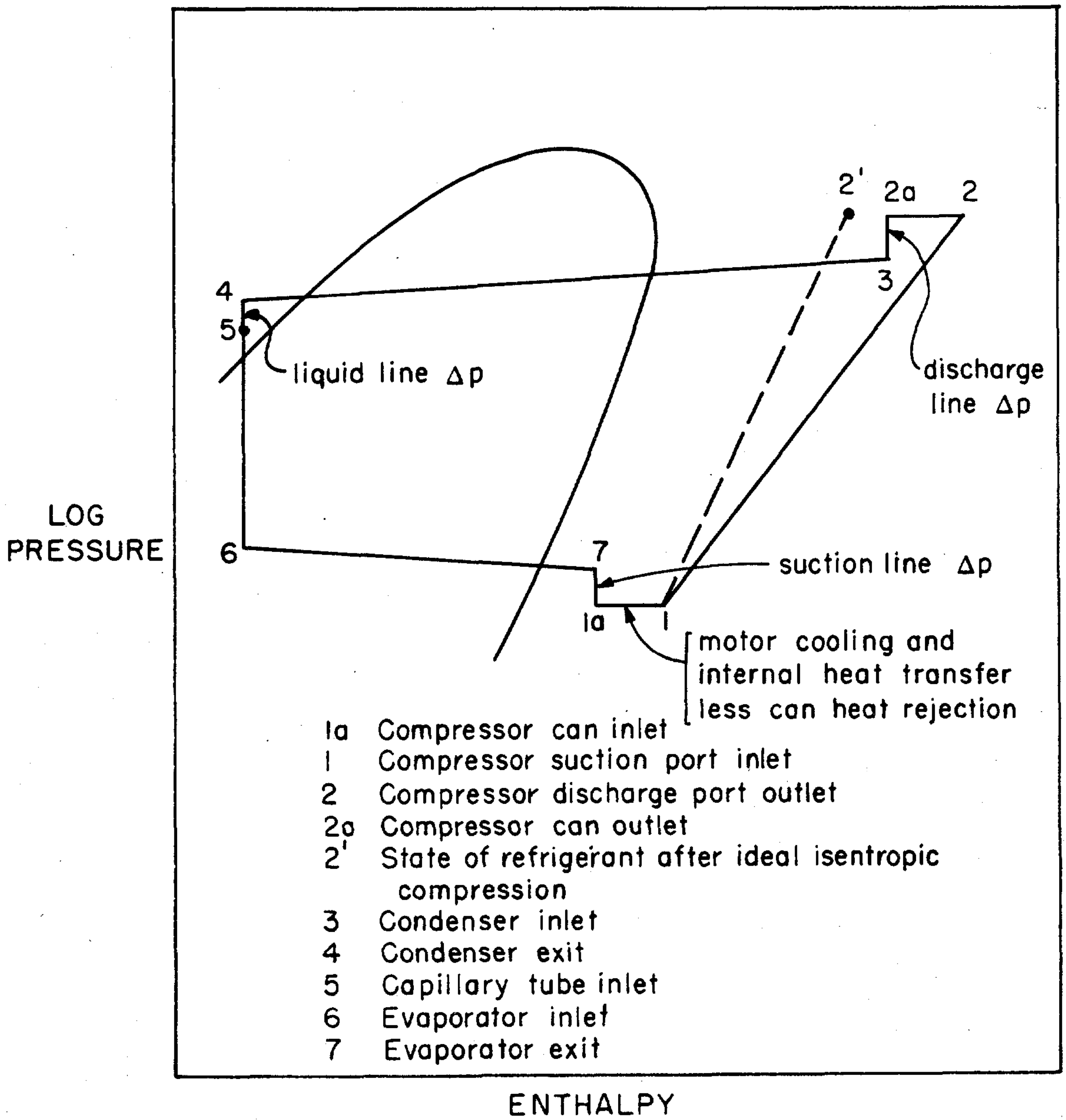

Fig. 1. Pressure vs enthalpy diagram for the heat pump cycle.

From the evaporating saturation temperature and superheat of the vapor (if evaporation is incomplete, quality is used), i.e., the state represented by point 1a on the diagram, and the estimated condensing temperature, the ORNL compressor routine calculates the refrigerant mass-flow rate, compressor motor power consumption, and the temperature, enthalpy, and pressure of the refrigerant at point 1, the compressor suction port, and at point 2a, the compressor can exit. This subroutine also calculates the pressure drop in the discharge line, that is, between points 2a and 3, the compressor exit and condenser entrance.

The pressure drop in the condenser must be calculated as though the entire condenser were experiencing two-phase flow because the length of condenser tubing occupied by the single-phase desuperheating and subcooling regions has not yet been found. Thus, the pressure at point 4 in the p-h diagram is known; calculation of the pressure drop in the liquid line from condenser to flow metering device yields the pressure at entry to that device, point 5.

If the flow metering device is a capillary tube (ORNL model only), refrigerant flow through it is calculated using the pressure just found and a routine based on curve fitting parameters that reproduce the *ASHRAE Guide and Data Book*[6] correlation. This flow through the capillary tube is compared to the flow rate predicted by the compressor routine; if the two do not agree, the condensing saturation temperature is adjusted and the entire calculation is repeated until the refrigerant mass flow predicted by the compressor model matches that which the capillary tube can accommodate.

If the flow metering device is a thermal expansion valve (TXV) as allowed in both models, it is necessary to calculate the pressure drops through the evaporator and suction line and thus the pressure at evaporator entry. The difference between this pressure and that at the entry to the thermal expansion valve is compared to the pressure drop calculated separately for the TXV and distributor nozzles and tubes as explained by Hiller and Glicksman.[1] If these two pressure drops differ, the condensing saturation temperature is adjusted and iteration proceeds until a pressure balance is achieved.

2.3 ORNL Compressor Model

The objective in formulating the ORNL compressor model was to utilize performance parameters that are descriptive of the efficiency of the device and for which quantitative values could possibly be derived from experimental data. This is in contrast to using design parameters for input, as is done for the heat exchanger models used in this simulation. The computation or simulation of compressor performance from design parameters is not a well-established art at present, and attempting to do so in this study would have led to considerable additional complication and risk. Accordingly, we have a model that will predict how changes in compressor efficiency affect the heat pump system, but the model cannot be used to determine which specific compressor design changes might lead to the improved efficiency. This is compatible with the intended use of the simulation.

2.3.1 Model formulation

The parameters used to model the compressor are the following:

Parameter	Definition
Motor efficiency	Ratio of shaft work to electrical energy input
Volumetric efficiency	Ratio of refrigerant volumetric flow rate at suction port to swept cylinder volume per unit of time
Isentropic efficiency	Ratio of ideal isentropic compression work to actual shaft work input required to achieve the same Δp (with this definition, mechanical losses, flow friction losses, and thermal effects are accounted for)

Parameter	Definition
Can heat loss	Heat rejection from the compressor can surface
Internal heat loss	Heat transfer from the discharge gas back to the suction gas inside the can, principally from the discharge tube

In addition, four operating variables are required as input to the compressor subroutine: can inlet pressure and temperature, can outlet pressure, and motor speed. Since the compressor is mounted inside a can, it is important to distinguish between the state of the refrigerant conditions at the inlet and outlet of the can and at the compressor suction and discharge ports, as they will generally be different.

Five energy balances are used in the model: one each for the can, suction gas, compressor, compressor motor, and discharge gas. Figure 2 illustrates the energy balance components we used.

For the compressor can, the enthalpy gain of the refrigerant is equal to electrical power input minus the heat rejection from the can, or

$$\dot{m}_{ref}(h_{can\ outlet} - h_{can\ inlet}) - \dot{q}_{electrical\ input} + \dot{q}_{can\ loss} = 0 \ , \qquad (1)$$

where $\dot{m}_{ref}$ = refrigerant mass flow rate,

h = specific enthalpy,

$\dot{q}$ = energy flow rate,

and the subscripts are self-explanatory. This is a combined energy balance, the sum of the remaining energy balances. For the suction gas, heating by the motor losses and the unavoidable internal heat transfer from the discharge are accounted for, as well as heat rejection from the can. (The inside of the can is at suction pressure; thus, can losses or gains come directly from the suction gas.) Accordingly,

$$\dot{m}_{ref}(h_{suct\ port} - h_{can\ inlet}) - \dot{q}_{internal} - \dot{q}_{motor\ cooling} + \dot{q}_{can\ loss} = 0 \ . \qquad (2)$$

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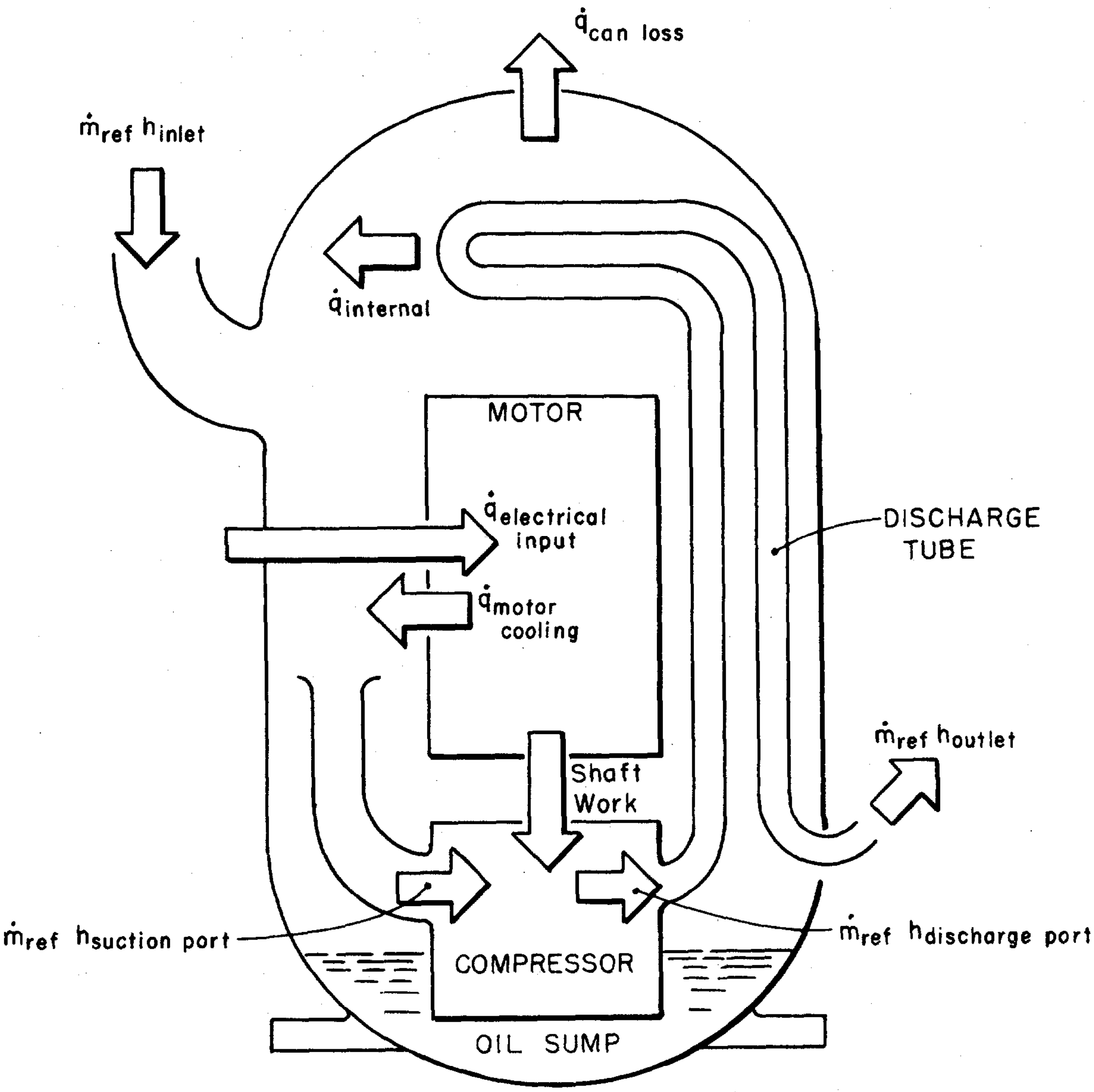

Fig. 2. Compressor can energy balance components.

Similarly, for the discharge gas,

$$\dot{m}_{ref}(h_{disch\ port} - h_{can\ outlet}) - \dot{q}_{internal} = 0 \ . \tag{3}$$

The actual compression work is computed as

$$\Delta h_{compressor} = h_{disch\ port} - h_{suct\ port} = \frac{\Delta h_{isentropic}}{\eta_{isentropic}} \ , \tag{4}$$

where $\Delta h_{isentropic}$ is obtained from the thermodynamic properties of the refrigerant and $\eta_{isentropic}$ is the input value of isentropic efficiency. The compressor energy balance is satisfied by

$$\text{shaft power} = \dot{m}_{ref}\Delta h_{compressor} \ , \tag{5}$$

wherein it is assumed that mechanical losses will be dissipated by heating the discharge gas. The motor power input is

$$\text{motor power input} = \text{shaft power}/\eta_{motor} \ , \tag{6}$$

where η_{motor} is the motor efficiency, and the heat rejected by the motor to the suction gas is given by

$$\dot{q}_{motor\ cooling} = (1 - \eta_{motor})(\text{motor power input}) \ . \tag{7}$$

Since the suction-gas heating is a function of motor power input, and motor power input is in turn a function of the state of the suction gas entering the compressor suction port, an iterative computational procedure is required. Given the conditions of the gas entering the can and the outlet pressure, the iteration is accomplished within the compressor subroutine.

Figure 1 shows the states of the refrigerant gas on a pressure vs enthalpy diagram. State 2′ represents the ideal isentropic discharge condition of the refrigerant.

The mass-flow rate of refrigerant is computed from the input value of volumetric efficiency as

$$\dot{m}_{ref} = \eta_{volumetric} \rho D N \ , \tag{8}$$

where $\eta_{volumetric}$ = volumetric efficiency,
ρ = refrigerant density at suction port,
D = compressor displacement,
N = compressor speed.

2.3.2 Model calibration

The can heat loss, $\dot{q}_{can\ loss}$, can be computed directly from experimental data using Eq. (1), assuming the pressures and temperatures of the refrigerant at can inlet and outlet are measured. It is also possible to derive estimates of can heat rejection analytically if the airflow velocity across the can is known. In the present model, $\dot{q}_{can\ loss}$ is entered as input; i.e., the magnitude of this loss is not computed within the subroutine.

It is not possible to determine the internal heat transfer from experimental data; however, analytically based estimates can be made.

Volumetric efficiency cannot be derived directly from experimental data for the heat pump system unless the temperature of the suction gas at the compressor suction port is measured. Because measurements inside the compressor can are difficult to obtain, this has not been done as yet in experimental work supporting this modeling effort. A first approximation of volumetric efficiency can be derived on the basis of reexpansion of the cylinder-clearance-volume gas. This value will be optimistic because it will not have accounted for throttling loss through the suction valve. It is also possible to compute directly the volumetric efficiency of open compressors from catalog data.

Similarly, isentropic compression efficiency cannot be computed directly from hermetic-compressor experimental data unless temperatures are measured internally at the suction and discharge ports, but it is possible to compute this parameter for open compressors from performance data.

Compressor motor efficiency can be determined by test outside the compressor can; also, ideally, manufacturer's data would be available. However, motor efficiency cannot be determined directly from heat pump system data.

Specifically for this study, estimates of can heat loss were determined both analytically and from experimental data; internal heat loss was estimated analytically; and typical values of volumetric, isentropic, and motor efficiencies were derived from published data. Starting with these estimates, parametric studies were made using the compressor model to determine which set or sets of parameters will produce the experimentally observed performance parameters.

It would be hoped that a single set of input parameters would uniquely duplicate the observed performance, and, for practical purposes, this proved to be the case. While precise estimates of the various efficiency parameters could not be determined by this procedure, a narrow range of the parameters could be selected that produced computed performance in reasonable agreement with observed performance.

2.4 Condenser and Evaporator Models

The condenser and evaporator models used in the ORNL program are unchanged from the MIT program. The models are predicated on the conventional crossflow configuration and staggered-tube and sheet-fin construction; accordingly, other surfaces in use such as spine-fin or bristle-fin cannot be accommodated at present. Principal input parameters are geometrical constants such as tube diameter and spacing, fin pitch and thickness, overall dimensions, number of parallel tube circuits, etc. All necessary correlations for fluid thermal properties, heat transfer coefficients, and flow friction factors, both air side and refrigerant side, are internal to the program.

2.4.1 Effectiveness-N_{tu} relationship

Performance calculations are based on the effectiveness-N_{tu}* method. Specifically, both models employ the effectiveness-N_{tu} relationship for a crossflow heat exchanger with both fluids unmixed. Thus, only certain refrigerant-side circuiting arrangements can be modeled rigorously, and nonequal parallel flow paths cannot be accommodated. In practice, this assumption probably does not impose serious restrictions on the validity of the model, as the effectiveness of evaporators and condensers in the two-phase (refrigerant) regions are relatively insensitive to flow arrangement. Nevertheless, it is not possible with the present program to model the variation in coil performance that can be obtained by changing refrigerant-side circuiting.

The exact equations for computing crossflow (with both fluids unmixed) effectiveness as a function of N_{tu} are not in closed form; Hiller and Glicksman[1] employ an approximate relationship that is in closed form.

2.4.2 Surface properties

Heat transfer correlations for single-phase refrigerant flow inside tubes and air-side flow are based on data from Kays and London,[7] in the form of "j" factor ($N_{St} \cdot N_{Pr}^{2/3}$) as a function of Reynolds number. The correlations for flow inside circular tubes are represented by three straight-line segments (in log-log coordinates) corresponding to laminar, transition, and turbulent flow. Air-side properties are represented by a single straight line (again, on a log-log plot).

Correlations for condensing coefficient are based on the method by Traviss, Baron, and Rohsenow,[8] and the evaporation coefficient is based on work by Tong.[9]

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*Effectiveness is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate as limited by the first and second laws of thermodynamics. N_{tu} is the ratio of surface heat transfer capacity to fluid heat transfer capacity, expressed as the product of heat transfer coefficient and surface area divided by the product of fluid flow rate and specific heat. Both are dimensionless parameters. Reference 7 presents a detailed explanation of the effectiveness-N_{tu} method of heat exchanger analysis.

Two-phase flow pressure drop is computed using the Lockhart-Martinelli correlation,[5] while single-phase pressure drop is calculated by conventional pipe-flow methods.

2.4.3 Condenser

In the condenser program, a computation is made to determine whether the wall temperature at the condenser entrance is less than the refrigerant saturation temperature. If it is not, the fraction of the condenser coil required for desuperheating the refrigerant is computed. Otherwise, it is assumed that two-phase flow begins at the entrance, even though the bulk temperature of the refrigerant may be above saturation.

The fraction of the coil needed to complete condensation (two-phase) is computed next. With the remaining fraction of the coil, the amount of refrigerant subcooling is calculated. Outlet air temperatures are then determined.

2.4.4 Evaporator

The model for the evaporator is similar to that for the condenser with the additional provision for computing the amount of air dehumidification, if any. In the method used, it is assumed that the heat transfer coefficient is unaffected by the presence of condensed moisture, and a heat-transfer/mass-transfer analogy is used to compute the rate of moisture removal. Total heat transfer rate is determined on the basis of enthalpy difference.

Initially, a computation is made to determine the dew point of the entering air and whether the wall temperature at the entrance is less than the dew point of the air. If it is determined that condensation from the air will not occur at the entrance, the fraction of the coil used only for sensible heat transfer is computed. (Since the air is being cooled in the evaporator while the temperature of the refrigerant is essentially constant in the two-phase region, the wall temperature will decrease in the direction of airflow and may drop below the dew point.) The performance of that section of the evaporator having two-phase evaporation on the refrigerant side and dehumidification on the air side is then computed. Finally, the amount of refrigerant superheating in the remaining fraction of the coil is computed with no allowance for further dehumidification on the air side.

At present, an error indication is given if heat transfer is insufficient to completely evaporate the refrigerant.

3. RESULTS

The compressor model was calibrated against observed values of refrigerant mass flow, compressor motor power consumption, and refrigerant temperatures and pressures measured at the inlet and outlet of the container housing the motor and compressor. These measurements were made under a variety of operating conditions. It was found that a single calibration of this preliminary version of the compressor model would not suffice for all system operating conditions because we have not yet incorporated routines that calculate the variation of efficiencies with changing load and pressure ratios. Thus for the case of superheated vapor reaching the compressor, two sets of loss parameters will be needed for this version; one set for more than 20°F of superheat, and another that reduces heat rejection from the can and internal heat transfer rates when the degree of superheat drops below 20°F. The loss parameters and efficiencies must all be reduced if the refrigerant reaching the compressor can is wet. It is hoped that further elaboration of the program will simplify the calibration of the model.

Using the compressor calibration obtained from two of the sets of laboratory measurements and the accompanying observations of operating conditions, we have run the ORNL heat pump model to calculate the performance of one of the heat pumps in our laboratory. Calculated values of refrigerant mass flow, compressor power consumption, heat exchange rates and coefficient of performance are compared in Table 1 to those observed in two of the laboratory runs. Inspection of the table reveals that agreement is generally good. The largest differences between calculated and observed quantities are those for refrigerant temperatures

Table 1. Comparison of calculated and observed performance of an air-to-air heat pump

	Run 12		Run 13	
	Observed	Calculated	Observed	Calculated
Compressor and flow balance model				
Refrigerant mass flow rate (lbm/hr)	384	383	353	353
Compressor motor power input (kW)	4.66	4.67	4.10	4.14
Refrigerant temperature at compressor exit (°F)	260.5	268	238	243
Saturation temperature at evaporator exit (°F)	34.7	—	28.1	—
Saturation temperature at condenser entry (°F)	138	136	130	128
Refrigerant pressure at capillary tube entry (psia)	325	314	295	285
Condenser model				
Air temperature, entry (°F)	72.5	—	70.0	—
Air temperature, exit (°F)	107.5	102.3	102.4	97
Refrigerant temperature, entry (°F)	233.8	231.2	205.5	211
Refrigerant temperature, exit (°F)	81.8	87.9	79.0	83
Refrigerant subcooling (°F)	56.2	47.1	51.0	45
Heat rejection rate (Btu/hr)	39,450	38,790	34,950	35,050
Evaporator model				
Air temperature, entry (°F)	64.0	66.8	49.9	53
Air temperature, exit (°F)	52.5	55.0	41.5	41.7
Refrigerant temperature, exit (°F)	63.2	66.4	49.5	52.4
Saturation temperature, exit (°F)	34.7	32.6	28.1	25.9
Refrigerant superheat (°F)	28.5	33.8	21.4	26.5
Heat absorption rate (Btu/hr)	30,790	29,751	28,640	27,278
System performance				
Coefficient of performance	2.12	2.13	2.05	2.08

at the condenser inlet and outlet (and consequently the amount of subcooling which is determined from outlet and saturation temperatures), an error that could be introduced by the model's neglect of temperature drops along the interconnecting pipes. However, use of the measured temperature drop along the discharge tube (see card 1 of the input data to the computer program, Appendix A) fails to eliminate the discrepancy. The rather good agreement of calculated and observed heat exchange rates and coefficient of performance leads to the conclusion that the model is working satisfactorily. Neither the ORNL nor the MIT model has been validated for a heat pump operating in the cooling mode.

4. PLANNED MODIFICATIONS

The computer model described herein represents a first generation simulation program that can be used to predict the system performance resulting from many of the possible heat pump system improvements that are being contemplated in this study. However, it is planned that additional development work will be conducted on the model to improve its versatility. The changes that are being considered are described in the following paragraphs.

4.1 Heat Exchanger Configuration

The present model can accommodate only the conventional staggered-tube, sheet-fin heat exchanger geometry. However, other types are in use, such as spine-fin and bristle-fin. In addition, the exploration of possible advantages of other surface geometries is a valid research concern. Accordingly, it is planned that the program will be modified to accept surface properties of other types of heat exchanger construction. Most likely, this will be handled by making provision for reading in up to two additional sets of friction factor and Colburn "j" factor, one for the condenser and one for the evaporator. Certain geometrical constants would be entered as input also. The program would simply be modified to use the input surface properties whenever they are entered.

A second contemplated revision in the heat exchanger routines is the accommodation of variations in tube circuiting. This may require that the use of an effectiveness-N_{tu} relationship be dropped and that some form of finite difference computational procedure be substituted. This procedure has not yet been formulated.

4.2 Alternative Refrigerant Metering Device

The model is presently equipped to compute refrigerant mass-flow rate in systems using either a capillary tube or thermostatic expansion valve for metering. Because some systems employ a fixed orifice for this purpose, it will be desirable to add an orifice model to the program. Such a model should be capable of simulating two-phase flow as well as the simpler single-phase case.

4.3 Variation in Compressor Loss and Efficiency Parameters

In the present model, all compressor loss and efficiency parameters must be specified as input to each computer run. It may be desirable to compute some of these parameters in the program. For example, motor efficiency and speed as a function of load could be modeled within the program in nondimensional form with peak efficiency and rated motor power as input parameters. With such a scheme, it would not be necessary to enter motor parameters for each computer run. However, this approach does require that the characteristics of the motor be known either from test data or manufacturer's data. Since a strong similarity in the characteristics of different motors of a given type can be expected, it may suffice to enter "typical" motor curves into the program. The original MIT program contained a motor speed and efficiency model for a specific motor.

It should also be feasible to derive an empirical mathematical expression for volumetric efficiency as a function of pressure ratio. A change in volumetric efficiency characteristics of a compressor could then be represented by a revised set of coefficients for the volumetric efficiency model.

At present, it does not appear to be either necessary or feasible to predict isentropic compression efficiency on the basis of operating conditions. While it might be possible to devise routines for predicting can external heat loss and internal heat transfer, it does not appear advantageous to try to do this at present.

4.4 Refrigerant Mass Inventory

In this program, no concern is given to the mass of refrigerant in the system; rather, it is implicitly assumed that the system is charged with exactly the correct amount. This is a satisfactory model for heat pump systems having a suction line accumulator; i.e., the accumulator is modeled satisfactorily by ignoring it. However, in systems that do not employ an accumulator, there can be an excess charge under certain operating conditions. Such a system, properly charged for the cooling cycle, may contain an excess charge during heating operation as a result of the lower system pressures, and the excess refrigerant will migrate to the condenser where it can partially block some of the heat transfer surface. To correctly model this type of system, a refrigerant mass inventory would be necessary as well as routines for deciding where the excess refrigerant will accumulate and what the effect on the thermodynamic cycle will be. No approach to accomplishing this has been formulated, but a study of possible approaches is planned.

4.5 Incomplete Condensation and Evaporation

The heat exchanger models developed by MIT are set up to print an error message if incomplete condensation or evaporation are encountered. However, with capillary tube control, heat pump systems will operate with liquid refrigerant entering the compressor (incomplete evaporation) under low outdoor temperature conditions. It is planned that the program will be revised to accommodate both incomplete condensation and evaporation. This should not be difficult — the MIT authors had anticipated the possible need for this change. The ORNL compressor model is already set up to handle wet suction gas.

5. UTILIZATION

The ORNL version of the heat pump model is organized for computer use as a batch job on our IBM Model 360 computer. Accordingly, decision making that might otherwise be left to the user of an interactive program has been incorporated in the calling program. The flow diagram shown in Fig. 3 displays the sequence of calculations and the decision points. Input parameters for all of the submodels are read in the subroutine DATAIN and are listed in Appendix A, along with the values of the parameters used to generate the sample output shown in Appendix B.

The program is written in FORTRAN IV and makes use of standard FORTRAN supplied mathematical functions and service subroutines; special subprograms and extended libraries of functions are not required. No tapes or other peripheral temporary storage devices are used. Thus, the only control cards needed to run the program are those to compile and link the program and to execute it. All input is from the card reader. The control cards used to run the model on our computers are shown in Appendix B. The program occupies 86K bytes of core and typically executes in less than 10 sec on our IBM 360/91 computer. A complete listing of the program is given in Appendix C.

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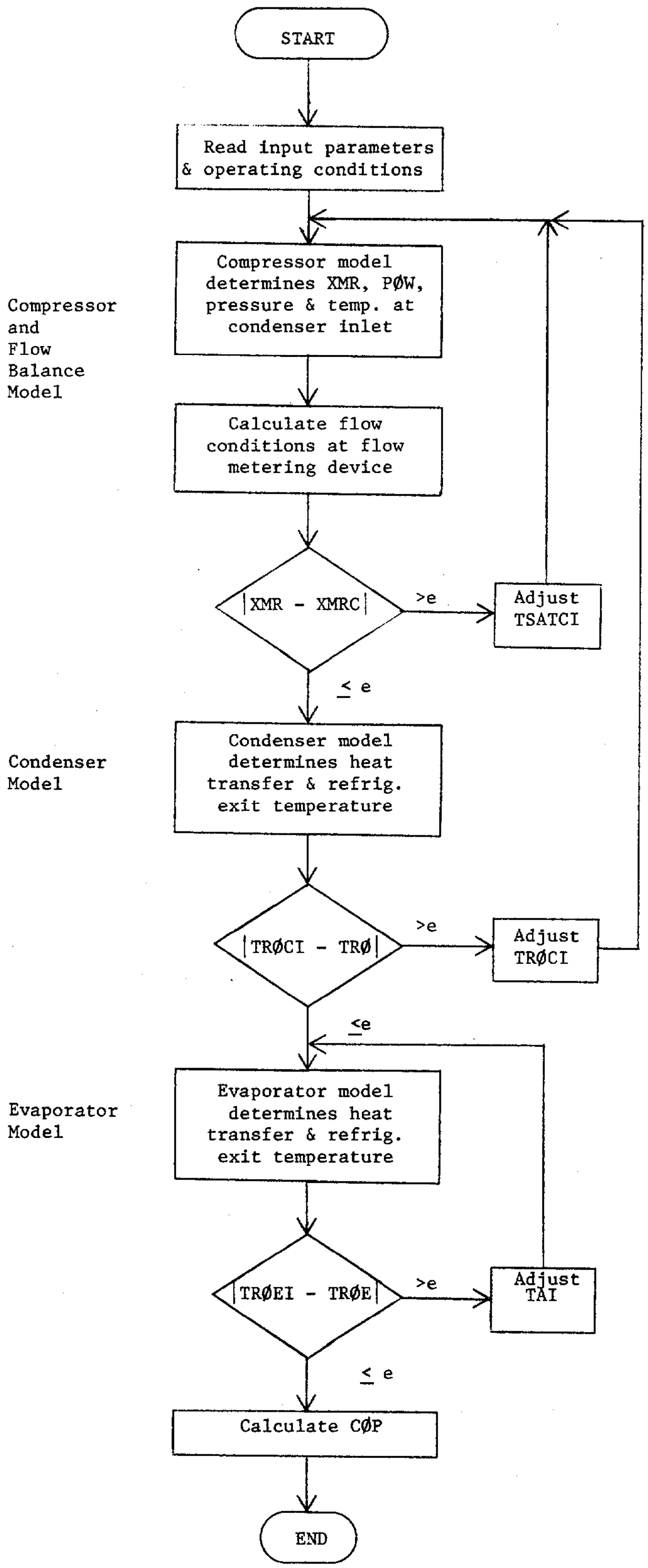

XMR	=	refrigerant mass-flow rate
PØW	=	compressor motor power
XMRC	=	flow capacity of cap. tubes (see text for alternative test if TX valve is used)
TSATCI	=	initial value for saturation temp. at condenser
e	=	maximum error allowed
TRØCI	=	initial value for refrig. temp. at condenser exit
TRØ	=	calculated value for refrigerant temperature at condenser exit
TRØEI	=	initial value for refrig. temp. at evaporator exit
TRØE	=	calculated value for refrig. temp. at evaporator exit
TAI	=	air temp. at evaporator inlet
COP	=	coefficient of performance

Fig. 3. Computer program flow diagram.

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APPENDICES

Appendix A

INPUT PARAMETERS FOR THE ORNL HEAT PUMP SIMULATOR

Symbol	Definition	Sample Value[a]
Card 1	Format (5F10.0)	
TLIMIT	Upper limit for difference between calculated subcooling of refrigerant leaving condenser and input (assumed) value of subcooling (see DTROC below). Used to define convergence (F)	10.0
DELTC	Temperature drop in discharge line (F)	32.0
XMRTI	Initial guess of refrigerant mass flow rate. Used only to estimate discharge line pressure drop for first iteration (lbm/hr)	353.0
FANPC	Energy consumed by condenser fan (Btu/hr)	2014.0
FANPE	Energy consumed by evaporator fan (Btu/hr)	1703.0
Card 2	Format (4F15.5)	
DLLOC	Diameter of liquid line coming from outdoor coil (ft)	0.0158
XLEQLO	Equivalent length of liquid line coming from outdoor coil (L/D - dimensionless)	1923.0
DLLIC	Diameter of liquid line coming from indoor coil (ft)	0.0158
XLEQLI	Equivalent length of liquid line coming from indoor coil (L/D - dimensionless)	1923.0
Card 3	(4F15.5)	
DSL	Diameter of suction line (vapor) (ft)	0.0567
XLEQSL	Equivalent length of suction line (L/D - dimensionless)	145.3
DDL	Diameter of discharge line (vapor) (ft)	0.0463
XLEQDL	Equivalent length of discharge line (L/D - dimensionless)	181.0
Card 4	(4F15.5)	
DOC	Inside diameter of tubes in outdoor coil (ft)	0.0280

[a]Values used to produce the output of the program shown in Appendix B.

Symbol	Definition	Sample Value[a]
DZOC	Refrigerant flow length in each parallel flow branch in the outdoor coil (ft)	64.0
DIC	Inside diameter of tubes in indoor coil (ft)	0.0280
DZIC	Refrigerant flow length in each parallel flow branch in the indoor coil (ft)	61.1
Card 5	(F10.4, 3I10)	
DTROC	Guess for amount of subcooling of refrigerant leaving condenser (F)	51.0
NCORH	Indicator for cooling or heating mode If "NCORH" = 1 - cooling mode If "NCORH" = 2 - heating mode	2
NSECTO	Number of parallel flow sections in outdoor coil	4
NSECTI	Number of parallel flow sections in indoor coil	3
Card 6	(3F10.2)	
TSATE	Saturation temp. at exit of evaporator (F)	28.1
TSATCI	Saturation temp., entrance to condenser. Initial guess	130.0
SUPER	Superheat of vapor leaving evaporator and entering the compressor (F)	25.1
Card 7	(7F10.2)	
RPM	Motor speed (rpm)	3450.0
DISPL	Compressor displacement (all cylinders) ($in.^3$)	4.525
ETAVOL	Volumetric efficiency of compressor (fraction.Lt.1)	0.59
ETAMOT	Compressor motor efficiency	0.65
ETAISN	Isentropic efficiency of compressor	0.70
QCAN	Heat rejection rate from compressor can (Btu/hr)	4500.0
QHILO	Heat transfer rate from compressor discharge line to inlet gas (Btu/hr)	500.0

[a]Values used to produce the output of the program shown in Appendix B.

Symbol	Definition	Sample Value[a]
Card 8	(I5, 5X, I5, 5X, F10.2)	
IREFC	Indicator for type of refrigerant flow control = 1 for thermal expansion valve[b] = 2 for capillary tube(s)	2
NCAP	Number of capillary tubes (omit if IREFC = 1)	1
CAPFLO	Flow factor for cap. tube. See *ASHRAE Guide and Data Book, Equipment Vol.* (1975), Fig. 41, pp. 20.23–20.28 (omit if IREFC = 1)	2.25
Card 9	(6F12.6) Begin Condenser Input	
DEAC	Outside diameter of tubes (ft)	0.0333
DERC	Inside diameter of tubes (ft)	0.0280
DELTAC	Fin thickness (ft)	0.00053
FPC	Fin pitch (fins/ft)	168.0
XKFC	Thermal conductivity of fins (Btu/hr-ft-F)	128.0
AAFC	Heat exchanger frontal area (ft^2)	3.1666
Card 10	(2I10)	
NTC	Number of tubes in direction of airflow	3
NSECTC	Number of parallel circuits in heat exchanger	3
Card 11	(3F15.5)	
HCONTC	Contact conductance between fins and tubes (Btu/hr-ft^2-F)	30000.
STC	Vertical spacing of tube passes (ft)	0.08333
WTC	Spacing of tube rows in direction of airflow (ft)	0.07292
Card 12	(2F10.4)	
QAC	Airflow rate (cfm)	1200.0
TAIIC	Air temperature entering condenser (F)	70.0

[a]Values used to produce the output of the program shown in Appendix B.

[b]Parameters for modeling the pressure drop across the TXV must be inserted in DATA statements in subroutine FLØBAL. See Hiller and Glicksman[1], pp. 59-61.

Symbol	Definition	Sample Value[a]
Card 13	(6F12.6) Begin Input for Evaporator	
DEAE	Outside diameter of tubes (ft)	0.0333
DERE	Inside diameter of tubes (ft)	0.0280
DELTAE	Fin thickness (ft)	0.00053
FPE	Fin pitch (fins/ft)	168.0
XKFE	Thermal conductivity of fins (Btu/hr-ft-F)	128.0
AAFE	Heat exchanger frontal area (ft^2)	5.1944
Card 14	(2I10)	
NTE	Number of tubes in direction of airflow	3
NSECTE	Number of parallel circuits in heat exchanger	4
Card 15	(3F15.5)	
HCONTE	Contact conductance between fins and tubes (Btu/hr-ft^2-F)	30000.
STE	Vertical spacing of tube passes (ft)	0.0833
WTE	Spacing of tube rows in direction of airflow (ft)	0.0729
Card 16	(2F10.4, I4, 2F10.4)	
QAE	Airflow rate (cfm)	2162.0
TAIIE	Air dry bulb temperature entering evaporator (F)	49.9
INDICE	Input indicator If "INDICE" = 1, inputs are TDB, and TWB If "INDICE" = 2, inputs are TDB, and RH	2
TWBIIE	Air wet bulb temperature entering evaporator (F)	not used
RHIE	Relative humidity of air entering evaporator	0.30

[a]Values used to produce the output of the program shown in Appendix B.

Appendix B

SAMPLE OUTPUT FROM HEAT PUMP SIMULATOR

Appendix B

SAMPLE OUTPUT FROM HEAT PUMP SIMULATOR[a]

```
TLIMIT--FOR CONVERGENCE TEST--                   =   5.00000

DELTDL--DELTA T IN DISC LINE--                   =  32.00000

XMRTI --TRIAL VALUE FOR REFRIG. MASS FLOW-- = 353.00000
      (USED TO CALC DELTA P IN DISCH LINE)

FANPC --CONDENSER  FAN POWER               -- =2014.00000

FANPE --EVAPORATOR FAN POWER               -- =1703.00000
```



```
FLOBAL INPUT ECHO:

    DOC     =   0.02800        DZOC    =  64.00000        DIC     =   0.02800        DZIC    =  61.09999
    DDLOC   =   0.01580        XLEQLO =1923.00000         DDLIC   =   0.01580        XLEQLI =1923.00000
    DSL     =   0.05670        XLEQSL = 145.29999         DDL     =   0.04630        XLEQDL = 181.00000
    IREFC   =   2              NCAP    =    1             CAPFLO  =   2.25000
    RPM     =3450.00000     DISPL  -   4.52500
    ETAVOL  =   0.59000     ETAMOT =   0.65000     ETAISN =   0.70000
    QCAN    =   4500.00     CHILO  =    500.00
    TSATEI  =  28.09999
    TSATCI  = 130.00000
    NSECTO  =          4       NSECTI  =          3
    SUPER   =  25.09999        DTROC   =  51.00000

END OF FLOBAL INPUT
```

[a] See program listing for glossary of symbols.

```
CONDENSER INPUT ECHO:

     DEA   =  0.03330        DER   =  0.02800       DELTA = 0.530E-03       FP     =  168.00         XKF   = 128.00
     AAF   =   3.167         NT    =   3            NSECT =   3
     HCONT =  30000.0        ST    =  0.0833        WT    =  0.0729
     QA    =   1200.0        TAII  =   70.00


   CALCULATED EXCHANGER CHARACTERISTICS :

     SIGA  =  0.547          P     =  0.08792       PTBO   =  0.10456
     ARFT  = 0.615E-03       ARHT  =   3.341        ALFAR =  14.469         ALFAA = 303.542
     XLF   =  0.0417         FAR   =  0.9484        CAR    =187.8796


END OF CONDENSER INPUT


EVAPORATOR INPUT ECHO:

     DEA   =  0.03333        DER   =  0.02800       DELTA = 0.500E-03       FP     = 168.00          XKF   = 128.00
     AAF   =   5.194         NT    =   3            NSECT =   4
     HCONT = 30000.00        ST    =  0.0833        WT    =  0.0729
     QA    =   2162.0        TAII  =   49.90           INDIC =   2
     TWBII =   54.00            RHI   =  0.300

CALCULATED EXCHANGER CHARACTERISTICS:

     SIGA  =  0.550          P     =  0.08792       PTBO   =*********
     ARFT  =0.6154E-03       ARHT  =   4.110        ALFAR =   14.469        ALFAA = 303.556
     XLF   =  0.0417         FAR   =  0.9480        CAR    =198.9131



END OF DATAIN---CALLING FLOBAL
```

```
TOP OF ITERATION LOOP
PRESENT SYSTEM VALUES ARE
TSATE  =  28.09999          TSATC  = 128.00000          XMR    = 352.70605          CXMR   = 361.43872


BOTTOM OF ITERATION LOOP:

DPDL    =    0.18         DELPC   =  -3.42         DPLL    =    15.08        CXMR   = 356.76
TROC    =     88.08       TIC     =    243.31      TSATC   =   128.00
TSATE   =     28.10
HIC     =    138.80       H1OE    =    114.04      H3      =     35.57
POC     =    285.34       PIC     =    303.84
XMR     =    353.25
POW     =    4.135
DPSYS   =
CAPE =        27720.44   CAPC =        36466.04
VELOCITIES IN RISERS:
VSR    = 0.29679E 05 FT/HR      VSACT= 0.78633E 66 FT/HR
VDR    = 0.12816E 05 FT/HR      VDACT= 0.35994E 05 FT/HR

CTXV=*********


END OF FLOBAL---CALLING COND


DATA SENT TO COND:

XMRI =   353.24707
TSA  =   128.00000
TRI  =   211.31250
```

```
        TAI    =   70.00
        QA     =   1200.0
        TRI    =  211.31
        TSA    =  128.00


    BEGINNING OF CALCULATION IN SUBROUTINE EXCH :

        XNTUTP=   0.977
      AOM          CPA          ALFAR        SEFFX        HA           ALFAA        HRTP
       0.0019       0.2400      14.4690       0.8177      10.4630      303.5415     424.6563

ETP    =        0.6237

RES    =        1.5252
      HRSPV
      94.2661

TRVDS =     211.3125
      TH            TC
     128.0000       70.0000

HFGDP =       83.6929
      HFG           CFRV         X3
      64.5361        0.2299       0.0

XMATP =     1135.1084
      XMR           CPA
     117.7490        0.2400

      XMA           ARHT         CR
    1797.0574        3.3411       1.0000

   F        XMASP         CA            RTOT          CMIN       EXFR       EXFS      PR        PS         TEST       VAL

    END OF ITERATION.  RESULT IS :
        F      =  0.0
        FTP    =  0.632
        FSC    =  0.368
```

RESULTS FROM EXCH :

```
P      =  0.0          FTP   =  0.632       FSC   =  0.368
QSP    =    0.0        QTP   = 9854.7578    QSC   = 1828.4192
TAOSP  =   70.00       TAOTP =   106.17     TAOSC =    81.51

TAI    =   70.00
TAO    =   97.09
TRI    =  211.31
TSA    =  128.00
TRO    =   83.38
SBCOOL=   44.62
```

OVERALL RESULTS FOR THIS TAI :

```
HA     =  10.46         HRV   =  94.27        HTP   = 424.66        HRL   = 86.492
QC     = 35049.53
HRO = H3 = H4 =   34.135
PD     =  -1.33
```

TEST FOR CONVERGENCE ON DTROC

TSTAC = 0.12800E 03

DTROC = 0.39917E 02

TEST = 0.88083E 02 = TSATC - DTROC

TRO = 0.83385E 02 FROM SR COND

IF (TEST-TRO), 0.46985E 01 .LE. TLIMIT, 0.50000E 01 GO ON. OTHERWISE, GO BACK TO FLOBAL

```
     DATA SENT TO EVAPR:

     XMRI =  353.24707
     TSA  =   28.09999
     H4   =   34.13484

     TAI    =   52.99
     TWBI   =   54.00
     RHI    =  0.300
     QA     =  2162.00
     TSA    =   28.10


BEGINNING OF CALCULATION IN SUBROUTINE EVAP:

     TADHI =    16.21          TAOTP =    37.81
NO MOISTURE REMOVAL OCCURS


FRACTION OF COIL USED FOR SINGLE-PHASE VAPOR FLOW IS
     F      =  0.2949


RESULTS FROM SUBROUTINE EVAP:

     FTP    = 0.705            F      = 0.295
     XMATP = 1768.92           XMASP =  739.84
                               EXFR  = 0.960
     QTP    =  6445.06         QSP   =    355.80
     TDB3   =   37.81          TAOSP =    50.99          TWB3   =     0.00

     TAI    =   52.99
     TWBI    =   40.81
     TSA    =   28.10
     TRO    =   52.01
     SUPER =   23.91

NOTE THAT THESE HEAT AND MASS FLOWS ARE FOR ONE SECTION ONLY
```

EVAPORATOR PERFORMANCE FOR THIS AIR INLET TEMP:

```
     XMA    =  10035.1        XMR   =  353.25
     GA     =   3515.0        GR    =  143493.8
     HA     =   11.27         HRV   =   59.08          HTP    =  511.65
     QTOT   =   27203.5       QLAT  = 7730555.0
     PD     =  -5.35
```

PRESSURE DROP THRU EVAPORATOR IS LARGE ENOUGH
TO DEPRESS SATURATION TEMP. CALCULATION WILL BE REPEATED
FOR TSA =   25.87

BEGINNING OF CALCULATION IN SUBROUTINE EVAP:

```
     TADHI =    19.27          TAOTP =    36.40
NO MOISTURE REMOVAL OCCURS
```

FRACTION OF COIL USED FOR SINGLE-PHASE VAPOR FLOW IS

```
     F      =  0.3567
```

RESULTS FROM SUBROUTINE EVAP:

```
     FTP    = 0.643           F      = 0.357
     XMATP = 1613.79          XMASP =  894.98
                              EXPR   = 0.978
     QTP    =  6427.51        QSP    =   392.11
     TDB3   =   36.40         TAOSP =    51.17          TWB3   =     0.00

     TAI    =   52.99
     TWBI    =   40.81
     TSA    =   25.87
     TRO    =   52.41
     SUPER =   26.54
```

NOTE THAT THESE HEAT AND MASS FLOWS ARE FOR ONE SECTION ONLY

EVAPORATOR PERFORMANCE FOR THIS AIR INLET TEMP:

```
XMA   =  10035.1       XMR   =  353.25
GA    =   3515.0       GR    =  143493.8
HA    =   11.27        HRV   =   58.82        HTP   =  522.59
QTOT  =   27278.5      QLAT  = 7730555.0
PD    =  -5.45

COP =        2.08
```


CONTROL CARDS AND ARRANGEMENT OF DECK
FOR RUN ON IBM 360/91 COMPUTER

```
//RDE13 JOB (14155),'R.D.ELLISON  9104-3'
/*ROUTE  PRINT REMOTE4
//*CLASS  CPU91=10S,RGN=270
// EXEC FORTHCLG,PARM.FORT='XREF',PARM.GO='DUMP=I',
//    REGION.GO=100K
//FORT.SYSIN DD *
   FORTRAN SOURCE DECKS
/*
//GO.FT05F001 DD *
   INPUT DATA CARDS
/*
//
```

Appendix C

COMPUTER PROGRAM LISTING

Appendix C

COMPUTER PROGRAM LISTING

```
C
C
C     PRELIMINARY VERSION OF ORNL HEAT PUMP SIMULATOR
C
C     SEE SUBROUTINE DATAIN FOR EXPLANATION OF INPUT PARAMETERS.
C
C     THE PROGRAM HAS NOT BEEN TESTED FOR COOLING MODE CALCULATIONS.
C
C
      COMMON/MPASS/ TLIMIT,DELTDL,XMRTI,FANPC,FANPE
C
      COMMON/FLOWBA/ DLLOC,XLEQLO,DLLIC,XLEQLI,DSL,XLEQSL,DDL,XLEQDL,
     1  DOC,DZOC,DIC,DZIC,DTROC,NCORH,NSECTO,NSECTI,TSATEI,DTE,NE,
     2  TSATCI,DTC,NC,SUPER,NCAP,CAPFLO,IREFC,
     3  DISPL,ETAVOL,ETAMOT,ETAISN,QCAN,QHILO
C
      COMMON/CONDEN/ NRUNC,DEAC,DERC,DELTAC,FPC,XKFC,AAFC,NTC,NSECTC,
     1  HCONTC,STC,WTC,SIGAC,ATBOC,PC,PTBOC,ARFTC,ARHTC,ALFARC,ALFAAC,
     2 XLFC,FARC,CARC,DXMRIC,NXMRC,QAC,TAIIC,DTAC,NTEMPC,QC
C
      COMMON/EVAPOR/ NRUNE,DEAE,DERE,DELTAE,FPE,XKFE,AAFE,NTE,
     1  NSECTE,HCONTE,STE,WTE,SIGAE,ATBOE,PE,PTBOE,ARFTE,ARHTE,ALFARE,
     2 ALFAAE,XLFE,FARE,CARE,DXMRE,NXMRE,QAE,TAIIE,
     3  DTAE,NTEMPE,INDICE,TWBIIE,DTWBIE,NTWBE,RHIE,TROE
C
      COMMON/COMPR/NCYL,VR,VD,SYNC,RPM,EFFIS,DPDI,DPS,DPFRAC,
     1  SDELAY,PMC,PHT,PHTD,EAD,EAS,XMR,POW,TIC,HIC,H1OE,PIC,
     2  P1OE,T1OE,POWMAX,PWRNL,EQAREA,DDELAY,XOIL,EFFME,DDISL,ELDISL,
     3  XMRT,DPDI
C
      COMMON/FPASS/XMRIC,TSAC,TRIC,TSATC,TSATE
      COMMON/CPASS/ XMRIE,TSAE,H4E,HBO,TRO
C
C
      CALL DATAIN
C
      PRINT 20
   20 FORMAT(//////////'0END OF DATAIN---CALLING FLOBAL',/'1')
C
      XMRT = XMRTI
      NITR = 0
   30 CALL FLOBAL
      NITR = NITR + 1
C
      PRINT 40
   40 FORMAT(///////////'0END OF FLOBAL---CALLING COND',/,'1')
C
      XMRIC=XMR
      TSAC=TSATC
      TRIC=TIC - DELTDL
C
      PRINT 50, XMRIC, TSAC, TRIC
   50 FORMAT('0DATA SENT TO COND:',/,'0XMRI = ',F10.5,/,' TSA  = ',
     1F10.5,/,' TRI  = ',F10.5)
      CALL COND
C
      TEST=TSATC-DTROC
      TMT=TEST-TRO
      PRINT 60, TSATC,DTROC,TEST,TRO,TMT,TLIMIT
   60 FORMAT('1TEST FOR CONVERGENCE ON DTROC',/,'0TSTAC = ',E12.5,/,
```

```
     1'0DTROC = ',E12.5,/,'0TEST  = ',E12.5,'   = TSATC - DTROC'/,
     2'0TRO = ',E12.5,'  FROM SR COND'/,'0IF (TEST-TRO) , ',E12.5,'
     3 .LE. TLIMIT, ',E12.5,' GO ON.  OTHERWISE, GO BACK TO FLOBAL')
      IF(ABS(TEST-TRO).LE.TLIMIT)GO TO 80
C
      DTROC = (DTROC+TSATC-TRO)/2.
      PRINT 70,DTROC
   70 FORMAT(///'0***************************************** TEST FAILED
     1 ***********************************************',/,'0SET DTROC
     2= ',E12.5,' AND GO BACK TO FLOBAL',/,'1')
C
      IF(NITR.LT.6) GO TO 30
      PRINT 75, NITR
   75 FORMAT(///' FAILED TO CONVERGE ON TRO AFTER',I3,' ATTEMPTS')
      STOP 75
   80 CONTINUE
C
      XMRIE=XMR
      TSAE=TSATE
      H4E=HRO
C
      PRINT 90, XMRIE, TSAE, H4E
   90 FORMAT(/////'0DATA SENT TO EVAPR:',/,'0XMRI = ',F10.5,/,
     1 ' TSA  = ',F10.5,/,' H4   = ',F10.5)
      NITR = 0
   95 CALL EVAPR
C
      TEST = TSATE + SUPER
      IF(ABS(TEST-TROE).LE.1.5) GO TO 97
      NITR = NITR + 1
      DELTAI = (TEST - TROE) / 2.
      TAIIE = TAIIE + DELTAI
      IF(NITR.LT.6) GO TO 95
      PRINT 96, NITR
   96 FORMAT(///'0FAILED TO CONVERGE ON EVAPR TRO AFTER', I3,
     2       ' ATTEMPTS')
      STOP 96
   97 IF(NCORH.EQ.1) GO TO 98
      EINDF = FANPC
      EOUTF = FANPE
      GO TO 99
   98 EINDF = FANPE
      EOUTF = FANPC
   99 COP = (QC + EINDF)/(3412.*POW + EINDF + EOUTF)
      PRINT 110, COP
  110 FORMAT(///10X,'COP = ', F10.2)
      STOP
      END
```

```
      SUBROUTINE DATAIN
C
C     PURPOSE
C        TO READ AND ECHO ALL INPUT FOR THE PROGRAM
C
C        PRELIMINARY VERSION
C
      COMMON/MPASS/ TLIMIT,DELTDL,XMRTI,FANPC,FANPE
C
      COMMON/FLOWBA/ DLLOC,XLEQLO,DLLIC,XLEQLI,DSL,XLEQSL,DDL,XLEQDL,
     1 DOC,DZOC,DIC,DZIC,DTROC,NCORH,NSECTO,NSECTI,TSATEI,DTE,NE,
     1 TSATCI,DTC,NC,SUPER,NCAP,CAPFLO,IREFC,
     1 DISPL,ETAVOL,ETAMOT,ETAISN,QCAN,QHILO
C
      COMMON/CONDEN/ NRUNC,DEAC,DERC,DELTAC,FPC,XKFC,AAFC,NTC, NSECTC,
     1 HCONTC,STC,WTC,SIGAC,ATBOC,PC,PTBOC,ARFTC,ARHTC,ALFARC,ALFAAC,
     1 XLFC,FARC,CARC,DXMRIC,NXMRC,QAC,TAIIC,DTAC,NTEMPC,QC
C
      COMMON/EVAPOR/ NRUNE,DEAE,DERE,DELTAE,FPE,XKFE,AAFE,NTE,NSECTE,
     1 HCONTE,STE,WTE,SIGAE,ATBOE,PE,PTBOE,ARFTE,ARHTE,ALFARE,ALFAAE,
     1 XLFE,FARE,CARE,DXMRIE,NXMRE,QAE,TAIIE,DTAE,NTEMPE,INDICE,
     1 TWBIIE,DTWBIE,NTWBE,RHIE,TROE
C
      COMMON/COMPR/NCYL,VR,VD,SYNC,RPM,EFFIS,DPDI,DPS,DPFRAC, SDELAY,
     1 PMC,PHT,PHTD,EAD,EAS,XMR,POW,TIC,HIC,H1OE,PIC, P1OE,T1OE,POWMAX,
     1 PWRNL,EQAREA,DDELAY,XOIL,EFFME,DDISL,ELDISL,XMRT,DPDL
C
C*****************************************************************
C
C          INPUT FOR MAIN
C
C*********************************************************************
        READ 100, TLIMIT, DELTDL, XMRTI, FANPC, FANPE
  100   FORMAT(5F10.0)
        PRINT 10, TLIMIT, DELTDL, XMRTI, FANPC, FANPE
   10   FORMAT('1 TLIMIT--FOR CONVERGENCE TEST--                 =',F10.5/
     2         '0 DELTDL--DELTA T IN DISC LINE--                 =',F10.5/
     2         '0 XMRTI --TRIAL VALUE FOR REFRIG. MASS FLOW-- =',F10.5/
     3         '           (USED TO CALC DELTA P IN DISCH LINE)'/
     4         '0 FANPC --CONDENSER  FAN POWER                -- =',F10.5/
     5         '0 FANPE --EVAPORATOR FAN POWER                -- =',F10.5)
C
C*****************************************************************
C
C        FLOBAL INPUT SECTION
C
C****************************************************************
C
C     EXPLICIT INPUT PARAMETERS
C        DLLOC-   DIAMETER OF LIQUID LINE COMING FROM
C                 OUTDOOR COIL (FT)
C        XLEQLO-  EQUIVALENT LENGTH OF LIQUID LINE COMING
C                 FROM OUTDOOR COIL (L/D - DIMENSIONLESS)
C        DLLIC-   DIAMETER OF LIQUID LINE COMING FROM INDOOR
C                 COIL (FT)
C        XLEQLI-  EQUIVALENT LENGTH OF LIQUID LINE COMING
C                 FROM INDOOR COIL (L/D - DIMENSIONLESS)
C        DSL  -   DIAMETER OF SUCTION LINE (VAPOR) (FT)
C        XLEQSL-  EQUIVALENT LENGTH OF SUCTION LINE
C                 (L/D - DIMENSIONLESS)
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```
C         DDL   -  DIAMETER OF DISCHARGE LINE (VAPOR) (FT)
C         XLEQDL-  EQUIVALENT LENGTH OF DISCHARGE LINE
C                  (L/D - DIMENSIONLESS)
C         DOC   -  INSIDE DIAMETER OF TUBES IN OUTDOOR COIL (FT)
C         DZOC -   REFRIGERANT FLOW LENGTH IN EACH PARALLEL
C                  FLOW BRANCH IN THE OUTDOOR COIL (FT)
C         DIC   -  INSIDE DIAMETER OF TUBES IN INDOOR COIL (FT)
C         DZIC -   REFRIGERANT FLOW LENGTH IN EACH PARALLEL
C                  FLOW BRANCH IN THE INDOOR COIL (FT)
C         DTROC-   GUESS FOR AMOUNT OF SUBCOOLING OF REFRIGERANT
C                  LEAVING CONDENSER (F)
C         NCORH-   INDICATOR FOR COOLING OR HEATING MODE
C                  IF 'NCORH' = 1 - COOLING MODE
C                  IF 'NCORH' = 2 - HEATING MODE
C         NSECTO - NUMBER OF PARALLEL FLOW SECTIONS IN OUTDOOR COIL
C         NSECTI - NUMBER OF PARALLET FLOW SECTIONS IN INDOOR COIL
C         TSATE-   SATURATION TEMP.AT EXIT OF EVAPORATOR (F)
C         TSATCI - SATURATION TEMP. AT ENTRANCE TO COND. INITIAL GUESS.
C         SUPER-   SUPERHEAT OF VAPOR LEAVING EVAPORATOR AND
C                  ENTERING THE COMPRESSOR (F)
C         RPM-     MOTOR SPEED, REV. PER MIN.
C         DISPL-   COMPRESSOR DISPLACEMENT (SUM FOR ALL CYLINDERS) (CU IN)
C         ETAVOL-  VOLUMETRIC EFFICIENCY OF COMPRESSOR (FRACTION.LT.1)
C         ETAMOT-  COMPRESSOR MOTOR EFFICIENCY
C         ETAISN-  ISENTROPIC EFFICIENCY OF COMPRESSOR
C         QCAN-    HEAT REJECTION RATE FROM COMPRESSOR CAN (BTU/HR)
C         QHILO-   HEAT TRANSFER RATE FROM COMPRESSOR DISCHARGE LINE
C                  TO INLET GAS (BTU/HR)
C         IREFC-   INDICATOR FOR TYPE OF REFRIGERANT FLOW CONTROL DEVICE
C                  =1 FOR THERMAL EXPANSION VALVE
C                  =2 FOR CAPILLARY TUBE(S)
C         NCAP-    NUMBER OF CAP TUBES (OMIT IF IREFC = 1)
C         CAPFLO-  FLOW FACTOR FOR CAP TUBE. SEE ASHRAE GUIDE AND DATA
C                  BOOK, EQUIPMENT VOL.(1972), FIG 40., PG. 227. (OMIT
C                  IF IREFC = 1)
C
C--BEGIN INPUT
C
      READ 10000, DLLOC,XLEQLO,DLLIC,XLEQLI,DSL,XLEQSL,DDL, XLEQDL
      READ 10100, DOC,DZOC,DIC,DZIC
      READ 10200, DTROC,NCORH,NSECTO,NSECTI
      READ 10300, TSATEI,TSATCI,SUPER
      READ 10450, RPM,DISPL,ETAVOL,ETAMOT,ETAISN,QCAN,QHILO
      READ 10500, IREFC,NCAP,CAPFLO
C
C--ECHO INPUT
C
      PRINT 10600, DOC,DZOC,DIC,DZIC
      PRINT 10700, DLLOC,XLEQLO,DLLIC,XLEQLI
      PRINT 10800, DSL,XLEQSL,DDL,XLEQDL
      PRINT 11000, IREFC,NCAP,CAPFLO
      PRINT 11050, RPM,DISPL,ETAVOL,ETAMOT,ETAISN,QCAN,QHILO
      PRINT 11100, TSATEI
      PRINT 11200, TSATCI
      PRINT 11300, NSECTO,NSECTI
      PRINT 11400, SUPER,DTROC
C
C***********************************************************
C**********************  END OF FLOBAL SECTION ****************
C***********************************************************
```

```
C
C************************************************************
C
C       CONDENSER INPUT SECTION
C
C**************************************************************
C
C     INPUT DATA FROM CARD READER (DESCRIBED FULLY BELOW)
C     DEAC,DERC,DELTAC,FPC,XKFC,AAFC,NTC,NSECTC,
C     HCONTC,STC,WTC,
C     QAC,TAIIC,DTAC,NTEMPC
C
C     INPUT HEAT EXCHANGER CHARACTERISTICS
C
C     DEAC    -  OUTSIDE DIAMETER OF TUBES (FT)
C     DERC    -  INSIDE DIAMETER OF TUBES (FT)
C     DELTAC  -  FIN THICKNESS (FT)
C     FPC     -  FIN PITCH (FINS/FT)
C     XKFC    -  THERMAL CONDUCTIVITY OF FINS (BTU/HR-FT-F)
C     AAFC    -  HEAT EXCHANGER FRONTAL AREA (SQ FT)
C     NTC     -  NUMBER OF TUBES IN DIRECTION OF AIR FLOW
C     NSECTC  -  NUMBER OF PARALLEL CIRCUITS IN HEAT EXCHANGER
C     HCONTC  -  CONTACT RESISTANCE BETWEEN FINS AND TUBES
C               (BTU/HR-SQ FT-F)
C     STC     -  VERTICAL SPACING OF TUBE PASSES (FT)
C     WTC     -  SPACING OF TUBE ROWS IN DIR.OF AIR FLOW (FT)
C
C       CALCULATED HEAT EXCHANGER QUANTITIES
C
C     SIGAC   -  SIGMA AIR (AIR FLOW AREA/FRONTAL AREA)
C     ATBOC   -  CROSS-SECTIONAL AREA OCCUPIED BY TUBE (SQ FT)
C     PC      -  INSIDE PERIMETER OF TUBES (FT)
C     PTBOC   -  OUTTER PERIMETER OF TUBE (FT)
C     ARFTC   -  CROSS-SECTIONAL FLOW AREA INSIDE TUBES (SQ FT)
C     ARHTC   -  TOTAL REFG.SIDE HEAT TRANS. AREA/NSECT (SQ FT)
C     ALFARC  -  ALPHA REFRIGERANT (REFRIGERANT SIDE HEAT
C               TRANS.AREA/TOTAL VOLUME OF HEAT EXCHANGER-1/FT)
C     ALFAAC  -  ALPHA AIR (AIR SIDE HEAT TRANSFER AREA/TOTAL
C               VOLUME OF HEAT EXCHANGER -1/FT)
C     XLFC    -  LENGTH OF FINS (FT)
C     FARC    -  RATIO - FIN HEAT TRANS.AREA/TOTAL H.T. AREA
C     CARC    -  RATIO - FIN HEAT TRANS.AREA/CONTACT AREA
C               TO ACCOUNT FOR CONTACT RESISTANCE BETWEEN
C               FINS AND TUBES
C
      READ 12100, DEAC,DERC,DELTAC,FPC,XKFC,AAFC,NTC,NSECTC
      READ 12200, HCONTC, STC,WTC
C
      SIGAC = (STC-DEAC)*(1.0-DELTAC*FPC)/STC
      ATBOC = 3.14*DEAC**2/4.0
      PC = 3.14*DERC
      PTBOC = 3.14*DEAC
      ARFTC = 3.14*DERC**2/4.0
      ARHTC = FLOAT(NTC)*3.14*DERC*AAFC/(STC*FLOAT(NSECTC))
      ALFARC = 3.14*DERC/(STC*WTC)
      ALFAAC=(2.0*(STC*WTC-ATBOC)*FPC +(1.0-DELTAC*FPC)*PTBOC)/(STC*WTC)
      XLFC = STC/2.0
      FARC=2.0*FPC*(STC*WTC-ATBOC)/(2.0*FPC*(STC*WTC-ATBOC)+PTBOC* (1.0-
     1  FPC*DELTAC))
      CARC =2.0*(STC*WTC-3.14*DEAC**2/4.0)/(3.14*DEAC*DELTAC)
```

```
C
C       END OF HEAT EXCHANGER CHARACTERISTICS-
C
C     INITIAL VALUES FOR AIR AND REFRIGERANT FLOW CONDITIONS
C
C     QAC    -  AIR FLOW RATE (CU FT/MIN)
C     TAIIC  -  AIR TEMPERATURE ENTERING CONDENSER (F)
C
      READ 12400, QAC,TAIIC
C
C--ECHO INPUT
C
      PRINT 12500, DEAC,DERC,DELTAC,FPC,XKFC,AAFC,NTC,NSECTC
      PRINT 12600, HCONTC,STC,WTC
      PRINT 12800, QAC,TAIIC
      PRINT 12900, SIGAC,PC,PTBOC,ARFTC,ARHTC,ALFARC,ALFAAC,XLFC,FARC ,
     1 CARC
C
C*****************************************************
C******************** END OF CONDENSER SECTION ********************
C*****************************************************************
C
C**************************************************************
C
C       EVAPORATOR INPUT SECTION
C
C**************************************************************
C
C     INPUT DATA FROM CARD READER (DESCRIBED FULLY BELOW)
C     DEAE,DERE,DELTAE,FPE,XKFE,AAFE,NTE,NSECTE,
C     HCONTE,STE,WTE,
C     QAE,TAIIE,INDICE,TWBIIE,RHIE
C
C       INPUT HEAT EXCHANGER CHARACTERISTICS
C
C     DEAE   -  OUTSIDE DIAMETER OF TUBES (FT)
C     DERE   -  INSIDE DIAMETER OF TUBES (FT)
C     DELTAE -  FIN THICKNESS (FT)
C     FPE    -  FIN PITCH (FINS/FT)
C     XKFE   -  THERMAL CONDUCTIVITY OF FINS (BTU/HR-FT-F)
C     AAFE   -  HEAT EXCHANGER FRONTAL AREA (SQ FT)
C     NTE    -  NUMBER OF TUBES IN DIRECTION OF AIR FLOW
C     NSECTE -  NUMBER OF PARALLEL CIRCUITS IN HEAT EXCHANGER
C     HCONTE -  CONTACT RESISTANCE BETWEEN FINS AND TUBES
C              (BTU/HR-SQ FT-F)
C     STE    -  VERTICAL SPACING OF TUBE PASSES (FT)
C     WTE    -  SPACING OF TUBE ROWS IN DIR.OF AIR FLOW (FT)
C
C--CALCULATED QUANTITIES
C
C     SIGAE  -  SIGMA AIR (AIR FLOW ARCA/FRONTAL AREA)
C     ATBOE  -  CROSS-SECTIONAL AREA OCCUPIED BY TUBE (SQ FT)
C     PE     -  INSIDE PERIMETER OF TUBES (FT)
C     PTBOE  -  OUTTER PERIMETER OF TUBE (FT)
C     ARFTE  -  CROSS-SECTIONAL FLOW AREA INSIDE TUBES (SQ FT)
C     ARHTE  -  TOTAL REFG.SIDE HEAT TRANS. AREA/NSECT (SQ FT)
C     ALFARE -  ALPHA REFRIGERANT (REFRIGERANT SIDE HEAT
C              TRANS.AREA/TOTAL VOLUME OF HEAT EXCHANGER-1/FT)
C     ALFAAE -  ALPHA AIR (AIR SIDE HEAT TRANSFER AREA/TOTAL
C              VOLUME OF HEAT EXCHANGER -1/FT)
```

```
C      XLFE    -  LENGTH OF FINS (FT)
C      FARE    -  RATIO - FIN HEAT TRANS.AREA/TOTAL H.T. AREA
C      CARE    -  RATIO - FIN HEAT TRANS.AREA/CONTACT AREA
C               TO ACCOUNT FOR CONTACT RESISTANCE BETWEEN
C               FINS AND TUBES
C
      READ 13100, DEAE,DERE,DELTAE,FPE,XKFE,AAFE,NTE,NSECTE
      READ 13200, HCONTE, STE,WTE
C
      SIGAE = (STE-DEAE)*(1.0-DELTAE*FPE)/STE
      ATBOE = 3.14*DEAE**2/4.0
      PE = 3.14*DERE
      PTBOE = 3.14*DEAE
      ARFTE = 3.14*DERE**2/4.0
      ARHTE = FLOAT(NTE)*3.14*DERE*AAFE/(STE*FLOAT(NSECTE))
      ALFARE = 3.14*DERE/(STE*WTE)
      ALFAAE=(2.0*(STE*WTE-ATBOE)*FPE +(1.0-DELTAE*FPE)*PTBOE)/(STE*WTE)
      XLFE = STE/2.0
      FARE=2.0*FPE*(STE*WTE-ATBOE)/(2.0*FPE*(STE*WTE-ATBOE)+PTBOE* (1.0-
     1  FPE*DELTAE))
      CARE=2.0*(STE*WTE-3.14*DEAE**2/4.0)/(3.14*DEAE*DELTAE)
C
C        END OF HEAT EXCHANGER CHARACTERISTICS
C
C      INITIAL VALUES FOR AIR AND REFRIGERANT FLOW CONDITIONS
C
C      QAE     -  AIR FLOW RATE (CU FT/MIN)
C      TAIIE   -  AIR DRY BULB TEMP. ENTERING EVAPORATOR (F)
C      INDICE  -  INPUT INDICATOR
C      IF 'INDICE' EQUALS 1, INPUTS ARE TDB, AND TWB
C      IF 'INDICE' EQUALS 2, INPUTS ARE TDB, AND RH
C      TWBIIE -  AIR WET BULB TEMP. ENTERING EVAP. (F)
C      RHIE    -  RELATIVE HUMIDITY OF AIR ENTERING EVAPORATOR
C
      READ 13400, QAE,TAIIE,INDICE,TWBIIE,RHIE
C
C--EXHO INPUT
C
      PRINT 13500, DEAE,DERE,DELTAE,FPE,XKFE,AAFE,NTE,NSECTE
      PRINT 13600, HCONTE,STE,WTE
      PRINT 13800,QAE,TAIIE,INDICE,TWBIIE,RHIE
      PRINT 13900, SIGAE,PE,PTBPE,ARFTE,ARHTE,ALFARE,ALFAAE,XLFE,FARE ,
     1 CARE
C
C*****************************************************************
C*********************** END OF EVAPORATOR SECTION *****************
C*****************************************************************
C
        RETURN
C
C*****************************************************************
C**********************BEGINNING OF FORMATS*****************
C*****************************************************************
C
10000 FORMAT(4F15.5)
10100 FORMAT(4F15.5)
10200 FORMAT(F10.4,3I10)
10300 FORMAT(3F10.2)
10400 FORMAT(F10.4,I10,F10.4)
10450 FORMAT(7F10.2)
```

```
10500 FORMAT(I5,5X,I5,5X,F10.0)
10600 FORMAT(1H1,'FLOBAL INPUT ECHO:'///5X,'DOC     =', F10.5,10X,
     1 'DZOC    =',F10.5,10X,'DIC     =',F10.5 ,10X,'DZIC    =',F10.5)
10700 FORMAT(5X,'DDLOC  =',F10.5,10X,'XLEQLO =',F10.5,10X ,'DDLIC  =',
     1 F10.5,10X,'XLEQLI =',F10.5)
10800 FORMAT(5X,'DSL     =',F10.5,10X,'XLEQSL =',F10.5,10X ,'DDL     =',
     1 F10.5,10X,'XLEQDL =',F10.5)
10900 FORMAT(5X,'TSATBP =',F10.5,10X,'ICONTR =',I4,16X,'CUTOFF =',F10.4)
11000 FORMAT(5X,'IREFC  =',I4,16X,'NCAP    =',I4,16X,'CAPFLO =',F10.5)
11050 FORMAT(5X,'RPM     =',F10.5,5X,'DISPL  -',F10.5/
     2       5X,'ETAVOL =',F10.5,5X,'ETAMOT =',F10.5,5X,'ETAISN =',F10.5/
     3         5X,'QCAN    =',F10.2,5X,'QHILO  =',F10.2)
11100 FORMAT(5X,'TSATEI =',F10.5)
11200 FORMAT(5X,'TSATCI =',F10.5)
11300 FORMAT(5X,'NSECTO =',I10,10X,'NSECTI =',I10)
11400 FORMAT(5X,'SUPER   =',F10.5,10X,'DTROC  =',F10.5///
     >  '0END OF FLOBAL INPUT')
11500 FORMAT(2F10.5,I10)
11600 FORMAT(I10)
12000 FORMAT(I10)
12100 FORMAT(6F12.6/2I10)
12200 FORMAT(3F15.5)
12400 FORMAT(2F10.4)
12500 FORMAT(1H1,4X,'CONDENSER INPUT ECHO:'//10X,'DEA     =',F9.5,8X,
     >'DER    =',
     1 F9.5,8X,'DELTA =',E10.3,7X,'FP      =',F8.2,9X,'XKF     =',F7.2/ 10X,
     1  'AAF     =',F8.3,9X,'NT      =',I4,13X,'NSECT =',I4)
12600 FORMAT(10X,'HCONT =',F9.1,8X,'ST      =',F8.4,9X,'WT      =',F8.4)
12800 FORMAT(10X,'QA      =',F9.1,8X,'TAII   =',F8.2)
12900 FORMAT(////,4X,'CALCULATED EXCHANGER CHARACTERISTICS :'// 10X,
     1 'SIGA   =',F7.3,10X,'P       =',F9.5,8X,'PTBO   =',F9.5/ 10X,
     1 'ARFT   =',E10.3,7X,'ARHT   =',F8.3,9X,'ALFAR =',F8.3,9X,
     1 'ALFAA =',F8.3/10X,'XLF     =',F8.4,9X,'FAR     =',F8.4,9X,'CAR    =',
     1  F8.4,////,'0END CF CONDENSER INPUT')
13000 FORMAT(I10)
13100 FORMAT(6F12.6/2I10)
13200 FORMAT(3F15.5)
13400 FORMAT(2F10.4,I4,2F10.4)
13500 FORMAT(1H1,4X,'EVAFORATOR INPUT ECHO:'// 10X,'DEA     =',F9.5,8X,
     >'DER    =' ,
     1 F9.5,8X,'DELTA =',E10.3,7X,'FP      =',F7.2,10X,'XKF     =',F7.2/
     1 10X,'AAF     =',F8.3,9X,'NT      =',I4,13X,'NSECT =',I4)
13600 FORMAT(10X,'HCONT =',F9.2,8X,'ST      =',F8.4,9X,'WT      =',F8.4)
13800 FORMAT(10X,'QA      =',F9.1,8X,'TAII   =',F8.2,
     1 13X,'INDIC =',I4,13X/10X,'TWBII =',F8.2,
     1 13X,'RHI     =',F7.3/)
13900 FORMAT(1H0,4X,'CALCULATED EXCHANGER CHARACTERISTICS:'// 10X,
     1 'SIGA   =',F7.3,10X,'P       =',F9.5,8X,'PTBO   =',F9.5/ 10X,
     1 'ARFT   =',E10.4,7X,'ARHT   =',F8.3,9X,'ALFAR =',F8.3,9X,
     1 'ALFAA =',F8.3/10X,'XLF     =',F8.4,9X,'FAR     =',F8.4,9X,'CAR    ='
     1 ,F8.4)
      END
```

```
      SUBROUTINE FLOBAL
C
C       SYSTEM FLCW BALANCE SUBROUTINE
C
C     PURPOSE
C        TO DETERMINE THE CONDENSER AND EVAPORATOR CONDITIONS
C        WHICH, WITH GIVEN THERMAL EXPANSION VALVE BEHAVIOR
C        AND A GIVEN COMPRESSOR (EITHER CONVENTIONAL OR
C        CAPACITY CONTROLLED), WILL PRODUCE A MASS FLOW
C        BALANCE IN THE SYSTEM
C
C***            ORNL VERSION,                                 ***
C***            MODIFIED FROM INDEPENDENT CALLING PROGRAM     ***
C***            WRITTEN BY C. C. HILLER AND L. R. GLICKSMAN,  ***
C***            REFORT NO. 24525-96,                          ***
C***            HEAT TRANSFER LABORATORY,                     ***
C***            MASSACHUSETTS INSTITUTE OF TECHNOLOGY.        ***
C
C     INPUT DATA CONSTANTS
C        SLPEMV & XINMV - COEFFICIENTS FOR DETERMINING
C                         VISCOSITY OF REFRIGERANT VAPOR
C        XM1-XM4        - COEFFICIENTS FOR DETERMINING
C                         VISCOSITY OF REFRIGERANT LIQUID
C        C1-C3          - COEFFICIENTS FOR DETERMINING THE
C                         THERMAL EXPANSION VALVE BEHAVIOR
C
C NOTE: THE INPUT DATA CONSTANTS ARE FOR REFRIGERANT 22 ONLY
C
C     OUTPUT PARAMETERS
C        TSATE ANE TSATC FOR A REFRIGERANT FLOW BALANCE (F)
C        XMR  -  REFRIGERANT MASS FLOW RATE AT BALANCE
C                CONDITIONS (LBM/HR)
C        POW  -  TOTAL CCMPRESSOR INPUT POWER AT FLOW
C                BALANCE CONDITIONS (KW)
C        TIC  -  TEMPERATURE OF REFRIGERANT ENTERING COND. (F)
C
C     REMARKS
C        THIS SUBROUTINE CALLS SUBROUTINE 'SATPRP' TO DETERMINE
C        SATURATICN PROPERTIES OF REFRIGERANTS
C        THIS PROGRAM CALLS SUBROUTINE 'COMP' TO DETERMINE
C        CCMPRESSOR PERFORMANCE
C        THIS PROGRAM CALLS SUBROUTINE 'DPLINE' TO DETERMINE
C        PRESSURE DROPS IN SINGLE PHASE REGIONS OF
C        CONNECTING PIPING
C        THIS PROGRAM CALLS SUBROUTINE 'PDROP' TO DETERMINE
C        PRESSURE DROPS IN TWO-PHASE FLOW IN THE HEAT EXCH.
C        THIS PROGRAM USES FUNCTION SUBPROGRAM 'TSAT' TO
C        DETERMINE SATURATION TEMPERATURES CORRESPONDING TO
C        GIVEN PRESSURES
C
      COMMON/FLOWBA/ DLLCC,XLEQLO,DLLIC,XLEQLI,DSL,XLEQSL,DDL,XLEQDL,
     1 DOC,DZOC,DIC,DZIC,DTROC,NCORH,NSECTO,NSECTI,TSATEI,DTE,NE,
     1 TSATCI,DTC,NC,SUPER,NCAP,CAPFLO,IREFC,
     1 DISPL,ETAVOL,ETAMOT,ETAISN,QCAN,QHILO
C
      COMMON/FPASS/XMRIC,TSAC,TRIC,TSATC,TSATE
C
      COMMON/COMPR/NCYL,VR,VD,SYNC,RPM,EFFIS,DPDI,DPS,DPFRAC, SDELAY,
     1 PMC,PHT,PHTC,EAD,EAS,XMR,POW,TIC,HIC,H10E,PIC, P10E,T10E,POWMAX,
     1 PWRNL,EQAREA,DDELAY,XOIL,EFFME,DDISL,ELDISL,XMRT,DPDL
```

```
C
      DATA SLPEMV,XINMV/.0000759,.0272/
      DATA XM1,XM2,XM3,XM4/-5.625E-08,1.525E-05,-2.982E-03, .646/
      DATA C1,C2,C3/2.128E-03,.2491,9.455/
      DDISL = DDL
      ELDISL = XLEQDL
      NR = 22
C
C--------LOOP FOR ITERATING ON CONDENSER TEMPERATURE-------
C
C     ITERATE TO FIND THE CONDENSER TEMPERATURE WHICH
C     GIVES A SYSTEM FLOW BALANCE FOR THE GIVEN TSATE,
C     THERMAL EXPANSION VALVE BEHAVIOR, AND COMPRESSOR BEHAVIOR
C
         TSATC = TSATCI
         TSATE = TSATEI
         DT = 2.0
         TSATC = TSATC - DT
         DO 80 I = 1,20
            TSATC = TSATC + DT
        PRINT 11300
        IF(IREFC.EQ.1) PRINT 11400, TSATE,TSATC,DPSYS,DPACT
        IF(IREFC.EQ.2) PRINT 11450, TSATE,TSATC,XMR,CXMR
        IF(IREFC.LT.1 .OR. IREFC.GT.2) CALL ERROR
C
C
C     CALCULATE THE GUESSED TEMP. 'TROC' FOR EXIT TEMP. OF
C     REFRIGERANT FROM CONDENSER (THIS MUST BE CHECKED
C     MANUALLY WITH THE OUTPUT OF THE CONDENSER PERFORMANCE
C     PROGRAM)
C
            TROC = TSATC - DTROC
C
C     DETERMINE PROPERTIES OF LIQUID REFRIGERANT LEAVING COND.
C
            CALL SATPRP(NR,TROC,P,VF,VG,H3,HFG,HG,SF,SG)
            RHO3 = 1.0/VF
            XMUL = XM1*TROC**3 + XM2*TROC**2 + XM3*TROC + XM4
C
C     CALL SUBROUTINE COMP TO DETERMINE THE COMPRESSOR
C     PERFORMANCE AND REFRIGERANT FLOW RATE 'XMR'
C
            CALL COMP(NR,TSATE,TSATC,SUPER,DISPL,ETAVOL,ETAMOT,ETAISN,
     2                QCAN,QHILO)
            IF (NCORH.EQ.1) GO TO 10
            IF (NCORH.EQ.2) GO TO 20
C
C     DEFINE VARIABLES IF OPERATING IN THE COOLING MODE
C
   10       DERC = DOC
            GRC = 4.0*XMR/(FLOAT(NSECTO)*3.14*DERC**2)
            DZTPC = DZOC
            DERE = DIC
            GRE = 4.0*XMR/(FLOAT(NSECTI)*3.14*DERE**2)
            DZTPE = DZIC
            DLL = DLLOC
            XLEQLL = XLEQLO
            NSECT = NSECTI
            GO TO 30
C
```

```
C     DEFINE VARIABLES IF OPERATING IN THE HEATING MODE
C
   20       DERC = DIC
            GRC = 4.0*XMR/(FLOAT(NSECTI)*3.14*DERC**2)
            DZTPC = DZIC
            DERE = DOC
            GRE = 4.0*XMR/(FLOAT(NSECTO)*3.14*DERE**2)
            DZTPE = DZOC
            DLL = DLLIC
            XLEQLL = XLEQLI
            NSECT = NSECTO
   30       E = 5.0E-06
C
C     DETERMINE LIQUID LINE PRESSURE DROP 'DPLL' (PSI)
C
            CALL DPLINE(DLL,XLEQLL,E,XMR,RHO3,XMUL,DPLL)
C
C     DETERMINE SATURATION PROPERTIES  OF REFRIGERANT IN COND.
C
            CALL SATPRP(NR,TSATC ,P,VF,VV,HF,HFG,HG,SF,SG)
            RHOL = 1.0/VF
            RHOV = 1.0/VV
            XMUL = XM1*TSATC **3 + XM2*TSATC **2 + XM3*TSATC + XM4
            XMUV = SLPEMV*TSATC + XINMV
C
C     DETERMINE PRESSURE DROP IN CONDENSER 'DELPC' (PSI)
C     ASSUMING THAT THE TWO-PHASE PRESSURE DROP IS APPROX.
C     THE TOTAL CONDENSER PRESSURE DROP
C
            CALL PDROP(4,DERC,E,GRC,XMUV,XMUL,RHOV,RHOL,1.0,1.0, DZTPC,
     1       0.0,1.0,VV,0.0,0.0,DELPC)
C
C     DETERMINE THE ACTUAL VAPOR VELOCITY IN THE DISCHARGE
C     RISER 'VDRACT' (FT/HR)
C
            VDRACT = XMR*4.0/(RHOV*3.14*DDL**2)
C
CC     DETERMINE THE PRESSURE DROP 'DPDL' (PSI) OF VAPOR
CC     IN THE DISCHARGE LINE
CC
C            CALL DPLINE(DDL,XLEQDL,E,XMR,RHOV,XMUV,DPDL)
CC
C     CALCULATE PRESSURE AT THE FLOW CONTROL DEVICE ENTRY, AND
C     CHECK FOR FLASHING IN THE LIQUID LINE
C
            CALL SATPRP(NR,TSATC,PSATC,VF,VV,HF,HFG,HG,SF,SG)
            POC = PSATC + DELPC  - DPLL
            T = TSAT(NR,POC)
            IF (T.LE.TROC) WRITE(6,10900)
C
C     BRANCH ON IREFC
C
         IF(IREFC.EQ.1) GO TO 40
C
C     CALCULATE MASS FLOW RATE ' CXMR '  OF REFRIGERANT IN THE CAP TUBES
C     FOR PRESSURE POC AT START OF TUBES
C
         EXK = 0.4035 + 0.4175*EXP(-0.04*DTROC)
         WO  = 356.0  + 0.641*((ABS(DTROC-31.0)/10.)**3.56)
         CXMR = NCAP*CAPFLO*WO*(POC/1500.)**EXK
```

```
C
        PRINT 10400, DPDL,DELPC,DPLL,CXMR
        PRINT 10050, TROC,TIC,TSATC,TSATE
        PRINT 10150, HIC,H10E,H3,POC,PIC
        PRINT 10600, XMR, POW
C
C     SET ARGUMENTS FOR TESTING CONVERGENCE
C
        ARG1 = CXMR
        ARG2 = XMR
        ARG3 = 0.01 * XMR
        GO TO 50
C
C     CALCULATE QUANTITIES NEEDED IF THERMAL EXPANSION VALVE IS USED
C
C     DETERMINE SATURATION PROPERTIES OF REFRIGERANT IN THE
C     EVAPORATOR
C
   40       CALL SATPRP(NR,TSATE,P,VF,VV,HLIQ,HFG,HG,SF,SG)
            RHOL = 1.0/VF
            RHOV = 1.0/VV
            XMUL = XM1*TSATE**3 + XM2*TSATE**2 + XM3*TSATE + XM4
            XMUV = SLPEMV*TSATE + XINMV
            XI = (H3-HLIQ)/HFG
C
C     DETERMINE DRESSURE DROP IN THE EVAPORATOR 'DELPE' (PSI)
C     ASSUMING THAT THE TWO-PHASE PRESSURE DROP IS APPROX.
C     THE TOTAL EVAPORATCR PRESSURE DROP
C
            CALL FDROP(3,DERE,E,GRE,XMUV,XMUL,RHOV,RHOL,1.0,1.0, DZTPE,
     1       1.0,XI,VV,0.0,0.0,DELPE)
C
C     DETERMINE ACTUAL VAPOR VELOCITY IN SUCTION RISER
C     'VSRACT' (FT/HR)
C
            VSRACT = XMR*4.0/(RHOV*3.14*DSL**2)
C
C     DETERMINE PRESSURE DROP OF VAPOR IN SUCTION LINE 'DPSL'
C     (PSI)
C
            CALL DPLINE(DSL,XLEQSL,E,XMR,RHOV,XMUV,DPSL)
            CAP = XMR*(H10E - H3)
            PIE = P10E - DELPE + DPSL
            CAPPT = CAP/FLOAT(NSECT)
C
C     DETERMINE PRESSURE DROP THROUGH DISTRIBUTOR NOZZLE
C     AND TUBES
C
            IF (TROC.LE.100.0) CORFAC=10.0**(-.006444*TROC+.6444)
            IF (TROC.GT.100.0) CORFAC = 10.0**(-.007133*TROC+.7133)
            TIE = TSAT(NR,PIE)
            IF (NCORH.EQ.1) CAPNOZ=10.0**(.004842*TIE+.59162)* 12000.0*
     1       CORFAC
            IF (NCORH.EQ.2) CAPNOZ=10.0**(.00511*TIE+.944803)* 12000.0*
     1       CORFAC
            IF (NCORH.EQ.1) CAPTUB=10.0**(.005629*TIE-.183775)* 12000.0*
     1        CORFAC
            IF (NCORH.EQ.2) CAPTUB = 10.0**(.005291*TIE-.487330)*
     1       12000.0*CORFAC
            IF (NCORH.EQ.1) CAP = CAP*4.0/9.0
```

```
            PCAPN = CAP/CAPNOZ
            PCAPT = CAPPT/CAPTUB
            IF (PCAPN.LE.1.2) DPNOZ = 25.0*PCAPN**1.8384
            IF (PCAPN.GT.1.2) DPNOZ = 29.408*PCAPN**.954735
            DPTUBE = 10.0*PCAPT**1.81217
            DPSYS = POC - PIE
C
C     THERMAL EXPANSION VALVE
C
C     DETERMINE  THE FLOW AREA COEFFICIENT 'CTXV' FOR EITHER
C     CONVENTIONAL OR CAPACITY CONTROLLED SYSTEMS
C
            CTXV = C1*TSATE**2 + C2*TSATE + C3
C
C     DETERMINE PRESSURE DROP THROUGH TXV 'DPTXV'(PSI)
C
            IF (NCORH.EQ.2) DPTXV = (XMR/CTXV)**2/RHO3
            IF (NCORH.EQ.1) DPTXV=(XMR*4.0/(9.0*1178.1))**2*71.236*
     1       100.0/RHO3
C
C     DETERMINE THE ACTUAL PRESSURE DROP 'DPACT' (PSI)
C     WHICH WOULD EXIST WITH THE GIVEN FLOW RATE
C
            DPACT = DPTXV + DPNOZ + DPTUBE
            WRITE(6,10500) CAP,CAPPT,CORFAC,CAPNOZ,CAPTUB,PCAPN,PCAPT
             WRITE(6,10300) DELPE,DELPC,DPTXV,DPNOZ,
     1       DPTUBE,DPLL, DPSL,DPDL
            WRITE(6,10000) TROC,TIE,TIC,TSATE,TSATC
            WRITE(6,10100) HIC,H10E,H3,POC,PIE,PIC
            WRITE(6,10600) XMR,POW,DPSYS,DPACT
C
C     SET ARGUMENTS FOR TESTING CONVERGENCE
C
        ARG1 = DPSYS
        ARG2 = DPACT
        ARG3 = 2.0
C
C     DETERMINE CAPACITY ' CAPE ' OF THE EVAPORATOR, AND
C               CAPACITY ' CAPC ' OF THE CONDENSER
C
   50       CAPE = XMR*(H10E - H3)
            CAPC = XMR*(HIC - H3)
            WRITE(6,10800) CAPE,CAPC
C
C     DETERMINE THE MINIMUM SUCTION RISER VAPOR VELOCITY
C     'VSR' (FT/HR) REQUIRED FOR OIL ENTRAINMENT
C
            VSR=60.0*10.0**(-.005875*TSATE+.5*ALOG10(DSL)+3.4826)
C
C     DETERMINE THE MINIMUM DISCHARGE  RISER VAPOR VELOCITY
C     'VDR' (FT/HR) REQUIRED FOR OIL ENTRAINMENT
C
            VDR=60.0*10.0**(-.00315*TSATC +.5*ALOG10(DDL)+3.40)
            WRITE(6,10700) VSR,VSRACT,VDR,VDRACT,CTXV
C
C     WRITE WARNING MESSAGE IF THERE IS INADEQUATE OIL RETURN
C
            IF (VSRACT.LT.VSR) WRITE(6,11000) VSRACT,VSR
            IF (VDRACT.LT.VDR) WRITE(6,11100) VDRACT,VDR
            IF (TIC.GE.280.0) WRITE(6,11200)
```

```
C
C     CHECK THE ACTUAL PRESSURE DROP ACROSS THE SYSTEM AT
C     THE GIVEN FLOW RATE 'DPACT' WITH THE AVAILABLE PRESSURE
C     DROP BETWEEN CONSENSER AND EVAPORATOR 'DPSYS', TO SEE
C     IF A FLOW BALANCE ACTUALLY EXISTS
C
            IF (ABS(ARG1 - ARG2).LT.ARG3) GO TO 90
            IF (ARG1 - ARG2) 70,90,60
   60       IF (I.EQ.1) DT = -DT
            IF (DT.LT.0.0) GO TO 80
            TSATC = TSATC - DT
            DT = DT/2.0
            GO TO 80
   70       IF (DT.LT.0.0) TSATC = TSATC - DT
            IF (DT.LT.0.0) DT = DT/2.0
   80       CONTINUE
C----------------END CONDENSER TEMPERATURE LOOP------------
   90    CONTINUE
      RETURN
10000 FORMAT(5X,'TROC    =',F9.2,6X,'TIE     =',F9.2,6X,'TIC     =',F9.2/
     1 5X,'TSATE  =',F9.2,6X,'TSATC  =',F9.2)
10050 FORMAT(5X,'TROC    =',F9.2,6X,'TIC     =',F9.2,6X,'TSATC  =',F9.2/
     2 5X,'TSATE  =',F9.2)
10100 FORMAT(5X,'HIC     =',F9.2,6X,'H1OE   =',F9.2,6X,'H3      =',F9.2/
     1 5X,'POC     =',F9.2,6X,'PIE     =',F9.2,6X,'PIC     =',F9.2)
10150 FORMAT(5X,'HIC     =',F9.2,6X,'H1OE   =',F9.2,6X,'H3      =',F9.2/
     2 5X,'POC     =',F9.2,6X,'PIC     =',F9.2)
10200 FORMAT(' TSATE=',F7.2,' TSATC=',F7.2,' CUTOFF=',F4.2, ' DPSYS=',
     1 F7.2,' DPACT=',F7.2)
10300 FORMAT(///5X,'BOTTOM OF ITERATION LOOP:'//5X,'DELPE  =',F7.2,8X,
     1 'DELPC  =',F7.2,8X,'DPTXV  =',F8.2,7X,'DPNOZ  =',F7.2,8X/5X,
     1 'DPTUBE =',F7.2,8X,'DPLL   =',F7.2,8X,'DPSL   =',F7.2,8X,
     1 'DPDL   =',F7.2)
10400 FORMAT(///5X,'BOTTOM OF ITERATION LOOP:'//5X,'DPDL   =',F7.2,8X,
     1 'DELPC  =',F7.2,8X,'DPLL   =',F8.2,7X,'CXMR   =',F7.2)
10500 FORMAT(5X,'CAP    =',F10.1,5X,'CAPPT  =',F10.1,5X,'CORFAC =',
     1 F6.2/5X,'CAPNOZ =',F10.1,5X,'CAPTUB =',F8.1,7X,'PCAPN  =',F6.3,
     1 9X,'PCAPT  =',F6.3)
10600 FORMAT(5X,'XMR    =',F9.2/5X,'POW    =',F8.3/5X,'DPSYS  =',F8.2/
     1 5X,'DPACT  =',F8.2//)
10700 FORMAT(5X,'VELOCITIES IN RISERS:'/5X,'VSR   =',E12.5,' FT/HR',5X,
     1 'VSACT=',E12.5,' FT/HR'/5X,'VDR   =',E12.5,' FT/HR',5X, 'VDACT=',
     1  E12.5,' FT/HR'//5X,'CTXV=',F9.3/////)
10800 FORMAT('    CAPE =',F15.2,'    CAPC =',F15.2)
10900 FORMAT(' ******FLASHING OCCURS IN LIQUID LINE******')
11000 FORMAT('*********INADEQUATE OIL RETURN IN SUCTION' ,
     1 ' RISER  VSRACT=',F15.5,'    VSR=',F15.5,'*********')
11100 FORMAT(' *************INADEQUATE OIL RETURN IN' ,
     1 ' DISCHARGE RISER  VDRACT=',F15.5,'    VDR=',F15.5, '*********')
11200 FORMAT(' ***********COMPRESSOR DISCHARGE TEMPERATURE' ,
     1 ' IS EXCESSIVE**********')
11300   FORMAT('1')
11400   FORMAT(5X,'TOP OF ITERATION LOOP'/5X,'PRESENT SYSTEM VALUES ARE'
     >/,5X,'TSATE  =',F10.5,10X,'TSATC  =',F10.5,10X,'DPSYS  =',F10.5,
     >10X,'DPACT  =',F10.5)
11450 FORMAT(5X,'TOP OF ITERATION LOOP'/5X,'PRESENT SYSTEM VALUES ARE'
     2 /,5X,'TSATE  =',F10.5,10X,'TSATC  =',F10.5,10X,'XMR    =',F10.5,
     2 10X,'CXMR   =',F10.5)
      END
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      SUBROUTINE COMP(NR,TSATEI,TSATCI,SUPERI,DISPL,ETAVOL,ETAMOT,
     2                ETAISN,QCAN,QHILO)
C
C     ORNL BAREBONES MODEL OF HEAT PUMP COMPRESSOR
C          PRELIMINARY VERSION
C          ALLOWS WET VAPOR AT COMPRESSOR ENTRY
C
C
      COMMON/COMPR/NCYL,VR,VD,SYNC,RPM,EFFIS,DPDI,DPS,DPFRAC,
     1SDELAY,PMC,PHT,PHTI,EAD,EAS,XMR,POW,TIC,HIC,H1OE,PIC,
     2P1OE,T1OE,POWMAX,PWRNL,EQAREA,DDELAY,XOIL,EFFME,DDISL,ELDISL,XMRT,
     3DPDL
C***
      COMMON /G/ ERRMSG(5)
      DATA TOLS,TCLH,DELTI /0.0005, 0.05, 5.0/
      DATA SLPEMV,XINMV,E /.0000759, .0272, 5.0E-06/
C***
      TSATE = TSATEI
      TSATC = TSATCI
      SUPER = SUPERI
      CALL SATPRP(NR,TSATE, PSATE, VFE,VGE,HFE,HFGE,HGE,SFE,SGE)
      CALL SATPRP(NR,TSATCI, PSATC, VF,VG,HF,HFG,HG,SF,SG)
C***          CALC THE PRESSURE DROP 'DPDL' (PSI) OF VAPOR
C             IN THE DISCHARGE LINE AND 'POCOMP' (PSIA) THE
C             PRESSURE AT THE COMPRESSOR EXIT
      XMUV = SLPEMV*TSATC + XINMV
      RHOV = 1./VG
      CALL DPLINE(DDISL,ELDISL,E,XMRT,RHOV,XMUV,DPDL)
      POCOMP = PSATC + DPDL
C
      QUAL = 0.
      IF(SUPER.GE.0.) GO TO 4
C***          SET QUALITY AND CALC H1B FOR WET VAPOR
      QUAL = -SUPER
      SUPER = 0.
      H1B = HFE + QUAL*HFGE
    4 T1 = TSATE + SUPER
C***          IF QUALITY = 0, ASSUME SUPERHEATED VAPOR AND
C***          CALCULATE H1B FOR SUPERHEATED VAPOR
      IF(QUAL.EQ.0) CALL VAPOR(NR,T1,PSATE,VVAP, H1B, SVAP)
      H1 = H1B
C***          LOOP ON ENTHALPY AT COMPRESSOR INLET (H1) UNTIL CONVERGED
    6 DO 50 I = 1, 20
      QUALO = QUAL
      IF(H1.LT.HGE) GO TO 10
C***          VAPOR ENTERING COMPRESSOR IS DRY
      TTRY = T1 - 5.
      TFSAT = TSAT(NR, PSATE)
      IF(TTRY.LT.TFSAT) TTRY = TFSAT
      CALL TRIAL(NR,TTRY,DELTI,PSATE, 3, H1,TOLH,V,H,S, T1)
      CALL VAPOR(NR,T1,PSATE, V1, H1, S1)
      IF(QUALO.EQ.0.) GO TO 20
      QUAL = 0.
      SUPER = T1 - TFSAT
      GO TO 20
C***          RECALC QUAL FOR NEW H1< HGE AND
C***          CALC S1 AND V1 FOR WET VAPOR
   10 QUAL = (H1-HFE) / HFGE
      V1 = VFE + QUAL*(VGE-VFE)
      S1 = SFE + QUAL*(SGE-SFE)
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   20 RHO1 = 1./V1
C***          CALCULATE MASS FLOW RATE (LBM/HR) OF REFRIGERANT
      XMR = ETAVOL * RHO1 * 60.*RPM * DISPL/1728.
C***          CALCULATE ENTHALPY AFTER ISENTROPIC COMPRESSION
      CALL TRIAL(NR,TSATC+5,DELTI,POCOMP, 4, S1, TOLS, V,H2P, S,T)
      H2 = H1 + (H2P-H1)/ETAISN
C***          CALCULATE POWER DELIVERED TO COMPRESSOR SHAFT
      POWCS = XMR* (H2 - H1)
      POW = POWCS / ETAMOT
C***          RECALCULATE H1 TAKING ACCOUNT OF MOTOR LOSS TO SUCTION GAS
C***          AND INTERNAL HEAT TRANSFER
C      CALL TRIAL(NR,TIC-5,DELTI,PSATC,3,H2,.05,V,H,S, TIC)
C       QHILO = CHILO*(TIC - T1)
      H1OLD = H1
      H1 = H1B + ((POW-POWCS)-QCAN+QHILO)/ XMR
      IF(ABS(H1-H1OLD).LE.0.25) GO TO 60
   50 CONTINUE
C***          FAILED TO CONVERGE
      PRINT 55, H1, H1OLD
   55 FORMAT('0*****   FAILED TO CONVERGE IN COMP. H1 =',F8.2,
     2        5X,'H1OLD =',F8.2,5X,'*****')
C***          RECALC DPDL FROM XMR JUST FOUND. IF IT DIFFERS FROM
C             DPDL CALC USING XMRT, REPEAT LOOP ON ENTHALPY H1 USING
C             NEW DPDL
   60 XMRT = XMR
      CALL DPLINE(DDISL,ELDISL,E,XMR,RHOV,XMUV,DPDLT)
      IF(ABS(DPDL-DPDLT).LE.0.5) GO TO 65
      DPDL = DPDLT
      POCOMP = PSATC + DPDL
      GO TO 6
C***      CALC VARIOUS QUANTITIES TO SEND BACK TO FLOBAL
   65 POW = POW/3412
      IF(H1.LT.HGE) GO TO 70
C***          VAPOR ENTERING COMPRESSOR IS DRY
      TTRY = T1 - 5
      TFSAT = TSAT(NR, PSATE)
      IF(TTRY.LT.TFSAT) TTRY = TFSAT
      CALL TRIAL(NR,TTRY,DELTI,PSATE, 3, H1,TOLH,V,H,S, T1)
      T1OE = T1
      QUAL = 0.
      GO TO 75
C***          VAPOR ENTERING COMPRESSOR IS WET
   70 QUAL = (H1-HFE) / HFGE
      T1OE = TSATE
   75 H2 = H2 - QHILO/XMR
      CALL TRIAL(NR,TSATC+5.,DELTI,POCOMP,3,H2,TOLH,V,H,S, TIC)
      HIC = H2
      PIC = POCOMP - DPDL
      P1OE = PSATE
      H1OE = H1
      RETURN
      END
```

```
      SUBROUTINE COND
C
C          CONDENSER SIMULATION SUBROUTINE
C
C     PURPOSE
C        TO COMPUTE CONDENSER PERFORMANCE
C        AIR COOLED, PLATE-FIN, CROSSFLOW TYPE
C
C***            ADAPTED FROM INDEPENDENT CALLING PROGRAM       ***
C***            WRITTEN BY C. C. HILLER AND L. R. GLICKSMAN,  ***
C***            REPORT NO. 24525-96,                          ***
C***            HEAT TRANSFER LABORATORY,                     ***
C***            MASSACHUSETTS INSTITUTE OF TECHNOLOGY.        ***
C
C     OUTPUT
C        QC    -  TOTAL HEAT TRANSFER RATE (BTU/HR)
C        TAO   -  AVERAGE AIR TEMPERATURE LEAVING COND. (F)
C        TRO   -  TEMPERATURE OF REFRIGERANT LEAVING COND.  (F)
C        HRO   -  ENTHALPY OF REFRIGERANT LEAVING COND.(BTU/LBM)
C
C     REMARKS
C        THIS SUBROUTINE CALLS SUBROUTINE SPHTC TO DETERMINE
C        SINGLE PHASE HEAT TRANSFER COEFFICIENTS
C        THIS PROGRAM CALLS SUBROUTINE SEFF TO DETERMINE
C        SURFACE EFFICIENCY OF FINNED SURFACE
C        THIS PROGRAM CALLS SUBROUTINE SATPRP TO DETERMINE
C        SATURATION THERMODYNAMIC PROPERTIES
C        THIS PROGRAM CALLS SUBROUTINE CHTC TO DETERMINE
C        THE CONDENSATION TWO-PHASE HEAT TRANSFER COEFFICIENT
C        FOR FORCED CONVECTION CONDENSATION INSIDE TUBES
C        THIS PROGRAM CALLS SUBROUTINE VAPOR TO DETERMINE
C        THERMODYNAMIC PROPERTIES OF SUPERHEATED REFRIGERANT
C        VAPOR
C        THIS PROGRAM CALLS SUBROUTINE EXCH TO DETERMINE
C        THE OVERALL HEAT EXCHANGER PERFORMANCE, HEAT TRANS.
C        RATES, AIR TEMPERATURES ETC.
C        THIS PROGRAM CALLS SUBROUTINE PDROP TO DETERMINE
C        PRESSURE DROP OF REFRIGERANT FLOWING IN THE COIL
C        THIS PROGRAM CALLS FUNCTION SUBPROGRAM TSAT TO
C        DETERMINE SATURATION TEMPERATURES CORRESPONDING
C        TO GIVEN PRESSURES
C
      COMMON/CONDEN/ NRUNC,DEAC,DERC,DELTAC,FPC,XKFC,AAFC,NTC, NSECTC,
     1 HCONTC,STC,WTC,SIGAC,ATBOC,PC,PTBOC,ARFTC,ARHTC,ALFARC,ALFAAC,
     1 XLPC,FARC,CARC,DXMRIC,NXMRC,QAC,TAIIC, DTAC,NTEMPC,QC
C
      COMMON/FPASS/XMRIC,TSAC,TRIC,TSATC,TSATE
      COMMON/CPASS/XMRIE,TSAE,H4E,HRO,TROC
C
      COMMON CPA,HA,SEFFX,HRV,HRL,CPRL,CPRV,XMR,XMA,X3, TRI,HTP,F,FTP,
     1 FSC,QSP,QTP,QSC,TAOSP,TAOTP,TAOSC,TAO, TRO,ARHT
C
C     ----------------- INPUT DATA CONSTANTS --------------
C
C AIR PROPERTIES
C     PRA   -  PRANDTL NUMBER OF AIR
C     XMUA  -  VISCOSITY OF AIR (LBM/HR-FT)
C     RAU   -  UNIVERSAL GAS CONSTANT FOR AIR (FT-LBF/LBM-R)
C     PA    -  ATMOSPHERIC PRESSURE (PSIA)
C     CPA   -  SPECIFIC HEAT AT CONST.PRES.OF AIR (BTU/LBM-R)
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      DATA PRA,XMUA,RAU,PA/.714,.043,53.34,14.7/
      CPA = .24
C
C REFRIGERANT PROPERTY VARIATION COEFFICIENTS
C     NR     -  NUMBER OF REFRIGERANT (12,22, OR 502)
C     NREF   -  NUMBER OF REFRIGERANT (USUALLY SAME AS NR)
C     SLPEMV & XINMV   -  COEFFICIENTS FOR VISCOSITY OF VAPOR
C     SLPEKV & XINKV   -  COEFFICIENTS FOR THERMAL
C                         CONDUCTIVITY OF VAPOR
C     SLPEKL & XINKL   -  COEFFICIENTS FOR THERMAL
C                         CONDUCTIVITY OF LIQUID
C     XM1 - XM4        -  COEFFICIENTS FOR VISCOSITY OF LIQ.
C     CP1 & CP2        -  COEFFICIENTS FOR SPECIFIC HEAT
C                         AT CONST. PRES. OF LIQUID
      NR = 22
      DATA NREF,SLPEMV,XINMV,SLPEKV,XINKV,SLPEKL,XINKL /22,.0000759,
     1 .0272,.00002,.00482,-.000159,.06299/
      DATA XM1,XM2,XM3,XM4/-5.625E-08,1.525E-05,-2.982E-03, .646/
      DATA CP1,CP2/2.98E-04,.2575/
C ****NOTE - THE ABOVE REFRIGERANT PROPERTY COEFFICIENTS
C     ARE FOR REFRIGERANT 22 ONLY
C
C AIR SIDE FLOW CHARACTERISTICS (SAME FOR BOTH EVAP.&COND.
C IF THEY ARE OF THE SAME TYPE)
C     C1A-C6A          -  COEFFICIENTS FOR EXPRESSING THE
C                         AIR SIDE HEAT TRANSFER COEFFICIENT
C     XLLA  -  LOWER REYNOLDS NUMBER LIMIT FOR LAMINAR
C              FLOW ON AIR SIDE
C     ULA   -  UPPER REYNOLDS NUMBER LIMIT FOR TURBULENT
C              FLOW ON AIR SIDE
      DATA C1A,C2A,C3A,C4A,C5A,C6A,XLLA,ULA /.2243,-.385,.2243,-.385,
     1 .2243,-.385,1000.0,2000.0/
C
C REFRIGERANT SIDE FLOW CHARACTERISTICS (SAME FOR BOTH
C EVAP.& COND. IF THEY ARE OF SAME TYPE)
C     C1R-C6R          -  COEFFICIENTS FOR EXPRESSING THE
C                         REFRIGERANT SIDE SINGLE PHASE HEAT
C                         TRANSFER COEFFICIENTS
C     XLLR  -  LOWER REYNOLDS NUMBER LIMIT FOR LAMINAR
C              FLOW ON REFRIGERANT SIDE (SINGLE PHASE)
C     ULR   -  UPPER REYNOLDS NUMBER LIMIT FOR TURBULENT
C              FLOW ON REFRIGERANT SIDE (SINGLE PHASE)
      DATA C1R,C2R,C3R,C4R,C5R,C6R,XLLR,ULR /1.164,-.7824,.000054,
     1 .49985,.00667,-.0897,2400.,3500./
C
C     ----------END OF  INPUT DATA CONSTANTS -------------
C
C     OUTER LOOP FOR MULTIPLE RUNS WHILE VARYING HEAT
C     EXCHANGER CHARACTERISTICS
C
      NREF=NREF+0
C
C
          DEA=DEAC
          DER=DERC
          DELTA=DELTAC
          FP=FPC
          XKF=XKFC
          AAF=AAFC
          NT=NTC
```

```
              NSECT=NSECTC
              HCONT=HCONTC
              ST=STC
              WT=WTC
              SIGA=SIGAC
              ATBO=ATBOC
              P=PC
              PTBO=PTBOC
              ARFT=ARFTC
              ARHT=ARHTC
              ALFAR=ALFARC
              ALFAA=ALFAAC
              XLF=XLFC
              FAR=FARC
              CAR=CARC
              XMRI=XMRIC
              DXMRI=DXMRIC
              NXMR=NXMRC
              TSA=TSAC
              TRI=TRIC
              QA=QAC
              TAII=TAIIC
              DTA=DTAC
C
C
      TAI = TAII
C
        PRINT 10700, TAI,QA,TRI,TSA
C
C
            VA = QA*60.0/(SIGA*AAF)
            GA = VA*PA*144.0/(RAU*(TAI + 460.0))
C     AOM   -  UNIT REFRIGERANT SIDE HEAT TRANSFER AREA/ UNIT
C     AIR FLOW RATE (SQ FT-HR/LBM DRY AIR)
            AOM = FLOAT(NT)*P/(ST*GA*SIGA)
C
C     SUBDIVIDE FLOW INTC PARALLEL CIRCUITS AND TREAT EACH
C     LIKE A SEPARATE HEAT EXCHANGER - CONVERT BACK TO TOTAL
C     FLOW AT THE END
C
            XMA = 60.0*QA*PA*144.0/(RAU*(TAI + 460.0)*FLOAT(NSECT))
C
C     DETERMINE AIR SIDE HEAT TRANS.COEF.'HA'(BTU/HR-SQ FT-F)
C
            CALL SPHTC(DEA,GA,C1A,C2A,C3A,C4A,C5A,C6A,XLLA,ULA, XMUA,
     1       CPA,FRA,REA,HA)
C
C     DETERMINE OVERALL SURFACE EFFICIENTCY 'SEFFX'
C
            CALL SEFF(XKF,DELTA,HA,XLF,FAR,CAR,HCONT,SEFFX)
            ICNT = 1
C
C     LOOP FOR VARYING REFRIGERANT FLOW RATE
C
            XMR = XMRI/FLOAT(NSECT)
C
C     DETERMINE SATURATION PROPERTIES OF REFRIGERANT
C
   10         CALL SATPRP(NR,TSA ,PSAT,VF,VG,HSATL,HFG,HSATV,SF,SG)
              RHOV = 1.0/VG
```

```
      RHOL = 1.0/VF
      IF (ICNT.EQ.1) P2 = PSAT
      XMUL = XM1*TSA **3 + XM2*TSA **2 + XM3*TSA + XM4
      CPRL = CP1*PSAT + CP2
      XKRL = SLPEKL*TSA + XINKL
      XMURV = SLPEMV*TSA + XINMV
      X3 = 0.0
      PRRL = XMUL*CPRL/XKRL
      GR = XMR/AFFT
C
C     DETERMINE CONDENSATION TWO-PHASE HEAT TRANS.COEF.'HTP'
C     (BTU/HR-SQ FT-F)
C
      CALL CHTC(DER,GR,X3,PRRL,XKRL,XMURV,XMUL,RHOL,RHOV,HTP)
C
C     DETERMINE SINGLE PHASE LIQUID HEAT TRANSFER COEF.
C     'HRL' (BTU/HR-SQ FT-F)
C
      CALL SPHTC(DER,GR,C1R,C2R,C3R,C4R,C5R,C6R,XLLR,ULR, XMUL,
     1    CPRL,PRRL,RERL,HRL)
C
C     DETERMINE SINGLE PHASE VAPOR PROPERTIES
C
      CALL VAPOR(NR,TRI,P2,V2I,H2I,S2I)
      XMURV = SLPEMV*(TSA + TRI)/2.0 + XINMV
      XKRV = SLPEKV*(TSA + TRI)/2.0 + XINKV
      CPRV = (H2I-HSATV)/(TRI-TSA )
      PRRV = XMURV*CPRV/XKRV
C
C     DETERMINE SINGLE PHASE VAPOR HEAT TRANSFER COEF.
C     'HRV' (BTU/HR-SQ FT-F)
C
      CALL SPHTC(DER,GR,C1R,C2R,C3R,C4R,C5R,C6R,XLLR,ULR,
     1    XMURV,CPRV,PRRV,RERV, HRV)
C
C     USE SUBROUTINE EXCH TO DETERMINE CONDENSER HEAT
C     TRANSFER PERFORMANCE AND RETURN ALL RESULTS THROUGH
C     COMMON
C
      CALL EXCH(4,AOM,ALFAR,ALFAA,TSA,TAI,HFG)
      DZTP=FTP*ARHT/P
      DZV = F*ARHT/P
      DZL = FSC*ARHT/P
      XIC = 1.0
      E = 5.0E-06
C
C     USE SUBROUTINE PDROP TO DETERMINE PRESSURE DROP OF
C     REFRIGERANT THROUGH CONDENSER 'PD' (PSI)
C
      CALL PDROP(4,DER,E,GR,XMURV,XMUL,RHOV,RHOL,RERV, RERL,
     1    DZTP,X3,XIC,V2I,DZV,DZL,PD)
C
C     CONVERT BACK TO TOTAL FLOW AND OVERALL PERFORMANCE
C     AND PRINT RESULTS
C
      SBCOOL = TSA - TRO
      QC = QSP + QTP + QSC
      XMA = XMA*FLOAT(NSECT)
      XMR = XMR*FLOAT(NSECT)
      QC = QC*FLOAT(NSECT)
```

```
                CALL SATPFP(NR,TRO,PDUMMY,VF,VG,HRO,HFG,HG,SF,SG)
                WRITE(6,10100)
                WRITE(6,10200) HA,HRV,HTP,HRL
                WRITE(6,10300) QC
                WRITE(6,10400) HRO
                WRITE(6,10500) PD
C
C     SUBDIVIDE FLOW AGAIN TO PREPARE FOR NEXT LOOP
C
                XMA = XMA/FLOAT(NSECT)
                XMR = XMR/FLOAT(NSECT)
                IF (ICNT.NE.1) GO TO 40
C
C     CHECK DROP IN SATURATION TEMPERATURE DUE TO PRESSURE
C     DROP IN COIL - IF THE DROP IN SATURATION TEMPERATURE
C     IS GREATER THAN 2 DEGREES F - REPEAT ALL CALCULATIONS,
C     USING AN AVERAGE VALUE OF SATURATION TEMPERATURE
C
                POUT = PSAT + PD
                TSATO = TSAT(NR,POUT)
                IF ((TSA-TSATO).LE.2.0) GO TO 50
C**********
                IF (ABS(TSA-TSATO).GT.(0.2*TSA)) GO TO 20
                TSA = (TSA + TSATO)/2.0
                GO TO 30
   20           TSA = 0.9*TSA
                WRITE(6,10000)
   30           ICNT = 2.0
C**********
                WRITE(6,10600) TSA
                GO TO 10
   40           TSA = 2.0*TSA - TSATO
                ICNT = 1
   50           CONTINUE
      TROC=TRO
      RETURN
10000 FORMAT('0********** TSA FORCED TO .9 OF OLD VALUE')
10100 FORMAT(//5X,'OVERALL RESULTS FOR THIS TAI  :'//)
10200 FORMAT(10X,'HA     =',F7.2,10X,'HRV    =',F7.2,10X,'HTP    =',F7.2,
     1 10X,'HRL    =',F7.3)
10300 FORMAT(10X,'QC     =',F9.2)
10400 FORMAT(10X,'HRO = H3 = H4 =',F8.3)
10500 FORMAT(10X,'PD     =',F7.2)
10600 FORMAT(/5X,'PRESSURE DROP THRU CONDENSER IS GREAT ENOUGH'/
     1'TO DEPRESS SATURATION TEMP.  CALCULATION WILL BE REPEATED'/
     1'FOR TSA =',F8.2//)
10700   FORMAT('1',9X,'TAI    =',F8.2/10X,'QA     =',F9.1/10X,'TRI    =',
     >F8.2/10X,'TSA    =',F8.2)
      END
```

```
      SUBROUTINE EXCH(M,AOM,ALFAR,ALFAA,TH,TC,HFG)
C
C     PURPOSE
C        TO DETERMINE THE HEAT TRANSFER AND RESULTING
C        TEMPERATURES IN THE CONDENSER, GIVEN ALL OF THE
C        NECESSARY COEFFICIENTS AND OTHER DETAILS
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED          ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,         ***
C***           HEAT TRANSFER LABORATORY,                       ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.          ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUTS
C        HEAT EXCHANGER GEOMETRY
C          AOM    -  UNIT REFRIGERANT SIDE HEAT TRANSFER
C                    AREA/UNIT AIR FLOW RATE
C                    (SQ FT-HR/LBM DRY AIR)
C          ALFAR -  ALPHA REFRIGERANT (REFRIGERANT SIDE
C                    HEAT TRANSFER AREA/TOTAL VOLUME OF HEAT
C                    EXCHANGER-1/FT)
C          ALFAA -  ALPHA AIR (AIR SIDE HEAT TRANSFER AREA/
C                    TOTAL VOLUME OF HEAT EXCHANGER-1/FT)
C          ARHT   -  TOTAL REFG. SIDE HEAT TRANS. AREA (SQ FT)
C
C        HEAT TRANSFER COEFFICIENTS
C          HA     -  AIR SIDE HEAT TRANS.COEF.(BTU/HR-SQ FT-F)
C          HRTP   -  REF. SIDE TWO-PHASE HEAT TRANS.
C                    COEF. (BTU/HR-SQ FT-F)
C          HRSPV -  REF. SIDE SINGLE PHASE VAPOR HEAT
C                    TRANS. COEF. (BTU/HR-SQ FT-F)
C          HRSPL -  REF. SIDE SINGLE PHASE LIQUID HEAT
C                    TRANS. COEF. (BTU/HR-SQ FT-F)
C
C        REFRIGERANT PROPERTIES
C          TRI    -  TEMP. OF REFG. ENTERING CONDENSER (F)
C          TH     -  SATURATED CONDENSING TEMP. OF REFG. (F)
C          HFG    -  LATENT ENTHALPY OF VAPORIZATION
C                    THE REFRIGERANT (BTU/LBM)
C          CPRV   -  SPECIFIC HEAT AT CONSTANT PRESSURE
C                    OF THE REFRIGERANT VAPOR (BTU/LBM-R)
C          CPRL   -  SPECIFIC HEAT AT CONSTANT PRESSURE OF
C                    THE REFRIGERANT LIQUID (BTU/LBM-R)
C          X3     -  EXIT QUALITY FROM THE CONDENSER
C          XMR    -  MASS FLOW RATE OF REFRIGERANT (LBM/HR)
C
C        AIR PROPERTIES
C          CPA    -  SPECIFIC HEAT AT CONSTANT PRESSURE OF
C                    THE AIR (BTU/LBM-R)
C          TC     -  TEMP. OF AIR ENTERING CONDENSER (F)
C          XMA    -  MASS FLOW RATE OF AIR (LBM/HR)
C
C        OTHER INPUTS
C          M      -  AN INDICATOR (NOT USED HERE)
C          SEFFX -  SURFACE EFFICIENCY OF FINNED SURFACE
C
C      OUTPUTS
C          F      -  SINGLE PHASE VAPOR FRACTION OF TOTAL
C                    HEAT EXCHANGER SURFACE
```

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C           FTP    -   TWO-PHASE FRACTION OF TOTAL HEAT
C                      EXCHANGER SURFACE
C           FSC    -   SUBCOOLING FRACTION OF TOTAL HEAT
C                      EXCHANGER SURFACE
C           QSP    -   HEAT TRANSFER RATE IN SINGLE PHASE
C                      VAPOR REGION  (BTU/HR)
C           QTP    -   HEAT TRANSFER RATE IN TWO-PHASE
C                      REGICN (BTU/HR)
C           QSC    -   HEAT TRANSFER RATE IN SUBCOOLING
C                      REGICN (BTU/HR)
C           TAOSP  -   AIR TEMPERATURE OUT OF SINGLE PHASE
C                      VAPOR REQION  (F)
C           TAOTP  -   AIR TEMPERATURE OUT OF TWO-PHASE
C                      REGICN (F)
C           TAOSC  -   AIR TEMPERATURE OUT OF SUBCOOLING
C                      REGICN (F)
C           TAO    -   AVERAGE, MIXED AIR TEMPERATURE LEAVING
C                      THE CONDENSER (F)
C           TRO    -   TEMP.OF REFRIGERANT LEAVING HEAT EXCH. (F)
C
C      REMARKS
C         SUBROUTINE EXF IS CALLED BY THIS PROGRAM TO
C         DETERMINE THE EFFECTIVENESS IN CROSSFLOW
C         (THIS PROGRAM USES THE EFFECTIVENESS-NTU METHOD
C         FOR CALCULATING HEAT TRANSFER PERFORMANCE)
C
      COMMON CPA,HA,SEFFX,HRSPV,HRSPL,CPRL,CPRV,XMR,XMA,
     1X3,TRI,HRTP,F,FTP,FSC,QSP,QTP,QSC,TAOSP,TAOTP,TAOSC,
     1TAO,TRO,ARHT
C
C      DETERMINE NTU AND EFFECTIVENESS FOR TWO-PHASE REGION
C
      XNTUTP=AOM/(CPA*(ALFAR/(SEFFX*HA*ALFAA)+1.0/HRTP))
      ETP = 1.0 - EXP(-XNTUTP)
      RES = 1.0 + HRSPV*ALFAR/(HA*ALFAA*SEFFX)
C
C      FIND THE REFG.TEMP.'TRVDS' (F) AT THE END OF THE
C      DESUPERHEATING OR SINGLE PHASE VAPOR REGION
C
      TRVDS = (TH*RES - TC)/(RES-1.0)
      IF(TRVDS.GE.TRI) TRVDS = TRI
C
C      CALCULATE HFG DOUBLE PRIME 'HFGDP' - THE EFFECTIVE
C      DRIVING ENTHALPY CIFFERENCE IN THE TWO-PHASE REGION
C
      HFGDP = (HFG + CPRV*(TRVDS - TH))*(1.0-X3)
      XMATP = XMR*HFGDP/(ETP*CPA*(TH-TC))
      WRITE(6,570) XNTUTP
C**********
      PRINT 900, AOM,CPA,ALFAR,SEFFX,HA,ALFAA,HRTP
  900 FORMAT(' ',T8,'AOM',T21,'CPA',T34,'ALFAR',T47,'SEFFX',
     2 T60,'HA',T73,'ALFAA',T86,'HRTP'/' ',7F13.4)
      PRINT 902, ETP, RES, HRSPV
  902 FORMAT('0ETP   =',F13.4/'0RES    =',F13.4/' ',T8,'HRSPV'/
     2 ' ',F13.4)
      PRINT 904, TRVDS, TH, TC
  904 FORMAT('0TRVDS =',F13.4/' ',T8,'TH',T21,'TC'/' ',2F13.4)
      PRINT 906, HFGDP, HFG, CPRV, X3
  906 FORMAT('0HFGDP =',F13.4/' ',T8,'HFG',T21,'CPRV',T34,'X3'/
     2 ' ',3F13.4)
```

```
      PRINT 908, XMATP, XMR, CPA
  908 FORMAT('0XMATP =',F13.4/' ',T8,'XMR',T21,'CPA'/' ',2F13.4)
      PRINT 910, XMA, ARHT, CR
  910 FORMAT('0',T8,'XMA',T21,'ARHT',T34,'CR'/' ',3F13.4/
     2 '0',T5,'F',T14,'XMASP',T28,'CA',T41,'RTOT',T54,'CMIN',T64,'EXFR',
     3 T74,'EXFS',T84,'PR',T94,'PS',T104,'TEST',T114,'VAL'/)
      F = 0.0
      CA = 1.0
      CR = 1.0
      IF(ABS(TRVDS-TRI).LE.2.0) GO TO 60
      IF(X3.GT.0.0) GO TO 100
      PS = 0.0
      PR = PS
      N = 0
C
C     ITERATE TO FIND THE FRACTION OF TOTAL HEAT EXCHANGER
C     SURFACE USED FOR THE DESUPERHEATING OR SINGLE PHASE
C     VAPOR REGION
C*********************************
C
      DF = .005
      WRITE(6,510)
      DO 50 I=1,100
    5 F = F + DF
      XMASP = F*XMA
      CA = XMASP*CPA
      CR = XMR*CPRV
      RTOT = (ALFAR/(SEFFX*HA*ALFAA) + 1.0/HRSPV)/(F*ARHT)
      CALL EXP(RTOT,CA,CR,CMIN,EXFR)
      EXFS=CR*(TRI-TRVDS)/(CMIN*(TRI-TC))
      TEST = ABS(EXFR-EXFS)
      VAL = .03*EXFR
      WRITE(6,530) F,XMASP,CA,RTOT,CMIN,EXFR,EXFS,PR,PS,TEST,VAL
      IF(ABS(EXFR-EXFS).LE.(.03*EXFR)) GO TO 60
      IF(I.EQ.1) GO TO 20
      IF((PR-PS)/(EXFR-EXFS)) 60,15,15
   15 IF((ABS(PR-PS).LT.ABS(EXFR-EXFS)).AND.(I.EQ.2))GO TO 12
      IF(ABS(PR-PS).LT.ABS(EXFR-EXFS)) GO TO 55
      GO TO 20
   12 F = F - 2.0*DF
C***********
      PRINT 920
  920 FORMAT(' GOT TO 12')
      DF = DF/2.0
      I = 1
      N = N + 1
      IF(N.GT.10) GO TO 55
      GO TO 5
   20 PR = EXFR
      PS = EXFS
   50 CONTINUE
   55 WRITE(6,500) M
      GO TO 250
   60 QSC = 0.0
      WRITE(6,511) F
      CASC = 1.0
      TAOSC = 5000.0
      TRO = 5000.0
C
C     CALCULATE THE TWO-PHASE AND SUBCOOLING FRACTIONS
```

```
C      OF TOTAL HEAT EXCHANGER SURFACE
C
C      IF THE SUBCOOLING FRACTION IS LESS THAN ZERO - PRINT
C      AN ERROR MESSAGE BECAUSE CONDENSATION IS INCOMPLETE
C
  100  FTP = XMATP/XMA
       FSC = 1.0-F-FTP
       WRITE(6,590) FTP,FSC
       IF(FSC) 105,120,110
   105 WRITE(6,595)
       GO TO 250
  110  IF(X3.GT.0.0) GO TO 120
       CRSC = XMR*CPRL
       CASC = FSC*XMA*CPA
       RTOT = (ALFAR/(SEFFX*HA*ALFAA) + 1.0/HRSPL)/(FSC*ARHT)
       CALL EXF(RTOT,CASC,CRSC,CMIN,EXFR)
C
C      CALCULATE HEAT TRANSFER RATES AND TEMPERATURES
C
       TRO = TH - EXFR*CMIN*(TH-TC)/CRSC
       SBCOOL = TH - TRO
       QSC = CRSC*(TH-TRO)
  120  QSP = CR*(TRI-TRVDS)
       QTP = XMR*HFGDP
       TAOSP = QSP/CA + TC
       TAOTP = QTP/(XMATP*CPA) + TC
       TAOSC = QSC/CASC + TC
       TAO = (QSC + QSP + QTP)/(XMA*CPA) + TC
       WRITE(6,512)
       WRITE(6,513) F,FTP,FSC
       WRITE(6,514) QSP,QTP,QSC
       WRITE(6,515) TAOSP,TAOTP,TAOSC
       WRITE(6,516) TC,TAO
       WRITE(6,517) TRI,TH,TRO,SBCOOL
       RETURN
  250  FSC = 0.0
       QSC = 0.0
       TRO = TH
       RETURN
  500  FORMAT('0',10X,'ITERATION ON VAPOR FRACTION OF H.E.'
      1, ,' DOES NOT CONVERGE  M='I2)
  510  FORMAT(1H0,4X,'START OF ITERATION ON DESUPERHEATING REGION')
  511  FORMAT(5X,'END OF ITERATION.  RESULT IS :'/10X,'F      =',F7.3)
  512  FORMAT(1H0,4X,'RESULTS FROM EXCH :')
  513  FORMAT(//10X,'F      =',F7.3,10X,'FTP    =',F7.3,10X,'FSC    =',F7.3)
  514  FORMAT(10X,'QSP    =',F10.4,7X,'QTP    =',F10.4,7X,'QSC    =',F10.4)
  515  FORMAT(10X,'TAOSP =',F8.2,9X,'TAOTP =',F8.2,9X,'TAOSC =',F8.2)
  516  FORMAT(1H0,9X,'TAI    =',F8.2/10X,'TAO    =',F8.2)
  517  FORMAT(10X,'TRI    =',F8.2/10X,'TSA    =',F8.2/10X,'TRO    =',F8.2/
      110X,'SBCOOL=',F8.2)
   530 FORMAT(' ',F6.3, 4F13.4, 6F10.4)
  570  FORMAT(///5X,'BEGINNING OF CALCULATION IN SUBROUTINE EXCH :'//
      110X,'XNTUTP=',F8.3)
  590  FORMAT(10X,'FTP    =',F7.3/10X,'FSC    =',F7.3)
  595  FORMAT('0','******INCOMPLETE CONDENSATION******')
       END
```

```
      SUBROUTINE  CHTC(DE,G,XE,PRL,XKL,XMUV,XMUL,RHOL,
     1RHOV,HAVG)
C     PURPOSE
C        TO DETERMINE THE FORCED CONVECTION CONDENSATION
C        TWO-PHASE HEAT TRANS. COEF. FOR FLOW IN TUBES
C        (BASED ON CORRELATIONS BY TRAVIS)
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED          ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,         ***
C***           HEAT TRANSFER LABORATORY,                       ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.          ***
C     DESCRIPTIONS OF PARAMETERS
C      INPUT
C        DE   -  EQUIVALENT DIAMETER OF FLOW PASSAGE (FT)
C        G    -  MASS FLOW PER UNIT AREA (LBM/HR-SQ FT)
C        XE   -  EXIT QUALITY
C        PRL  -  PRANDTL NUMBER OF THE LIQUID PHASE
C        XKL  -  THERMAL COND. OF LIQ. PHASE(BTU/HR-FT-F)
C        XMUV -  VISCOSITY OF VAPOR PHASE (LBM/HR-FT)
C        XMUL -  VISCOSITY OF LIQ. PHASE (LBM/HR-FT)
C        RHOL -  DENSITY OF LIQ. PHASE (LBM/CU FT)
C        RHOV -  DENSITY OF VAPOR PHASE (LBM/CU FT)
C      OUTPUT
C        HAVG -  AVERAGE CONDENSATION TWO-PHASE
C        HEAT TRANSFER COEF. (BTU/HR-SQ FT-F)
C     INITIAL CONDITIONS
      HP = 5000.0
      HIINT = 0.0
C     INTEGRATE FROM QUALITY EQUALS 1 TO QUALITY EQUALS XE
      X = 1.0
      DX = .05
      DO 10 I=1,20
      X = X-DX
      IF(X.LE.XE) GO TO 15
      XTT = (XMUL/XMUV)**.1*(RHOV/RHOL)**.5*((1.0-X)/X)**.9
      FXTT = .15*(1.0/XTT + 2.85*XTT**(-.476))
      REL = G*DE*(1.0-X)/XMUL
      IF(REL.LT.50.0) F2 = .707*PRL*REL**.5
      IF((REL.GE.50.0).AND.(REL.LE.1125.0)) F2=5.0*PRL + 5.
     10*ALOG(1.0+PRL*(.09636*REL**.585-1.0))
      IF(REL.GT.1125.0) F2 = 5.0*PRL + 5.0*ALOG(1.0 + 5.0*
     1PRL)+2.5*ALOG(.00313*REL**.812)
      IF(FXTT.LE..1) GO TO 9
C     EVALUATION OF LOCAL HEAT TRANS. COEF.
      IF(FXTT.LT.1.0) HLOC=XKL*PRL*REL**.9*FXTT/(DE*F2)
      IF((FXTT.GE.1.0).AND.(FXTT.LT.15.0))HLOC=XKL*PRL*REL
     1**.9*FXTT**1.15/(DE*F2)
      IF(FXTT.GE.15.0) GO TO 9
      HINVM = (1.0/HLOC + 1.0/HP)/2.0
      HP = HLOC
      HIINT =-DX*HINVM + HIINT
      GO TO 10
    9 IF(I.GT.19) GO TO 10
      WRITE(6,500) FXTT
   10 CONTINUE
C     INTEGRATED AVERAGE HEAT TRANS. COEF.
   15 HAVG = (XE-1.0)/HIINT
      RETURN
  500 FORMAT('0',10X,'FXTT LIMIT EXCEEDED FXTT=',F10.2)
      END
```

```
      SUBROUTINE EVAPR
C     EVAPORATOR  SIMULATION SUBROUTINE
C
C    PURPOSE
C       TO COMPUTE EVAPCRATOR PERFORMANCE, INCLUDING
C       MOISTURE REMOVAL, FOR AIR IN CROSS FLOW, PLATE-FIN TYPE
C
C***          ADAPTED FROM INDEPENDENT CALLING PROGRAM      ***
C***          WRITTEN BY C. C. HILLER AND L. R. GLICKSMAN,  ***
C***          REPORT NO. 24525-96,                          ***
C***          HEAT TRANSFER LABORATORY,                     ***
C***          MASSACHUSETTS INSTITUTE OF TECHNOLOGY.        ***
C
C    OUTPUT
C       QTOT -  TOTAL HEAT TRANSFER RATE (BTU/HR)
C       QLAT -  LATENT HEAT REMOVAL RATE (BTU/HR)
C       TDB3 -  AIR DRY BULB TEMP. (F) LEAVING EVAP.
C       TWB3 -  AIR WET BULB TEMP. (F) LEAVING EVAP.
C       TRO  -  TEMP.OF REFRIGERANT VAPOR LEAVING EVAP.(F)
C
C    REMARKS
C       THIS PROGRAM CAILS SUBROUTINE SPHTC TO DETERMINE
C       SINGLE PHASE HEAT TRANSFER COEFFICIENTS
C       THIS PROGRAM CAILS SUBROUTINE SEFF TO DETERMINE
C       SURFACE EFFICIENCY OF FINNED SURFACE
C       THIS PROGRAM CAILS SUBROUTINE SATPRP TO DETERMINE
C       SATURATION THERMODYNAMIC PROPERTIES
C       THIS PROGRAM CAILS SUBROUTINE EHTC TO DETERMINE
C       THE EVAPCRATION TWO-PHASE HEAT TRANSFER COEFFICIENT
C       FOR FORCED CONVECTION EVAPORATION INSIDE TUBES
C       THIS PROGRAM CAILS SUBROUTINE VAPOR TO DETERMINE
C       THERMODYNAMIC PROPERTIES OF SUPERHEATED REFRIGERANT
C       VAPOR
C       THIS PROGRAM CAILS SUBROUTINE PDROP TO DETERMINE
C       PRESSURE DROP OF REFRIGERANT FLOWING IN THE COIL
C       THIS PROGRAM CAILS FUNCTION SUBPROGRAM TSAT TO
C       DETERMINE SATURATION TEMPERATURES CORRESPONDING
C       TO GIVEN PRESSURES
C       THIS PROGRAM CAILS SUBROUTINE EVAP TO DETERMINE
C       THE OVERALL HEAT EXCHANGER PERFORMANCE, HEAT TRANSFER
C       RATES, AIR TEMPERATURES, ETC.
C    ALL TEMPERATURES ARE IN DEGREES F
C    ALL HEAT TRANSFER RATES ARE IN BTU/HR
C    ALL MASS FLOW RATES ARE IN LBM/HR
C
     COMMON/CPASS/XMRIE,TSAE,H4E,HRO,TROC
C
     COMMON/EVAPOR/ NRUNE,DEAE,DERE,DELTAE,FPE,XKFE,AAFE,NTE, NSECTE,
    1 HCONTE,STE,WTE,SIGAE,ATBOE,PE,PTBOE,ARFTE,ARHTE,ALFARE,ALFAAE,
    1 XLFE,FARE,CARE,DXMRIE,NXMRE,QAE,TAIIE, DTAE, NTEMPE,INDICE,
    1 TWBIIE,DTWBIE,NTWBE,RHIE,TROE
C
     COMMON CPA,HA,SEFFX,HRV,CPRV,XMR,XMA,X4,HTP,F,FTP,QSP, QTP,TAOSP,
    1 TAOTP,TRO,ARHT,XMH20,TWBI,RHI,INDIC,PA,J
C
C    ----------------- INPUT DATA CONSTANTS --------------
C
C AIR PROPERTIES
C     PRA   -  PRANDTL NUMBER OF AIR
C     XMUA  -  VISCOSITY OF AIR (LBM/HR-FT)
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C      RAU    -  UNIVERSAL GAS CONSTANT FOR AIR (FT-LBF/LBM-R)
C      PA     -  ATMOSPHERIC PRESSURE (PSIA)
C      CPA    -  SPECIFIC HEAT AT CONST.PRES.OF AIR (BTU/LBM-R)
       DATA PRA,XMUA,RAU/.714,.043,53.34/
       PA = 14.7
       CPA = .24
C
C REFRIGERANT PROPERTY VARIATION COEFFICIENTS
C      NR     -  NUMBER OF REFRIGERANT (12,22, OR 502)
C      NREF   -  NUMBER OF REFRIGERANT (USUALLY SAME AS NR)
C      SLPEMV & XINMV  -  COEFFICIENTS FOR VISCOSITY OF VAPOR
C      SLPEKV & XINKV  -  COEFFICIENTS FOR THERMAL
C                         CONDUCTIVITY OF VAPOR
C      SLPEKL & XINKL  -  COEFFICIENTS FOR THERMAL
C                         CONDUCTIVITY OF LIQUID
C      SLPCPV & XINCPV -  COEFFICIENTS FOR SPECIFIC HEAT
C                         AT CONST.PRES. OF VAPOR
C      XM1 - XM4       -  COEFFICIENTS FOR VISCOSITY OF LIQ.
C      CP1 & CP2       -  COEFFICIENTS FOR SPECIFIC HEAT
C                         AT CONST. PRES. OF LIQUID
C      VISCOSITIES IN LBM/(HR-FT)
C      THERMAL CONDUCTIVITIES IN BTU/(HR-FT-F)
C      SPECIFIC HEATS IN BTU/(LBM-R)
       NR = 22
       DATA NREF,SLPEMV,XINMV,SLPEKV,XINKV,SLPEKL,XINKL /22,.0000759,
      1 .0272,.00002,.00482,-.000159,.06299/
       DATA SLPCPV,XINCPV/.000433,.1394/
       DATA XM1,XM2,XM3,XM4/-5.625E-08,1.525E-05,-2.982E-03, .646/
       DATA CP1,CP2/ 2.981-04,.2575/
C*****NOTE - THE ABOVE REFRIGERANT COEFFICIENTS ARE FOR
C      REFRIGERANT 22 ONLY
C
C AIR SIDE FLOW CHARACTERISTICS (SAME FOR BOTH EVAP.&COND.
C IF THEY ARE OF THE SAME TYPE)
C      C1A-C6A         -  COEFFICIENTS FOR EXPRESSING THE
C                         AIR SIDE HEAT TRANSFER COEFFICIENT
C      XLLA   -  LOWER REYNOLDS NUMBER LIMIT FOR LAMINAR
C                FLOW ON AIR SIDE
C      ULA    -  UPPER REYNOLDS NUMBER LIMIT FOR TURBULENT
C                FLOW ON AIR SIDE
       DATA C1A,C2A,C3A,C4A,C5A,C6A,XLLA,ULA /.2243,-.385,.2243,-.385,
      1 .2243,-.385,1000.0,2000.0/
C
C REFRIGERANT SIDE FLOW CHARACTERISTICS (SAME FOR BOTH
C EVAP.& COND. IF THEY ARE OF SAME TYPE)
C      C1R-C6R         -  COEFFICIENTS FOR EXPRESSING THE
C                         REFRIGERANT SIDE SINGLE PHASE HEAT
C                         TRANSFER COEFFICIENTS
C      XLLR   -  LOWER REYNOLDS NUMBER LIMIT FOR LAMINAR
C                FLOW ON REFRIGERANT SIDE (SINGLE PHASE)
C      ULR    -  UPPER REYNOLDS NUMBER LIMIT FOR TURBULENT
C                FLOW ON REFRIGERANT SIDE (SINGLE PHASE)
       DATA C1R,C2R,C3R,C4R,C5R,C6R,XLLR,ULR /1.164,-.7824,.000054,
      1 .49985,.00667,-.0897,2400.,3500./
C
C      -----------END OF  INPUT DATA CONSTANTS -------------
C
C      OUTER LOOP FOR MULTIPLE RUNS WHILE VARYING HEAT
C      EXCHANGER CHARACTERISTICS
C
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```
      J=6
      NREF=NREF+0
         DEA=DEAE
         DER=DERE
         DELTA=DELTAE
         FP=FPE
         XKF=XKFE
         AAF=AAFE
         NT=NTE
         NSECT=NSECTE
         HCONT=HCONTE
         ST=STE
         WT=WTE
         SIGA =SIGAE
         P =PE
         PTBO =PTBOE
         ARFT =ARFTE
         ARHT =ARHTE
         ALFAR =ALFARE
         ALFAA=ALFAAE
         XLF =XLFE
         FAR=FARE
         CAR=CARE
         XMRI=XMRIE
         DXMRI=DXMRIE
         NXMR=NXMRE
         TSA=TSAE
         H4=H4E
         QA=QAE
         TAII=TAIIE
         DTA=DTAE
         NTEMP=NTEMPE
         INDIC=INDICE
         TWBII=TWBIIE
         DTWBI=DTWBIE
         NTWB=NTWBE
         RHI=RHIE
C
C
      TAI = TAII
      TWBI = TWBII
C
            WRITE (6,10600)
C
               WRITE(6,10700)  TAI,TWBI,RHI,QA,TSA
C
C
               VA = QA*60.0/(SIGA*AAF)
               GA = VA*PA*144.0/(RAU*(TAI + 460.0))
               AOM = FLOAT(NT)*P/(ST*GA*SIGA)
C
C     SUBDIVIDE FLOW INTC PARALLEL CIRCUITS AND TREAT EACH
C     LIKE A SEPARATE HEAT EXCHANGER - CONVERT BACK TO TOTAL
C     FLOW AT THE END
C
               XMA=60.0*CA*PA*144.0/(RAU*FLOAT(NSECT)*(TAI+460.0))
C
C     DETERMINE AIR SIDE HEAT TRANS.COEF.'HA'(BTU/HR-SQ FT-F)
C
               CALL SPHTC(DEA,GA,C1A,C2A,C3A,C4A,C5A,C6A,XLLA,ULA, XMUA,
```

```
     1            CPA,PRA,REA,HA)
C
C     DETERMINE OVERALL SURFACE EFFICIENTCY 'SEFFX'
C
                CALL SEFF(XKF,DELTA,HA,XLF,FAR,CAR,HCONT,SEFFX)
                ICNT = 1
C
C
C
                XMR = XMRI/FLOAT(NSECT)
C
C     DETERMINE SATURATICN PROPERTIES OF REFRIGERANT
C
   10             CALL SATPRP(NR,TSA,PSAT,VF,VG,HSATL,HFG,HSATV,SF,SG)
                  RHOV = 1.0/VG
                  RHOL = 1.0/VF
                  CPRL = CP1*PSAT + CP2
                  XMUL = XM1*TSA**3 + XM2*TSA**2 + XM3*TSA + XM4
                  XKRL = SLPEKL*TSA + XINKL
                  XKRV = SLPEKV*TSA + XINKV
                  XMURV = SLPEMV*TSA + XINMV
                  PRRL = XMUL*CPRL/XKRL
                  CPRV = SLPCPV*PSAT + XINCPV
                  PRRV = XMURV*CPRV/XKRV
                  GR = XMR/ARFT
C
C     DETERMINE SINGLE PHASE VAPOR HEAT TRANSFER COEF.
C     'HRV' (BTU/HR-SQ FT-F)
C
                  CALL SPHTC(DER,GR,C1R,C2R,C3R,C4R,C5R,C6R,XLLR,ULR,
     1             XMURV,CPRV,PRRV,RERV,HRV)
                  X4 = (H4 - HSATL)/HFG
                  IF (X4.LT.0.0) WRITE(J,10800) X4
C
C     DETERMINE EVAPORATION TWO-PHASE HEAT TRANS. COEF.'HTP'
C     (BTU/HR-SQ FT-F)
C
                  CALL EHTC(DER,GR,X4,1.0,PRRL,XKRL,XMURV,XMUL,RHOL,
     1             RHOV,HTP)
C     USE SUBROUTINE EVAP TO DETERMINE EVAPORATOR HEAT
C     TRANSFER PERFORMANCE AND RETURN ALL RESULTS THROUGH COMMON
                  CALL EVAP(AOM,ALFAR,ALFAA,TSA,TAI,HFG)
C
C     RETURN TO TOTAL FLCW RATE REPRESENTATION
C
                  TROE = TRO
                  SUPER = TRO - TSA
                  QTOT=FLOAT(NSECT)*(QSP+QTP)
                  QLAT = FLOAT(NSECT)*XMH20*1057.0
                  XMA=XMA*FLOAT(NSECT)
                  XMR=XMR*FLOAT(NSECT)
                  DZTP = FTP*ARHT/P
                  DZV = F*ARHT/P
                  DZL = 0.0
                  E = 5.0E-06
C
C     USE SUBROUTINE PDRCP TO DETERMINE PRESSURE DROP OF
C     REFRIGERANT THROUGH EVAPORATOR 'PD' (PSI)
C
                  CALL PDROP(3,DER,E,GR,XMURV,XMUL,RHOV,RHOL,RERV, RERL,
```

```
     1                 DZTP,1.0,X4,VG,DZV,DZL,PD)
C
C      PRINT OVERALL RESULTS
C
                       WRITE(6,10000)
                       WRITE(6,10100)  XMA,XMR
                       WRITE(6,10200)  GA,GR
                       WRITE(6,10300)  HA,HRV,HTP
                       WRITE(6,10400)  QTOT,QLAT
                       WRITE(6,10500)  PD
C
C      SUBDIVIDE FLOW AGAIN TO PREPARE FOR NEXT LOOP
C
                       XMA = XMA/FLOAT(NSECT)
                       XMR=XMR/FLOAT(NSECT)
                       IF (ICNT.NE.1) GO TO 20
C
C      CHECK DROP IN SATURATION TEMPERATURE DUE TO PRESSURE
C      DROP IN COIL - IF THE DROP IN SATURATION TEMPERATURE
C      IS GREATER THAN 2 DEGREES F - REPEAT ALL CALCULATIONS,
C      USING AN AVERAGE VALUE OF SATURATION TEMPERATURE
C
                       POUT=PSAT+PD
                       TSATO = TSAT(NR,POUT)
                       IF (ABS(TSA-TSATO).LE.2.0) GO TO 30
                       TSA = (TSA + TSATO)/2.0
                       ICNT = 2
                       WRITE(6,10900) TSA
                       GO TO 10
    20                 TSA = 2.0*TSA - TSATO
                       ICNT = 1
    30                 CONTINUE
       RETURN
 10000 FORMAT(5X,'EVAPORATOR PERFORMANCE FOR THIS AIR INLET TEMP:'//)
 10100 FORMAT(10X,'XMA    =',F9.1,8X,'XMR    =',F8.2)
 10200 FORMAT(10X,'GA     =',F9.1,8X,'GR     =',F10.1)
 10300 FORMAT(10X,'HA     =',F8.2,9X,'HRV    =',F8.2,9X,'HTP    =',F8.2)
 10400 FORMAT(10X,'QTOT   =',F10.1,7X,'QLAT   =',F10.1)
 10500 FORMAT(10X,'PD     =',F7.2)
 10600 FORMAT(1H1)
 10700 FORMAT(10X,'TAI    =',F8.2/10X,'TWBI   =',F8.2/10X,'RHI    =', F7.3/
     1 10X,'QA     =',F9.2/10X,'TSA    =',F8.2)
 10800 FORMAT(' *******X4 IS NEGATIVE - X4=',F10.5,'*******')
 10900 FORMAT(1H0,4X,'PRESSURE DROP THRU EVAPORATOR IS LARGE ENOUGH'/
     15X,'TO DEPRESS SATURATION TEMP.  CALCULATION WILL BE REPEATED'/
     15X,'FOR TSA =',F8.2//)
       END
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      SUBROUTINE EVAP(AOM,ALFAR,ALFAA,TSA,TAI,HFG)
C
C     PURPCSE
C        TO DETERMINE HEAT TRANSFER, MOISTURE REMOVAL,
C        AND RESULTING TEMPERATURES AND HUMIDITIES
C        IN THE EVAPORATOR, GIVEN ALL OF THE NECESSARY
C        COEFFICIENTS ANE OTHER DETAILS
C
C***  AUTHORS  C. C. HIILER AND L. R. GLICKSMAN              ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED         ***
C***           FRCM THAT GIVEN IN REPORT NO. 24525-96,        ***
C***           HEAT TRANSFER LABORATORY,                      ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.         ***
C
C     DESCRIPTICN OF PARAMETERS
C      INPUTS
C        HEAT EXCHANGER GEOMETRY
C          ALFAR -  ALPHA REFRIGERANT (REFRIGERANT SIDE
C                   HEAT TRANSFER AREA/TOTAL VOLUME OF HEAT
C                   EXCHANGER - 1/FT)
C          ALFAA -  ALPHA AIR (AIR SIDE HEAT TRANSFER AREA/
C                   TOTAL VOLUME OF HEAT EXCHANGER -1/FT)
C          ARHT  -  TOTAL REFG. SIDE HEAT TRANS. AREA (SQ FT)
C          AOM   -  UNIT REFRIGERANT SIDE HEAT TRANSFER
C                   AREA/UNIT AIR FLOW RATE
C                   (SQ FT-HR/LBM DRY AIR)
C        HEAT TRANSFER CCEFFICIENTS
C          HA    -  AIR SIDE HEAT TRANS.COEFF.(BTU/HR-SQ FT-F)
C          HTP   -  REF. SIDE TWO-PHASE HEAT TRANS.
C                   COEF. (BTU/HR-SQ FT-F)
C          HRV   -  REF. SIDE SINGLE PHASE VAPOR HEAT
C                   TRANS.COEF. (BTU/HR-SQ FT-F)
C
C        REFRIGERANT PROPERTIES
C          TSA   -  REFRIGERANT SATURATION TEMP. (F)
C          HFG   -  LATENT ENTHALPY OF VAPORIZATION OF
C                   THE REFRIGERANT (BTU/LBM)
C          X4    -  ENTERING QUALITY OF THE REFRIGERANT
C          XMR   -  MASS FLOW RATE OF REFRIGERANT (LBM/HR)
C          CPRV  -  SPECIFIC HEAT AT CONSTANT PRESSURE
C                   OF THE REFRIGERANT VAPOR (BTU/LBM-R)
C        AIR PROPERTIES
C          CPA   -  SPECIFIC HEAT AT CONSTANT PRESSURE OF
C                   THE AIR (BTU/LBM-R)
C          XMA   -  MASS FLOW RATE OF AIR (LBM/HR)
C          TAI   -  DRY BULB TEMP.OF AIR ENTERING EVAP. (F)
C          TWBI  -  WET BULB TEMP.OF AIR ENTERING EVAP. (F)
C          RHI   -  RELATIVE HUMIDITY OF AIR ENTERING EVAP.
C          INDIC -  INPUT INDICATOR
C          IF 'INDIC' EQUALS 1, INPUTS ARE TAI, AND TWBI
C          IF 1INDIC' EQUALS 2, INPUTS ARE TAI, AND RHI
C          PA    -  ATMOSPHERIC PRESSURE (PSIA)
C        OTHER INPUTS
C          SEFFX -  SURFACE EFFICIENCY OF FINNED SURFACE
C        OUTPUTS
C          F     -  SINGLE PHASE VAPOR FRACTION OF TOTAL
C                   HEAT EXCHANGER SURFACE
C          FTP   -  TWO-PHASE FRACTION OF TOTAL HEAT
C                   EXCHANGER SURFACE
C          QSP   -  HEAT TRANSFER RATE IN SINGLE PHASE
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C                   VAPOR REGION (BTU/HR)
C          QTP    -  HEAT TRANSFER RATE IN TWO-PHASE
C                   REGION (BTU/HR)
C          TRO    -  TEMP.OF REFRIGERANT LEAVING EVAP. (F)
C          XMH20 -  RATE OF MOISTURE REMOVAL FROM AIR (LBM/HR)
C          TAOSP -  EXIT AIR TEMP.FROM SINGLE PHASE REGION (F)
C          TAOTP -  EXIT AIR DRY BULB TEMP. ASSUMING
C                   NO MOISTURE REMOVAL OCCURS (F)
C          TWB3   -  WET BULB TEMP. LEAVING EVAP. IF MOISTURE
C                   REMOVAL OCCURS (F)
C          TDB3   -  EXIT AIR DRY BULB TEMP.LEAVING EVAP.,
C                   ASSUMING MOISTURE REMOVAL OCCURS (F)
C      REMARKS
C         THIS PROGRAM CALLS SUBROUTINE XMOIST TO DETERMINE
C         THE HUMIDITY , AND DEHUMIDIFICATION BEHAVIOR
C         OF THE EVAPORATOR
C         THIS PROGRAM CALLS SUBROUTINE EXP TO DETERMINE
C         THE EFFECTIVENESS IN CROSS FLOW
C         (THIS PROGRAM USES THE EFFECTIVENESS-NTU METHOD
C         OF CALCULATING HEAT TRANSFER PERFORMANCE IF NO
C         MOISTURE REMOVAL OCCURS, AND IN THE SINGLE PHASE
C         VAPOR REGION.
C
      COMMON CPA,HA,SEFFX,HRV,CPRV,XMR,XMA,X4,HTP,F,FTP,QSP,
     1QTP,TAOSP,TAOTP,TRO,ARHT,XMH20,TWBI,RHI,INDIC,PA,J
C
C     DETERMINE THE REPRESENTATIVE COIL CHARACTERISTIC 'COIL'
C
      COIL=HA*(ALFAA/(HTP*ALFAR)+1.0/(SEFFX*HA)-1.0/HA)/CPA
      QTP = XMR*(1.0 - X4)*HFG
      WRITE(6,714)
C
C     DETERMINE BULK AIR DRY BULB TEMP.'TADHI' WHEN
C     DEHUMIDIFICATION OF MOISTURE REMOVAL BEGINS
C
      CALL XMOIST(TAI,TWBI,RHI,INDIC,PA,HAIRI,WSATI,WAIRI,
     1TWALLI)
      TADHI=(HA*TWALLI*(1.0/(SEFFX*HA)+ALFAA/(HTP*ALFAR))
     1-TSA)/(HA*(1.0/(SEFFX*HA)+ALFAA/(HTP*ALFAR))-1.0)
C
C     DETERMINE NTU AND EFFECTIVENESS FOR SENSIBLE HEAT
C     TRANSFER IN THE TWO-PHASE REGION, ASSUMING NO MOISTURE
C     REMOVAL OCCURS
C
      XNTUTP=AOM/(CPA*(ALFAR/(SEFFX*HA*ALFAA)+1.0/HTP))
      ETP=1.0-EXP(-XNTUTP)
      XMATP=QTP/(ETP*CPA*(TAI-TSA ))
      FTP=XMATP/XMA
      IF(FTP.GT.1.0) WRITE(J,710) FTP
C
C     DETERMINE THE EXIT AIR TEMP.'TAOTP' FROM THE TWO-PHASE
C     REGION, ASSUMING NO MOISTURE REMOVAL OCCURS
C
      TAOTP=TAI-QTP/(XMATP*CPA)
      WRITE(J,705) TADHI,TAOTP
C
C     CHECK TO SEE IF MOISTURE REMOVAL ACTUALLY OCCURS
C     IF MOISTURE REMOVAL DOES NOT OCCUR, I.E. TADHI IS LESS
C     THAN TAOTP, THEN SKIP THE MOISTURE REMOVAL SECTION
C
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      IF (TADHI.LT.TAOTP) WRITE(6,706)
      IF(TADHI.LT.TAOTP) TDB3=TAOTP
      IF(TADHI.LT.TAOTP) GO TO 140
      IF (TADHI.GT.TAOTP) WRITE(6,641)
C
C ---------------MOISTURE REMOVAL SECTION---------------
C
C     NOTE: IT IS ASSUMED THAT MOISTURE REMOVAL ONLY OCCURS
C     IN THE TWO-PHASE REGION OF THE COIL
C
C     IF TADHI IS GREATER THAN THE INITIAL DRY BULB
C     TEMPERATURE 'TAI', THEN MOISTURE REMOVAL BEGINS AT THE
C     LEADING EDGE OF THE COIL - HENCE SKIP TO STEP 36
C
      IF(TADHI.GT.TAI) GO TO 36
C
C     DETERMINE THE FRACTION 'FSENS' OF THE LEADING EDGE OF
C     THE COIL SURFACE WHICH IS USED ONLY FOR SENSIBLE
C     HEAT TRANSFER
C
      FSENS=XMA*CPA*(1.0/(SEFFX*HA)+ALFAA/(HTP*ALFAR))*
     1ALOG((TAI-TSA)/(TADHI-TSA))/(ARHT*ALFAA/ALFAR)
      IF((FSENS.GT.1.0).OR.(FSENS.LT.0.0))WRITE(J,720) FSENS
      GO TO 37
C
C     ITERATE TO FIND THE CORRECT WALL TEMP.'TWALLI' AT WHICH
C     MOISTURE REMOVAL BEGINS ON LEADING EDGE OF COIL
C
   36 T = TSA
      DT = 1.0
      WRITE(6,713)
      DO 30 L = 1,30
      T = T + DT
      CALL XMOIST(T,T,RH,1,PA,HWALLI,WWALLI,WAIR,TWALLI)
      TS = TSA  + (HAIRI - HWALLI)*COIL
      IF(ABS(T-TS).LE..1) GO TO 35
      IF(T-TS) 30,35,25
   25 T = T-DT
      DT = DT/2.0
   30 CONTINUE
      WRITE(6,717)
   35 TWALLI = T
      FSENS = 0.0
      TADHI = TAI
   37 HAIR1 = HAIRI - CPA*(TAI-TADHI)
      FMOIST = 1.0 -FSENS
      WRITE(6,711) TWALLI
C
C     SPLIT MOISTURE REMOVAL REGION INTO 2 PARTS
C
C
C     ITERATE TO DETERMINE EXIT AIR ENTHALPY 'HAIR2', AND
C     WALL TEMP.'TWALL2' AT THE END OF THE FIRST MOISTURE
C     REMOVAL REGION
C
      T = TSA
      DT = 1.0
      WRITE(6,707)
      DO 50 L = 1,30
      T = T + DT
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```
      CALL XMOIST(T,T,RH,1,PA,HWALL2,WWALL2,WAIR2,TWALL2)
      HAIR2 = HWALL2 + (T-TSA )/COIL
      HAIR2S= HAIR1-FMOIST/2.0*ARHT*ALFAA/ALFAR*HA*(TWALLI
     1-TWALL2)/(COIL*XMA*ALOG((TWALLI-TSA)/(TWALL2-TSA))*CPA)
      IF(ABS(HAIR2-HAIR2S).LE..05) GO TO 60
      IF(HAIR2-HAIR2S) 50,60,45
   45 T = T - DT
      DT = DT/2.0
   50 CONTINUE
      WRITE(J,740)
   60 TWALL2 = T
      WRITE(6,708) HAIR2,TWALL2
C
C     ITERATE TO DETERMINE EXIT AIR ENTHALPY 'HAIR3', AND
C     WALL TEMP.'TWALL3' AT THE END OF THE SECOND MOISTURE
C     REMOVAL REGION
C
      T = TSA
      DT = 1.0
      WRITE(6,709)
      DO 90 L = 1,30
      T = T + DT
      CALL XMOIST(T,T,RH,1,PA,HWALL3,WWALL3,WAIR3,TWALL3)
      HAIR3 = HWALL3 + (T - TSA )/COIL
      HAIR3S=HAIR2-FMOIST/2.0*ARHT*ALFAA/ALFAR*HA*(TWALL2
     1-TWALL3)/(COIL*XMA*ALOG((TWALL2-TSA)/(TWALL3-TSA))    *CPA)
      IF(ABS(HAIR3-HAIR3S).LE..05) GO TO 100
      IF(HAIR3 - HAIR3S) 90,100,80
   80 T = T - DT
      DT = DT/2.0
   90 CONTINUE
      WRITE(J,760)
  100 TWALL3 = T
      WRITE(6,700) HAIR3,TWALL3
C
C     ITERATE TO DETERMINE THE WET BULB TEMP.'TWB3' LEAVING
C     THE EVAPORATOR
C
      T = TSA
      DT = 1.0
      WRITE(6,701)
      DO 105 L = 1,30
      T = T + DT
      CALL XMOIST(T,T,RH,1,PA,HAIR3S,WSAT3,WAIR,TWALL)
      IF(ABS(HAIR3S-HAIR3).LE..05) GO TO 106
      IF(HAIR3S-HAIR3) 105,106,104
  104 T = T - DT
      DT = DT/2.0
  105 CONTINUE
      WRITE(J,764)
  106 TWB3 = T
      WRITE(6,702) TWB3
C
C     DETERMINE THE FRACTION 'FTP' OF THE HEAT EXCHANGER
C     WHICH IS IN TWO-PHASE FLOW
C
      FTP=QTP/(XMA*(HAIRI-HAIR3))
      WRITE(6,770) FTP
      IF((1.0-FTP).LT.0.0) GO TO 190
C
```

```
C     ITERATE TO DETERMINE THE AMOUNT OF WATER REMOVED FROM
C     THE AIR 'XMH20' , AND THE FINAL DRY BULB TEMP. 'TDB3'
C     LEAVING THE EVAPORATOR
C
      T = TWB3
      DT = .50
      WRITE(6,703)
      DO 120 L = 1,50
      T = T + DT
      CALL XMOIST(T,TWB3,RH3,1,PA,HAIR,WSAT,WAIR3,TWALL)
      XMH20 = (WAIRI-WAIR3)*FTP*XMA
      HAIR3S=.24*(T-32.0) +WAIR3*(1060.9 + .444*T)
      IF(ABS(HAIR3S-HAIR3).LE..05) GO TO 130
      IF(HAIR3S-HAIR3) 110,130,120
 110  T = T - DT
      DT = DT/2.0
 120  CONTINUE
      WRITE(J,780)
 130  TDB3 = T
      WRITE(6,704) XMH20,TDB3
C
C ------------- END OF MOISTURE REMOVAL SECTION ----------
C
C     DETERMINE FRACTION OF HEAT EXCHANGER 'F' USED FOR
C     SINGLE PHASE VAPOR (SUPERHEATING) REGION
C
 140  F = 1.0 - FTP
      WRITE (6,790) F
C
C     IF 'F' IS LESS THAN ZERO, INCOMPLETE EVAPORATION OCCURS
C     HENCE, PRINT AN ERROR MESSAGE
C
      IF(F) 190,145,150
 145  F = .000001
 150  XMASP = F*XMA
      XMATP=FTP*XMA
C
C     USE THE EFFECTIVENESS-NTU METHOD TO DETERMINE HEAT
C     TRANSFER IN THE SINGLE PHASE VAPOR (SUPERHEATING)
C     REGION
C
      CA = XMASP*CPA
      CR = XMR*CPRV
      RTOT = (ALFAR/(SEFFX*HA*ALFAA)+1.0/HRV)/(F*ARHT)
      CALL EXF(RTOT,CA,CR,CMIN,EXFR)
C
C     CALCULATE AND PRINT THE HEAT TRANSFER RATES
C     AND TEMPERATURES OF INTEREST
C
      TAOTP=TDB3
      TRO = TSA +EXFR*CMIN*(TAI-TSA )/CR
      SUPER = TRO - TSA
      QSP = CR*(TRO-TSA )
      TAOSP = TAI-QSP/CA
      WRITE(6,629)
      WRITE(6,628) FTP,F,XMATP,XMASP,EXFR
      WRITE(6,626) QTP,QSP,TDB3,TAOSP,TWB3
      WRITE(6,627) TAI,TWBI,TSA,TRO,SUPER
      RETURN
 190  WRITE(J,840) FTP
```

```
      QSP=0.0
      F=0.0
      XMASP=0.0
      XMH20=(WAIRI-WAIR3)*XMA
      RETURN
  626 FORMAT(10X,'QTP   =',F9.2,8X,'QSP   =',F9.2/
     110X,'TDB3  =',F8.2,9X,'TAOSP =',F8.2,9X,'TWB3  =',F8.2)
  627 FORMAT(1H0,9X,'TAI   =',F8.2/10X,'TWBI   =',F8.2/
     110X,'TSA   =',F8.2/10X,'TRO   =',F8.2/10X,'SUPER =',F8.2//
     25X,'NOTE THAT THESE HEAT AND MASS FLOWS ARE FOR ONE SECTION ONLY'
     3////)
  628 FORMAT(10X,'FTP   =',F6.3,11X,'F     =',F6.3/
     110X,'XMATP =',F8.2,9X,'XMASP =',F8.2/
     234X,'EXFR  =',F6.3)
  629 FORMAT(////5X,'RESULTS FROM SUBROUTINE EVAP:'/)
  641 FORMAT(5X,'MOISTURE REMOVAL OCCURS'//)
  700 FORMAT (5X,'END OF ITERATION.  RESULTS ARE'/
     110X,'HAIR3 =',F8.3,9X,'TWALL3=',F8.2/)
  701 FORMAT(5X,'START OF ITERATION ON EXIT WET BULB TEMP')
  702 FORMAT(5X,'END OF ITERATION.  RESULT IS'/
     110X,'TWB3  =',F8.2/)
  703 FORMAT(5X,'START OF ITERATION ON WATER REMOVAL RATE AND FINAL',
     1' AIR TEMP.')
  704 FORMAT(5X,'END OF ITERATION.  RESULTS ARE'/
     110X,'XMH20 =',F9.3,8X,'TDB3  =',F8.2/)
  705 FORMAT(1H0,9X,'TADHI =',F8.2,9X,'TAOTP =',F8.2)
  706 FORMAT(5X,'NO MOISTURE REMOVAL OCCURS'//)
  707 FORMAT(5X,'START OF ITERATION ON FIRST MOISTURE REMOVAL SECTION')
  708 FORMAT(5X,'END OF ITERATION.  RESULTS ARE'/
     110X,'HAIR2 =',F8.2,9X,'TWALL2=',F8.2/)
  709 FORMAT(5X,'START OF ITERATION ON SECOND MOISTURE REMOVAL SECTION')
  710 FORMAT('0****FTP IS LARGER THAN 1 FTP=',F10.5,'****'/)
  711 FORMAT(5X,'END OF ITERATION.  RESULT IS'/
     110X,'TWALLI=',F8.2/)
  713 FORMAT(5X,'START OF ITERATION ON WALL TEMP.')
  714 FORMAT(///5X,'BEGINNING OF CALCULATION IN SUBROUTINE EVAP:')
  715 FORMAT(3F10.4,I10,4F12.5)
  717 FORMAT('     *********NO SENSIBLE HEAT REMOVAL'
     1,,' ITERATION DOES NOT CONVERGE*********')
  720 FORMAT(' *****FSENS IS IN ERROR FSENS=',F10.5,'****')
  740 FORMAT(' **********FIRST MOISTURE REMOVAL REGION ITER'
     1,,'ATION DOES NOT CONVERGE************')
  760 FORMAT(' ********SECOND MOISTURE REMOVAL REGION ITERA'
     1,,'TION DOES NOT CCNVERGE********')
  764 FORMAT(' **********ITERATION ON TWB3 DOES NOT '
     1,,'CONVERGE *********')
  770 FORMAT(1H0,4X,'FRACTION OF COIL USED FOR TWO-PHASE FLOW IS'/
     110X,'FTP   =',F8.4/)
  780 FORMAT(' **********EXIT DRY BULB TEMP DOES NOT '
     1,,'CCNVERGE ********')
  790 FORMAT(1H0,4X,'FRACTION OF COIL USED FOR SINGLE-PHASE VAPOR FLOW',
     1' IS'/10X,'F     =',F8.4/)
  840 FORMAT(' *****INCOMPLETE EVAPORATION FTP=',F10.5,'**')
      END
```

```
      SUBROUTINE XMOIST(TDB,TWB,RH,INDIC,PATM,HAIR,WSAT,
     1WAIR,TWALL)
C
C     PURPOSE
C        TO DETERMINE THE ENTHALPY, SATURATION MOISTURE
C        CONTENT, AND ACTUAL MOISTURE CONTENT OF MOIST AIR,
C        AND ALSO, THE NECESSARY WALL TEMPERATURE TO INDUCE
C        MCISTURE REMOVAL, GIVEN DRY BULB TEMPERATURE AND
C        EITHER WET BULB TEMPERATURE OR RELATIVE HUMIDITY
C        (NOTE - THIS PROGRAM ESSENTIALLY REPRODUCES
C        PSYCHROMETRIC CHART DATA)
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                 ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED            ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,           ***
C***           HEAT TRANSFER LABORATORY,                         ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.            ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        TDB   -  DRY BULB TEMPERATURE (F)
C        TWB   -  WET BULB TEMPERATURE (F)
C        RH    -  RELATIVE HUMIDITY
C        INDIC-   INPUT INDICATOR
C        IF 'INDIC' = 1, INPUTS ARE TDB, AND TWB
C        IF 'INDIC' = 2, INPUTS ARE TDB, AND RH
C        PATM -   ATMOSPHERIC PRESSURE (PSIA)
C      OUTPUTS
C        HAIR -   ENTHALPY OF MOIST AIR (BTU/LBM DRY AIR)
C        WSAT -   SATURATION HUMIDITY (LBM WATER/LBM DRY AIR)
C                 CORRESPONDING TO THE EXISTING WET BULB TEMP.
C        WAIR -   ACTUAL HUMIDITY (LBM WATER/LBM DRY AIR)
C                 CORRESPCNDING TO THE GIVEN DRY BULB TEMP.,
C                 PRES., AND REL.HUMIDITY OR WET BULB TEMP.
C        TWALL-   SATURATICN OR DEW POINT TEMPERATURE (F)
C                 CORRESPONDING TO THE GIVEN TDB,PATM, AND
C                 TWB, OR RH
C
      K = 0
      I = 1
      IF(INDIC.NE.1) GO TO 30
      T = TWB
C
C     DETERMINING SATURATION PARTIAL PRESSURE 'PS' (PSIA)
C     OF WATER VAPOR AT THE GIVEN TEMPERATURE
   10 IF(T.LE.0.0) PS=.00077*T + .0185
      IF(T.GT.0.0) PS=.00124*T + .0185
      IF(T.GT.10.0) PS=.00196*T + .0113
      IF(T.GT.20.0) PS=.00317*T - .0129
      IF(T.GT.32.0) PS= .004145*T - .0441
      IF(T.GT.40.0) PS = .005641*T - .10394
      IF(T.GT.50.0) PS = .007819*T - .21284
      IF(T.GT.60.0) PS = .01068*T - .3845
      IF(T.GT.70.0) PS = .01438*T - .6435
      IF(T.GT.80.0) PS = .01913*T - 1.0235
      IF(T.GT.90.0) PS = .0251*T - 1.5608
      W    = 1.004*18.01*PS/(28.967*(PATM-PS))
      IF(K.NE.0) GO TO 50
      IF(INDIC.EQ.2) GO TO 40
      IF(I.NE.1) GO TO 20
```

```
      I = 2
      WSAT = W
      WAIR = WSAT -.000236*(TDB -T)
      HAIR = .24*(TWB-32.0) + WSAT*(1060.9 + .444*TWB)
      P=PATM/(1.004*18.01/(28.967*WAIR)+1.0)
      T = TDB
      GO TO 10
C
C     FINDING THE CORRESPONDING RELATIVE HUMIDITY,
C     GIVEN THE WET BULB TEMPERATURE
   20 RH = P/PS
      GO TO 90
   30 T = TDB
      GO TO 10
   40 P = RH*PS
      WAIR = RH*W*(PATM-PS)/(PATM-P)
C
C     FINDING THE CORRESPONDING WET BULB TEMPERATURE,
C     GIVEN THE RELATIVE HUMIDITY
      DT = -10.0
      DO 70 K=1,30
      T = T+DT
      GO TO 10
   50 WS = W     - .000236*(TDB-T)
      IF(ABS(WS-WAIR).LE..00005) GO TO 80
      IF(WS-WAIR) 60,80,70
   60 T = T-DT
      DT = DT/2.0
   70 CONTINUE
      WRITE(6,100)
   80 TWB = T
      WSAT = W
      HAIR = .24*(TWB-32.0) + WSAT*(1060.9 + .444*TWB)
C
C     DETERMINING THE SATURATION OR DEW POINT TEMP. 'TWALL'
C     CORRESPONDING TO THE GIVEN PRESSURE, DRY BULB
C     TEMPERATURE, AND RELATIVE HUMIDITY OR WET BULB TEMP.
   90 IF(P.LE..0185) TWALL=(P-.0185)/.00077
      IF(P.GT..0185) TWALL = (P-.0185)/.00124
      IF(P.GT..0309) TWALL=(P-.0113)/.00196
      IF(P.GT..0505) TWALL=(P+.0129)/.00317
      IF(P.GT..0885) TWALL=(P+.0441)/.004145
      IF(P.GT..12170) TWALL=(P+.10394)/.005641
      IF(P.GT..17811) TWALL=(P+.21284)/.007819
      IF(P.GT..2563) TWALL=(P+.3845)/.01068
      IF(P.GT..3631) TWALL = (P+.6435)/.01438
      IF(P.GT..5069) TWALL = (P+1.0235)/.01913
      IF(P.GT..6982) TWALL = (P+1.5608)/.0251
  100 FORMAT(' ***** ITERATION IN XMOIST DOES NOT CONVERGE')
      RETURN
      END
```

```
      SUBROUTINE EHTC(DE,G,XI,XE,PRL,XKL,XMUV,XMUL,RHOL,
     1RHOV,HTC)
C
C     PURPOSE
C        TO DETERMINE THE EVAPORATION TWO-PHASE HEAT TRANS.
C        COEFFICIENT FOR FORCED CONVECTION FLOW
C        INSIDE TUBES
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED          ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,         ***
C***           HEAT TRANSFER LABORATORY,                       ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.          ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        DE   -  EQUIVALENT DIAMETER OF FLOW PASSAGE (FT)
C        G    -  MASS FLOW PER UNIT AREA (LBM/HR-SQ FT)
C        XI   -  INITIAL QUALITY
C        XE   -  EXIT QUALITY
C        PRL  -  PRANDTL NUMBER OF THE LIQUID PHASE
C        XKL  -  THERMAL COND. OF LIQ. PHASE (BTU/HR-FT-F)
C        XMUV -  VISCOSITY OF VAPOR PHASE (LBM/HR-FT)
C        XMUL -  VISCOSITY OF LIQUID PHASE (LBM/HR-FT)
C        RHOL -  DENSITY OF LIQUID PHASE (LBM/CU FT)
C        RHOV -  DENSITY OF VAPOR PHASE (LBM/CU FT)
C      OUTPUT
C        HTC  -  EVAP.HEAT TRANS. COEF.(BTU/HR-SQ FT-F)
C
      HTC = .023*.325*2.50*XKL*(G/XMUL)**.8*DE**(-.2)*PRL**
     1.4*(RHOL/RHOV)**.375*(XMUV/XMUL)**.075*(XE-XI)/
     2(XE**.325-XI**.325)
      RETURN
      END
```

```
      SUBROUTINE PDROP(N,D,E,G,XMUV,XMUL,RHOV,RHOL,REV,REL,
     1DZTP,XF,XI,VV,DZV,DZL,PD)
C
C     PURPOSE
C        TO DETERMINE BOTH SINGLE PHASE AND TWO-PHASE
C        PRESSURE DROPS FOR FLOW IN TUBES
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN              ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED        ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,       ***
C***           HEAT TRANSFER LABORATORY,                     ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.        ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        N    -  INDICATOR (2 OR 3 MEANS EVAPORATOR)
C        D    -  EQUIVALENT DIAMETER OF FLOW PASSAGE (FT)
C        E    -  SURFACE ROUGHNESS OF FLOW PASSAGE (FT)
C        G    -  MASS FLOW PER UNIT AREA (LBM/HR-SQ FT)
C        XMUV -  VISCOSITY OF VAPOR PHASE (LBM/HR-FT)
C        XMUL -  VISCOSITY OF LIQ. PHASE (LBM/HR-FT)
C        RHOV -  DENSITY OF VAPOR PHASE (LBM/CU FT)
C        RHOL -  DENSITY OF LIQ. PHASE (LBM/CU FT)
C        REV  -  REYNOLDS NUMBER OF VAPOR PHASE REQION
C        REL  -  REYNOLDS NUMBER OF LIQUID PHASE REGION
C        DZTP -  LENGTH OF TWO-PHASE REGION (FT)
C        XF   -  FINAL QUALITY
C        XI   -  INITIAL QUALITY
C        VV   -  EXIT SPECIFIC VOL.OF VAPOR PHASE (CU FT/LBM)
C        DZV  -  LENGTH OF SINGLE PHASE VAPOR REGION (FT)
C        DZL  -  LENGTH OF SINGLE PHASE LIQ. REGION (FT)
C      OUTPUT
C        DPV  -  PRES.DROP IN SINGLE PHASE VAPOR REGION (PSI)
C        DPL  -  PRES. DROP IN SINGLE PHASE LIQ. REGION (PSI)
C        DPTP -  PRES.DROP IN TWO-PHASE REGION (PSI)
C        PD   -  TOTAL PRESSURE DROP (PSI)
C **** CAUTION - WATCH SIGN CONVENTION ***********
C
C     REMARKS
C        THIS PROGRAM CALLS SUBROUTINE FRICT, FOR
C        DETERMINING THE GENERAL MOODY FRICTION FACTOR
C        FOR SINGLE PHASE FLOW IN TUBES
C
C     MOMENTUM COMPONENT OF TWO-PHASE PRES. DROP
      DPM =((XF**2-XI**2)*(1.0+RHOV/RHOL -(RHOV/RHOL)**.333
     1-(RHOV/RHOL)**.667)-(XF-XI)*(2.0*RHOV/RHOL-(RHOV/
     2RHOL)**.333-(RHOV/RHOL)**.667))*G**2/(RHOV*32.2*
     33600.0**2*144.0)
      C1 = (XF-XI)/DZTP
      C2 = .09*XMUV**.2*G**1.8/(C1*RHOV*D**1.2*32.2*3600.0
     1**2*144.0)
      C3 = 2.85*(XMUL/XMUV)**.0523*(RHOV/RHOL)**.262
C
C     FRICTION COMPONENT OF TWO-PHASE PRES. DROP
      DPF =C2*(.357*(XF**2.8-XI**2.8)+2.0*C3*(.429*(XF**2.33
     1-XI**2.33)-.141*(XF**3.33-XI**3.33)-.0287*(XF**4.33
     2-XI**4.33))+C3**2*(.538*(XF**1.86-XI**1.86)-.329*(XF
     3**2.86-XI**2.86)))
C
C     TOTAL TWO-PHASE PRESSURE DROP
```

```
      DPTP = DPM + DPF
      CALL FRICT(REV,E,D,FFV)
      IF((N.EQ.2).OR.(N.EQ.3)) GO TO 20
C
C     CONDENSER SINGLE PHASE PRESSURE DROPS
      DPV=G**2*(1.0/RHOV-VV+FFV*DZV*(1.0/RHOV+VV)/D)/
     1(32.2*3600.0**2*144.0)
      CALL FRICT(REL,E,D,FFL)
      DPL = 2.0*FFL*DZL*G**2/(D*RHOL*32.2*3600.0**2*144.0)
      GO TC 40
C
C     EVAPORATOR SINGLE PHASE PRESSURE DROPS
   20 DPV=G**2*(VV-1.0/RHOV+FFV*DZV*(VV+1.0/RHOV)/D)/
     1(32.2*3600.0**2*144.0)
      DPL = 0.0
C
C     TOTAL PRESSURE DROP
   40 PD = -(DPTP + DPV + DPL)
      RETURN
      END
```

```
      SUBROUTINE DPLINE(D,XLEQ,E,XMR,RHO,XMU,DPLNE)
C
C     PURPOSE
C        TO DETERMINE SINGLE PHASE PRESSURE DROPS
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                 ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED           ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,          ***
C***           HEAT TRANSFER LABORATORY,                        ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.           ***
C
C     DESCRIPTICN OF PARAMETERS
C      INPUT
C        D    -  EQUIVALEN3 D9 M5T59 OF FLOW PASSAG5 (FT)
C        XLEQ -  EQUIVALENT LENGTH (L/D - NON DIMENSIONAL)
C        E    -  SURFACE ROUGHNESS OF FLOW PASSAGE (FT)
C        XMR  -  MASS FLCW RATE (LBM/HR)
C        RHO  -  DENSITY OF FLUID (LBM/CU FT)
C        XMU  -  VISCOSITY OF FLUID (LBM/HR-FT)
C      OUTPUT
C        DPLNE-  SINGLE PHASE PRESSURE DROP (PSI)
C
C      REMARKS
C        THIS PROGRAM CAILS SUBROUTINE FRICT FOR
C        DETERMINING THE GENERAL MOODY FRICTION FACTOR
C        FOR SINGLE PHASE FLOW IN TUBES
C
       RE = 4.0*XMR/(3.14*D*XMU)
       CALL FRICT(RE,E,D,FF)
       DPLNE =4.0*FF*XLEQ*(4.0*XMR/(3.14*D**2))**2/
     1(2.0*RHO*32.2*3600.0**2*144.0)
       RETURN
       END
```

```
      SUBROUTINE FRICT(RE,E,DI,FF)
C
C     PURPOSE
C        TO DETERMINE THE GENERAL MOODY FRICTION FACTOR
C        FOR SINGLE PHASE FLOW IN TUBES
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                    ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED              ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,             ***
C***           HEAT TRANSFER LABORATORY,                           ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.              ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        RE    -  REYNOLDS NUMBER
C        E     -  SURFACE ROUGHNESS OF FLOW PASSAGE (FT)
C        DI    -  EQUIVALENT DIAMETER OF FLOW PASSAGE (FT)
C      OUTPUT
C        FF    -  MOODY FRICTION FACTOR
C
C     LAMINAR FLOW REGIME
      IF(RE.LE.2300.0) FF = 16.0/RE
      IF(RE.LE.2300.0) GO TO 30
C
C     TRANSITION AND TURBULENT FLOW REGIMES
      D = DI
      FF = .020
      DF = -.005
      DO 20 I = 1,30
      FF = FF + DF
      IF(FF.LE.0.0) FF = .0001
      A = -2.0*ALOG10(2.51/(RE*SQRT(4.0*FF)) + E/(3.7*D))
      B = 1.0/SQRT(4.0*FF)
      IF(ABS(A-B).LE.(.001*B)) GO TO 30
      IF(A-B) 15,30,20
   15 FF = FF - DF
      DF = DF/2.0
   20 CONTINUE
      WRITE(6,100)
   30 RETURN
  100 FORMAT(' *****FRICTION FACTOR FAILS TO CONVERGE*****')
      END
```

```
      SUBROUTINE TABLES(NR,I)
C
C     PURPOSE
C        TO PROVIDE CORRECT VALUES FOR CONSTANTS IN THE
C        THERMODYNAMIC PROPERTIES SUBPROGRAMS, CORRESPONDING
C        TO THE DESIRED REFRIGERANT (12,22, OR 502)
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                    ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED              ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,             ***
C***           HEAT TRANSFER LABORATORY,                           ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.              ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        NR   -  REFRIGERANT NUMBER (12,22, OR 502)
C      OUTPUT
C        ALL OF THE CONSTANTS HELD IN COMMON BLOCKS
C        THE REFRIGERANT INDICATOR 'I'
C
      REAL K,LE10,L10E,J
C     DESCRIPTION OF CONSTANTS
C        VAPOR PRESSURE CONSTANTS
      COMMON/SAT/AVP,BVP,CVP,DVP,EVP,FVP
C        CRITICAL POINT PROPERTIES  TC,  PC,  VC
C        INITIAL APPROXIMATION CONSTANTS  A,  B
C        MISCELLANEOUS CONSTANTS  TFR,  LE10
      COMMON/SUPER/ TC,PC,VC,A,B,TFR,LE10
C        EQUATION OF STATE CONSTANTS
      COMMON/STATEQ/R,B1,A2,B2,C2,A3,B3,C3,A4,B4,C4,A5,B5,
     1C5,A6,B6,C6,K,ALPHA,CPR
C
C        SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C        ACV,BCV,CCV,DCV,ECV,FCV
C        ENTHALPY AND ENTROPY OF VAPOR CONSTANTS  X,  Y
C        MISCELLANEOUS CONSTANTS  L10E,  J
      COMMON/OTHER/ACV,BCV,CCV,DCV,ECV,FCV,X,Y,L10E,J
      IWRITE = 6
C     SET REFRIGERANT INDICATOR 'I'
      I = 0
      IF(NR.EQ.12) I=1
      IF(NR.EQ.22) I=2
      IF(NR.EQ.502) I=3
      IF(I.EQ.0) GO TO 999
      J = .185053
      L10E = .434294
      LE10 = 2.302585
      GO TO(10,20,30) , I
C CONSTANTS FOR REFRIGERANT 12
   10 AVP = 39.883817
      BVP = -3436.63228
      CVP = -12.471522
      DVP = 4.730442E-03
      EVP = 0.0
      FVP = 0.0
      TC = 693.3
      PC = 596.9
      VC = .02870
      A = 120.0
      B = 312.0
```

```
      TFR = 459.7
      R = .088734
      B1 = 6.509389E-03
      A2 = -3.409727
      B2 = 1.594348E-03
      C2 = -56.762767
      A3 = 6.023945E-02
      B3 = -1.879618E-05
      C3 = 1.311399
      A4 = -5.487370E-04
      B4 = 0.0
      C4 = 0.0
      A5 = 0.0
      B5 = 3.468834E-09
      C5 = -2.543907E-05
      A6 = 0.0
      B6 = 0.0
      C6 = 0.0
      K = 5.475
      ALPHA = 0.0
      CPR = 0.0
      ACV = 8.0945E-03
      BCV = 3.32662E-04
      CCV = -2.413896E-07
      DCV = 6.72363E-11
      ECV = 0.0
      FCV = 0.0
      X = 39.556551
      Y = -1.653794E-02
      RETURN
C CONSTANTS FOR REFRIGERANT 22
  20  AVP = 29.357545
      BVP = -3845.193152
      CVP = - 7.861031
      DVP = 2.190939E-03
      EVP = .445747
      FVP = 686.1
      TC = 664.5
      PC = 721.906
      VC = .030525
      A = 120.0
      B = 388.0
      TFR = 459.69
      R = .124098
      B1 = .002
      A2 = -4.353547
      B2 = 2.407252E-03
      C2 = -44.066868
      A3 = -.017464
      B3 = 7.62789E-05
      C3 = 1.483763
      A4 = 2.310142E-03
      B4 = -3.605723E-06
      C4 = 0.0
      A5 = -3.724044E-05
      B5 = 5.355465E-08
      C5 = -1.845051E-04
      A6 = 1.363387E08
      B6 = -1.672612E05
      C6 = 0.0
```

```
      K = 4.2
      ALPHA = 548.2
      CPR = 0.0
      ACV = 2.812836E-02
      BCV = 2.255408E-04
      CCV = -6.509607E-08
      DCV = 0.0
      ECV = 0.0
      FCV = 257.341
      X = 62.4009
      Y = -4.53335E-02
      RETURN
C CONSTANTS FOR REFRIGERANT 502
   30 AVP = 10.644955
      BVP = -3671.153813
      CVP = -  .369835
      DVP = -1.746352E-03
      EVP = .816114
      FVP = 654.0
      TC = 639.56
      PC = 591.00
      VC = .028571
      A = 117.0
      B = 279.0
      TFR = 459.67
      R = .096125
      B1 = .00167
      A2 = -3.261334
      B2 = 2.057629E-03
      C2 = -24.24879
      A3 = 3.486675E-02
      B3 = -.867913E-05
      C3 = .332748
      A4 = -8.576568E-04
      B4 = 7.024055E-07
      C4 = 2.241237E-02
      A5 = 8.836897E-06
      B5 = -7.916809E-09
      C5 = -3.716723E-04
      A6 = -3.825373E07
      B6 = 5.581609E04
      C6 = 1.537838E09
      K = 4.2
      ALPHA = 609.0
      CPR = 7.E-07
      ACV = 2.0419E-02
      BCV = 2.996802E-04
      CCV = -1.409043E-07
      DCV = 2.210861E-11
      ECV = 0.0
      FCV = 64.058511
      X = 35.308
      Y = -.07444
      RETURN
C     PRINT ERROR MESSAGE IF
C     'NR' DOES NOT EQUAL 12,22, OR 502
  999 WRITE(IWRITE,1000)
 1000 FORMAT('  ************ERROR IN SUBROUTINE -TABLES-')
      RETURN
      END
```

```
      FUNCTION TSAT(NR,PSAT)
C
C     PURPOSE
C        TO EVALUATE THE SATURATION TEMPERATURE
C        OF REFRIGERANT 12,22, OR 502
C        GIVEN THE SATURATION PRESSURE
C
C***  AUTHORS  C. C. HILIER AND L. R. GLICKSMAN                   ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED             ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,            ***
C***           HEAT TRANSFER LABORATORY,                          ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.             ***
C
C     DESCRIPTION OF PARIMETERS
C      INPUT
C        NR   -  REFRIGERANT NUMBER (12,22, OF 502)
C        PSAT -  SATURATION PRESSURE (PSIA)
C      OUTPUT
C        TSAT -  SATURATION TEMPERATURE (F)
C     REMARKS
C        SUBROUTINE TABLES CALLED BY THIS FUNCTION
      REAL LE10
C
C     CONSTANTS
C
C        VAPOR PRESSURE CONSTANTS
      COMMON/SAT/AVP,BVP,CVP,DVP,EVP,FVP
C
C        CRITICAL POINT PROPERTIES    TC,    PC,    VC
C        INITIAL APPROXIMATION CONSTANTS    A,   B
C        MISCELLANEOUS CONSTANTS    TFR,  LE10
      COMMON/SUPER/ TC,PC,VC,A,B,TFR,LE10
C
      IWRITE = 6
C
C     OBTAIN VALUES OF THE CONSTANTS FOR THE
C     DESIRED REFRIGERANT FROM SUBROUTINE 'TABLES'
C     (THROUGH COMMON)
      CALL TABLES(NR,I)
C
C     CHECK 'PSAT'
      IF(PSAT.LE.0.0) GO TO 999
C
C     COMPUTE INITIAL ESTIMATE OF 'TSAT' FROM
C     LINEAR APPROXIMATION
      PLOG = ALOG10(PSAT)
      TR=A*PLOG + B
      ITER = 0
C
C     ITERATE TO WITHIN .01 USING NEWTON ITERATION
    1 TRO = TR
      ITER = ITER + 1
      IF(ITER.GT. 30) GO TO 998
      C = ALOG10(ABS(FVP - TRO))
      F=AVP+BVP/TRO+CVP*ALOG10(TRO)+DVP*TRO+EVP*((FVP-TRO)/
     1TRO)*C-PLOG
      FP=-BVP/TRO**2+CVP/(LE10*TRO)+DVP-EVP*(1./(LE10*TRO)+
     1FVP*C/TRO**2)
      TR=TRO-F/FP
      IF(ABS(TR-TRO).GT..01) GO TO 1
```

```
      TSAT=TR-TPR
      RETURN
C
C     PRINT ERROR MESSAGE IF
C        PSAT IS LESS THAN OR EQUAL TO ZERO
C        NUMBER OF ITERATIONS IS GREATER THAN 30
  998 TSAT=TR-TPR
      WRITE(IWRITE,1000)
      RETURN
  999 TSAT=0
      WRITE(IWRITE,1000)
 1000 FORMAT(10X,'ERROR IN CALLING SUBROUTINE -TSAT- ')
      RETURN
      END
```

```
      FUNCTION SPVOL(NR,TF,PPSIA)
C
C     PURPOSE
C        TO EVALUATE THE SPECIFIC VOLUME OF THE VAPOR PHASE
C        OF REFRIGERANT 12,22, OR 502
C        GIVEN THE PRESSURE AND TEMPERATURE
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED           ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,          ***
C***           HEAT TRANSFER LABORATORY,                        ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.           ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        NR    -  REFRIGERANT NUMBER (12,22, OR 502)
C        TF    -  TEMPERATURE (F)
C        PPSIA-   PRESSURE (PSIA)
C      OUTPUT
C        SPVOL-   SPECIFIC VOLUME (CU FT/LBM)
C
C     REMARKS
C        FUNCTION SUBPROGRAM TSAT CALLED BY THIS FUNCTION
C        SUBROUTINE TABLES CALLED BY THIS SUBROUTINE
      REAL K,LE10
C
C     CONSTANTS
C
C        CRITICAL POINT PROPERTIES   TC,  PC,  VC
C        INITIAL APPROXIMATION CONSTANTS  A,  B
C        MISCELLANEOUS CONSTANTS   TFR,  LE10
      COMMON/SUPER/ TC,PC,VC,A,B,TFR,LE10
C
C     EQUATION OF STATE CONSTANTS
      COMMON/STATEQ/R,B1,A2,B2,C2,A3,B3,C3,A4,B4,C4,A5,B5,
     1C5,A6,B6,C6,K,ALPHA,CPR
C
      IWRITE = 6
C
C     OBTAIN VALUES OF THE CONSTANTS CORRESPONDING TO THE
C     DESIRED REFRIGERANT FROM SUBROUTINE TABLES
C     (THROUGH COMMON)
      CALL TABLES(NR,I)
C
C     CONVERT 'TF' TO 'T' AND CHECK VALUE
      T = TF + TFR
      IF(T.LE.0.0) GO TO 999
C
C     CALCULATE 'TFSAT' AND COMPARE WITH 'TF'
      TFSAT=TSAT(NR,PPSIA)
      IF(TF.LT.(TFSAT-0.050)) GO TO 999
C
C     CHECK 'PPSIA'
      IF(PPSIA.LE.0.0) GO TO 999
C
C     CALCULATE CONSTANTS
      ES0 = EXP(-K*T/TC)
      ES1=PPSIA
      ES2 = R*T
      ES3=A2+B2*T+C2*ES0
```

```
      ES4=A3+B3*T+C3*ES0
      ES5=A4+B4*T+C4*ES0
      ES6=A5+B5*T+C5*ES0
      ES7=A6+B6*T+C6*ES0
      ES32=2.*ES3
      ES43=3.*ES4
      ES54=4.*ES5
      ES65=5.*ES6
C
C     COMPUTE INITIAL ESTIMATE OF 'V' FROM IDEAL GAS LAW
      VN=R*T/PPSIA
      ITER = 0
C
C     COMPUTE 'V' TO WITHIN 1.0E-06 BY NEWTON ITERATION
    1 ITER = ITER + 1
      IF(ITER.GT.30) GO TO 998
      V = VN
      V2 = V**2
      V3 = V**3
      V4 = V**4
      V5 = V**5
      V6 = V**6
      Z = ALPHA*(V+B1)
      IF(Z.GT.150.0) Z=150.0
      EMAV=EXP(-Z)
      GO TO (2,2,3),I
    2 F=ES1-ES2/V-ES3/V2-ES4/V3-ES5/V4-ES6/V5-ES7*EMAV
      FV=ES2/V2+ES32/V3+ES43/V4+ES54/V5+ES65/V6+ES7*ALPHA*E
     1MAV
      GO TO 4
    3 EM2AV = EMAV**2
      F=ES1-ES2/V-ES3/V2-ES4/V3-ES5/V4-ES6/V5-ES7*EM2AV/(EM
     1AV+CPR)
      FV=ES2/V2+ES32/V3+ES43/V4+ES54/V5+ES65/V6+ES7*ALPHA*E
     1M2AV*(EMAV+2.*CPR)/(EMAV+CPR)**2
    4 VN=V-F/FV
      IF(ABS((VN-V)/V).GT.1.E-06) GO TO 1
      SPVOL = VN+B1
      RETURN
C
C     PRINT ERROR MESSAGE IF
C        TF IS LESS THAN OR EQUAL TO ZERO DEGREE R
C        TF IS LESS THAN TFSAT CORRESPONDING TO PSAT = PPSIA
C        PPSIA IS LESS THAN OR EQUAL TO ZERO
C        MORE THAN 30 ITERATIONS ARE NEEDED
  998 SPVOL = VN + B1
      WRITE(IWRITE,9)
      RETURN
  999 SPVOL=0.
      WRITE(IWRITE,9)
    9 FORMAT(' *****ERROR IN CALLING SUBROUTINE -SPVOL-')
      RETURN
      END
```

```
      SUBROUTINE VAPOR(NR,TF,PPSIA,VVAP,HVAP,SVAP)
C
C     PU9POS5
C        TO EVALUATE THE THERMODYNAMIC PROPERTIES
C        OF THE SUPERHEATED VAPOR PHASE
C        OF REFRIGERANT 12,22, OR 502
C        GIVEN THE TEMPERATURE AND PRESSURE
C
C***  AUTHORS   C. C. HILLER AND L. R. GLICKSMAN                 ***
C***            THIS SUBPROGRAM APPEARS HERE UNCHANGED           ***
C***            FROM THAT GIVEN IN REPORT NO. 24525-96,          ***
C***            HEAT TRANSFER LABORATORY,                        ***
C***            MASSACHUSETTS INSTITUTE OF TECHNOLOGY.           ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        NR    -  REFRIGERANT NUMBER (12,22, OR 502)
C        TF    -  TEMPERATURE (F)
C        PPSIA-   PRESSURE (PSIA)
C      OUTPUT
C        VVAP -   SPECIFIC VOLUME OF VAPOR (CU FT/LBM)
C        HVAP -   ENTHALPY OF VAPOR (BTU/LBM)
C        SVAP -   ENTROPY OF VAPOR (BTU/LBM - R)
C     REMARKS
C        FUNCTION SUBPROGRAM SPVOL CALLED BY THIS SUBROUTINE
C        FUNCTION SUBPROGRAM TSAT CALLED BY THIS SUBROUTINE
C        SUBROUTINE TABLES CALLED BY THIS SUBROUTINE
      REAL K,J,KTDTC,LE10,L10E
C
C     CONSTANTS
C        CRITICAL POINT PROPERTIES  TC,  PC,  VC
C        INITIAL APPROXIMATION CONSTANTS  A, B (NOT USED)
C        MISCELLANEOUS CONSTANTS  TFR,  LE10
      COMMON/SUPER/ TC,PC,VC,A,B,TFR,LE10
C
C        EQUATION OF STATE CONSTANTS
      COMMON/STATEQ/R,B1,A2,B2,C2,A3,B3,C3,A4,B4,C4,A5,B5,
     1C5,A6,B6,C6,K,ALPHA,CPR
C        SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C        ACV,BCV,CCV,DCV,ECV,FCV
C        ENTHALPY AND ENTROPY OF VAPOR CONSTANTS   X,  Y
C        MISCELLANEOUS CONSTANTS   L10E,  J
      COMMON/OTHER/ACV,BCV,CCV,DCV,ECV,FCV,X,Y,L10E,J
C
C     OBTAIN VALUES OF THE CONSTANTS CORRESPONDING TO THE
C     DESIRED REFRIGERANT FROM SUBROUTINE TABLES
C     (THROUGH COMMON)
      CALL TABLES(NR,I)
C
      IWRITE = 6
C
C     CONVERT 'TF' TO 'T' AND CHECK VALUE
      T = TF + TFR
      IF(T.LE.0.0) GO TO 999
C
C     CALCULATE 'TFSAT' AND COMPARE WITH 'TF'
      TFSAT = TSAT(NR,PPSIA)
      IF(TF.LT.TFSAT) GO TO 999
C
C     CHECK 'PPSIA'
```

```
      IF(PPSIA.LE.0.0) GO TO 999
C
C     CALCULATE 'VVAP'
      VVAP = SPVOL(NR,TF,PPSIA)
C
C     CALCULATE 'HVAP' AND 'SVAP'
      T2 = T**2
      T3 = T**3
      T4 = T**4
      VR = VVAP-B1
      VR2 = 2.*VR**2
      VR3 = 3.*VR**3
      VR4 = 4.*VR**4
      KTDTC = K*T/TC
      EKTDTC = EXP(-KTDTC)
      Z = ALPHA*VVAP
      IF(Z.GT.150.0) Z = 150.0
      EMAV = EXP(-Z)
      H1=ACV*T+BCV*T2/2.+CCV*T3/3.+DCV*T4/4.-FCV/T
      H2 = J*PPSIA*VVAP
      H3=A2/VR+A3/VR2+A4/VR3+A5/VR4
      H4=C2/VR+C3/VR2+C4/VR3+C5/VR4
      S1=ACV*ALOG(T)+BCV*T+CCV*T2/2.+DCV*T3/3.-FCV/(2.*T2)
      S2 = J*R*ALCG(VR)
      S3=B2/VR+B3/VR2+B4/VR3+B5/VR4
      S4 = H4
      GO TO(6,4,5),I
    4 H3 = H3+A6/ALPHA*EMAV
      S3 = S3+B6/ALPHA*EMAV
      GO TO 6
    5 H0=1./ALPHA*(EMAV-CPR*ALOG(1.+EMAV/CPR))
      H3 = H3+A6*H0
      H4 = H4 -C6*H0
      S3 = S3+B6*H0
      S4 = S4-C6*H0
    6 HVAP=H1+H2+J*H3+J*EKTDTC*(1.+KTDTC)*H4+X
      SVAP=S1 +S2-J*S3+J*EKTDTC*K/TC*S4+Y
      RETURN
C
C     PRINT ERROR MESSAGE IF
C        TF IS LESS THAN OR EQUAL TO ZERO DEGREE R
C        TF IS LESS THAN TFSAT CORRESPONDING TO PSAT = PPSIA
C        PPSIA IS LESS THAN OR EQUAL TO ZERO
  999 WRITE(IWRITE,1000)
 1000 FORMAT(' *******ERROR IN CALLING SUBROUTINE -VAPOR-')
      RETURN
      END
```

```
      SUBROUTINE SATPRP(NR,TF,PSAT,VF,VG,HF,HFG,HG,SF,SG)
C
C     DIMENSION AND TYPE STATEMENTS
      DIMENSION AL(3),BL(3),CL(3),DL(3),EL(3)
      REAL J,K,KTDTC,LE10,L10E
C
C     PURPOSE
C        TO EVALUATE THE SATURATION THERMODYNAMIC PROPERTIES
C        OF REFRIGERANT 12,22, OR 502
C        GIVEN THE SATURATION TEMPERATURE
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN               ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED          ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,         ***
C***           HEAT TRANSFER LABORATORY,                       ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.          ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        NR   -  REFRIGERANT NUMBER (12,22, OR 502)
C        TF   -  TEMPERATURE (F)
C      OUTPUT
C        PSAT - SATURATION PRESSURE (PSIA)
C        VF   -  SPECIFIC VOLUME OF SATURATED LIQ.(CU FT/LBM)
C        VG   -  SPECIFIC VOLUME OF SATURATED VAP.(CU FT/LBM)
C        HF   -  ENTHALPY OF SATURATED LIQUID (BTU/LBM)
C        HFG  -  LATENT ENTHALPY OF VAPORIZATION (BTU/LBM)
C        HG   -  ENTHALPY OF SATURATED VAPOR (BTU/LBM)
C        SF   -  ENTROPY OF SATURATED LIQUID (BTU/LBM - R)
C        SG   -  ENTROPY OF SATURATED VAPOR (BTU/LBM - R)
C
C     REMARKS
C        FUNCTION SUBPROGRAM SPVOL CALLED BY THIS SUBROUTINE
C        SUBROUTINE TABLES CALLED BY THIS SUBROUTINE
C        FUNCTION SUBPROGRAM TSAT AVAILABLE FOR CALCULATING
C        THE SATURATION TEMPERATURE GIVEN THE SATURATION
C        PRESSURE
C
C     CONSTANTS
C
C        VAPOR PRESSURE CONSTANTS
      COMMON/SAT/AVP,BVP,CVP,DVP,EVP,FVP
C
C        CRITICAL POINT PROPERTIES   TC,  PC,  VC
C        INITIAL APPROXIMATION CONSTANTS A, B (NOT USED)
C        MISCELLANEOUS CONSTANTS   TFR,  LE10
      COMMON/SUPER/ TC,PC,VC,A,B,TFR,LE10
C
C        EQUATION OF STATE CONSTANTS
      COMMON/STATEQ/R,B1,A2,B2,C2,A3,B3,C3,A4,B4,C4,A5,B5,
     1C5,A6,B6,C6,K,ALPHA,CPR
C
C        SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C        ACV,BCV,CCV,DCV,ECV,FCV
C        ENTHALPY AND ENTROPY OF VAPOR CONSTANTS   X,  Y
C        MISCELLANEOUS CONSTANTS   L10E,  J
      COMMON/OTHER/ACV,BCV,CCV,DCV,ECV,FCV,X,Y,L10E,J
C
C        LIQUID DENSITY CONSTANTS
      DATA AL,BL,CL,DL,EL/34.84,32.76,35.0,.02696,54.634409
```

```
     1,53.48437,.834921,36.74892,63.86417,6.02683,-22.29256
     26,-70.08066,-.655549E-05,20.473289,48.47901/
C
C     OBTAIN VALUES OF THE CONSTANTS CORRESPONDING TO THE
C     DESIRED REFRIGERANT FROM SUBROUTINE TABLES
C     (THROUGH COMMON)
      CALL TABLES(NR,I)
C
      IWRITE = 6
C
C     CONVERT 'TF' TO 'T' AND CHECK VALUE
      T = TF + TFR
      IF(T.LE.0.0) GO TO 999
C
C     COMPARE 'T' WITH 'TC'
      IF(T.GT.TC) GO TO 999
C
C     CALCULATE 'PSAT'
      GO TO(10,11,11), I
   10 PSAT=10.**(AVP+BVP/T+CVP*ALOG10(T)+DVP*T)
      GO TO 12
   11 PSAT=10.**(AVP+BVP/T+CVP*ALOG10(T)+DVP*T+EVP*((FVP-T)
     1/T)*ALOG10(FVP-T))
C
C     CALCULATE 'VG'
   12 VG = SPVOL(NR,TF,PSAT)
C
C     CALCULATE 'VF'
      GO TO (1,2,2), I
    1 TCMT = TC-T
      VF=1./(AL(I)+BL(I)*TCMT+CL(I)*TCMT**(1./2.)+DL(I)*TCM
     1T**(1./3.)+EL(I)*TCMT**2)
      GO TO 3
    2 TR1 = 1.-T/TC
      VF=1./(AL(I)+BL(I)*TR1**(1./3.)+CL(I)*TR1**(2./3.)+DL
     1(I)*TR1+EL(I)*TR1**(4./3.))
C
C     CALCULATE 'HFG' BY CLAUSIUS CLAPEYRON EQUATION
    3 GO TO(31,32,32),I
   31 HFG=(VG-VF)*PSAT*LE10*(-BVP/T+CVP/LE10+DVP*T)*J
      GO TO 33
   32 HFG=(VG-VF)*PSAT*LE10*(-BVP/T+CVP/LE10+DVP*T-EVP*(L10
     1E+FVP*ALOG10(FVP-T)/T))*J
   33 SFG = HFG/T
C
C     CALCULATE 'HG' AND 'SG'
      T2 = T**2
      T3 = T**3
      T4 = T**4
      VR = VG-B1
      VR2 = 2.*VR**2
      VR3 = 3.*VR**3
      VR4 = 4.*VR**4
      KTDTC = K*T/TC
      EKTDTC = EXP(-KTDTC)
      Z = ALPHA*VG
      IF(Z.GT.150.0) Z = 150.0
      EMAV = EXP(-Z)
      H1=ACV*T+BCV*T2/2.+CCV*T3/3.+DCV*T4/4.-FCV/T
      H2 = J*PSAT*VG
```

```
      H3=A2/VR+A3/VR2+A4/VR3+A5/VR4
      H4=C2/VR+C3/VR2+C4/VR3+C5/VR4
      S1=ACV*ALOG(T)+BCV*T+CCV*T2/2.+DCV*T3/3.-FCV/(2.*T2)
      S2 = J*R*ALCG(VR)
      S3=B2/VR+B3/VR2+B4/VR3+B5/VR4
      S4 = H4
      GO TO(6,4,5), I
    4 H3=H3+A6/ALPHA*EMAV
      S3=S3+B6/ALPHA*EMAV
      GO TO 6
    5 H0=1./ALPHA*(EMAV-CPR*ALOG(1.+EMAV/CPR))
      H3=H3+A6*H0
      H4=H4-C6*H0
      S3 = S3+B6*H0
      S4 = S4-C6*H0
    6 HG=H1+H2+J*H3+J*EKTDTC*(1.+KTDTC)*H4+X
      SG=S1+S2-J*S3+J*EKTDTC*K/TC*S4+Y
C
C     CALCULATE 'HF' AND 'SF'
      HF = HG - HFG
      SF = SG-SFG
      RETURN
C
C     PRINT ERROR MESSAGE IF
C        TF IS LESS THAN OR EQUAL TO ZERO DEGREE R
C        TF IS GREATER THAN THE CRITICAL TEMPERATURE
  999 WRITE(IWRITE,1000)
 1000 FORMAT(' *****ERROR IN CALLING SUBROUTINE -SATPRP-')
      RETURN
      END
```

```
      SUBROUTINE TRIAL(NR,TI,DTI,P,N,ARG,TOL,V,H,S,T)
C
C     PURPOSE
C        TO DETERMINE REMAINING SUPERHEATED VAPOR PROPERTIES,
C        GIVEN THE PRESSURE AND ONE OTHER PROPERTY
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                 ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED           ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,          ***
C***           HEAT TRANSFER LABORATORY,                        ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.           ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        NR    -  REFRIGERANT NUMBER (12,22, OR 502)
C        TI    -  INITIAL T5MPERATUR5 GUESS  (F)
C        DTI   -  INITIAL STEP SIZE 6OR TEMP. ITERATION (F)
C        P     -  PRESSURE 'PSIA)
C        N     -  ARGUMENT INDICATOR
C        IF N = 2, THE SECOND KNOWN PROPERTY IS SPECIFIC VOL.
C        IF N = 3, THE SECOND KNOWN PROPERTY IS ENTHALPY
C        IF N = 4, THE SECOND KNOWN PROPERTY IS ENTROPY
C        ARG   -  THE SECOND KNOWN PROPERTY
C        TOL   -  CONVERGENCE TOLLERANCE
C      OUTPUT
C        V     -  SPECIFIC VOLUME OF VAPOR (CU FT/LBM)
C        H     -  ENTHALPY OF VAPOR (BTU/LBM)
C        S     -  ENTROPY OF VAPOR (BTU/LBM-R)
C        T     -  TEMPERATURE OF VAPOR (F)
C     REMARKS
C        THIS PROGRAM CALLS SUBROUTINE VAPOR TO DETERMINE
C        THE DESIRED REFRIGERANT PROPERTIES
C
      T = TI
      DT = DTI
      DO 20 I = 1,40
      T = T+DT
      CALL VAPOR(NR,T,P,VVAP,HVAP,SVAP)
      IF(N.EQ.2)ARGN = VVAP
      IF(N.EQ.3) ARGN = HVAP
      IF(N.EQ.4) ARGN = SVAP
      IF((N.NE.2).AND.(N.NE.3).AND.(N.NE.4)) GO TO  25
      IF(DT.LT.0.0) DIFF = ARG - ARGN
      IF(DT.GT.0.0) DIFF = ARGN - ARG
      IF(DT.EQ.0.0) GO TO 25
      IF(ABS(DIFF).LE.TOL) GO TO 30
      IF(DIFF) 20,30,10
   10 T = T - DT
      DT = DT/2.0
   20 CONTINUE
   25 WRITE(6,100) N
   30 V = VVAP
      H = HVAP
      S = SVAP
      RETURN
  100 FORMAT(' *****TRIAL DOES NOT CONVERGE N=',I2,' ******')
      END
```

```
      SUBROUTINE SPFHT(NR,TF,PPSIA,CV,CP,GAMMA,SONIC)
C
C     PURPOSE
C        TO CALCULATE SPECIFIC HEAT AT CONSTANT VOLUME,
C        SPECIFIC HEAT AT CONSTANT PRESSURE, SPECIFIC
C        HEAT RATIO, AND SONIC VELOCITY FOR
C        REFRIGERANT 12,22, OR 502
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                   ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED             ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,            ***
C***           HEAT TRANSFER LABORATORY,                          ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.             ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        NR    -   REFRIGERANT NUMBER (12,22, OR 502)
C        TF    -   TEMPERATURE (F)
C        PPSIA-    PRESSURE (PSIA)
C      OUTPUT
C        CV    -   SPECIFIC HEAT AT CONSTANT VOL. (BTU/LBM-R)
C        CP    -   SPECIFIC HEAT AT CONSTANT PRES. (BTU/LBM-R)
C        GAMMA-    SPECIFIC HEAT RATIO
C        SONIC-    SONIC VELOCITY (FPS)
C     REMARKS
C        FUNCTION SUBPROGRAM SPVOL CALLED BY THIS SUBROUTINE
C        FUNCTION SUBPROGRAM TSAT CALLED BY THIS SUBROUTINE
C        SUBROUTINE TABLES CALLED BY THIS SUBROUTINE
      REAL K
C     CONSTANTS
C        CRITICAL POINT PROPERTIES  TC,  PC,   VC
C        INITIAL APPROXIMATION CONSTANTS  A, B (NOT USED)
C        MISCELLANEOUS CONSTANTS   TFR,   LE10
      COMMON/SUPER/ TC,PC,VC,A,B,TFR,LE10
C       EQUATION OF STATE CONSTANTS
      COMMON/STATEQ/R,B1,A2,B2,C2,A3,B3,C3,A4,B4,C4,A5,B5,
     1C5,A6,B6,C6,K,ALPHA,CPR
C        SPECIFIC HEAT AT CONSTANT VOLUME CONSTANTS
C        ACV,BCV,CCV,DCV,ECV,FCV
C        ENTHALPY AND ENTROPY OF VAPOR CONSTANTS    X,   Y
C        MISCELLANEOUS CONSTANTS    L10E,  J
      COMMON/OTHER/ACV,BCV,CCV,DCV,ECV,FCV,X,Y,L10E,J
C
C     OBTAIN VALUES OF THE CONSTANTS CORRESPONDING TO THE
C     DESIRED REFRIGERANT FROM SUBROUTINE TABLES
C     (THROUGH COMMON)
      CALL TABLES(NR,I)
C
      IWRITE = 6
C     CONVERT 'TF' TO 'T' AND CHECK VALUE
      T = TF + TFR
      IF(T.LE.0.0) GO TO 999
C     CALCULATE 'TFSAT' AND COMPARE WITH 'TF'
      TFSAT = TSAT(NR,PPSIA)
      IF(TF.LT.TFSAT) GO TO 999
C
C     CHECK 'PPSIA'
      IF(PPSIA.LE.0.0) GO TO 999
C
C     CALCULATE 'VVAP'
```

```
      VVAP = SPVOL(NR,TP,PPSIA)
C
C     CALCULATION OF DERIVATIVES
      V1 = VVAP - B1
      V2 = V1**2
      V3 = V1**3
      V4 = V1**4
      V5 = V1**5
      V6 = V1**6
      EKTTC=EXP(-K*T/TC)
      Z = ALPHA*VVAP
      Z2 = 2.*Z
      Z3=3.*Z
      IF(Z.GT.150.0) Z = 150.0
      IF(Z2.GT.150.0) Z2 = 150.0
      IF(Z3.GT.150.0) Z3=150.0
      GO TO(1,2,3),I
    1 FDPDV=0.0
      FDPDT = 0.0
      GO TO 4
    2 FDPDV=-ALPHA*EXP(-Z)*(A6+B6*T)
      FDPDT=B6*EXP(-Z)
      GO TO 4
    3 FDPDV=-(ALPHA*(EXP(-Z3)+2.*CPR*EXP(-Z2))/(EXP(-Z2)+2.
     1*CPR*EXP(-Z)+CPR**2))*(A6+B6*T+C6*EKTTC)
      FDPDT=(B6-K*C6*EKTTC/TC)*EXP(-Z2)/(EXP(-Z)+CPR)
    4 DPDV=-R*T/V2-2.*(A2+B2*T+C2*EKTTC)/V3-3.*(A3+B3*T+C3*
     1EKTTC)/V4-4.*(A4+B4*T+C4*EKTTC)/V5-5.*(A5+B5*T+C5*EKT
     2TC)/V6+FDPDV
      DPDT=R/V1+(B2-K*C2*EKTTC/TC)/V2+(B3-K*C3*EKTTC/TC)/V3
     1+(B4-K*C4*EKTTC/TC)/V4+(B5-K*C5*EKTTC/TC)/V5+FDPDT
      GO TO(5,5,10),I
    5 FCCV = 0.0
      GO TO 15
   10 FCCV=C6*EXP(-Z)/ALPHA-(C6*CPR/ALPHA)*ALOG(1.+EXP(-Z)/
     1CPR)
C
C     CALCULATE 'CV'
   15 CV=ACV+BCV*T+CCV*T**2+DCV*T**3+FCV/T**2-(.185053*K**2
     1*T*EKTTC/TC**2)*(C2/V1+C3/(2.*V2)+C4/(3.*V3)+C5/(4.*V
     24)+FCCV)
C
C     CALCULATE 'CP'
      CP = CV-.185053*T*DPDT**2/DPDV
C
C     CALCULATE 'GAMMA'
      GAMMA = CP/CV
C
C     CALCULATE 'SONIC'
      SONIC=VVAP*SQRT(857.36091*T*DPDT**2/CV-4633.056*DPDV)
      RETURN
C
C     PRINT ERROR MESSAGE IF
C        TF IS LESS THAN OR EQUAL TO ZERO DEGREE R
C        TF IS LESS THAN TFSAT CORRESPONDING TO PSAT = PPSIA
C        PPSIA IS LESS THAN OR EQUAL TO ZERO
  999 WRITE(IWRITE,1000)
 1000 FORMAT(' ********ERROR IN CALLING SUBROUTINE -SPFHT-')
      RETURN
      END
```

```
      SUBROUTINE SPHTC(DE,G,C1,C2,C3,C4,C5,C6,XLL,UL,XMU,
     1CP,PR,RE,HTC)
C
C     PURPOSE
C        TO DETERMINE SINGLE PHASE HEAT TRANSFER
C        COEFFICIENTS AND REYNOLDS NUMBERS
C        IN LAMINAR,TRANSITION, OR TURBULENT FLOW
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED           ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,          ***
C***           HEAT TRANSFER LABORATORY,                        ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.           ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        DE     -  EQUIVALENT DIAMETER OF FLOW PASSAGE (FT)
C        G      -  MASS FLOW PER UNIT AREA (LBM/HR-SQ FT)
C        C1-C6- CONSTANTS DESCRIBING DESIRED HEAT
C                  TRANSFER COEFFICIENT RELATION
C        XLL    -  LOWER REYNOLDS NUMBER LIMIT FOR LAMINAR FLOW
C        UL     -  UPPER REYNOLDS NUMBER LIMIT FOR TURB. FLOW
C        XMU    -  VISCOSITY OF FLUID (LBM/HR-FT)
C        CP     -  SPECIFIC HEAT AT CONSTANT PRES.(BTU/LBM-R)
C        PR     -  PRANDTL NUMBER
C      OUTPUT
C        RE     -  REYNOLDS NUMBER
C        HTC    -  SINGLE PHASE HEAT TRANS.COEF.(BTU/HR-SQ FT-F)
C
      RE = DE*G/XMU
C
C     LAMINAR FLOW REGIME
      IF(RE.LT.XLL) HTC = C1*G*CP*PR**(-.667)*RE**C2
C
C     TRANSITION FLOW REGIME
      IF((RE.GE.XLL).AND.(RE.LT.UL)) HTC=C3*G*CP*PR**(-.667
     1)*RE**C4
C
C     TURBULENT FLOW REGIME
      IF(RE.GE.UL) HTC = C5*G*CP*PR**(-.667)*RE**C6
      RETURN
      END
```

```
      SUBROUTINE SEFF(XK,DELTA,HA,XL,FAR,CAR,HCONT,SEFFR)
C
C     PURPOSE
C        TO DETERMINE THE SURFACE EFFICIENCY
C        FOR A FINNED SURFACE, ACCOUNTING FOR CONTACT
C        RESISTANCE BETWEEN FINS AND BASE
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN             ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED       ***
C***           FROM THAT GIVEN IN REPORT NO. 24525-96,      ***
C***           HEAT TRANSFER LABORATORY,                    ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.       ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        XK   -  THERMAL CONDUCTIVITY OF FIN (BTU/HR-FT-F)
C        DELTA-  FIN THICKNESS (FT)
C        HA   -  EXTERNAL HEAT TRANS.COEF.(BTU/HR-SQ FT-F)
C        XL   -  LENGTH CF FIN (FT)
C        FAR  -  RATIO - FIN HEAT TRANS.AREA/TOTAL H.T. AREA
C        CAR  -  RATIO - FIN HEAT TRANS.AREA/CONTACT AREA
C        TO ACCOUNT FOR CONTACT RESISTANCE BETWEEN FINS
C        AND BASE
C        HCONT-  CONTACT RESISTANCE (BTU/HR-SQ FT-F)
C      OUTPUT
C        SEFFR-  OVERALL SURFACE EFFICIENCY
C
C     FIN EFFICIENCY
      XM = SQRT(2.0*HA/(XK*DELTA))
      FINEF =  (EXP(XM*XL)-EXP(-XM*XL))/((EXP(XM*XL)+EXP(-XM
     1*XL))*XM*XL)
C
C     SURFACE EFFICIENCY
      SEFFR=1.0-FAR*(1.0-1.0/(CAR*HA/HCONT+1.0/FINEF))
      RETURN
      END
```

```
      SUBROUTINE EXF(RTOT,CA,CR,CMIN,EXFR)
C
C     PURPOSE
C        TO DETERMINE THE EFFECTIVENESS OF A CROSS FLOW HEAT
C        EXCHANGER USING THE EFFECTIVENESS-NTU METHOD
C
C***  AUTHORS  C. C. HILLER AND L. R. GLICKSMAN                    ***
C***           THIS SUBPROGRAM APPEARS HERE UNCHANGED               ***
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C***           HEAT TRANSFER LABORATORY,                            ***
C***           MASSACHUSETTS INSTITUTE OF TECHNOLOGY.               ***
C
C     DESCRIPTION OF PARAMETERS
C      INPUT
C        RTOT -  TOTAL RESISTANCE TO HEAT FLOW
C        BETWEEN FLUIDS ((HR-F)/BTU)
C        CA   -  TOTAL HEAT CAPACITY OF FLUID A (BTU/R)
C        CR   -  TOTAL HEAT CAPACITY OF FLUID R (BTU/R)
C      OUTPUT
C        CMIN -  THE SMALLER OF CA AND CR (BTU/R)
C        EXFR -  EFFECTIVENESS OF CROSS FLOW HEAT EXCHANGER
C
C     DETERMINE CMIN AND NTU
      IF(CR/CA.LT..999) GO TO 5
      IF(CA/CR.LT..999) GO TO 10
      CMIN = CA
      CMAX = CR
      XNTU = 1.0/(CMIN*RTOT)
      ECF = XNTU/(1.0 + XNTU)
      GO TO 20
    5 CMIN = CR
      CMAX = CA
      GO TO 15
   10 CMIN = CA
      CMAX = CR
   15 XNTU = 1.0/(CMIN*RTOT)
C
C     EVALUATE COUNTER FLOW EFFECTIVENESS
      ECF = (1.0-EXP(-XNTU*(1.0-CMIN/CMAX)))/(1.0-CMIN/CMAX
     1*EXP(-XNTU*(1.0 - CMIN/CMAX)))
C
C     APPLY CORRECTION FACTOR TO COUNTER FLOW EFFECTIVENESS
C     TO OBTAIN CROSS FLOW EFFECTIVENESS
   20 EXFR= ECF/((1.0 + .047*CMIN/CMAX)*XNTU**
     1(.036*CMIN/CMAX))
      RETURN
      END
```

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