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SIMULATION MODEL OF A SINGLE-STAGE LITHIUM BROMIDE - WATER

ABSORPTION COOLING UNIT

by David Miao

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SUMMARY

The performance and load capability of a given $LiBr$-H_2O absorption chiller operating with a hot-water heat source depends on six quantities: the inlet temperatures and flow rates of the hot-water source, the cooling-tower water, and the return chiller water. Based on this, a computer model for a single-stage absorption cooling machine has been developed which does not require data relative to the interior characteristics of the machine (heat-transfer rates and surfaces). The model considers both heat-transfer and thermodynamic processes. It consists of two algorithms, one for the design, or reference conditions, and the other for the off-design analysis. It is constructed from the steady-state equations but may also be used for the transient analysis of a cooling system.

The program can be used in an independent mode or as a subroutine, as for example, with TRNSY'S, for the analysis of a cooling system. For a given size of machine the model can be used to predict off-design cooling-system performance, the only input requirements being a set of reference or rated conditions for the machine.

INTRODUCTION

The $LiBr$-H_2O absorption liquid chiller has been used in the refrigeration and air-conditioning industry for some time. One of the primary reasons for using this type of machine is that steam or hot water, whichever is available, can be directly used as an energy source to power the machine. This characteristic is particularly attractive for solar-cooling applications.

In a typical solar-cooling application, water heated through the passages of a bank of solar energy collectors is used to power an absorption machine to provide chilled water which in turn is used to air condition the building.

Typically an absorption chiller is designed to handle the maximum expected load of the building. The design point thus represents a set of fixed operating conditions. However, the actual load varies with building heat-transfer characteristics as well as local weather conditions. The design load may seldom be experienced. Since the chilled-water temperature is likely to increase with decreasing heat load (part-load operation), the chiller may be incapable of dehumidification.

An approach is, prior to machine selection, to simulate various loading conditions through a computer model of the machine. The typical models available today are either empirical (ref. 1), or based upon a thermodynamic approach. The former generally represents a specific machine, and therefore its usefulness is limited; the latter is useful for providing a set of design conditions to the machine manufacturer to determine the size of an absorption machine.

A thermodynamic approach can be used for simulating various operating conditions but such a model does not recognize limitations of the heat-transfer processes. A better approach is to take both heat-transfer and thermodynamic processes into consideration. Furthermore, if an existing machine is selected for a specific job, the heat-transfer surfaces in the machine are fixed but often not known, and therefore it will be difficult to determine the capability of the machine over a range of operating conditions. The only known inputs are three sets of inlet flows and temperatures to the machine: namely, the flow rates and corresponding temperatures of the return chilled water, the cooling water, and the incoming hot water. The unknowns required to be established are the corresponding outlet temperatures of the three flow streams. A computer model for handling this type of problem is not generally available. The purpose of this report is to document a method for modeling the system.

THERMODYNAMIC CYCLE

The thermodynamic cycle of the absorption machine is well known (refs. 2 to 4). Figure 1 represents a typical arrangement of a single-stage machine. The machine basically consists of five heat exchangers called a generator, a condenser, an evaporator, an absorber, and a solution heat exchanger. For a heat load imposed on the evaporator E, the LiBr-H$_2$O strong solution is pumped through the solution heat exchanger X to the generator G. Heat energy is added in the generator G to drive out the refrigerant (in this case, water is the refrigerant). The remaining solution is called the weak solution. A portion of the weak solution is forced through the solution exchanger X and a pressure reducing valve V1 back to the absorber A for the next cycle. To make a strong solution in the absorber A, the refrigerant leaving the generator G must also be brought back to the absorber through a condenser-evaporator path. In the process, the refrigerant is first condensed by removing its latent heat in the condenser C; then in passing

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through an expansion valve V2, the pressure and the temperature of the refrigerant are reduced. The refrigerant is evaporated due to heat load addition in the evaporator E. The refrigerant vapor is then brought to the absorber A to be absorbed. When the heat of absorption is removed, the strong solution is restored and the new cycle begins.

Most commercial machines are built on this basis. To simulate machine performance, a thermodynamic cycle analysis is used to perform heat balance calculations in order to establish heat input and cooling requirement for a refrigeration load. Heat inputs and outputs of the machine are marked in figure 1. The solid arrow lines indicate the direction of heat flow as well as fluid flow interior to the machine while the dashed lines indicate heat or fluid flowing into or out of the machine. Figure 1 is used to construct the thermodynamic portion of the machine model.

To perform such calculations, thermodynamic properties of the water and the LiBr-H_2O solution are also needed. Such information is readily found in reference 2 (the formulas used may be found in appendix A).

HEAT-TRANSFER CONSIDERATIONS

The thermodynamic analysis determines the cycle temperatures and the required heat flows for the five heat exchangers in the absorption machine as shown in figure 1. For a given refrigeration load, the heat exchangers must be designed to satisfy the aforementioned requirements. Once the heat exchangers are designed, the heat-transfer surfaces are fixed and heat transfer is limited by the surfaces provided in the machine. Therefore, for all operating loads the performance of the machine is determined from the actual heat-transfer surface areas.

In terms of heat-transfer processes on the LiBr-H_2O solution side, the heat exchangers may be classified into two types: The solution heat exchanger X (fig. 1) which deals strictly with sensible heat transfer is one type - and the other four: G, A, E, and C (fig. 1) which involve latent heat are another type. Heat exchangers G and A deal also with the heat of absorption, but since their heat-transfer coefficients are high and their temperature profiles are fairly constant, the heat-transfer analysis is treated in the same manner as those of exchangers E and C. The following equations (ref. 5) are used for these four exchangers:

$$EFFN = \frac{T_1 - T_2}{T_1 - T}$$ (1)

where

EFFN   temperature effectiveness of heat exchanger

T_1 inlet temperature of heating or cooling medium

T_2 outlet temperature of heating or cooling medium

T   temperature of LiBr-H_2O solution of refrigerant (water) undergoing evaporation, absorption, or condensation process

To relate the temperature field to the heat transfer, EFFN is rewritten as

$$EFFN = 1 - e^{-UA/GC_p} \qquad (2)$$

where

U   overall heat-transfer coefficient of heat exchanger

A   total heat-transfer surface

G   flow rate of heating or cooling medium

C_p heat capacity of medium

Equations (1) and (2) are used to solve for the required outlet temperatures T_2's of the four heat exchangers involving external fluid flows. Ideally, if all temperatures and flow rates are given at the design load, equations (1) and (2) should resolve four UA's for that machine.

To simulate various heat loads other than the design, the corresponding UA's must be calculated from additional equations so that equations (1) and (2) can be used to obtain the various outlet temperatures T_2's. However, the information about the heat-transfer surface is usually not available and the UA terms are inseparable. Therefore, the next equations are derived on the UA term basis.

Heat exchangers of this kind are typical shell-tube type. The cooling or heating medium is usually on the tube side, and the refrigerant (water) or LiBr-H_2O solution is on the shell side. The heat-transfer process is governed by the mechanism of the fluid flow on both sides and the tube wall thermal resistance. By definition U is written as

$$\frac{1}{U} - \frac{1}{h_w} + \frac{1}{h} + R_t + F \qquad (3a)$$

where

h_w tube-side coefficient due to forced convection

h   shell-side coefficient

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R_t tube wall resistance

F   sum of fouling factors on both sides

The R_t term in formula (3a) is a function of the tube wall thickness and the mate-rial of construction. Typically, its magnitude is very small because of low pressure operation and the use of high conductivity copper based tube material.

The design or selected fouling factor F (ref. 6) is also rather small. The true foul-ing factor varies with water conditioning and plant operation and cannot be established without test data. Both R_t and F may be considered constant throughout machine operation.

The h term, due to latent heat transfer, is very high for a good cost effective heat exchanger design. The h value for boiling water or steam condensation may be on the order of two to six times the forced convection coefficient h_w (ref. 7). Therefore, it is not a strong factor on the overall heat-transfer coefficient U, which may be conveniently written as

$$U = h_w \left(\frac{1}{1 + h_w R} \right) \tag{3b}$$

where R is the sum of the resistances $(1/h) + R_t + F$.

Equation (3b) implies that U can be found if h_w is known.

To find h_w on the tube side, the following forced convection formula for turbulent flow (ref. 7) is used:

$$\frac{h_w D}{k} = (0.23) \left(\frac{DG}{\mu A_c} \right)^{0.8} \left(\frac{C_p \mu}{K} \right)^{0.4} \tag{4a}$$

where

D   inside diameter of tube

K   thermal conductivity

μ viscosity

A_c flow area

Equation (4a) indicates that the change of h_w is sensitive to the changes of the flow rate G (eight-tenth power function) but less dependent on the heat transport properties. Furthermore, the fluid temperature variations for an absorption machine are rather small, especially in a solar application; thus these temperature dependent properties remain practically constant. Therefore equation (4a) may be rewritten as

$$h_w \propto G^{0.8}$$

Since proportionality can be established, h_w may be written as follows in terms of a reference condition with the subscript 0:

$$h_w = \left(\frac{G}{G_0}\right)^{0.8} h_{w0} \tag{4b}$$

$$U_0 = h_{w0}\left(\frac{1}{1 + h_{w0}R_0}\right) \tag{3}$$

By combining equations (3b), (3c), and (4b) and solving for U, we obtain

$$U = \left(\frac{G}{G_0}\right)^{0.8}\left(\frac{1 + h_{w0}R_0}{1 + h_w R}\right)U_0 \tag{3d}$$

As long as the term $h_w R$ is not substantially different from $h_{w0}R_0$, the factor $(1 + h_{w0}R_0)/(1 + h_w R)$ is approaching unity. If this term is assumed to be one, the expected error in U is 5 to 10 percent. Under the worst conditions, the error may be as high as 20 percent. Therefore, equation (3d) may be reduced to

$$U = \left(\frac{G}{G_0}\right)^{0.8} U_0$$

or

$$UA = \left(\frac{G}{G_0}\right)^{0.8}(UA)_0 \tag{3e}$$

Equation (3e) implies that, if a reference condition is known, the UA term at other conditions can be found given the right flow proportions. To find a reference UA, equations (1) and (2) must be used and flow rates are referred to the reference condition. Using actual measured values in the aforementioned formulas instead of the machine design values for the reference point is desirable wherever possible.

The second type of heat exchanger in the absorption machine is a liquid to liquid exchanger (exchanger X in fig. 1). This exchanger is placed in the absorption circuit to improve cycle efficiency. It is also typical of a shell-tube type with a true counterflow arrangement for better heat recovery. The strong solution (rich with water refrigerant)

is pumped through the tubes and the weak solution flows across the tube bundles, with flow deflecting baffles. As was pointed out previously, the heat-transfer rate is a strong function of the flow rate. The strong solution flow rate is greater than that of the weak one. To achieve a high heat-transfer coefficient on the tube side, it is natural for the heat exchanger designer to place the strong solution in the tubes. In addition, the better heat transport properties of the strong solution (more water content) aid in achieving a high coefficient. The lower shell-side coefficient of the weak solution can be improved by using spaced baffles.

Equation (4a) is used to calculate the tube-side coefficient. Equation (4b) is also applicable if the heat transport properties remain practically constant.

As indicated previously, equation (4a) or (4b) is applicable for turbulent flow. For a true counterflow type of heat exchanger, or single-tube pass arrangement, the velocity in the tubes may be reduced under some part load operation. It is possible the flow pattern may shift into the laminar region. Then equation (4a) or (4b) would not be applicable, and the formula for laminar flow (ref. 7) would have to be used.

Since this report is concerned with the simulation of a previously designed machine without knowing the interior arrangement of the heat-transfer surface areas, the laminar formula, even if it is available, is probably not useful for model construction. However, it is reasonable to assume that the turbulent flow formula is used for calculating the tube-side heat-transfer coefficient. In these machines, the heat exchanger with longer tube lengths (thus small flow area and high velocity in the tube) is commonly seen in commercial machines.

The formula for the shell-side coefficient (ref. 7) may be written as follows because the heat transport properties remain practically constant:

$$\frac{h_{gw} D_e}{K} = 0.33 \left(\frac{D_e G_w}{\mu A_{cross}} \right)^{0.6} \left(\frac{\mu C_p}{K} \right)^{0.3}$$

or

$$h_{gw} \propto G_w^{0.6} \tag{5}$$

where

D_e equivalent diameter

h_{gw} coefficient of weak solution flow rate

A_{cross} flow passage area measured along shell inside diameter

Unlike the tube-side formula, equation (5) is not restricted by the turbulent flow. The shell-side coefficient can be increased by means of closer baffle spacings.

Therefore, it is reasonable to assume that the weak solution with less flow rate is on the shell side.

The relation between the overall heat transfer and the individual coefficients is the same as that of equation (3a). In this case the controlling resistance is on the tube side because of the single tube pass arrangement. The magnitude may be on the order of the shell-side coefficient. Since heat-transfer coefficients on both sides are poor, the magnitude of $(1/h_w) + (1/h)$ in equation (3a) is much larger than that of R_t and F (perhaps 10 times larger); therefore, R_t and F are neglected and equation (3a) may be rewritten as

$$\frac{1}{U_x} = \frac{1}{h_{gs}} + \frac{1}{h_{gw}} \tag{6a}$$

where

x   refers to solution exchanger

gs   refers to strong solution

gw   refers to weak solution

For a referenced condition, equation (6a) becomes

$$\frac{1}{U_{x0}} = \frac{1}{h_{gs0}} + \frac{1}{h_{gw0}} \tag{6b}$$

Once again for a given machine, where the interior construction of the machine is not known, equation (6b) cannot be solved without making assumptions. If h_{gs0} and h_{gw0} are assumed equal, equation (6b) becomes

$$h_{gs0} = h_{gw0} = 2U_{x0} \tag{7}$$

By combining equations (7) and (4a) or (5), h_{gs} and h_{gw} can be obtained for other simulated conditions; specifically

$$h_{gs} = \left(\frac{G_s}{G_{s0}}\right)^{0.8} \qquad h_{gs0} = \left(\frac{G_s}{G_{s0}}\right)^{0.8} (2U_0) \tag{8}$$

$$h_{gw} = \left(\frac{G_w}{G_{w0}}\right)^{0.6} \qquad h_{gw0} = \left(\frac{G_w}{G_{w0}}\right)^{0.6} (2U_0) \tag{9}$$

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Then substituting equations (8) and (9) into equation (6a) and rearranging the terms yield

$$U_x = (2U_{x0}) \left[\frac{1}{\left(\dfrac{G_{s0}}{G_s}\right)^{0.8} + \left(\dfrac{G_{w0}}{G_w}\right)^{0.6}} \right] \tag{10}$$

Since the heat-transfer surface area is fixed, equation (10) may be written as

$$(UA)_x = 2(UA)_{x0} \left[\frac{1}{\left(\dfrac{G_{s0}}{G_s}\right)^{0.8} + \left(\dfrac{G_{w0}}{G_w}\right)^{0.6}} \right] \tag{11a}$$

Equation (11a) again shows that the overall heat-transfer rate at any other condition can be established through a known reference condition (design or test). Equations (8) and (9) can also be extended to include the property corrections if better accuracy is desired. The heat transport properties except thermal conductivity may be found in reference 3. For thermal conductivity values for various LiBr-H_2O solutions, a fraction of water conductivity proportional to water concentration are suggested. In general these effects on heat-transfer coefficients are small and will not be taken into consideration at this time.

The aforementioned equations were derived on the assumption that $h_{gs0} = h_{gw0}$; the assumption appears valid because (1) the fluid properties on both shell and tube sides are similar and (2) the flow rates are not substantially different within the operating range of the solution concentration. However, if h_{gs0} is substantially different from h_{gw0}, equation (11a) may be generalized as

$$(UA)_x = (F1)(UA)_{x0} \left[\frac{1}{\left(\dfrac{G_{s0}}{G_s}\right)^{0.8} + (F2)\left(\dfrac{G_{w0}}{G_w}\right)^{0.6}} \right] \tag{11b}$$

where, for example,

$$h_{gs0} = h_{gw0} \qquad F1 = 2 \text{ and } F2 = 1$$

$$h_{gs0} \ll h_{gw0} \qquad F1 = 1 \text{ and } F2 = 0$$

$$h_{gs0} = 1.5h_{w0} \qquad F1 = 2.5 \text{ and } F2 = 2/3$$

Equation (11b) may be useful to experimentally determine the actual values of F1 and F2 for use in the program for a given machine.

Equation (11a) or (11b) can be solved if $(UA)_{x0}$ is known or may be found from a given set of the design temperatures. The effectiveness is given in terms of the temperatures (refs. 1 and 4) as

$$EFFNX = \frac{T_g - T_5}{T_g - T_a} \tag{12}$$

where

T_g temperature of generator

T_5 outlet temperature of weak solution

T_a temperature of absorber

In general the exchanger is designed with the effectiveness $EFFNX_0 = 0.7$ to 0.8. If T_5 in equation (12) for the design load is not known, the relation between $EFFNX_0$ and T_{50} may be established by heat balance (ref. 1).

When $EFFNX_0$ is found together with flow rates G_{s0} and G_{w0} and the solution heat capacities C_{s0} and C_{w0}, then $(UA)_{x0}$ is calculated from the following equation:

$$EFFNX = \frac{1 - e^{-NTU_x\left[(1 - (C_{min}/C_{max})\right]}}{1 - \left(\dfrac{C_{min}}{C_{max}}\right)e^{-NTU_x\left[1-(C_{min}/C_{max})\right]}} \tag{13}$$

where

$NTU_x \quad (UA)_x/C_{min}$

$C_{min} \quad G_w C_w$

$C_{max} \quad G_s C_s$

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C_w heat capacity of weak solution

C_s heat capacity of strong solution

The subscript 0 used previously has been deliberately omitted in equations (12) and (13) for the purpose of generalization. Then $C_{min} = (G_w C_w)$ and $C_{max} = (G_s C_s)$ because $G_w < G_s$ and $C_w < C_s$ for LiBr-H_2O absorption machine. The $(UA)_{x0}$ is solved implicitly in equation (13).

OTHER CONSIDERATIONS

The equations derived in the previous section together with the thermodynamic equations discussed in the section THERMODYNAMIC CYCLE are the working formulas for the five heat exchangers to be used in the construction of the simulation model. In addition to these formulas, heat losses, pump capacity, operating range of the solution concentrations, and operating temperature limits should be included. Unfortunately machine construction does vary with the design approach of different manufacturers, and the construction information is usually not available. It is difficult to generalize all the limitations to be accommodated by the model. Nevertheless, some of the important considerations that should be taken into account follow.

Heat Losses

The heat losses vary with the specific design and the ambient environment in which the machine is installed. Heat may leak out of or into the machine, and between the partition shells separating the heat exchangers in the machine. The result is that additional heat supply is required to accommodate these losses. To account for these losses, a simplistic approach is to add a fixed percentage to the heat supply. A few percent may be sufficient for the type machine considered herein. The thermodynamic equations (appendix A) may be modified as follows:

$$Q_G = (G_w H_5 - G_s H_1 + G_R H_7)(FGQ) \tag{14}$$

$$Q_C = G_R(H_7 - H_8)\left[1 + \left(\frac{Q_G}{Q_G + Q_E}\right)(1 - F_{QG})\right] \tag{15}$$

$$Q_A = (G_w H_5 - G_s H_1 + G_R H_{10})\left[1 + \left(\frac{Q_G}{Q_G + Q_E}\right)(1 - F_{QG})\right] \tag{16}$$

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where

F_{QG} multiplication factor

$F_{QG} = 1$ (no heat loss considered)

$F_{QG} = 1.02$ (equivalent 2 percent loss)

Solution Pump Capacity

Normally the pump capacity is chosen to meet the design load. For part load oper-
ation, the required flow rate may or may not exceed the maximum capacity. For a par-
ticular load demand, if heat source temperature is low and/or the cooling water temper-
ature is high, the machine, based on the thermodynamic cycle analysis, tends to demand
more solution flow. Since the flow control is not known and varies somewhat with differ-
ent machines, it is assumed that the solution flow rate cannot exceed the capacity of the
design point.

Concentration of the LiBr-H_2O Solution

For an absorption process to exist in operation, there are limits on the solution con-
centrations. If the concentration is too rich, crystallization will occur. If the concen-
tration is too lean, no absorption process will occur. Reference 2 suggested that the
concentrations should be kept within 0.5 to 0.65 range. For this model a range from
0.4 to 0.68 has been used.

Temperatures and Temperature Differences

The temperature limitations, like the solution concentrations, are set for the oper-
able absorption process. Usually these are the outlet temperatures of the external fluids
in heat exchanger G, C, A, and E (fig. 1). The limits of these temperatures have been
placed in the program (see appendix B).

In addition to the temperature limits, the temperature difference across the heat ex-
changer surfaces are also limited by the heat-transfer processes. In general the tem-
perature differences between the two heat exchange mediums at outlet condition will be
used for setting the limits (see appendix B).

When the aforementioned limits and the concentration limits are properly set, the
solution heat exchanger temperature as well as the pressure limits may be neglected.

MODELING ALGORITHM

    With the necessary equations and the limiting conditions established, the next step is
to formulate an algorithm for computer operation. The desired solution for a given set
of inputs is the one that achieves the lowest possible outlet temperature of the chilled
water. The heat balance is not only required to satisfy the thermodynamic analysis but
also simultaneously satisfy the heat exchanger equations.

    The model consists of two different algorithms. One part is used to solve for the
reference or design conditions. Another part is used to solve for the off-design condition
based on the established reference condition. The second part is simply to perform an
internal heat balance to establish the corresponding outlet temperatures of the three flow
streams, namely hot water GH, cooling water GC, and chilled water GE. The calcula-
tion sequence for this part is first outlined as follows:

(1) Input GH, GC, GE, TH1, TA1, TE1 and an off-design tonnage, (see fig. 1).

(2) Calculate flow rate per ton for flow GH, GC, and GE.

(3) Calculate effectiveness (eq. (2)) for exchanger G, C, A, and E.

(4) Calculate TE2, TE, TH2, and TG.

(5) Calculate TC2 with an assumed COP.

(6) Assume TA.

(7) Calculate TC.

(8) If TA or TC exceed limits, change tonnage.

(9) Calculate TG, TC, TA, and TE with newly assumed tonnage.

(10) Calculate solution concentration.

(11) If X1 or X4 exceeds limits, change tonnage.

(12) Calculate enthalpies H8 and H10 of refrigerant at outlets of condenser C
     and evaporator E, respectively.

(13) Calculate refrigerant flow GR and solution flows GS and GW, respectively.

(14) Calculate effectiveness EFFNX of solution exchanger.

(15) Calculate two outlet temperatures T3 and T5 of solution exchanger.

(16) Calculate refrigerant enthalpy H7 at outlet of generator G, weak solution
     enthalpy H5 at outlet of solution exchanger X, and strong solution enthalpy
     H, at outlet of absorber A.

(17) Calculate generator heat QG, condenser heat QC, and absorber heat QA.

(18) Calculate COP.

(19) If TA is not agreeable with assumed value, adjust TA to suit.

(20) If COP is not agreeable with assumed value, adjust COP to suit.

(21) Check temperature difference limits.

(22) Check pumping rate limits.

(23) Check concentration limits.

(24) Force tonnage to maximum.

(25) Check chilled water outlet temperature TE2 at set point.

(26) Calculate pressure PE and PC.

To establish the reference conditions, several of the aforementioned indicated steps are repeated. The algorithm used depends upon the information available.

If all the design or reference temperatures are given but the flow rates are not, steps (10) to (18) and step (26) are repeated. The flow rates and all reference (UA)'s are the calculated outputs. The effectiveness of the solution heat exchanger can be calculated from the known temperatures (eq. (12) as an input to the program).

If all three external flow rates are known instead of their outlet temperatures, steps (1) to (18) and step (26) are repeated. In this case the corresponding outlet temperatures are determined.

If the outlet temperature of the solution heat exchanger T5 or its effectiveness is not given, an assumed effectiveness must be used as an input until a rated reference tonnage is found.

PROGRAM DESCRIPTION

The computer program was written in FORTRAN IV language. It can be used as a subroutine to simulate the absorption machine performance in a cooling system. Although the equations derived are steady-state type, no restriction is imposed for use in the transient analysis of a cooling system.

When used as a subroutine, the program may have to be modified to accept a set of the design or the test conditions. The flow rates and the inlet and outlet temperatures of the three external fluid streams are system connected to run the simulation. If additional outputs such as heat loads, COP, and operating pressures are required, they may be system linked or printed out for analysis.

When used as an independent program, the first case is treated as the reference case. The program calculates additionally needed reference values and stores these values automatically in the program. Starting with the next case, the user inputs as many off-design cases as are desired. NAMELIST input is used in the program.

All tolerances for the limitation conditions discussed previously have been prestored in the program but can be changed as desired. The units system used to perform the calculation is metric but provision to use British units for inputs and outputs is included. Changing either the units or the tolerances shall be discussed in the next section and appendix B.

OPERATION OF THE PROGRAM

Use as a Subroutine

If the program is used as a subroutine, the reference data and program controls must be inserted as data statements or their equivalent by the user. The required data are UAG0, UAC0, UAE0, UAA0, UAX0, GS0, GW0, and TON0. The controls are FQG, METRIC, KLBHR, and JWRITE (see appendixes B and C).

The input variables are currently placed in an array called XIN. These variables (listed in order), are GHT, GCT, GET, TH1, GA1, TE1, and TONX (see appendixes B and C).

The output variables are arranged in an array OUT. These variables are GHT, GCT, GET, TH2, TC2, TE2, and TON. If additional outputs such as COP, PC, and PE are required, the user may place these variables in the additional locations of array OUT (see appendixes B and C).

Use as the Main Program

If the program is used independently, the reference data must be calculated from this program based upon the available design or experimental informations. The input variables in this case will be TH2, TA2, or TC2, TE2, TH1, TA1, TE1, TG, TC, TA, TE, TON0, TONX, KLBHR, METRIC, and JREF (see appendix B and fig. 1). TONX is the initial guess of the actual load. The data are entered via a NAMELIST read and are for reference case. The NAMELIST name is REF. The first tabulated output will be the results of the design conditions and the table is identified with a case marked 0.

To run other cases with fixed heat-transfer surfaces (the same machine), additional cases are placed in the run stream with a NAMELIST name of VAR. As many cases as desired can be run. The input for these cases are GH, CC, GE, TH1, TA1, TE1, and TONX (see appendixes B and C). The outputs are tabulated as before, and the case is identified with a case number greater than 0.

The convergence is controlled by KTA, KCOP, KTON1, and KTON2. If the number of the iterations is excessive, the output may be incorrect. The user must examine the results to decide whether he should increase the number of iterations, or discontinue his run because of exceeding machine operating constraints.

The tolerance controls for the temperatures and concentrations are currently pre-stored in the program (see appendixes B and C). The values may be changed to suit the user's purpose.

SAMPLE CALCULATIONS

Two sample computer printouts are included to demonstrate the use of the program in appendix C.

Sample 1 shows that, for a given set of the design conditions, the program not only finds the correct design load but generates the results for the off-design loads as well.

The absorption machine used in the sample calculations is a TRANE model C1H (ref. 6). This model was designed for a nominal rated tonnage at 174 tons. The print-out table (case 0) shows that the calculated tonnages agree with the design load. The output of this case is then stored in the program as the reference data of the machine to be used for the off-design runs.

A total of 130 off-design cases (the off-design loads and operating conditions in table 2C1H of ref. 6), have been run with the program. Most of the calculated tonnages agree with the data in reference 6 within 2 percent and generally are slightly greater than the table values (two typical cases are shown in appendix C). In some of the cases, however, the calculated values are high by 9 percent. These cases usually are associated with the extremely high or low outlet temperature of the chilled water. All cases were run on the assumption that the nominal design flow rates were chosen to establish the rated table values. If these flow rates are not nominal but varied within the design range, the program calculated tonnages can be brought to agreement with those tables indicated.

Sample 2 was intended to show that, with minor changes, the program can be used as a subroutine in a system program. In this case the system program is TRNSYS (ref. 1). Sample 2 is a solar assisted building cooling system modeled with TRNSYS program (see appendix C).

CONCLUDING REMARKS

A computer model of a $LiBr-H_2O$ single-stage absorption machine has been developed. By utilizing a given set of design data but without knowing the interior characteristics of the machine, the off-design performance can be simulated or evaluated. Although the model is not validated experimentally, it can be a useful tool for analyzing the capability of a given machine, or for studying the machine performance in a cooling system.

Lewis Research Center,
　　National Aeronautics and Space Administration,
　　　　Cleveland, Ohio, May 16, 1978,
　　　　　　776-22.

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APPENDIX A

SYMBOL LIST, THERMODYNAMIC FORMULAS,

AND EQUATIONS FROM REFERENCE 1

Strong concentration ($X1 > 0.5$):

$$X1 = \frac{(49.04 + 1.125\ TA - TE)}{(134.65 + 0.47\ TA)} \quad \frac{\text{kg LiBr}}{\text{kg solution}}$$

Weak concentration ($X4 < 0.65$):

$$X4 = \frac{(49.04 + 1.125\ TG - TC)}{(134.65 + 0.47\ TG)} \quad \frac{\text{kg LiBr}}{\text{kg solution}}$$

Enthalpy of condenser outlet:

$$H8 = (TC - 25) \quad \text{kcal/kg}$$

Enthalpy of evaporator outlet:

$$H10 = (572.8 + 0.417\ TE) \quad \text{kcal/kg}$$

Refrigerant flow:

$$GR = \frac{QE}{(H10 - H8)} \quad \frac{\text{kg}}{\text{hr}}$$

Strong solution flow:

$$GS = GR\ \frac{X4}{(X4 - X1)} \quad \frac{\text{kg}}{\text{hr}}$$

Weak solution flow:

$$GN = GR\ \frac{X1}{(X4 - X1)} \quad \frac{\text{kg}}{\text{hr}}$$

Heat capacity of strong solution:

$$CX1 = 1.01 - 1.23(X1) + 0.48(X1)^2 \quad kcal/(kg)(^{o}C)$$

Heat capacity of weak solution:

$$CX4 = 1.01 - 1.23(X4) + 0.48(X4)^2 \quad kcal/(kg)(^{o}C)$$

Outlet temperature of weak solution

$$T5 = TG - (EFFNX)(TG - TA) \quad ^{o}C$$

Outlet temperature of strong solution:

$$T3 = TA + (EFFNX)\left(\frac{X1}{X4}\right)\left(\frac{CX4}{CX1}\right)(TG - TA) \quad ^{o}C$$

Enthalpy of absorber outlet:

$$H1 = \left[42.81 - 425.92(X1) + 404.67(X1)^2\right] + \left[1.01 - 1.23(X1) + 0.48(X1)^2\right](TA) \quad kcal/kg$$

Enthalpy of weak solution at heat exchanger outlet:

$$H5 = \left[42.81 - 425.92(X4) + 404.67(X4)^2\right] + \left[1.01 - 1.23(X4) + 0.48(X4)^2\right](T5) \quad kcal/kg$$

Enthalpy of refrigerant at generator outlet:

$$H7 = (572.8 + 0.46\ TG - 0.043\ TC) \quad kcal/kg$$

Condenser heat load:

$$QC = (GR)(H7 - H8) \quad kcal/hr$$

Generator heat load:

$$QG = (GW)(H5) + (GR)(H7) - (GS)(H1) \quad kcal/hr$$

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Absorber heat load:

$$QA = (GW)(H5) + (GR)(H10) - (GS)(H1) \qquad kcal/hr$$

Coefficient of performance:

$$COP = \frac{QE}{QG}$$

Evaporator heat load:

$$QE = 3024.0 \qquad kcal/hr$$

Evaporator pressure:

$$PE = antilog_{10} \quad 7.8553 - \frac{1555}{TE + 273.15} - \frac{11.2414 \times 10^4}{(TE + 273.15)^2} \qquad mm \ Hg$$

Condenser pressure:

$$PC = antilog_{10} \quad 7.8553 - \frac{1555}{TC + 273.15} - \frac{11.2414 \times 10^4}{(TC + 273.15)^2} \qquad mm \ Hg$$

APPENDIX B

SYMBOL LIST FOR HEAT-TRANSFER CALCULATIONS IN COMPUTER PROGRAM

Flow rates, gal/min, lb/hr, kg/hr

GH	(Hot water supply)
GC	(Cooling water supply)
GA	(Cooling Water supply)
GE	(Returning chilled water)
GR	(Refrigerant - water)
GW	(Weak solution)
GS	(Strong solution)

Temperatures, $^{\circ}$F, $^{\circ}$C

TH1, TH2	(Inlet and outlet conditions of GH)
TC1, TC12, or TA2	(Inlet and outlet conditions of GA)
TC12, TC2	(Inlet and outlet conditions of GC)
TE1, TE2	(Inlet and outlet conditions of GE)
TG	(Generator)
TC	(Condenser)
TA	(Absorber)
TE	(Evaporator)

Heat-transfer rates, Btu/(hr)($^{\circ}$F), cal/(hr)($^{\circ}$C)

UAG	(Generator)
UAC	(Condenser)
UAA	(Absorber)
UAE	(Evaporator)
UAX	(Heat exchanger)
First digit	Overall heat-transfer coefficient
Second digit	Overall heat-transfer surface
Third digit	Component symbol

Number of heat-transfer units

NTUG	(Generator)
NTUC	(Condenser)
NTUA	(Absorber)
NTUE	(Evaporator)
NTUX	(Heat exchanger)

Heat-transfer effectiveness

EFFNG	(Generator)
EFFNC	(Condenser)
EFFNA	(Absorber)
EFFNE	(Evaporator)
EFFNX	(Heat exchanger)

(A digit 0 following aforementioned symbols signifies a reference or a design condition being used. A digit T following aforementioned symbols and symbols in appendix A signifies total quantities.)

TON0	(Reference refrigerant tonnage)
TON	(Tonnage calculated)
TONX	(Tonnage variable)
COPX	(COP variable)
TAX	(TA variable)
GSC1	(Product of strong solution flow and heat capacity)
GWC4	(Product of weak solution flow and heat capacity)
CRATIO	=GWC4/GSC4
EXPX	(Exponential function for heat exchanger)

Controls and limits

METRIC	(Input to be metric units > 0)
KLBHR	(Input to be lb/hr > 0)
JWRITE	(Write output > 0)
KTA	(TA converging cycle = 50)
KCOP	(COP converging cycle = 50)

KTON1 and KTON2   (TONX converging cycle = 100)

ACONST = 1.0° C   Limits of (TE2 - TE)

BCONST = 1.296° C   Limits of (TA - TC12)

CCONST = 1.425° C   Limits of (TC - TC2)

DCONST = 1.919° C   Limits of (TH1 - TG)

TELO - 2.22° C   (Lowest temperature limits of TE)

TE2SET = 4.43° C   (Lowest temperature limits of TE2)

COPHI = 0.93   (Highest limits of COP)

COPLO = 0.60   (Lowest limits of COP)

FQG = 1.0   (No heat loss added)

EFFNX = 0.71428   (Initialization of EFFNX)

SAMPLES 1 AND 2 WITH PROGRAM LISTINGS

Sample 1: LiBr-H$_2$O Single-Stage Absorption Machine Used as a Main Program

```
 1*      C    USE THIS TO EVALUATE OUTPUT OF AN ABSORPTION MACHINE WITH FIXED --UA--
 2*      C    ALL WATER SPECIFIC HEAT & DENSITY ASSUMED TO BE --1.0-- EXCEPT HOT WATER
 3*           DIMENSION  XIN(10),PAR(13),XNTU(6),EFFN(6)
 4*           DIMENSION  X(6),Y(6),GIN(3)
 5*           DIMENSION  TONGVN(160),TONCAL(160)
 6*      C
 7*      C--METRIC=0,BRITISH UNITS USED.-----------JWRITE=1 WRITE ALL,JWRITE=0 NO WRITE
 8*      C    KLBHR=0,GPM FOR FLOW INPUT.----KLBHR=1,  LBS/HR INPUT
 9*           DATA METRIC/0/,KLBHR/0/,JWRITE/1/
10*           DATA   PDKG/.4536/
11*           DATA   TFTC1/32./,TFTC2/1.8/
12*           DATA   CALBTU/3.96831/
13*      C
14*      C
15*      C    CONST1 & CONST4 ARE CONCENTRATION LIMITS
16*           DATA CONST1/0.4/,CONST4/0.68/
17*      C    A-B-C-D-CONST ARE LIMITS FOR EVAP., ABSORP., COND.,& GENERATOR
18*           DATA ACONST/1./,BCONST/1.296/,CCONST/1.423/,DCONST/1.919/
19*      C
20*           DATA TELO/2.22/,TE2SET/4.43/
21*      C    COP LIMITS       ---HEAT LOSS FACTOR
22*           DATA COPHI/0.93/,COPLO/0.60/,FQG/1.0/
23*      C    EFFNX=0.71428     FOR TS=135 F       EFFNX=(TG-T5)/(TG-TA)
24*           DATA EFFNX/0.71428/
25*      C
26*           DIMENSION XINRSV(10)
27*           DIMENSION AJTE2(4)
28*           DATA      AJTE2(1),AJTE2(2),AJTE2(3),AJTE2(4) / 3HTH1 , 3HTE1 ,
29*          1 3HTH2 , 3HTE2 /
30*           DIMENSION AJREF(2)
31*           DATA AJREF(1),AJREF(2)/ 3HTC2 , 3HTA2 /
32*           DATA JTE2 / 0 /
33*           DTLIM=0.25
34*           DTLIM=0.1
35*           NAMELIST /REF/ TH2,TA2,TC2,TE2,TH1,TA1,TE1,TG,TC,TA,TE,TONL,
36*          1 KLBHR,METRIC,JREF,CONST1,CONST4,ACONST,BCONST,CCONST,DCONST,
37*          2 COPHI,COPLO,FQG,EFFNX,TELO,TE2SET
38*           NAMELIST /VAR/ GH,GC,GE,TH1,TA1,TE1,TONX,JTE2,TE2,TH2,LVAR
39*      C
40*      C   JREF=0,RUN NO REF.  -JREF=1,TC2=XIN(2).--JREF=2,TA2 OR TC12=XIN(2)
41*      300 READ(5,REF)
42*           LVAR=0
43*           XIN(1)=TH2
44*           IF(JREF.EQ.1) XIN(2)=TC2
45*           IF(JREF.EQ.2) XIN(2)=TA2
46*           XIN(3)=TE2
47*           XIN(4)=TH1
48*           XIN(5)=TA1
49*           TC1=TA1
50*           XIN(6)=TE1
51*           XIN(7)=TG
52*           XIN(8)=TC
53*           XIN(9)=TA
54*           XIN(10)=TE
55*           DO 302 I=1,10
56*           XINRSV(I)=XIN(I)
57*      302 CONTINUE
58*           TC2RSV=TC2
59*           TA2RSV=TA2
60*           KERROR=0
61*      C
62*      C
63*      C
```

```
64*              IF(METRIC.GT.0)  TFTC1=0.0
65*              IF(METRIC.GT.0)  TFTC2=1.0
66*              IF(METRIC.GT.0)  PDKG=1.0
67*              IF(METRIC.GT.0)  CALBTU=1.0
68*              IF(METRIC.GT.C)  BPH=1.0
69*      C
70*              BPH=500.0
71*              IF(KLBHR.GT.0)   BPH=1.0
72*      C
73*              IF(JREF.GT.0)  GO TO 19
74*         7 CONTINUE
75*      C    --------UA VALUES ARE PER TON BASIS--------
76*              TOND=TON
77*              GSO=GS*PDKG
78*              GWO=GW*PDKG
79*              GHO=GHT
80*              GEO=GET
81*              GCO=GCT
82*              PAR(1)=UAG*PDKG
83*              PAR(2)=UAC*PDKG
84*              PAR(3)=UAE*PDKG
85*              PAR(4)=UAA*PDKG
86*              PAR(5)=UAX*PDKG
87*              UAXO=PAR(5)
88*      C
89*      C
90*              INPUT=1
91*      C
92*        990 CONTINUE
93*              JREF=0
94*              READ(5,VAR,END=999)
95*              XIN(1)=GH
96*              XIN(2)=GC
97*              XIN(3)=GE
98*              XIN(4)=TH1
99*              XIN(5)=TA1
100*             TC1=TA1
101*             XIN(6)=TE1
102*             XIN(7)=TONX
103*             GESAV=XIN(3)
104*             TE2SAV=TE2
105*             TH2SAV=TH2
106*             KERROR=0
107*      C    TON IS AN ASSUMED VALUE TO START
108*             TONX=XIN(7)
109*             TONREF=TONO*0.5
110*             TONMIN=TONO*0.1
111*             TONMAX=TOND*1.2
112*             IF(XIN(7).LE.TONREF)  TONX=TONREF
113*      C
114*         19 CONTINUE
115*      C
116*             KGC=0
117*          9 CONTINUE
118*      C
119*      C    -----FLOW RATES ARE PER TON BASIS     -------
120*      C        PER TON BASIS
121*             QE=3023.9573
122*             H1=0.
123*             H5=0.
124*             H7=0.
125*             H8=0.
126*             H10=0.
127*             TON=0.0
128*             KTON1=0
129*             KTON2=0
130*             KTONX=-1
```

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```
131*          X4=0.67
132*          X1=C.41
133*          IWRITE=C
134*       11 CONTINUE
135*    C     COPX=.722
136*          IF(COPX.LE.COPLO.OR.COPX.GE.COPHI)   COPX=0.722
137*          KCOP=C
138*       16 CONTINUE
139*              GH=XIN(1)/TONX*PDKG*BPH*0.975
140*              GC=XIN(2)/TONX*PDKG*BPH
141*              GE=XIN(3)/TONX*PDKG*BPH
142*              TH1=(XIN(4)-TFTC1)/TFTC2
143*              TC1=(XIN(5)-TFTC1)/TFTC2
144*              TE1=(XIN(6)-TFTC1)/TFTC2
145*          TE2SVM=(TF2SAV-TFTC1)/TFTC2
146*          TH2SVM=(TH2SAV-TFTC1)/TFTC2
147*    C
148*          IF(JREF.EQ.0)   GO TO 20
149*          TH2=(XIN(1)-TFTC1)/TFTC2
150*          TA2=(XIN(2)-TFTC1)/TFTC2
151*          IF(JREF.EQ.2)   TC12=TA2
152*          IF(JREF.EQ.1)   TC2=TA2
153*          TE2=(XIN(3)-TFTC1)/TFTC2
154*           TG=(XIN(7)-TFTC1)/TFTC2
155*           TC=(XIN(8)-TFTC1)/TFTC2
156*           TA=(XIN(9)-TFTC1)/TFTC2
157*           TE=(XIN(10)-TFTC1)/TFTC2
158*          GO TO 21
159*       20 CONTINUE
160*    C     ASSUME TUBE SIDE WATER FILM COEF. IS CONTROLLING
161*          GH1=(XIN(1)/GHO)**0.8
162*          GC1=(XIN(2)/GCO)**J.8
163*          GE1=(XIN(3)/GEC)**0.8
164*    C
165*    C     TOTAL BASIS    IN METRIC UNITS
166*          GIN(1)=GH/GH1*TONX
167*          GIN(2)=GC/GC1*TONX
168*          GIN(3)=GE/GE1*TONX
169*    C
170*          DO 10 I=1,4
171*          XNTU(I)=PAR(I)/GIN(I)*1.D*TONO
172*          IF(I.EQ.4)   XNTU(I)=PAR(I)/GIN(2)*TONO
173*          IF(XNTU(I).GE.1C.) GO TO 8
174*          EFFN(I)=1.C-EXP(-XNTU(I))
175*          GO TO 10
176*        8 CONTINUE
177*          EFFN(I)=0.999
178*       1C CONTINUE
179*    C
180*    C
181*          TE2=TE1-QE/GE
182*          TH2=TH1-(QE/COPX)/GH
183*    C
184*    C     FOR CHECKING TRANE TABLE FIGURES ONLY        TE2 +TH2 KNOWN INSTEAD
185*          IF(JTF2.LE. C ) GO TO 6D3
186*          TE2=TE1
187*          TH2=TH1
188*    C     TE2=TF2SAV
189*    C     TH2=TH2SAV
190*          TE2=TF2SVM
191*          TH2=TH2SVM
192*          TE1=TE2+QE/GE
193*          TH1=TH2+(QE/COPX)/GH
194*      6CC CONTINUE
195*    C
196*    C
197*          TE=TE1-(TF1-TE2)/EFFN(3)
```

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```
198*            TG=TH1-(TH1-TH2)/EFFN(1)
199*            TC2=TC1+(1.0+1.0/COPX)*QE/GC
200*    C     ASSUMED A VALUE FOR  TA
201*            TA2=(TC1+TC2)*0.5
202*            TA=TC1-(TC1-TA2)/EFFN(4)
203*            KTA=0
204*         15 CONTINUE
205*            TC=TC2/EFFN(2)-(1.0/EFFN(2)-1.0)*(TC1+EFFN(4)*(TA-TC1))
206*            IF(TC.LE.TA)  GO TO 40
207*            IF(TE.GE.TA)  GO TO 41
208*            IF(TC.GE.TG)  GO TO 41
209*    C
210*         21 CONTINUE
211*            X1=(49.04+1.125*TA-TE)/(134.65+0.47*TA)
212*            X4=(49.04+1.125*TG-TC)/(134.65+0.47*TG)
213*            IF(X1.LT.CONST1)  GO TO 45
214*            IF(X4.LE.X1)  GO TO 43
215*    C
216*            H8=TC-25.0
217*            H10=572.8+0.417*TE
218*            GR=QE/((H10-H8)
219*            GS=GR*X4/(X4-X1)
220*            GW=GS*(X1/X4)
221*    C
222*            CX1=1.01-1.23*X1+0.48*X1**2
223*            CX4=1.01-1.23*X4+0.48*X4**2
224*            GSC1=GS*CX1
225*.           GWC4=GW*CX4
226*            CRATIO=GWC4/GSC1
227*            IF(JREF.GT.0)  GO TO 22
228*    C
229*    C     ASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
230*            F1=2.0
231*            F2=1.0
232*    C  F1=2,F2=1,HGS=HGW.--F1=1,F2=0,HGS>>HGW.--F1=2.5,F2=2/3,HGS=1.5HGW. FOR UAX
233*            RGS=((GSC/GS)*(TOND/TONX))**0.8
234*            RGW=((GWD/GW)*(TOND/TONX))**0.6
235*            UAX=F1*UAXD*(1.0/(RGS+F2*RGW))
236*    C
237*            IF(GWC4.GT.GSC1)  GO TO 17
238*            XNTUX=UAX/GWC4*(TOND/TONX)
239*            GO TO 18
240*    C
241*         17 CONTINUE
242*            XNTUX=UAX/GSC1*(TOND/TONX)
243*            CRATIO=GSC1/GWC4
244*         18 CONTINUE
245*    C
246*            IF(ABS(1.0-CRATIO).LT.0.01)  GO TO 13
247*            IF((XNTUX*(1.-CRATIO)).GE.10.)  GO TO 12
248*            EXPX=EXP(-XNTUX*(1.0-CRATIO))
249*            EFFNX=(1.0-EXPX)/(1.0-CRATIO*FXPX)
250*            GO TO 14
251*    C
252*         12 CONTINUE
253*            EFFNX=0.999
254*            GO TO 14
255*         13 CONTINUE
256*            EFFNX=XNTUX/(1.0+XNTUX)
257*         14 CONTINUE
258*         22 CONTINUE
259*    C
260*    C
261*            T5=TG-EFFNX*(TG-TA)
262*            T3=TA+(EFFNX*CRATIO*(TG-TA))
263*    C
264*            H1=(42.81-425.92*X1+404.67*X1**2)+CX1*TA
```

```
265*              H5=(42.81-425.92*X4+404.67*X4**2)+CX4*T5
266*              H7=572.8+0.46*TG-0.043*TC
267*    C
268*    C     FQG=1.0,NO HEAT LOSS.--FQG>1.0,&<2.0,% HEAT LOSS
269*              IF(FQG.LE.1.0)   FQG=1.0
270*              QG=(GW*H5-GS*H1+GR*H7)*FQG
271*              QC=GR*(H7-H8)*(1.0+QG/(QG+QE)*(1.0-FQG))
272*              QA=(GW*H5-GS*H1+GR*H10)*(1.0+QG/(QG+QE)*(1.0-FQG))
273*              COP=QE/QG
274*    C
275*              IF(JREF.GT.0)   GO TO 60
276*    C
277*              TC12=TC1+QA/GC
278*              TAX=TC1-(TC1-TC12)/EFFN(4)
279*    C
280*       40 CONTINUE
281*              IF(TC.LE.TA)   TAX=TC
282*              IF(ABS(TAX-TA).LT.0.00001)     GO TO 41
283*              IF(KTA.EQ.50)   GO TO 41
284*              TA=(TAX+TA)*0.5
285*              KTA=KTA+1
286*              GO TO 15
287*       41 CONTINUE
288*    C
289*              IF(ABS(COPX-COP).LT.0.00001)   GO TO 42
290*              IF(KCOP.EQ.50)   GO TO42
291*              COPX=(COPX+COP)*0.5
292*              KCOP=KCOP+1
293*              GO TO 16
294*       42 CONTINUE
295*    C
296*              X(1)=TE2-TE
297*              X(2)=TA-TC12
298*              X(3)=TC-TC2
299*              X(4)=TH2-TG
300*              Y(1)=ACONST
301*              Y(2)=BCONST
302*              Y(3)=CCONST
303*              Y(4)=DCONST
304*    C
305*              DO 47 I=1,4
306*              IF(X(I).LT.Y(I).AND.KTONX.EQ.1)   GO TO 60
307*              IF(X(I).LT.Y(I))   GO TO 45
308*       47 CONTINUE
309*    C
310*              IF(X1.GT.CONST1.AND.X4.LT.CONST4.AND.X4.GT.X1)   GO TO 46
311*    C
312*       45 CONTINUE
313*              IF(KTON2-100)   49,43,43
314*       49 CONTINUE
315*              TONMIN=TONX
316*              TONX=(TONX+TONMAX)*0.5
317*              ITONX=IFIX(TONX)
318*              TONX=TONX + DTLIM
319*              KTON2=KTON2+1
320*              GO TO 11
321*    C
322*       43 CONTINUE
323*              IF(KTON1-100)   44,65,65
324*       44 CONTINUE
325*              TONMAX=TONX
326*              TONX=(TONX+TONMIN)*0.5
327*              ITONX=IFIX(TONX)
328*              IF(TON.LE.0.0.AND.TONX.LE.(TONMIN+1.0)) GO TO 60
329*              IF(TONX.LE.TON)        GO TO 50
330*              TONX=FLOAT(ITONX)-1.0
331*              TONX=TONX - DTLIM
```

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```
332*            KTON1=KTON1+1
333*            GO TO 11
334*      C
335*         46 CONTINUE
336*            IF(KTONX.EQ.1.OR.TONX.LE.0.0)  GO TO 60
337*            IF(TON.GE.TONX)  GO TO 50
338*      C    CHECK MAX. STRONG SOLUTION PUMP RATE ----------------
339*            GSTO=GS0*TONC
340*            GSPUMP=GS*TONX
341*            IF(GSPUMP.GT.GSTO)  GO TO 43
342*      C
343*            TON=TONX
344*            IF(TE2.LT.TE2SET.OR.TE.LE.TEL0)  GO TO 48
345*            GO TO 49
346*         48 CONTINUE
347*            TON=TON*(TE1-TE2SET)/(TE1-TE2)
348*      C
349*         50 CONTINUE
350*            IF(KTONX.EQ.1.OR.TON.LE.0.0)  GO TO 60
351*            TONX=TON
352*            KTONX=1
353*            GO TO 11
354*      C
355*         60 CONTINUE
356*         65 IF(JREF.GT.0.OR.KTONX.EQ.1.OR.KGC.GE.30)   GO TO 66
357*            KGC=KGC+1
358*            XIN(3)=XIN(3)*(TONX-1.0)/TONX
359*            GO TO 9
360*         66 CONTINUE
361*      C
362*      C
363*      C-----ALL SPEC HEAT = 1. ---------------
364*            IF(JREF.EQ.0)  GO TO 35
365*            TON=TON0
366*            YY=(1.-EFFNX*CRATIO)/(1.-EFFNX)
367*            XNTUX=ALOG(YY)/(1.-CRATIO)
368*            GH= QG/(TH1-TH2)
369*            GE= QE/(TE1-TE2)
370*            IF(JREF.EQ.1)   GC=(QA+QC)/(TC2-TC1)
371*            IF(JREF.EQ.2)   GC=QA/(TC12-TC1)
372*            IF(JREF.EQ.1)   TC12=TC1+QA/GC
373*            IF(JREF.EQ.2)   TC2=TC12+QC/GC
374*            EFFN(1)=(TH1-TH2)/(TH1-TG)
375*            EFFN(2)=(TC12-TC2)/(TC12-TC)
376*            EFFN(3)=(TE1-TE2)/(TE1-TE)
377*            EFFN(4)=(TC1-TC12)/(TC1-TA)
378*            DO 31 K=1,4
379*            XNTU(K)=(-1.)*ALOG(1.-EFFN(K))
380*         31 CONTINUE
381*      C
382*         35 CONTINUE
383*            UAG=XNTU(1)*GH
384*            UAC=XNTU(2)*GC
385*            UAE=XNTU(3)*GE
386*            UAA=XNTU(4)*GC
387*            UAX=XNTUX*GWC4
388*      C
389*            A=ALOG(10.0)
390*            B=1555.0/(TE+273.15)
391*            C=11.2414E4/(TE+273.15)**2
392*            PE=EXP(A*(7.8553-B-C))
393*            B=1555.0/(TC+273.15)
394*            C=11.2414E4/(TC+273.15)**2
395*            PC=EXP(A*(7.8553-B-C))
396*      C
397*            QG=QG*CALBTU
398*            QC=QC*CALBTU
```

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```
399*              QE=QE*CALBTU
400*              QA=QA*CALBTU
401*              H1=H1*CALBTU
402*              H5=H5*CALBTU
403*              H7=H7*CALBTU
404*              H8=H8*CALBTU
405*              H10=H10*CALBTU
406*      C
407*              T3=T3*TFTC2+TFTC1
408*              T5=T5*TFTC2+TFTC1
409*      C
410*              TH1=TH1*TFTC2+TFTC1
411*              TH2=TH2*TFTC2+TFTC1
412*              TC1=TC1*TFTC2+TFTC1
413*              TC12=TC12*TFTC2+TFTC1
414*              TA2=TC12
4' ..             TC2=TC2*TFTC2+TFTC1
416*              TE1=TE1*TFTC2+TFTC1
417*              TE2=TE2*TFTC2+TFTC1
418*              TE =TE *TFTC2+TFTC1
419*              TA =TA *TFTC2+TFTC1
420*              TC =TC *TFTC2+TFTC1
421*              TG =TG *TFTC2+TFTC1
422*      C
423*              UAG=UAG/PDKG
424*              UAC=UAC/PDKG
425*              UAE=UAE/PDKG
426*              UAA=UAA/PDKG
427*              UAX=UAX/PDKG
428*              GH=GH/PDKG
429*              GC=GC/PDKG
430*              GA=GC
431*              GE=GE/PDKG
432*              GR=GR/PDKG
433*              GW=GW/PDKG
434*              GS=GS/PDKG
435*              GSC1=GSC1/PDKG
436*              GWC4=GWC4/PDKG
437*      C
438*              QGT=QG*TON
439*              QCT=QC*TON
440*              QET=TON
441*              QAT=QA*TON
442*              UAGT=UAG*TON
443*              UACT=UAC*TON
444*              UAET=UAE*TON
445*              UAAT=UAA*TON
446*              GHT=GH*TON/BPH/0.975
447*              GCT=GC*TON/BPH
448*              GAT=GCT
449*              GET=GF*TON/BPH
450*              DT12E=TE1-TE2
451*              DT12A=TA2-TC1
452*              DT12C=TC2-TA2
453*              DT12G=TH1-TH2
454*              DTE2=TE2-TE
455*              DTA2=TA-TA2
456*              DTC2=TC-TC2
457*              DTG2=TH2-TG
458*      C
459*              IF(KTA.GE.50.OR.KCOP.GE.50)  GO TO 58
460*              IF(KTON2.GE.100.OR.KTON1.GE.100)  GO TO 58
461*              IF(JWRITE.EQ.0)  GO TO 59
462*              GO TO 430
463*           58 CONTINUE
464*              KERROP=1
465*      C
```

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```
466*          43C IF(METRIC.GT.0) WRITE(6,420)
467*          420 FORMAT(1H1,20X,'OUTPUT IS IN SI UNITS DEGREES C, KG/HR, CAL ' / )
468*              IF(METRIC.EQ.0) WRITE(6,421)
469*          421 FORMAT(1H1,20X,'OUTPUT IS IN U.S. CUSTOMARY UNITS - DEGREES F, GPM
470*              1, BTU ' / )
471*              IF(KERROR.EQ.1) WRITE(6,431)
472*          431 FORMAT(///20X,'**********  ITERATIONS FAILED TO CONVERGE  ********
473*              1**  ' )
474*              IF(METRIC.EQ.0 .AND. INPUT.EQ.0) WRITE(6,93) AJREF(JREF)
475*              IF(METRIC.GT.0 .AND. INPUT.EQ.0) WRITE(6,193) AJREF(JREF)
476*              IF(INPUT.EQ.0) WRITE(6,94) (XIN(I),I=1,10),TON0,JREF,INPUT
477*              IF(INPUT.EQ.0) GO TO 57
478*              JOUT=1
479*              IF(JTE2.GT.0) JOUT=3
480*              IF(METRIC.GT.0) WRITE(6,195) AJTE2(JOUT),AJTE2(JOUT+1)
481*              IF(METRIC.EQ.0) WRITE(6,95) AJTE2(JOUT),AJTE2(JOUT+1)
482*              IF(JTE2.EQ.0)
483*             1WRITE(6,98) KTA,KCOP,KTON2,KTON1,(XIN(I),I=1,6),TONX,XIN(7),INPUT
484*              IF(JTE2.GT.0) WRITE(6,98) KTA,KCOP,KTON2,KTON1,XIN(1),XIN(2),
485*             1 XIN(3),TH2SAV,XIN(5),TF2SAV,TONX,XIN(7),INPUT
486*           57 CONTINUE
487*   C
488*              WRITE(6,403)
489*              WRITE(6,402) X1,X4,CX1,CX4,GR,GS,GW,GSC1,GWC4,EXPX,CRATIO,UAX
490*              WRITE(6,407)
491*              WRITE(6,402) TA,T5,T3,TG,H1,H5,H7,H8,H10,XNTUX,EFFNX,COP
492*              WRITE(6,406)
493*              WRITE(6,405) GE,TE1    ,TE2,TE    ,XNTU(3),EFFN(3),PE,UAE,QE,GET,UAE
494*             XT,QET
495*              WRITE(6,404) GA,TC1    ,TA2,TA    ,XNTU(4),EFFN(4),PE,UAA,QA,GAT,UAA
496*             XT,QAT
497*              WRITE(6,401) GC,TA2,TC2,TC    ,XNTU(2),EFFN(2),PC,UAC,OC,GCT,UACT,Q
498*             XCT
499*              WRITE(6,400) GH,TH1    ,TH2,TG    ,XNTU(1),EFFN(1),PC,UAG,QG,GHT,UAG
500*             XT,QGT
501*          400 FORMAT(1X,4HG---,7F10.3,5E10.3//)
502*          401 FORMAT(1X,4HC---,7F10.3,5E10.3/)
503*          402 FORMAT(1X,4HX---,12F10.3/)
504*          403 FORMAT(5X,120H        X1          X4          CX1         CX4         GR
505*             X    GS         GW         GSC1        GWC4        EXPX        CRATIO      UAX
506*             X   )
507*          404 FORMAT(1X,4HA---,7F10.3,5E10.3/)
508*          405 FORMAT(1X,4HE---,7F10.3,5E10.3/)
509*          406 FORMAT(5X,120H        G           T1          T2          T           NTU
510*             X    EFFN        P          UA          Q           GT          UAT         QT
511*             X    )
512*          407 FORMAT(5X,120H        TA          T5          T3          TG          H1
513*             X    H5         H7          H8          H10         NTUX        EFFNX       COP
514*             X    )
515*   C
516*              WRITE(6,96)
517*              WRITE(6,97) DT12E,DTE2,TE2,DT12A,DTA2,TA2,DT12C,DTC2,TC2,DT12G,DTG
518*             X2,TH2
519*           93 FORMAT(10X,'TH2-F',5X,A3,'-F',5X,'TE2-F',5X,'TH1-F',5X,'TC1-F',
520*             1 5X,'TE1-F',5X,'TG-F',6X, 'TC-F',6X,'TA-F',6X,'TE-F',4X,'TON-PEF',
521*             2 5X,'JREF',5X,'NO.' )
522*          193 FORMAT(10X,'TH2-C',5X,A3,'-C',5X,'TE2-C',5X,'TH1-C',5X,'TC1-C',
523*             1 5X,'TE1-C',5X,'TG-C',6X, 'TC-C',6X,'TA-C',6X,'TE-C',4X,'TON-REF',
524*             2 5X,'JREF',5X,'NO.' )
525*           94 FORMAT(5X,11F10.3,I10,3X,I3/)
526*           95 FORMAT(10X,'KTA          KCOP         KTON2        KTON1      GHT-GPM    GCT-GP
527*             1M    GET-GPM',5X,A3,'-F    TC1-F',5X,A3,'-F    TON-CAL   TON-START
528*             2 NO.' )
529*          195 FORMAT(10X,'KTA          KCOP         KTON2        KTON1      GHT-KPH    GCT-KP
530*             1H    GET-KPH',5X,A3,'-C    TC1-C',5X,A3,'-C    TON-CAL   TON-START
531*             2 NO.' )
532*           96 FORMAT(5X,120H        DT12E       DTE2        TE2         DT12A       DTA2
```

```
533*          X   TA2          DT12C        DTC2         TC2          DT12G        DTG2         TH2
534*          X       )
535*       97 FORMAT(1X,4HTEMP,12F10.3///)
536*       98 FORMAT(5X,4(I8,2X),8F10.3,3X,I3/)
537*    C
538*       59 CONTINUE
539*          IF(JREF.GT.0)      GO TO 7
540*    C
541*       61 CONTINUE
542*    C
543*          TONGVN(INPUT)=XIN(7)
544*        . TONCAL(INPUT)=TON
545*          INPUT=1+INPUT
546*          GH=XIN(1)
547*          GC=XIN(2)
548*          GE=GESAV
549*          TH1=XIN(4)
550*          TA1=XIN(5)
551*          TE1=XIN(6)
552*          TONX=XIN(7)
553*          TE2=TE2SAV
554*          TH2=TH2SAV
555*          IF(LVAR.EQ.0) GO TO 990
556*          DO 301 I=1,10
557*          XINRSV(I)=XIN(I)
558*      301 CONTINUE
559*          TC2=TC2RSV
560*          TA2=TA2RSV
561*          GO TO 300
562*      999 CONTINUE
563*          WRITE(6,601)
564*    C     WRITE(6,602)    (TONGVN(M),TONCAL(M),M=1,160)
565*          WRITE(6,602)    (M,TONGVN(M),TONCAL(M),M=1,160)
566*      601 FORMAT(1X,110HTHE FOLLOWING ARE KNOWN TON VS CALCULATED FOR   TRANE
567*         1 MODEL C1H/DS-ABS1    TH2,TE2,TC1 ARE KNOWN                           )
568*    C 602 FORMAT(1X,6(4X,2F8.2)/ /(1X,6(4X,2F8.2))/)
569*      602 FORMAT(1X,6(I4,2F8.2)/ /(1X,6(I4,2F8.2))/)
570*    C
571*          STOP
572*          END
```

OUTPUT IS IN U.S. CUSTOMARY UNITS – DEGREES F, GPM, BTU

	TH2-F	TA2-F	TE2-F	THI-F	TC1-F	TE1-F	TG-F	TC-F	TA-F	TE-F	TON-REF	JREF	Case
	230.300	95.003	44.000	270.000	85.000	54.000	210.000	112.000	105.000	40.000	174.000	2	0

	X1	X4	CX1	CX4	GP	GS	GW	GSC1	GWC4	EXPX	CRATIO	UAX
X---	.587	.643	.453	.420	12.007	145.916	133.909	66.161	56.197	.000	.849	119.237

	TA	T5	T3	TG	H1	H5	H7	H8	H10	NTUX	EFFNX	COP
X---	105.000	135.001	168.705	210.000	-195.964	-158.932	2445.978	77.162	2280.403	2.122	.714	.721

	G	T1	T2	T	NTU	EFFN	P	UA	Q	GT	UAT	QT
E---	1199.983	54.000	44.000	40.000	1.253	.714	6.234	.150+04	.120+05	.418+03	.262+06	.174+03
A---	1573.675	85.000	95.000	105.000	.693	.500	6.234	.109+04	.157+05	.548+03	.190+06	.274+07
C---	1573.675	95.000	103.198	112.000	.658	.482	69.925	.104+04	.129+05	.548+03	.180+06	.224+07
G---	415.964	270.000	230.000	210.000	1.099	.667	69.925	.457+03	.166+05	.148+03	.795+05	.290+07

	DT12E	DTE2	TE2	DT12A	DTA2	TA2	DT12C	DTC2	TC2	DT12G	DTG2	TH2
TEMP	10.000	4.000	44.000	10.000	10.000	95.000	8.198	8.802	103.198	40.000	20.000	230.000

OUTPUT IS IN U.S. CUSTOMARY UNITS – DEGREES F, GPM, BTU

	KTA	KCOP	KTON2	KTON1	GHT-GPM	GCT-GPM	GET-GPM	THI-F	TC1-F	TE1-F	TON-CAL	TON-START	Case
	18	15	0	0	150.000	553.000	417.600	270.470	80.000	50.428	161.902	181.000	1

	X1	X4	CX1	CX4	GP	GS	GW	GSC1	GWC4	EXPX	CRATIO	UAX
X---	.588	.651	.453	.413	11.978	123.773	111.794	56.045	46.147	.671	.823	104.353

	TA	T5	T3	TG	H1	H5	H7	H8	H10	NTUX	EFFNX	COP
X---	100.341	129.187	166.358	209.364	-200.533	-161.478	2445.731	67.912	2276.534	2.261	.735	.734

	G	T1	T2	T	NTU	EFFN	P	UA	Q	GT	UAT	QT
E---	1147.870	50.428	39.974	35.792	1.253	.714	5.276	.144+04	.120+05	.418+03	.262+06	.182+03
A---	1520.046	80.000	90.157	100.341	.692	.499	5.276	.105+04	.154+05	.553+03	.191+06	.281+07
C---	1520.046	90.157	98.656	107.804	.657	.482	61.929	.999+03	.129+05	.553+03	.182+06	.235+07
G---	402.002	270.470	229.779	209.364	1.096	.666	61.929	.441+03	.164+05	.150+03	.802+05	.298+07

	DT12E	DTE2	TE2	DT12A	DTA2	TA2	DT12C	DTC2	TC2	DT12G	DTG2	TH2
TEMP	10.454	4.182	39.974	10.157	10.184	90.157	8.499	9.149	98.656	40.691	20.415	229.779

OUTPUT IS IN U.S. CUSTOMARY UNITS – DEGREES F, GPM, BTU

	KTA	KCOP	KTON2	KTON1	GHT-GPM	GCT-GPM	GET-GPM	THI-F	TC1-F	TE1-F	TON-CAL	TON-START	Case
	18	17	2	2	150.000	553.000	417.600	265.096	80.000	50.081	175.864	172.000	2

	X1	X4	CX1	CX4	GP	GS	GW	GSC1	GWC4	EXPX	CRATIO	UAX
X---	.585	.645	.455	.416	11.966	128.347	116.381	58.338	48.422	.684	.830	108.254

	TA	T5	T3	TG	H1	H5	H7	H8	H10	NTUX	EFFNX	COP
X---	99.670	128.275	164.246	206.075	-201.447	-163.724	2442.486	65.827	2276.662	2.236	.731	.734

	G	T1	T2	T	NTU	EFFN	P	UA	Q	GT	UAT	QT
E---	1187.279	50.081	39.974	35.931	1.253	.714	5.306	.149+04	.120+05	.418+03	.262+06	.176+03
A---	1572.235	80.000	89.822	99.670	.692	.499	5.306	.109+04	.154+05	.553+03	.191+06	.272+07
C---	1572.235	89.822	98.027	106.859	.657	.482	60.239	.103+04	.129+05	.553+03	.182+06	.227+07
G---	415.804	265.096	225.793	206.075	1.096	.666	60.239	.456+03	.163+05	.150+03	.802+05	.287+07

	DT12E	DTE2	TE2	DT12A	DTA2	TA2	DT12C	DTC2	TC2	DT12G	DTG2	TH2
TEMP	10.137	4.043	39.974	9.822	9.848	89.822	8.205	8.832	98.027	39.303	19.718	225.793

Sample 2: LiBr-H_2O Single-Stage Absorption Machine Used as a Subroutine in TRNSYS

```
1*              SUBROUTINE TYPE17(TIME,XIN,OUT,T,DTDT,PAR)
2*              COMMON /PR2/ TIME0,TFINAL,DELT
3*      C       USE THIS TO EVALUATE OUTPUT OF AN ABSORPTION MACHINE WITH FIXED --UA--
4*      C       ALL WATER SPECIFIC HEAT & DENSITY ASSUMED TO BE --1.0-- EXCEPT HOT WATER
5*              DIMENSION  PAR(10),XIN(10),OUT(10)
6*              DIMENSION  X(6),Y(6),CIN(3),XNTU(6),EFFN(6),PPR(5)
7*      C
8*      C--METRIC=0,BRITISH UNITS USED.-----------JWRITE=1 WRITE ALL,JWRITE=0 NO WRITE
9*      C   KLBHR=0,GPM FOR FLOW INPUT.----KLBHR=1,  LBS/HR INPUT
10*             DATA METRIC/0/,KLBHR/1/,JWRITE/1/
11*             DATA METRIC/0/,KLBHR/1/,JWRITE/0/
12*             DATA  PDKG/.4536/
13*             DATA  TFTC1/32./,TFTC2/1.8/
14*             DATA  CALBTU/3.96831/
15*      C
16*      C   CONST1 & CONST4 ARE CONCENTRATION LIMITS
17*             DATA CONST1/0.4/,CONST4/0.68/
18*      C   A-B-C-D-CONST ARE LIMITS FOR EVAP., ABSORP., COND.,& GENERATOR
19*             DATA ACONST/1./,BCONST/1.296/,CCONST/1.423/,DCONST/1.919/
20*             DATA TEL0/2.22/,TE2SET/4.43/
21*      C   COP LIMITS    --HEAT LOSS FACTOR
22*             DATA COPHI/0.93/,COPLO/0.60/,FQG/1.0/
23*      C   EFFNX=0.71428      FOR T5=135 F      EFFNX=(TG-T5)/(TG-TA)
24*             DATA EFFNX/0.71428/
25*      C
26*      C
27*      C
28*      C
29*             INPUT=1
30*       990 CONTINUE
31*             H1=0.
32*             H5=0.
33*             H7=0.
34*             H8=0.
35*             H10=0.
36*      C
37*      C     -------UA VALUES ARE PER TON BASIS--------
38*             UAG=456.981*PDKG
39*             UAC=1011.869*PDKG
40*             UAE=1503.294*PDKG
41*             UAA=1102.8*PDKG
42*             UAX=118.929*PDKG
43*             UAXO=118.929*PDKG
44*             GSO=144.077*PDKG
45*             GWO=131.323*PDKG
46*             GHO=150.786*500.*0.975
47*             GEO=417.600 *500.
48*             GCO=553.674*500.
49*             TONO=174.
50*      C
51*      C
52*      C
53*      C
54*             PPR(1)=UAG
55*             PPR(2)=UAC
56*             PPR(3)=UAE
57*             PPR(4)=UAA
58*             PPR(5)=UAX
59*      C
60*             JREF=0
61*         7 CONTINUE
62*             TONX=XIN(7)/12000.
63*             TONREF=TONO*0.5
64*             TONMIN=TONO*0.1
65*             TONMAX=TONO*1.2
```

```
66*      C
67*      C     KLBHR=0,GPM GPM INPUT.--KLBHR=1,BPH INPUT FOR  FLOW RATE
68*            BPH=500.0
69*            IF(KLBHR.GT.0)  BPH=1.0
70*      C
71*         9 CONTINUE
72*      C
73*      C     -----FLOW RATES ARE PER TON BASIS     -------
74*      C          PER TON BASIS
75*            TON=1.0
76*            KTON1=0
77*            KTON2=0
78*            KTONX=-1
79*            X4=0.67
80*            X1=0.41
81*      C     S --IS A CONTROL COST.--S=0. OUT=INLET--S=1 OUT CALCULATED
82*            S=1.0
83*        11 CONTINUE
84*            GS=GS0
85*            KCOP=0
86*        16 CONTINUE
87*            IF(COPX.LE.COPLO.OR.COPX.GE.COPHI)  COPX=0.722
88*      C
89*      C
90*               GH=XIN(1)/TONX*PDKG*BPH*0.975
91*               GC=XIN(2)/TONX*PDKG*BPH
92*               GE=XIN(3)/TONX*PDKG*BPH
93*               TH1=(XIN(4)-TFTC1)/TFTC2
94*               TC1=(XIN(5)-TFTC1)/TFTC2
95*               TE1=(XIN(6)-TFTC1)/TFTC2
96*            QE=3023.9573
97*            TC12=TC1
98*            TG=TH1
99*            TA=TC1
100*           TC=TC1
101*           TE=TE1
102*           T3=TA
103*           T5=TG
104*           DO 6 I=1,7
105*           IF(XIN(I).LE.0.0001)  S=0.0
106*         6 CONTINUE
107*           IF(S.LE.0.0001)  GO TO 5
108*     C
109*     C     ASSUME TUBE SIDE WATER FILM COEF. IS CONTROLLING
110*           GH1=(XIN(1)/GH0)**0.8
111*           GC1=(XIN(2)/GC0)**0.8
112*           GE1=(XIN(3)/GE0)**0.8
113*     C
114*     C     TOTAL BASIS    IN METRIC UNITS
115*           GIN(1)=GH/GH1*TONX
116*           GIN(2)=GC/GC1*TONX
117*           GIN(3)=GE/GE1*TONX
118*     C
119*           DO 10 I=1,4
120*           IF(GIN(I).LE.0.0)  GO TO 8
121*           XNTU(I)=PBR(I)/GIN(I)*1.0*TON0
122*           IF(I.EQ.4)  XNTU(I)=PBR(I)/GIN(2)*TON0
123*           IF(XNTU(I).GE.10.) GO TO 8
124*           EFFN(I)=1.0-EXP(-XNTU(I))
125*           GO TO 10
126*         8 CONTINUE
127*           EFFN(I)=0.999
128*        10 CONTINUE
129*     C
130*     C
131*         5 CONTINUE
132*           IF(TIME.LE.TIME0.OR.TE1.LE.TE2SET)  TE1=TE2SET
```

```
133*              IF(TE1.LE.TE2SET)  S=0.0
134*              TE2=TF1-QE/GE*S
135*              TH2=TH1-(QE/COPX)/GH*S
136*              TC2=TC1+(1.0+1.0/COPX)*QE/GC*S
137*               IF(S.LE.0.0001)  GO TO 80
138*      C
139*              TE=TE1-(TE1-TE2)/EFFN(3)
140*              TG=TH1-(TH1-TH2)/EFFN(1)
141*      C   ASSUMED A VALUE FOR  TA
142*              TA2=(TC1+TC2)*0.5
143*              TA=TC1-(TC1-TA2)/EFFN(4)
144*              KTA=0
145*           15 CONTINUE
146*      C       IF(TA.LE.(TC1+1.0))  GO TO 43
147*              TC=TC2/EFFN(2)-(1.0/EFFN(2)-1.0)*(TC1+EFFN(4)*(TA-TC1))
148*      C
149*      C
150*              IF(TC.LE.TA)  GO TO 40
151*              IF(TE.GE.TA)  GO TO 41
152*              IF(TC.GE.TG)  GO TO 41
153*      C
154*              X1=(49.04+1.125*TA-TE)/(134.65+0.47*TA)
155*              X4=(49.04+1.125*TG-TC)/(134.65+0.47*TG)
156*              IF(X1.LT.CONST1)  GO TO 45
157*              IF(X4.LE.X1)  GO TO 43
158*      C
159*              H8=TC-25.0
160*              H10=572.8+0.417*TE
161*              GR=QE/(H10-H8)
162*              GS=GR*X4/(X4-X1)
163*              GW=GS*(X1/X4)
164*      C
165*              CX1=1.01-1.23*X1+0.48*X1**2
166*              CX4=1.01-1.23*X4+0.48*X4**2
167*              GSC1=GS*CX1
168*              GWC4=GW*CX4
169*              CRATIO=GWC4/GSC1
170*      C
171*      C   ASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
172*              F1=2.0
173*              F2=1.0
174*      C  F1=2,F2=1,HGS=HGW.--F1=1,F2=0,HGS>>HGW.--F1=2.5,F2=2/3,HGS=1.5HGW. FOR UAX
175*              RGS=((GS0/GS)*(TON0/TONX))**0.8
176*              RGW=((GW0/GW)*(TON0/TONX))**0.6
177*              UAX=F1*UAX0*(1.0/(RGS+F2*RGW))
178*      C
179*               IF(GWC4.GT.GSC1)  GO TO 17
180*              XNTUX=UAX/GWC4*(TON0/TONX)
181*              GO TO 18
182*      C
183*           17 CONTINUE
184*              XNTUX=UAX/GSC1*(TON0/TONX)
185*              CRATIO=GSC1/GWC4
186*           18 CONTINUE
187*      C
188*              IF(ABS(1.0-CRATIO).LT.0.01)  GO TO 13
189*              IF((XNTUX*(1.-CRATIO)).GE.10.)  GO TO 12
190*              EXPX=EXP(-XNTUX*(1.0-CRATIO))
191*              EFFNX=(1.0-EXPX)/(1.0-CRATIO*EXPX)
192*              GO TO 14
193*      C
194*           12 CONTINUE
195*              EFFNX=0.999
196*              GO TO 14
197*           13 CONTINUE
198*              EFFNX=XNTUX/(1.0+XNTUX)
199*           14 CONTINUE
```

```
200*      C
201*      C
202*              T5=TG-EFFNX*(TG-TA)
203*              T3=TA+(EFFNX*CRATIO*(TG-TA))
204*      C
205*              H1=(42.81-425.92*X1+404.67*X1**2)+CX1*TA
206*              H5=(42.81-425.92*X4+404.67*X4**2)+CX4*T5
207*              H7=572.8+0.46*TG-0.043*TC
208*      C
209*      C   FQG=1.0,NO HEAT LOSS.--FQG>1.0,&<2.0,% HEAT LOSS
210*             IF(FQG.LE.1.0)   FQG=1.0
211*             QG=(GW*H5-GS*H1+GR*H7)*FQG
212*             QC=GR*(H7-H8)*(1.0+QG/(QG+QE)*(1.0-FQG))
213*             QA=(GW*H5-GS*H1+GR*H10)*(1.0+QG/(QG+QE)*(1.0-FQG))
214*             COP=QE/QG
215*      C
216*             TC12=TC1+QA/GC
217*             IF(TC12.GE.TC2)   TC12=TC1+1.0
218*             TAX=TC1-(TC1-TC12)/FFFN(4)
219*      C
220*         40 CONTINUE
221*             IF(TC.LE.TA)   TAX=TC
222*             IF(ABS(TAX-TA).LT.0.00001)   GO TO 41
223*             IF(KTA.EQ.50)   GO TO 41
224*             TA=(TAX+TA)*0.5
225*             KTA=KTA+1
226*             GO TO 15
227*         41 CONTINUE
228*      C
229*             IF(ABS(COPX-COP).LT.0.00001)   GO TO 42
230*             IF(KCOP.EQ.50)   GO TO42
231*             COPX=(COPX+COP)*0.5
232*             KCOP=KCOP+1
233*             GO TO 16
234*         42 CONTINUE
235*      C
236*             X(1)=TE2-TE
237*             X(2)=TA-TC12
238*             X(3)=TC-TC2
239*             X(4)=TH2-TG
240*             Y(1)=ACONST
241*             Y(2)=RCONST
242*             Y(3)=CCONST
243*             Y(4)=DCONST
244*      C
245*             DO 47 I=1,4
246*             IF(X(I).LT.Y(I).AND.KTONX.EQ.1)   GO TO 60
247*             IF(X(I).LT.Y(I))   GO TO 45
248*         47 CONTINUE
249*      C
250*             IF(X1.GT.CONST1.AND.X4.LT.CONST4.AND.X4.GT.X1)   GO TO 46
251*      C
252*         45 CONTINUE
253*             IF(KTON2-100)   49,43,43
254*         49 CONTINUE
255*             TONMIN=TONX
256*             TONX=(TONX+TONMAX)*0.5
257*             ITONX=IFIX(TONX)
258*             TONX=FLOAT(ITONX)+1.0
259*             KTON2=KTON2+1
260*             GO TO 11
261*      C
262*         43 CONTINUE
263*             IF(KTON1-100)   44,50,50
264*         44 CONTINUE
265*             TONMAX=TONX
266*             TONX=(TONX+TONMIN)*0.5
```

36

```
267*              ITONX=IFIX(TONX)
268*              IF(TON.LE.1.0.AND.TONX.LE.(TONMIN+1.0)) GO TO 50
269*              IF(TONX.LE.TON)      GO TO 50
270*              TONX=FLOAT(ITONX)-1.0
271*              KTON1=KTON1+1
272*              GO TO 11
273*      C
274*         46 CONTINUE
275*              IF(KTONX.EQ.1.OR.TONX.LE.0)           GO TO 60
276*              IF(TON.GE.TONX)  GO TO 50
277*      C    CHECK MAX. STRONG SOLUTION PUMP RATE ---------------
278*              GSTO=GSO*TONO
279*              GSPUMP=GS*TONX
280*              IF(GSPUMP.GT.GSTO)  GO TO 43
281*      C
282*              TON=TONX
283*              IF(TE2.LT.TE2SET.OR.TE.LE.TELO)  GO TO 48
284*              GO TO 49
285*         48 CONTINUE
286*              TON=TON*(TE1-TE2SET)/(TE1-TE2)
287*      C
288*         50 CONTINUE
289*              IF(KTONX.EQ.1)         GO TO 60
290*              TONX=TON
291*              IF(TON.LE.1.0)  S=0.0
292*              KTONX=1
293*              GO TO 11
294*      C
295*         60 CONTINUE
296*      C
297*      C
298*      C-----ALL SPEC HEAT = 1. ---------------
299*              UAG=XNTU(1)*GH
300*              UAC=XNTU(2)*GC
301*              UAE=XNTU(3)*GE
302*              UAA=XNTU(4)*GC
303*      C
304*              A=ALOG(10.0)
305*              B=1555.0/(TF+273.15)
306*              C=11.2414E4/(TE+273.15)**2
307*              PE=EXP(A*(7.8553-B-C))
308*              B=1555.0/(TC+273.15)
309*              C=11.2414E4/(TC+273.15)**2
310*              PC=EXP(A*(7.8553-B-C))
311*      C
312*         80 CONTINUE
313*              QG=QG*CALBTU
314*              QC=QC*CALBTU
315*              QE=QE*CALBTU
316*              QA=QA*CALBTU
317*              H1=H1*CALBTU
318*              H5=H5*CALBTU
319*              H7=H7*CALBTU
320*              H8=H8*CALBTU
321*              H10=H10*CALBTU
322*      C
323*              T3=T3*TFTC2+TFTC1
324*              T5=T5*TFTC2+TFTC1
325*      C
326*              TH1=TH1*TFTC2+TFTC1
327*              TH2=TH2*TFTC2+TFTC1
328*              TC1=TC1*TFTC2+TFTC1
329*              TC12=TC12*TFTC2+TFTC1
330*              TA2=TC12
331*              TC2=TC2*TFTC2+TFTC1
332*              TF1=TE1*TFTC2+TFTC1
333*              TF2=TF2*TFTC2+TFTC1
```

```
334*              TE =TE *TFTC2+TFTC1
335*              TA =TA *TFTC2+TFTC1
336*              TC =TC *TFTC2+TFTC1
337*              TG =TG *TFTC2+TFTC1
338*      C
339*              UAG=UAG/PDKG
340*              UAC=UAC/PDKG
341*              UAE=UAE/PDKG
342*              UAA=UAA/PDKG
343*              UAX=UAX/PDKG
344*              GH=GH/PDKG
345*              GC=GC/PDKG
346*              GA=GC
347*              GE=GE/PDKG
348*              GR=GR/PDKG*S
349*              GW=GW/PDKG*S
350*              GS=GS/PDKG*S
351*              GSC1=GSC1/PDKG*S
352*              GWC4=GWC4/PDKG*S
353*      C
354*              QGT=QG*TON*S
355*              QCT=QC*TON*S
356*              QET=TON
357*              QAT=QA*TON*S
358*              UAGT=UAG*TON
359*              UACT=UAC*TON
360*              UAET=UAE*TON
361*              UAAT=UAA*TON
362*              GHT=GH*TON/BPH/0.975
363*              GCT=GC*TON/BPH
364*              GAT=GCT
365*              GET=GE*TON/BPH
366*              DT12E=TE1-TF2
367*              DT12A=TA2-TC1
368*              DT12C=TC2-TA2
369*              DT12G=TH1-TH2
370*              DTE2=TE2-TE
371*              DTA2=TA-TA2
372*              DTC2=TC-TC2
373*              DTG2=TH2-TG
374*      C
375*      C
376*              IF(JWRITE.EQ.0)  GO TO 59
377*              IF(AMOD(TIME,1.000).GT.DELT)  GO TO 500
378*              WRITE(6,95)
379*              TONXIN=XIN(7)
380*              XIN(7)=TONXIN/12000.
381*              WRITE(6,98) KTA,KCOP,KTON2,KTON1,(XIN(I),I=1,6),TONX,XIN(7),INPUT
382*              XIN(7)=TONXIN
383*              WRITE(6,403)
384*              WRITE(6,402) X1,X4,CX1,CX4,GR,GS,GW,GSC1,GWC4,EXPX,CRATIO,UAX
385*              WRITE(6,407)
386*              WRITE(6,402) TA,T5,T3,TG,H1,H5,H7,H8,H10,XNTUX,EFFNX,COP
387*              WRITE(6,406)
388*              WRITE(6,405) GE,TE1    ,TE2,TE   ,XNTU(3),EFFN(3),PE,UAE,QE,GET,UAE
389*             XT,QFT
390*              WRITE(6,404) GA,TC1    ,TA2,TA   ,XNTU(4),EFFN(4),PE,UAA,QA,GAT,UAA
391*             XT,QAT
392*              WRITE(6,401) GC,TA2,TC2,TC   ,XNTU(2),EFFN(2),PC,UAC,QC,GCT,UACT,Q
393*             XCT
394*              WRITE(6,400) GH,TH1    ,TH2,TG   ,XNTU(1),EFFN(1),PC,UAG,QG,GHT,UAG
395*             XT,QGT
396*        400 FORMAT(1X,4HG---,7F10.3,5E10.3//)
397*        401 FORMAT(1X,4HC---,7F10.3,5E10.3/)
398*        402 FORMAT(1X,4HX---,12F10.3/)
399*        403 FORMAT(5X,120H          X1          X4          CX1          CX4          GR
400*             X   GS          GW          GSC1          GWC4          EXPX          CRATIO          UAX
```

```
401*              X      )
402*        404 FORMAT(1X,4HA---,7F10.3,5E10.3/)
403*        405 FORMAT(1X,4HE---,7F10.3,5E10.3/)
404*        406 FORMAT(5X,120H      G           T1          T2          T         NTU
405*              X   EFFN        P          UA          Q           GT          UAT         OT
406*              X      )
407*        407 FORMAT(5X,120H        TA          T5          T3          TG          H1
408*              X   H5          H7          H8          H10         NTUX        EFFNX       COP
409*              X      )
410*     C
411*           WRITE(6,96)
412*           WRITE(6,97) DT12E,DTE2,TE2,DT12A,DTA2,TA2,DT12C,DTC2,TC2,DT12G,DTG
413*           X2,TH2
414*        95 FORMAT(5X,127H      KTA         KCOP        KTON2       KTON1     GHT-GPM
415*              X GCT-GPM     GET-GPM     TH1-F       TC1-F       TE1-F     TON-CAL   TON-ST
416*           XART    NO. )
417*        96 FORMAT(5X,120H        DT12E       DTE2        TE2         DT12A       DTA2
418*              X   TA2         DT12C       DTC2        TC2         DT12G       DTG2        TH2
419*              X      )
420*        97 FORMAT(1X,4HTEMP,12F10.3///)
421*        98 FORMAT(5X,4(I8,2X),8F10.3,3X,I3/)
422*        99 FORMAT(7F10.1)
423*     C
424*        59 CONTINUE
425*       500 CONTINUE
426*           OUT(1)=TH2
427*           OUT(2)=XIN(1)
428*           OUT(3)=TON*OE
429*           OUT(4)=TH2
430*           OUT(5)=OGT
431*           OUT(6)=TE2
432*           OUT(7)=XIN(3)
433*           OUT(8)=TC2
434*           OUT(9)=XIN(3)
435*           OUT(10)=TON*OE
436*     C
437*           INPUT=1+INPUT
438*           RETURN
439*     C    STOP
440*           END
```
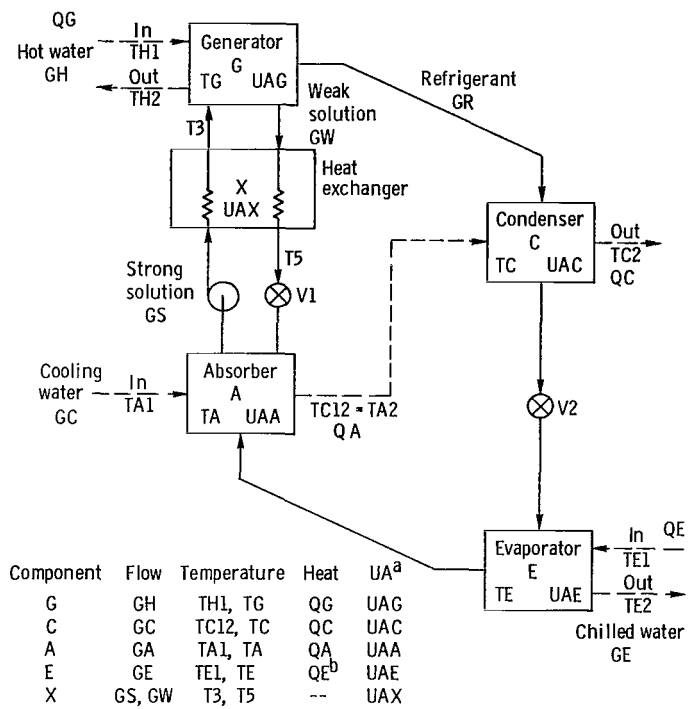
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Component	Flow	Temperature	Heat	UA^a
G	GH	TH1, TG	QG	UAG
C	GC	TC12, TC	QC	UAC
A	GA	TA1, TA	QA	UAA
E	GE	TE1, TE	QE^b	UAE
X	GS, GW	T3, T5	--	UAX

[a]UA = Product of overall heat-transfer coefficient and its surface area.

[b]QE = 1 TON; QET = Total (not shown with total flows, heats, and UA's).

Figure 1. - Flow diagram of single-stage LiBr-H_2O absorption unit.

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15. Supplementary Notes

16. Abstract

A computer model of a LiBr-H_2O single-stage absorption machine has been developed. The model, utilizing a given set of design data such as water-flow rates and inlet or outlet temperatures of these flow rates but without knowing the interior characteristics of the machine (heat transfer rates and surface areas), can be used to predict or simulate off-design performance. Results from 130 off-design cases for a given commercial machine agree with the published data within 2 percent.

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