Simulation Model of a Single-Stage Lithium Bromide-Water Absorption Cooling Unit

David Miao

AUGUST 1978
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Lewis Research Center
Cleveland, Ohio
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ABSORPTION COOLING UNIT
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SUMMARY

The performance and load capability of a given LiBr-H₂O 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-H₂O 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–H₂O 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
through an expansion valve $V_2$, 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\(_2\)O solution of refrigerant (water) undergoing evaporation, absorption, or condensation process

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

\[
EFFN = 1 - e^{-\frac{UA}{GC_p}}
\]

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\(_2\)O 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

\[
\frac{1}{U} = \frac{1}{h_w} + \frac{1}{h} + R_t + F
\]

where

\( h_w \) tube-side coefficient due to forced convection

\( h \) shell-side coefficient
$R_t$  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 material 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 fouling 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
*$\mu$  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 $0$:

$$h_w = \left(\frac{G}{G_0}\right)^{0.8} h_{w0}$$  \hspace{1cm} (4b)

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

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

$$U = \left(\frac{G}{G_0}\right)^{0.8} \left(\frac{1 + h_{w0}R_0}{1 + h_wR}\right) U_0$$  \hspace{1cm} (3d)

As long as the term $h_wR$ is not substantially different from $h_{w0}R_0$, the factor $(1 + h_{w0}R_0)/(1 + h_wR)$ 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

$$UA = \left(\frac{G}{G_0}\right)^{0.8} (UA)_0$$  \hspace{1cm} (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

\[
h_{gw} \propto G_w^{0.6}
\]

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

\[
\frac{1}{U_x} = \frac{1}{h_{gs}} + \frac{1}{h_{gw}}
\]

where

- \(x\) refers to solution exchanger
- \(gs\) refers to strong solution
- \(gw\) refers to weak solution

For a referenced condition, equation (6a) becomes

\[
\frac{1}{U_{x0}} = \frac{1}{h_{gs0}} + \frac{1}{h_{gw0}}
\]

where

- \(U_{x0}\) refers to solution exchanger
- \(gs0\) refers to strong solution
- \(gw0\) refers to weak solution

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

\[
h_{gs0} = h_{gw0} = 2U_{x0}
\]

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

\[
h_{gs} = \left(\frac{G_s}{G_{s0}}\right)^{0.8} h_{gs0} = \left(\frac{G_s}{G_{s0}}\right)^{0.8} (2U_0)
\]

\[
h_{gw} = \left(\frac{G_w}{G_{w0}}\right)^{0.6} h_{gw0} = \left(\frac{G_w}{G_{w0}}\right)^{0.6} (2U_0)
\]
Then substituting equations (8) and (9) into equation (6a) and rearranging the terms yield

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

(10)

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

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

(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-H₂O 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

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

(11b)
where, for example,

\[ \begin{align*}
    h_{gs0} &= h_{gw0} & F_1 &= 2 \quad \text{and} \quad F_2 = 1 \\
    h_{gs0} &<< h_{gw0} & F_1 &= 1 \quad \text{and} \quad F_2 = 0 \\
    h_{gs0} &= 1.5h_{w0} & F_1 &= 2.5 \quad \text{and} \quad F_2 = 2/3
\end{align*} \]

Equation (11b) may be useful to experimentally determine the actual values of \( F_1 \) and \( F_2 \) 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

\[
    \text{EFFNX} = \frac{T_g - T_5}{T_g - T_a}
\]  

(12)

where

\( T_g \) \hspace{1cm} \text{temperature of generator}

\( T_5 \) \hspace{1cm} \text{outlet temperature of weak solution}

\( T_a \) \hspace{1cm} \text{temperature of absorber}

In general the exchanger is designed with the effectiveness \( \text{EFFNX}_0 = 0.7 \) to 0.8. If \( T_5 \) in equation (12) for the design load is not known, the relation between \( \text{EFFNX}_0 \) and \( T_{50} \) may be established by heat balance (ref. 1).

When \( \text{EFFNX}_0 \) is found together with flow rates \( G_{so} \) and \( G_{w0} \) and the solution heat capacities \( C_{so} \) and \( C_{w0} \), then \((UA)_{x0}\) is calculated from the following equation:

\[
    \text{EFFNX} = \frac{1 - e^{-\text{NTU}_x \left[(1 - C_{\min}/C_{\max})\right]}}{1 - \left(\frac{C_{\min}}{C_{\max}}\right) e^{-\text{NTU}_x \left[1-(C_{\min}/C_{\max})\right]}}
\]  

(13)

where

\( \text{NTU}_x \) \hspace{1cm} (UA)_{x}/C_{\min}

\( C_{\min} \) \hspace{1cm} G_{w}C_{w}

\( C_{\max} \) \hspace{1cm} G_{s}C_{s}
The subscript 0 used previously has been deliberately omitted in equations (12) and (13) for the purpose of generalization. Then \( C_{\text{min}} = (G_w C_w) \) and \( C_{\text{max}} = (G_s C_s) \) because \( G_w < C_s \) and \( C_w < C_s \) for LiBr-H\( _2\)O absorption machine. The \((UA)_{x0}\) is solved implicitly in equation (13).

THREE 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:

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

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

\[
Q_A = (G_w H_5 - G_s H_1 + G_R H_7) \left[ 1 + \left( \frac{Q_G}{Q_G + Q_E} \right)(1 - F_{QG}) \right] \tag{16}
\]
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 operation, the required flow rate may or may not exceed the maximum capacity. For a particular load demand, if heat source temperature is low and/or the cooling water temperature 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 different machines, it is assumed that the solution flow rate cannot exceed the capacity of the design point.

Concentration of the LiBr - H₂O Solution

For an absorption process to exist in operation, there are limits on the solution concentrations. If the concentration is too rich, crystallization will occur. If the concentration 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 operable 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 exchanger surfaces are also limited by the heat-transfer processes. In general the temperature 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 calculation 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.
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, KTONI, 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 printout 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-H₂O 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.
APPENDIX A

SYMBOL LIST, THERMODYNAMIC FORMULAS, 
AND EQUATIONS FROM REFERENCE 1

Strong concentration (X1 > 0.5):

\[ X_1 = \frac{(49.04 + 1.125 T_A - T_E)}{(134.65 + 0.47 T_A)} \]  \( \text{kg LiBr} \)
\[ \text{kg solution} \]

Weak concentration (X4 < 0.65):

\[ X_4 = \frac{(49.04 + 1.125 T_G - T_C)}{(134.65 + 0.47 T_G)} \]  \( \text{kg LiBr} \)
\[ \text{kg solution} \]

Enthalpy of condenser outlet:

\[ H_8 = (T_C - 25) \]  \( \text{kcal/kg} \)

Enthalpy of evaporator outlet:

\[ H_{10} = (572.8 + 0.417 T_E) \]  \( \text{kcal/kg} \)

Refrigerant flow:

\[ G_R = \frac{Q_E}{(H_{10} - H_8)} \]  \( \text{kg/hr} \)

Strong solution flow:

\[ G_S = G_R \frac{X_4}{(X_4 - X_1)} \]  \( \text{kg/hr} \)

Weak solution flow:

\[ G_N = G_R \frac{X_1}{(X_4 - X_1)} \]  \( \text{kg/hr} \)
Heat capacity of strong solution:

\[ CX_1 = 1.01 - 1.23(X_1) + 0.48(X_1)^2 \] kcal/(kg)(\degree C)

Heat capacity of weak solution:

\[ CX_4 = 1.01 - 1.23(X_4) + 0.48(X_4)^2 \] kcal/(kg)(\degree C)

Outlet temperature of weak solution

\[ T_5 = T_G - (E_{FFNX})(T_G - T_A) \] \degree C

Outlet temperature of strong solution:

\[ T_3 = T_A + (E_{FFNX}) \left( \frac{X_1}{X_4} \right) \left( \frac{CX_4}{CX_1} \right) (T_G - T_A) \] \degree C

Enthalpy of absorber outlet:

\[ H_1 = \left[ 42.81 - 425.92(X_1) + 404.67(X_1)^2 \right] + \left[ 1.01 - 1.23(X_1) + 0.48(X_1)^2 \right](T_A) \] kcal/kg

Enthalpy of weak solution at heat exchanger outlet:

\[ H_5 = \left[ 42.81 - 425.92(X_4) + 404.67(X_4)^2 \right] + \left[ 1.01 - 1.23(X_4) + 0.48(X_4)^2 \right](T_5) \] kcal/kg

Enthalpy of refrigerant at generator outlet:

\[ H_7 = (572.8 + 0.46 T_G - 0.043 T_C) \] kcal/kg

Condenser heat load:

\[ QC = (GR)(H_7 - H_8) \] kcal/hr

Generator heat load:

\[ QG = (GW)(H_5) + (GR)(H_7) - (GS)(H_1) \] kcal/hr
Absorber heat load:

\[ QA = (GW)(H5) + (GR)(H10) - (GS)(H1) \quad \text{kcal/hr} \]

Coefficient of performance:

\[ COP = \frac{QE}{QG} \]

Evaporator heat load:

\[ QE = 3024.0 \quad \text{kcal/hr} \]

Evaporator pressure:

\[ PE = \text{antilog}_{10} \left(7.8553 - \frac{1555}{TE + 273.15} - \frac{11.2414 \times 10^4}{(TE + 273.15)^2}\right) \text{ mm Hg} \]

Condenser pressure:

\[ PC = \text{antilog}_{10} \left(7.8553 - \frac{1555}{TC + 273.15} - \frac{11.2414 \times 10^4}{(TC + 273.15)^2}\right) \text{ mm Hg} \]
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, °F, °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)(°F), cal/(hr)(°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

<table>
<thead>
<tr>
<th>NTUG</th>
<th>(Generator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTUC</td>
<td>(Condenser)</td>
</tr>
<tr>
<td>NTUA</td>
<td>(Absorber)</td>
</tr>
<tr>
<td>NTUE</td>
<td>(Evaporator)</td>
</tr>
<tr>
<td>NTUX</td>
<td>(Heat exchanger)</td>
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</tbody>
</table>

Heat-transfer effectiveness

<table>
<thead>
<tr>
<th>EFFNG</th>
<th>(Generator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFFNC</td>
<td>(Condenser)</td>
</tr>
<tr>
<td>EFFNA</td>
<td>(Absorber)</td>
</tr>
<tr>
<td>EFFNE</td>
<td>(Evaporator)</td>
</tr>
<tr>
<td>EFFNX</td>
<td>(Heat exchanger)</td>
</tr>
</tbody>
</table>

(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.)

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

Controls and limits

<table>
<thead>
<tr>
<th>METRIC</th>
<th>(Input to be metric units &gt; 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KLBHR</td>
<td>(Input to be lb/hr &gt; 0)</td>
</tr>
<tr>
<td>JWRITE</td>
<td>(Write output &gt; 0)</td>
</tr>
<tr>
<td>KTA</td>
<td>(TA converging cycle = 50)</td>
</tr>
<tr>
<td>KCOP</td>
<td>(COP converging cycle = 50)</td>
</tr>
</tbody>
</table>
KTON1 and KTON2  (TONX converging cycle = 100)
ACONST = 1.0º C  Limits of (TE2 - TE)
BCONST = 1.296º C  Limits of (TA - TC12)
CCONST = 1.425º C  Limits of (TC - TC2)
DCONST = 1.919º C  Limits of (TH1 - TG)
TELO = 2.22º C  (Lowest temperature limits of TE)
TE2SET = 4.43º 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)
APPENDIX C
SAMPLES 1 AND 2 WITH PROGRAM LISTINGS

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

```plaintext
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* C DIMENSION XIN(10),PAR(13),XNTU(6),EFFN(6)
4* C DIMENSION X(6),Y(6),GIN(3)
5* C DIMENSION TONGV(160),TONCAL(160)
6* C
7* C--METRIC=D,BRITISH UNITS USED.---------JWRITE=1 WRITE ALL,JWRITE=0 NO WRITE
8* C KLRHR=G,GPM FOR FLOW INPUT.----HLBHR=1, LBS/HR INPUT
9* DATA METRIC=O, KLRHR=C, JWRITE=1/
10* DATA PMLK=.4536/
11* DATA TFC1/32.*/TFCC2/1.8/
12* DATA CALBTU/3.96831/
13* C
14* C
15* C CONST1 & CONST4 ARE CONCENTRATION LIMITS
16* DATA CONST1/O.4/,CONST4/C.68/
17* C A-B-C-D=CONST ARE LIMITS FOR EVAP., ABSOPP., COND., & GENERATOR
18* DATA ACONST/1.296/ BCONST/1.423/ CCONST/1.919/
19* C
20* C DATA TELO/2.22/,TESE/4.43/
21* C COP LIMITS -----HEAT LOSS FACTOR
22* DATA COPHT/0.93/, COPLOT/1.6/, FG/1.0/
23* C EFFNX=D.71426 FOR TS=135 F EFFFX=(TG-TS)/(TG-TA)
24* DATA EFFNX/O.71428/
25* C
26* C DIMENSION XNRSV(10)
27* C DIMENSION AJTE(4)
28* DATA AJTE(1),AJTE(2),AJTE(3),AJTE(4) / 3HT1 , 3HT2 /
29* 1 3HT2 , 3HT1 /
30* C DIMENSION AJREF(2)
31* DATA AJREF(1),AJREF(2) / 3HTC , 3HTA /
32* C DATA JTE2 / 0/ 3HTC , 3HTA /
33* C DTLIM=D.25 3HTC , 3HTA /
34* C DTLIM=D.1 3HTC , 3HTA /
35* C NAMESTT /REF/ TH2,TA2,TC2,TE?,TH1,TA1,TE1,TG,TG,TC,TA,TE,TONG,
36* 1 KLRHR,METRIC,JREF,CONST1,CONST4,ACONST,BCONST,CCONST,DCONST,
37* 2 COPHT,COPLOT,FG,EFFNX,TELO,TESE
38* C NAMESTT /VAR/ GH,GC,GE,TH1,TA1,TE1,TG,TG,TC,TA,TE,TONG,
39* C
40* C JREF=O, RUN NO REF. --JREF=1,TC2=XIN(2).--JREF=2,TA2 OR TC12=XIN(2)
41* C 3C0 READ(5,REF)
42* C 3C0 LVAR=0
43* C XIN(1) = TH2
44* C IF(JREF.EQ.1) XIN(2):= TC2
45* C IF(JREF.EQ.2) XIN(2):= TA2
46* C XIN(3):= TE?
47* C XIN(4):= TH1
48* C XIN(5):= TA1
49* C TC1:= TA1
50* C XIN(6):= TE1
51* C XIN(7):= TG
52* C XIN(8):= TC
53* C XIN(9):= TA
54* C XIN(10):= TE
55* C DO 302 I=1,1C
56* C XINRSV(I):=XIN(I)
57* C 302 CONTINUE
58* C TC2RSV:= TC2
59* C TA2RSV:= TA2
60* C KERROR=0
61* C
62* C
63* C
```
IF(METRIC.GT.0) TFTC1=0.0
IF(METRIC.GT.0) TFTC2=1.0
IF(METRIC.GT.0) PDKG=1.0
IF(METRIC.GT.0) CALB1U=1.0
IF(METRIC.GT.0) BPH=1.0

C
BPH=500.0
IF(KLCHR.GT.0) BPH=1.0

C
IF(JREF.GT.0) GO TO 19

7 CONTINUE
C
----------UA VALUES ARE PER TON BASIS----------
TONT=TON
GSO=GS*PD
GWD=GW*PD
GD=GHT
GDO=GET
GDO=GCT
PAR(1)=UAG*PD
PAR(2)=UAC*PD
PAR(3)=UAF*PD
PAR(4)=UAA*PD
PAR(5)=UAX*PD
UAXD=PAR(5)

C
INPUT=1

C
990 CONTINUE
C
JREF=0
READ(5,VAR,END=999)
XIN(1)=GH
XIN(2)=GC
XIN(3)=GE
XIN(4)=THI
XIN(5)=TAI
TCI=TAI
XIN(6)=TE1
XIN(7)=TONX
GESAV=XIN(3)
TE2SAV=TE2
TH2SAV=TH?
KERROR=0
TON IS AN ASSUMED VALUE TO START
TONX=XIN(7)
TONREF=TONO/*5
TONMIN=TONO/*1
TONMAX=TONO/*1.2
IF(XIN(7).LE.TONREF) TONX=TONREF

C
19 CONTINUE
C
K6C=0

C
----------FLOW RATES ARE PER TON BASIS----------
QE=3223.9573
41=0.
45=0.
H7=0.
H8=0.
H1O=0.
TON=0.0
KTON1=0
KTON2=0
KTONX=-1
X4=0.67
X1=C=4.1
WRITE=0
11 CONTINUE

C COPX=.722
16 CONTINUE

IF(COPX.*F.COPLO.OR.COPX.GE.COPHI) COPX=0.722

16 CONTINUE

GH=XIN(1)/TONX*PDKG*BPH*Q.975
GC=XIN(2)/TONX*PDKG*BPH
GE=XIN(3)/TONX*PDKG*BPH
TH1=(XIN(4)-TFTC1)/TFTC2
TC1=(XIN(5)-TFTC1)/TFTC2
TE1=(XIN(6)-TFTC1)/TFTC2
TE2SW=(TF2SAV-TFTC1)/TFTC2
TH2SW=(TH2SAV-TFTC1)/TFTC2

16 CONTINUE

IF(JREF.EQ.0) GO TO 20
TH2=(XIN(1)-TFTC1)/TFTC2
TA2=(XIN(2)-TFTC1)/TFTC2
IF(JREF.EQ.2) TC2=TA2
IF(JREF.EQ.1) TC2=TA2
TE2=(XIN(3)-TFTC1)/TFTC2
TG=(XIN(7)-TFTC1)/TFTC2
TC=(XIN(8)-TFTC1)/TFTC2
TA=(XIN(9)-TFTC1)/TFTC2
TE=(XIN(10)-TFTC1)/TFTC2

18 CONTINUE

20 CONTINUE

ASSUME TUBE SIDE WATER FILM COEF. IS CONTROLLING

180* (1) =90.8
SC1=(XIN(3)/GEC)*90.8
TOTAL BASIS IN METRIC UNITS
SIN(1)=GH/GH1*TONX
GIY(Z)=GC/GC1*TONX
GIY(3)=GE/GE1*TONX

25 CONTINUE
TG=TH1-(TH1-TH2)/EFFN(1)
TC2=TC1*(1.0+1.0/COPX)*QE/6C

C ASSUMED A VALUE FOR TA
TA2=(TC1+TC2)*0.5
TA=TC1-(TC1-TC2)/EFFN(4)

15 CONTINUE
TG=TH1-(TH1-TH2)/EFFN(1)
TC2=TC1*(1.0+1.0/COPX)*QE/6C

C ASSUMED A VALUE FOR TA
TA2=(TC1+TC2)*0.5
TA=TC1-(TC1-TC2)/EFFN(4)

21 CONTINUE

XI1=(49.04+1.035*TA-TE)/(134.5+3.47*TA)
XI4=(49.04+1.035*TG-TC)/(134.5+3.47*TG)

IF(X11.LT.CONST1) GO TO 45
IF(X11.GE.TG) GO TO 41
IF1TC.GE.TG) GO TO 41

C TA1=(TC1+TC2)*0.5
TA=TCl-(TCl-TAZ)/EFFN(4)

C TA1=(TC1+TC2)*0.5
TA=TCl-(TCl-TAZ)/EFFN(4)

C ASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

F1=2.0
F2=1.0

C GSC=GC1*GC1

C ASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

C GSC=GC1*GC1

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F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
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CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
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F2=1.0

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F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0

CASSUMING ORIGINAL FILM COEF. EQUAL ON BOTH SIDES.--GW ON SHELL SIDE
F1=2.0
F2=1.0
H5=(42.81-425.92*Y4+40.67*Y4**2)+CX4*T5
H7=572.8+4.46*TG-D.043*TC
C
FQG=1.0, NO HEAT LOSS. if FQG>1.0, L<2.0, % HEAT LOSS
IF(FQG.LE.1.0) FQG=1.0
QG=(GW*HS-58*H1*GR*H7)*FQG
QC=GR*(H7-H8)*(1.0+QG/(QG+QE)*(1.0-FQG))
QA=(GW*HS-58*H1*GR*H10)*(1.0+QG/(QG+QE)*(1.0-FQG))
COP=QG/QG
C
IF(JREF.GT.0) GO TO 60
C
TC12=TC1+QA/GC
TAX=TC1-(TC1-TC12)/EFFN(4)
C
CONTINUE
IF(TC.LE.TA) TAX-TC
IF(ABS(TAX-TA).LT.0.00001) GO TO 41
IF(KTA.EQ.50) GO TO 41
COPX=I+COPX+COP*0.5
COP=KCOP+1
GO TO 16
C
CONTINUE
IF(ABS(COPX-COP).LT.0.00001) GO TO 42
COPX=COPX+COP*0.5
GO TO 16
C
X(1)=TE1-TE
X(2)=TA-TC12
X(3)=TC-TC2
X(4)=TH2-TG
Y(1)=ACONST
Y(2)=CONST
Y(3)=BCONST
Y(4)=DCONST
C
DO 47 I=1,4
IF(X(I).LT.Y(I).AND.KTONX.EQ.1) GO TO 60
GO TO 45
CONTINUE
C
IF(X1.GT.CONST1.AND.X4.LT.CONST4.AND.X4.GT.X1) GO TO 46
C
CONTINUE
IF(KTON2.100) 49,43,43
CONTINUE
TOMIN=TONX
TONX=INT(TONX+TOMAX)*0.5
IFX=INTX(TONX)
TONX=TONX+DLIM
KTON2=KTON2+1
GO TO 11
C
CONTINUE
IF(KTON1.100) 44,65,65
CONTINUE
TOMAX=TONX
IFX=INTX(TONX)
IFX=INTX(TONX)
IFX=INTX(TONX)
IFX=INTX(TONX)
GO TO 60
IFX=INTX(TONX)
GO TO 50
TONX=FLOAT(TONX)-1.0
TONX=TONX-DLIM
CONTINUE
46  IF(KTONX.EQ.1.00.OR.TONX.LE.D) GO TO 60
47  IF(TONX.GE.KTONX) GO TO 50
48  GO TO 49
49  48 CONTINUE
50  TON=TON*(TE1-TE2SET)/(TE1-TE2)
51  CONTINUE
52  IF(KTONX.EQ.1.00.OR.TONX.LE.D) GO TO 60
53  TONX=1
54  GO TO 11
55  60 CONTINUE
56  IF(JREF.GT.O.OR.KTONX.EQ.1.00.KGC.GE.30) GO TO 66
57  KGC=KGC+1
58  CONTINUE
59  66 CONTINUE
60  ALL SPEC HEAT = 1. ---------------
61  IF(JREF.EQ.0.0) GO TO 35
62  TON=TON
63  35 CONTINUE
64  YY=(1.-EFFNX*CRATIO)/(1.-CRATIO)
65  XNTUX=AUX+LOG(YY)/(1.-CRATIO)
66  GH=.56/(TH1-TH2)
67  GE=.56/(TE1-TE2)
68  IF(JREF.EQ.0.1) GC=(QA+QC)/(TC1-TC1)
69  IF(JREF.EQ.0.2) GC=QA/(TC1-TC1)
70  IF(JREF.EQ.0.3) TC12=TC1+QA/GE
71  IF(JREF.EQ.0.4) TC12=TC1+QA/GC
72  EFFN(1)=(TH1-TH2)/(TH1-TH2)
73  EFFN(2)=(TC12-TC1)/(TC12-TC1)
74  EFFN(3)=(TE1-TE2)/(TE1-TE2)
75  EFFN(4)=(TC1-TC12)/(TC1-TC1)
76  DO 31 K=1,4
77  XNTU(X)=-1.0*AUX*(1.-EFFN(K))
78  CONTINUE
79  31 CONTINUE
80  C
81  35 CONTINUE
82  UAG=XNTU(1)*GH
83  UAC=XNTU(2)*GC
84  UAE=XNTU(3)*GE
85  UAX=XNTU(4)*GC
86  C
87  31 CONTINUE
88  C
89  A=AUX*(10.0)
90  B=1555.0/(TC+273.15)
91  C=11.2414/(4/(TC+273.15)**2
92  PE=EXP(A*(7.8553-E-C))
93  F=1555.0/(TC+273.15)
94  C=11.24144/(TC+273.15)**2
95  PC=EXP(A*(7.8553-F-C))
96  C
97  DG=DG+CALPTU
98  QC=QC+CALPTU

KTON1=KTON1+1
GO TO 11
46 CONTINUE
46  IF(KTONX.EQ.1.00.OR.TONX.LE.D) GO TO 60
47  IF(TONX.GE.KTONX) GO TO 50
48  GO TO 49
49  48 CONTINUE
50  TON=TON*(TE1-TE2SET)/(TE1-TE2)
51  CONTINUE
52  IF(KTONX.EQ.1.00.OR.TONX.LE.D) GO TO 60
53  TONX=1
54  GO TO 11
55  60 CONTINUE
56  IF(JREF.GT.O.OR.KTONX.EQ.1.00.KGC.GE.30) GO TO 66
57  KGC=KGC+1
58  CONTINUE
59  66 CONTINUE
60  ALL SPEC HEAT = 1. ---------------
61  IF(JREF.EQ.0.0) GO TO 35
62  TON=TON
63  35 CONTINUE
64  YY=(1.-EFFNX*CRATIO)/(1.-CRATIO)
65  XNTUX=AUX+LOG(YY)/(1.-CRATIO)
66  GH=.56/(TH1-TH2)
67  GE=.56/(TE1-TE2)
68  IF(JREF.EQ.0.1) GC=(QA+QC)/(TC1-TC1)
69  IF(JREF.EQ.0.2) GC=QA/(TC1-TC1)
70  IF(JREF.EQ.0.3) TC12=TC1+QA/GE
71  IF(JREF.EQ.0.4) TC12=TC1+QA/GC
72  EFFN(1)=(TH1-TH2)/(TH1-TH2)
73  EFFN(2)=(TC12-TC1)/(TC12-TC1)
74  EFFN(3)=(TE1-TE2)/(TE1-TE2)
75  EFFN(4)=(TC1-TC12)/(TC1-TC1)
76  DO 31 K=1,4
77  XNTU(X)=-1.0*AUX*(1.-EFFN(K))
78  CONTINUE
79  31 CONTINUE
80  C
81  35 CONTINUE
82  UAG=XNTU(1)*GH
83  UAC=XNTU(2)*GC
84  UAE=XNTU(3)*GE
85  UAX=XNTU(4)*GC
86  C
87  31 CONTINUE
88  C
89  A=AUX*(10.0)
90  B=1555.0/(TC+273.15)
91  C=11.2414/(4/(TC+273.15)**2
92  PE=EXP(A*(7.8553-E-C))
93  F=1555.0/(TC+273.15)
94  C=11.24144/(TC+273.15)**2
95  PC=EXP(A*(7.8553-F-C))
96  C
97  DG=DG+CALPTU
98  QC=QC+CALPTU

28
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 T3=T3*TFC2+TFTC1
407* TS=TS*TFC2+TFC1
410* C TH1=TH1*TFC2+TFTC1
411* TH2=TH2*TFC2+TFTC1
412* TC1=TC1*TFC2+TFTC1
413* TC12=TC12*TFC2+TFTC1
414* TA2=TA12
416* TE1=TE1*TFC2+TFTC1
417* TE2=TE2*TFC2+TFTC1
418* TE=TE*TFC2+TFTC1
419* TA=TA*TFC2+TFTC1
420* TC=TC*TFC2+TFTC1
421* TG=TG*TFC2+TFTC1
423* C 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=ESC1/PDKG
436* GWC4=GWC4/PDKG
437* C GAT=GAT*TON
438* GCT=GCT*TON
439* Q6T=Q6T*TON
440* QAT=QAT*TON
441* UAGT=UAG*TON
442* UACT=UAC*TON
443* UAET=UA*TON
444* UAT=UAA*TON
445* GHT=GH*TON/BPH/1.975
446* GC=GC*TON/BPH
447* GAT=GAT
448* GET=GET*TON/BPH
449* DT12E=TE1-TE2
450* DT12A=TA12-TC1
451* DT12C=TC2-TC2
452* DT12G=TH1-TH2
453* LTE2=TE2-TE
454* DTA2=TA-2A
455* DTC2=TC-TC2
456* DGT2=TH2-TE
458* C IF(KTA,GE,50.0 OR, KCHP,GE,50) GO TO 58
459* IF(KTON2,GE,100.0 OR, KTON1,GE,100) GO TO 58
460* IF(JWRITE,EQ.,C) GO TO 59
461* GO TO 430
462* KEPROP=1
463* 56 CONTINUE
466* 43 IF METRIC.GT.0) WRITE(6,420)
467* 420 FORMAT(1X,'OUTPUT IS IN SI UNITS DEGREES C, KG/M^3, CAL * /)
468* 41 IF METRIC.EQ.0) WRITE(6,421)
469* 421 FORMAT(1X,'OUTPUT IS IN U.S. CUSTOMARY UNITS - DEGREES F, GPM
470* 41, 1, B'TU' /)
471* 4 IFERROR(EQ.0) WRITE(6,431)
472* 431 FORMAT(///20X,********** IFRACTIONS FAILED TO CONVERGE **********
473* 1** ' *
474* 4 IF METRIC.EQ.0 .AND. INPUT.EQ.0) WRITE(6,93) AJREF(JREF)
475* 4 IF METRIC.GT.0 .AND. INPUT.EQ.0) WRITE(6,94) (XIN(I),I=1,10),TONX,JREF,INPUT
476* 4 IF INPUT.EQ.0) GO TO 57
477* 4 JOUT=1
478* 4 IF(JTE2.GT.0) JOUT=3
479* 4 WRITE(6,195) KTA,KCOP,KTON2,KTON1,(XIN(I),I=1,6),TONX,XIN(7),INPUT
480* 4 IF(JTE2.GT.0) WRITE(6,98) KTA,KCOP,KTON2,KTON1,XIN(1),XIN(2),
481* 4 XIN(3),TH2SAV,XIN(5),TE2SAV,TONX,XIN(7),INPUT
482* 57 CONTINUE
483* 5 C
484* 4 WRITE(6,403)
485* 4 WRITE(6,402) X1,X4,CX1,CX4,GR,GS,GW,GSC1,GWC4,EXPX,CRATIO,UAX
486* 4 WRITE(6,407)
487* 4 WRITE(6,406) TA,T5,T3,TG,H1,H5,H7,H8,H10,XNTUX,EFFNX,COP
488* 4 WRITE(6,405) GE,TE1,TE2,TE3,XNTU(3),EFFN(3),PE,UA,UE,GET,UAE
489* 4 XT,GET
490* 4 WRITE(6,404) GA,TC1,TA2,TA,XNTU(4),EFFN(4),PE,UA,GA,GAT,UAA
491* 4 XT,GAT
492* 4 WRITE(6,401) GC,TA2,TC2,TC,XNTU(2),EFFN(2),PC,UAC,OC,GCT,UCT,Q
493* 4 XCT
494* 4 WRITE(6,400) GH,TH1,TH2,TH3,XNTU(1),EFFN(1),PC,UAG,QG,GHT,UAG
495* 4 XT,GAT
496* 46 FORMAT(1X,4H5=-,-7F10.3,5E10.3/)
497* 401 FORMAT(1X,4HC=-,-7F10.3,5E10.3/)
498* 402 FORMAT(1X,4HX=-,-12F10.3/)
499* 403 FORMAT(5X,12H) X1 X4 CX1 CX4 GR
500* 405 X GS GW GSC1 GWC4 EXPX CRATIO UAX
501* 406 X
502* 407 FORMAT(1X,4HA=-,-7F10.3,5E10.3/)
503* 408 FORMAT(1X,4HC=-,-7F10.3,5E10.3/)
504* 409 FORMAT(5X,12H) G T1 T2 T NTU
505* 410 X EFFN P UA Q GT UAT QT
506* 411 X
507* 412 FORMAT(5X,12H) TA T5 T3 TG H1
508* 413 X H5 H7 H8 H10 XNTUX EFFNX COP
509* 414 X
510* 415 C
511* 416 WRITE(6,96)
512* 417 WRITE(6,97) DT12E,DTE2,TE2,DT12A,DTA2,TA2,DT12C,DT2,DT12G,DTG
513* 418 X2,TH2
514* 419* 93 FORMAT(10X,'TH2-F',5X,A3,'-F',5X,'TE2-F',5X,'TH1-F',5X,'TC1-F',
515* 5X,'TE1-F',5X,'TG-F',6X,'TC-F',6X,'TA-F',6X,'TE-F',4X,'TON-PF',
516* 2 X,'JREF',5X,'NO.',)
517* 522* 193 FORMAT(10X,'TH2-C',5X,A3,'-C',5X,'TE2-C',5X,'TH1-C',5X,'TC1-C',
518* 5X,'TE1-C',5X,'TG-C',6X,'TC-C',6X,'TA-C',6X,'TE-C',4X,'TON-REF',
519* 2 X,'JREF',5X,'NO.',)
520* 525* 94 FORMAT(10X,11F10.3,10X,3X,13/)
521* 526* 95 FORMAT(10X,'KTA KCOP KTON2 KTON1 GHT-GPM GCT-GP
522* 14 GET-6PM',5X,A3,'-F TC1-F',5X,A3,'-F TON-CAL TON-START
523* 2 NO.',)
524* 529* 195 FORMAT(10X,'KTA KCOP KTON2 KTON1 GHT-KPH GCT-KP
525* 1H GET-KPH',5X,A3,'-C TC1-C',5X,A3,'-C TON-CAL TON-START
526* 2 NO.',)
527* 532* 96 FORMAT(10X,12H DT12E DTE2 TE2 DT12A DTA2
533*    X  TA2  DT12C  DTC2  TC2  DT12G  DTG2  TH2
534*  
535*  97 FORMAT(1X,4HTEMP,12F10.3///)
536*  98 FORMAT(5X,4(I6,2X),8F10.3,3X,I3/)
537*  C
538*  59 CONTINUE
539*  IF(IJREF.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=TF2SAV
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
565*  WRITE(6,602) (TONGVN(M),TONCAL(M),M=1,160)
566*  WRITE(6,602) (M,TONGVN(M),TONCAL(M),M=1,160)
567*  601 FORMAT(1X,110DTHE FOLLOWING ARE KNOWN TON VS CALCULATED FOR TRAN)
568*  C 602 FORMAT(1X,6(4X,7F8.2))/ (1X,6(4X,2F8.2))/
569*  C 602 FORMAT(1X,6(4X,7F8.2))/ (1X,6(4X,2F8.2))/
570*  C
571*  STOP
572*  END
### OUTPUT IS IN U.S. CUSTOMARY UNITS - DEGREES F, GPM, BTU

<table>
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<th>TH2-F</th>
<th>TA2-F</th>
<th>TE2-F</th>
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</table>

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

| TH1A | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X|
Sample 2: LiBr-H₂O Single-Stage Absorption Machine Used as a Subroutine in TRNSYS

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* SAMPLE 2: LI BR-H2O SINGLE-STAGE ABSORPTION MACHINE USED AS A SUBROUTINE IN TRNSYS

1* SUBROUTINE TYPE 17 (TIME, XIN, OUT, T, DTNT, PAR)
2* COMMON /PR2/ TIME, 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), PR(5)
7*
8* C -------METRIC=U,BRITISH UNITS USED.--------- WRITE ALL, JWRITE=1 WRITE ALL, JWRITE=0 NO WRITE
9* C KLBHR=1.6PM FOR FLOW INPUT.-------KLBHR=1, LBS/HR INPUT
10* DATA METRIC/G/, YLRHR/l/, JWRITE/1/
11* DATA METRIC/G/, YLRHR/l/, JWRITE/0/
12* DATA PKG/4536/
13* DATA TFC1/32./, TFC2/1.8/
14* DATA CALBTU/3.96831/
15*
16* C CONST & CONST ARE CONCENTRATION LIMITS
17* DATA CONST/0.4/, CONST/0.68/
18* C A-R-C-O-CONST ARE LIMITS FOR EVAP., ABSORP., COND., & GENERATOR
19* DATA LOG/1., BCONST/1.296/, CCONST/1.423/, DCONST/1.919/
20* DATA TEO/2.22/, TES/4.43/
21* C COP LIMITS --HEAT LOSS FACTOR
22* DATA COPHI/0.93/, COPLO/0.66/, FOG/0.75/
23* C EFFNX=0.71428 FOR T5=135 F EFFNX=(TG-T5)/(TG- TA)
24* DATA EFFNX/0.71428/
25* C CONTE=0. C
27* C E-CONT=10. C
28* C
29* C INPUT=1
30* CONTINUE
31* H1=C.
32* H5=C.
33* H7=C.
34* H8=C.
35* H10=0.
36* C -------UA VALUES ARE PER TON BASIS-------
37* UAG=456.981*PKG
38* UAC=1011.869*PKG
39* UAE=1503.294*PKG
40* UAA=1102.8*PKG
41* UAX=118.929*PKG
42* UAXO=118.929*PKG
43* GSO=144.077*PKG
44* GGC=131.323*PKG
45* GHD=150.786*500.*3.975
46* GEO=417.600 *500.
47* GCC=553.674*500.
48* TONC=174.
49* C
50* C
51* C
52* C
53* C
54* PR(1)=UAG
55* PR(2)=UAC
56* PR(3)=UAE
57* PR(4)=UAA
58* PR(5)=UAX
59* C
60* JREF=5
61* CONTINUE
62* TON=XIN(7)/1200.
63* TONREF=TONC*0.5
64* TONX=TONC*0.1
65* TONX=TONC*1.2
```
9 CONTINUE
91 CONTINUE
95 COP=7
96 16 CONTINUE
97 IF(COPX.LE.COPO.OR.COPX.GE.COPHI) COPX=C.722
98 C
99 GHP=XIN(1)/TONX*PDKG*BPH*G.975
100 GC=XIN(2)/TONX*PDKG*BPH
101 GE=XIN(3)/TONX*PDKG*BPH
102 TH1=XIN(4)-TFTC1)/TFTC2
103 TC1=XIN(5)-TFTC1)/TFTC2
104 TE1=XIN(6)-TFTC1)/TFTC2
105 Q1=3.239.573
106 T12=TC1
107 TA=TH1
108 TE=TE1
109 T1=TA
112 IF(XIN(I).LE.O.CODI) S=G.L GO TO 5
113 C
114 C ASSUME TUBE SIDE WATER FILM COEF. IS CONTROLLING
115 GH1=XIN(1)/GH1**0.8
116 GC1=XIN(2)/GC1**0.8
117 GE1=XIN(3)/GE1**0.8
118 C
119 C TOTAL BASIS IN METRIC UNITS
120 GIN(1)=GH/GH1*TONX
121 GIN(2)=GC/GE1*TONX
122 GIN(3)=GE/GE1*TONX
123 C
124 DO 10 I=1,7
125 IF(GIN(I).LE.C.UJ 60 TO 8
126 XNTU(I)=XNTU(I)/GIN(I)**TNC
127 EFF(I)=L.3-EXP(-XNTU(I))
128 CONTINUE
123 C
130 C
131 5 CONTINUE
132 IF(TIME.LE.TIME0.OR.TE1.LE.TE2SET) TE1=TE2SET
133* IF(TC1.LE.TE2SET) S=0.0
134* TE2=TF1-0.8/GE*S
135* TH2=TH1-(QE/TCOPX)/GS*S
136* TC2=TC1+(1.3+0.9/TCOPX)*GE/GE*S
137* IF(S.LE.0.001) GO TO 80
138* C
139* TF=TE1-(TE1-TE2)//EFFN(3)
140* T6=TH1-(TH1-T142)/EFFN(1)
141* C ASSUMED A VALUE FOR TA
142* TA2=(TC1+TC2)*0.5
143* TA=TC1-(TC1-TC2)/EFFN(4)
144* KTA=C
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(T6.GE.TA) GO TO 41
152* IF(TA.GE.TG) GO TO 41
153* C
154* X1=(4.9+0.125*TA-TE1)/(134.65+0.47*TA)
155* X4=(4.9+0.125*T6-TC1)/(134.65+0.47*T6)
156* IF(X1.LT.CONST1) GO TO 45
157* IF(X4.LE.X1) GO TO 43
158* C
159* HF=TC-25.0
160* HI=572.8+0.47*TE
161* GR=GE/(HI0-H8)
162* GS=GR*X4/(X4-X1)
163* GW=GS*(X4/X4)
164* C
165* CX1=1.01-1.23*X1+5.48*X1**2
166* CX4=1.01-1.23*X4+0.48*X4**2
167* GSCI=GS*CX1
168* GWC=GW*CX4
169* CRATIO=GWC/GSCI
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* RCS=((GSCI/GS)*TONX/TONX)**G.8
176* RGW=(GWS/GW)*TONX/TONX)**G.6
177* UAX=F1*UAX0*(1.0/(RGW+F2*RGW))
178* C
179* IF(GWC4.GT.GSCI) GO TO 17
180* XNTUX=UAX/GWC4*TONX/TONX
181* GO TO 10
182* C
183* 17 CONTINUE
184* XNTUX=UAX/GSCI*(TONX/TONX)
185* CRATIO=GSCI/GWC4
186* 18 CONTINUE
187* C
188* IF(ABS(1.0-CRATIO).LT.0.01) GO TO 13
189* IF(XNTUX*(1.-CRATIO).LT.0.1) GO TO 12
190* EFPX=EXP1-XNTUX*(1.-CRATIO)
191* EFFNX=(1.0-EFPX)/(1.0-CRATIO*EFPX)
192* GO TO 14
193* C
194* 12 CONTINUE
195* EFFNX=L.999
196* GO TO 14
197* 13 CONTINUE
198* EFFNX=XNTUX/(1.0*XNTUX)
199* 14 CONTINUE
TS=6F-FFNX*(TG-TA)
T3=TA*FFNX*CRATTO*(TG-TA)
H1=(42.81-425.92*X1+404.67*X1**2)+CX1+TA
H5=(42.81-425.92*X4+404.67*X4**2)+CX4+T5
H7=572.8+0.46*TG-0.043*TC
F0G=1.0, NO HEAT LOSS,-,FOG>1.0,,L<2.0, % HEAT LOSS
IF(F0G<=1.0) F0G=1.0
QC=(GW*HS-6*S+H1*GP*H7)*F0G
QC=GR*H7-H8)*(1.0+QG/QE)*(1.0-F0G)
QA=(GW*HS-6*S+H1*GP*H7)*(1.0+QG/QE)*(1.0-F0G)
CO=QE/QG
TC12=TC1+0A/GC
IF(TC12+GE,TC2) TC12=TC1+1.0
TAX=TC1-(TC1-TC12)/FFNN(4)
43 CONTINUE
IF(FC.6.E.TA) TAX=TC
IF(AABS(TAX-TA).LT.0.00001) GO TO 41
IF(I*KT=EQ.50) GO TO 41
TAK=(TAX+TA)*0.5
KTA=KTA+1
GO TO 15
41 CONTINUE
GO TO 46
44 CONTINUE
43 CONTINUE
IF(KTON1-13C) KTON1+1
GO TO 46
45 CONTINUE
IF(KTON2-100) 49,43,43
49 CONTINUE
TONMIN=TONX
TONX=(TONX+TONMAX)*C.5
TONX=FIX(TONX)
TONX=FLOAT(TONX)+1.0
KTON=KTON2+1
GO TO 11
41 CONTINUE
IF(KTON1-100) 44,5C,CC
44 CONTINUE
TONMAX=TONX
TONX=(TONX+TONMIN)*C.5
ITONX=IFIX(TONX)
IF(TONX.LE.1.0) GO TO 50

ITONX=IF(TONX.LE.TON) GO TO 50

TONX=FLOAT(ITONX)-1.0
KTON1=KTON1+1
GO TO 11
C
CONTINUE
IF(KTONX.EQ.1.0) GO TO 60
IF(TONX.LE.TON) GO TO 11

CHECK MAX. STRONG SOLUTION PUMP RATE
GSTC=GSD*TOND
GSPUMP=G*T*TONX
IF(GSPUMP.GT.GSTD) GO TO 43
C
TONX=TONX
IF(TE2.EQ.TE2SET.OR.TE.LE.TELO) GO TO 48
GO TO 49
CONTINUE
TON=TON*(TE1-TE2SET)/(TE1-TE2)

CONTINUE
IF(KTONX.EQ.1) GO TO 60
TONX=TON
IF(TONX.LE.1.0) GO TO 11
KTONX=1
GO TO 11
C
60 CONTINUE
C
C
C
ALL SPEC HEAT = 1. 
UAG=XNTU(11)*GH
UAC=XNTU(2)*GC
UAE=XNTU(3)*GE
UA=A*XNTU(4)*GC
C
A=ALOG(11.0)
B=1555.0/(TF+273.15)
C=11.2414E4/(TE+273.15)**2
PE=EXP(A+(7.8553-8.0-C))
B=1555.0/(TC+273.15)
C=11.2414E4/(TC+273.15)**2
PC=EXP(A+(7.8553-8.0-C))
CONTINUE
R
QG=QG*CALBTU
QC=QC*CALBTU
QF=QF*CALBTU
QA=QA*CALBTU
H1=H1*CALBTU
H2=H2*CALBTU
H3=H3*CALBTU
H4=H4*CALBTU
H5=H5*CALBTU
H6=H6*CALBTU
H7=H7*CALBTU
H8=H8*CALBTU
H9=H9*CALBTU
H10=H10*CALBTU
C
T3=T3*TFC2+TFC1
T5=T5*TFC2+TFC1
C
TH1=TH1*TFC2+TFC1
TH2=TH2*TFC2+TFC1
TC1=TC1*TFC2+TFC1
TC12=TC12*TFC2+TFC1
TA2=TC12
TC2=TC2*TFC2+TFC1
TC1=TC1*TFC2+TFC1
TC12=TC12*TFC2+TFC1
TA2=TC12
334* TL = TE + TFC2 + TFC1  
335* TA = TA + TFC2 + TFC1  
336* TC = TC + TFC2 + TFC1  
337* TG = TG + TFC2 + TFC1  
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* G  
347* GE = GE/PDKG  
348* GP = GP/PDKG  
349* GC = GC/PDKG  
350* GS = GS/PDKG  
351* GSC = GSC/PDKG  
352*  
353* C  
354* QT = QT + TON*S  
355* QCT = QCT + TON*S  
356* QET = QT  
357* QAT = QA + TON*S  
358* UAGT = UAG + TON  
359* UACT = UAC + TON  
360* UAET = UAE + TON  
361* UAT = UAT + TON  
362* GHT = GHT + TON/BPH/D  
363* GCT = GC + TON/BPH  
364* GAT = GCT  
365* GCT = GCT + TON/BPH  
366* DT12E = TE1 - TF2  
367* DT12A = TA2 - TC1  
368* DT12C = TC2 - TC1  
369* DT12G = TH1 - TH2  
370* DT12Z = TE2 - TE  
371* DTAP = TA2 - TA2  
372* DTGC = TC2 - TC2  
373* DTG2 = TH2 - TG  
374* C  
375* C  
376* IF (WRITE (EQ, 0) .GE. 50) GO TO 59  
377* IF (AMOD (TIME, 1.000) .GT. DELT) GO TO 503  
378* WRITE (6, 95)  
379* XTONX = XIN(7)  
380* XIN(7) = TONXIN/12000.*  
381* WRITE (6, 98) KTA, KCP, KTON2, KTON1, (XIN(I), I = 1, 61, TONX, XIN(7), INPUT  
382* XIN(7) = TONXIN  
383* WRITE (6, 93)  
384* WRITE (6, 94) X1, X4, CX1, CX4, GR, GS, GX, GSC, GWC, EXPX, CRATIO, UAX  
385* WRITE (6, 95)  
386* WRITE (6, 96) TA, T5, T3, TG, H1, H5, H7, H9, H10, XNTUX, EFFNX, COP  
387* WRITE (6, 96)  
388* WRITE (6, 97) GE, TE1 , TF, TE , XNTU(3), EFFN(3), PE, UAA, QE, GET, UAA  
389* XTF, OFF  
390* WRITE (6, 94) GA, TC1 , TA2, TA , XNTU(4), EFFN(4), PE, UAA, QA, GAT, UAA  
391* XTF, QAT  
392* WRITE (6, 911) GC, TA2, TC2, TC , XNTU(2), EFFN(2), PC, UAC, QC, GCT, UACT, QC  
393* XCT  
394* WRITE (6, 900) GH, TH1 , TH2, TG , XNTU(1), EFFN(1), PC, UAG, QS, GHT, UAG  
395* XCT, GGT  
396* IF (WRITE (EQ, 4) .GE. 7) 400 FORMAT (1X, 4HG, --, 7F10.3, 5E10.3//)  
397* IF (WRITE (EQ, 4) .GE. 7) 401 FORMAT (1X, 4HC, --, 7F10.3, 5E10.3//)  
398* IF (WRITE (EQ, 4) .GE. 12) 402 FORMAT (1X, 4NX, --, 12F10.3//)  
399* IF (WRITE (EQ, 4) .GE. 5X, 120H) X1, X4, CX1, CX4, GR  
400* X GS, GW, GSC1, GWC4, EXPX, CRATIO, UAX
401* X }
404* 404 FORMAT(1X,4HA---,7F10.3,5E10.3/
405* 405 FORMAT(1X,4HE---,7F10.3,5E10.3/
406* 406 FORMAT(5X,170H G T1 T2 T NTU
409* 410* X EFFN P UA Q GT UAT QT
412* 413* X }
415* 407 FORMAT(5X,120H TA T5 T3 TG H1
418* 419* X H5 H7 H8 H10 NTUX EFFNX COP
421* 422* X }
424* 425* C 
426* 427* WRITE(6,96) 
428* 429* WRITE(6,97) DT12E, DTE2, TE2, DT12A, DTA2, TA2, DT12C, DTC2, TC2, DT12G, DTG
430* 431* 95 FORMAT(5X,127H KTA, KCOP, KTON2, KTON1, GHT-GPM
432* 433* X GCT-GPM GET-GPM TH1-F TC1-F TE1-F TON-CAL TON-ST
434* 435* XART NO. J
437* 438* 96 FORMAT(5X,120H DT12E DTE2 TE2 DT12A DTA2
439* 440* X TA2 DT12C DTC2 TC2 DT12G DTG2 TH2
442* 443* X }
446* 447* 97 FORMAT(1X,4HTEMP,12F10.3///)
448* 449* 98 FORMAT(5X,4(I8,2X), 8F10.3, 3X, I3///)
451* 452* 99 FORMAT(7F10.1)
455* 456* 59 CONTINUE
457* 458* 563 CONTINUE
459* 460* OUT(1)=TH2
461* 462* OUT(2)=XIN(1)
463* 464* OUT(3)=TON*OE
467* 468* OUT(4)=TH2
470* 471* OUT(5)=OTG
472* 473* OUT(6)=TF2
476* 477* OUT(7)=XIN(3)
478* 479* OUT(8)=TC2
482* 483* OUT(9)=XIN(3)
484* 485* OUT(10)=TON*OE
488* 489* C 
490* 491* INPUT=1+INPUT
492* 493* RRETURN
494* 495* C STOP
496* 497* END
REFERENCES


Figure 1. - Flow diagram of single-stage LiBr-H<sub>2</sub>O absorption unit.
<table>
<thead>
<tr>
<th>1. Report No.</th>
<th>NASA TP-1296</th>
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<td></td>
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<td></td>
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<td>SIMULATION MODEL OF A SINGLE-STAGE LITHIUM BROMIDE - WATER ABSORPTION COOLING UNIT</td>
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<tr>
<td>5. Report Date</td>
<td>August 1978</td>
</tr>
<tr>
<td>6. Performing Organization Code</td>
<td></td>
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<td>7. Author(s)</td>
<td>David Miao</td>
</tr>
<tr>
<td>9. Performing Organization Name and Address</td>
<td>National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135</td>
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<td>10. Work Unit No.</td>
<td>776-22</td>
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<td>15. Supplementary Notes</td>
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<tr>
<td>16. Abstract</td>
<td>A computer model of a LiBr-H$_2$O 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.</td>
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<tr>
<td>17. Key Words (Suggested by Author(s))</td>
<td>Absorption machine; LiBr-H$_2$O; Cooling unit; Air conditioning; Refrigeration; Solar cooling</td>
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<td>18. Distribution Statement</td>
<td>Unclassified - unlimited</td>
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