PRELIMINARY PERFORMANCE ESTIMATES OF
BINARY GEOTHERMAL CYCLES USING MIXED-HALOCARBON WORKING FLUIDS

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The performance of Rankine cycle binary systems for power generation using a hydrothermal resource has been investigated as a part of the DOE/GTD Heat Cycle Research Program. To date mixtures of paraffin-type hydrocarbons and water-ammonia mixtures have been investigated. This report gives the first results of the consideration of mixtures of halocarbons as working fluids in these power cycles. The performance of mixtures of Refrigerant-114 (R-114) and Refrigerant-22 (R-22) in combinations from pure R-114 to pure R-22 was calculated for such cycles. Various alternatives were considered: 1. minimum geofluid outlet temperature constraint/no constraint, 2. dry turbine expansion/expansion through vapor dome, 3. use of a turbine exhaust gas recuperator/no recuperator.

Results of the study indicate that the halocarbon mixtures are at least as good as the hydrocarbon mixtures previously analyzed for a 360°F resource. The magnitude of the net geofluid effectiveness (net energy produced per unit mass geofluid flow) for the R-114/R-22 mixtures is the same as for the best hydrocarbon mixtures previously analyzed. The percentage improvement in effectiveness in using mixtures over using the pure fluids as working fluids is comparable for both classes of working fluids.

Recommendations are made to continue investigation of the halocarbon mixtures as possible alternatives to the hydrocarbon working fluids.
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I. SUMMARY

1. Background

The performance of Rankine cycle binary systems for power production using hydrothermal resources has been investigated using a number of different working fluids. As part of the DOE/Geothermal Technology Division (GTD) Heat Cycle Research Program, binary mixtures of paraffin-series hydrocarbons and mixtures of water and ammonia have been investigated analytically, and the hydrocarbon mixtures are being tested experimentally at the Heat Cycle Research Facility. As the focus of power production turns to smaller units, the use of nonflammable fluids becomes more interesting. Well-head units would be more economical if flammable working fluids were not needed. This report contains the results of a preliminary study of binary mixtures of halocarbons (Freons) to assess the merit of this class of fluid for geothermal power production.

2. Approach

The method of accomplishing this objective was to determine the performance of power generating systems using mixtures of Refrigerant 22 (R-22) and Refrigerant 114 (R-114) (from 0 to 100 percent R-114). This was made using the same assumptions about the system as were made in previous studies: 360°F subcooled (liquid) hydrothermal resource, 70°F cooling water from a wet-cooling tower, shell-and-tube heater and condenser. Cases assuming a 160°F geofluid-outlet-temperature constraint (to prevent silica precipitation) as well as cases without that constraint were investigated, and the possible use of a turbine exhaust gas recuperator to preheat the working fluid was also considered. In addition, the performance improvement as a result of expanding the turbine through the two-phase region was determined.
3. Conclusions and Recommendations

The results of the study and the conclusions reached are summarized below:

1. The performance of halocarbons appears to be as good as that of hydrocarbons as measured by the net geofluid effectiveness (watt-hr/lb geofluid flow).

2. The incremental increase in performance for halocarbon mixtures (relative to single-component halocarbons) is at least as large as that for hydrocarbon mixtures. With no geofluid outlet temperature restriction and no recuperation: a 7.8 percent increase in geofluid effectiveness for the best mixture (over the better pure substance) was obtained with dry turbine expansion, and a 6.0 percent increase was found when expansion through vapor dome was allowed. With the 160°F geofluid outlet temperature restriction: 3.0 percent increase was obtained with no turbine exhaust recuperator and an 8.8 percent increase with a recuperator.

3. Turbine exhaust recuperation increases the optimum performance with the 160°F geofluid-outlet-temperature constraint to within 1.4 percent of the unconstrained optimum. (The geofluid effectiveness for the unrecuperated case with the geofluid-outlet-temperature restriction is 10.3 percent below the unrestricted case.)

4. There is some indication that tertiary mixtures may give better results than binary mixtures for the halocarbons (while this was not the case for the paraffin-series hydrocarbons).
As a result of this preliminary study, recommendations are that:

1. Further study of the halocarbon mixtures as working fluids in geothermal power plants be made. This work should include: a. A study to consider the effect on performance of optimizing the condenser pressure. b. Thermodynamic performance studies of other halocarbon mixtures (including tertiary mixtures). c. A second law (availability) analysis of the systems. d. Studies estimating the cost of electricity for a halocarbon plant.

2. A more critical look at the thermodynamic properties of the halocarbon mixtures be made. This might require the use of the National Bureau of Standards computer code EXCST to evaluate the mixture properties. Preliminary investigations indicate that this code predicts the published thermodynamic properties of pure halocarbons quite well.
II. INTRODUCTION

The performance of Rankine cycle binary systems for power generation using hydrothermal resources has been investigated, and those systems are now being used in a number of applications. The selection of a working fluid to maximize performance and/or minimize cost of production of electrical energy for a particular resource is a primary concern. The use of paraffin-series hydrocarbons alone and in binary mixtures has been studied fairly extensively by Demuth and Kochan (References 1 and 2) and Milora and Tester (Reference 3). Bliem considered mixtures of water and ammonia (Reference 4). Milora and Tester have shown that pure halocarbons (Freons) are comparable with the hydrocarbons in performance. References 1 and 2 showed an increase in performance of binary mixtures of the hydrocarbons over the pure hydrocarbons of about 7 to 9 percent. One would expect similar increases for the halocarbons. The Freon Products Laboratory of E. I. DuPont de Nemours & Company has recently developed computer programs (Reference 5) to determine the thermodynamic properties of binary mixtures of the Freons. Data for two such mixtures are available. Because of all of these developments, it was decided that this would be a good time to investigate halocarbon mixtures in geothermal Rankine cycle systems. The purpose of the present work was to conduct a preliminary investigation of the halocarbons; it was not to be an exhaustive study. Therefore, this report investigates only one promising mixture, R-22 and R-114, realizing that there are, probably, better mixtures. However, all of the information needed to develop the thermodynamic data required in the analysis was available for this mixture.

Overall, the report investigates the feasibility of using mixtures of halocarbons in geothermal power plants. The following section contains a discussion of the halocarbons as represented by the standard refrigerants and their possible applicability. Next is a section on the approach and assumptions made in the study. Results and conclusions are presented in the final sections.
II. HALOCARBON WORKING FLUIDS

Halocarbons or halogenated hydrocarbons have been used as refrigerants for a long period of time. These substances are stable (at normal temperature), nonflammable, and nontoxic. They have been synthetically produced, particularly for their refrigerating properties, by the substitution of a halogen for one or more of the hydrogen atoms in methane, ethane and propane. The halogens used are fluorine, chlorine and sometimes bromine. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has developed a numerical system for designation of different refrigerants. The last digit in the designation (the one on the right) indicates the number of fluorine atoms in the molecule formed. The second digit from the right is one more than the number of hydrogen atoms remaining, and the third digit is one less than the number of carbon atoms (blank indicating methane structure, 1, ethane structure and 2, propane structure). If bromine is used, this designation is followed by a B with the number of bromine atoms after the B.

Figure 1 shows the critical pressures and temperatures of some of these refrigerants. Experimental values are shown by the open circles for the methane-based halocarbons (10-40), and by the open squares for some of the ethane-based halocarbons. The shaded circles and squares represent computed values for critical properties deduced from the molecular structure of the compounds. Experimental values for the paraffin-series hydrocarbons are shown on the plot, as references, with shaded triangles. The dashed line connects the normal form of each of the hydrocarbons from ethane (C2) through heptane (C7). The other dots are the isomers of each hydrocarbon (for example, the dot at C4 not on the line is isobutane and the point on the line is normal butane). It can be seen that the halocarbons have critical states which bracket the range of critical states for the hydrocarbons.
Figure 1: Critical States for Hydrocarbons and Halocarbons
The choice of a halocarbon mixture for this initial study was made using the information in Figure 1. It was felt that mixture critical temperature was an important parameter in determination of thermodynamic performance. Previous studies cited in References 1 and 2 indicated that the best performance for a 360°F resource was obtained with mixtures of isobutane and a very small quantity of heptane (4 percent by mass), and propane with 5 percent hexane. To a first approximation, the mixture critical temperature is the mole-weighted average of the constituent critical temperatures. It was, therefore, felt that halocarbons spanning the range of critical temperatures between isobutane and propane might give good thermodynamic results. Refrigerants R-22 and R-114 fit the desired criterion. DuPont had supplied the interaction parameter needed to represent these mixtures with their computer codes, so no additional experimental work was necessary to determine the thermodynamic properties of any mixture of these refrigerants.

One additional point may be deduced from Figure 1. The earlier studies of mixtures of the paraffin-type hydrocarbons indicated that a binary mixture gave as high a thermodynamic performance as a tertiary mixture of these hydrocarbons. The mole-weighted average critical pressure gives a first order approximation of the mixture critical pressure. This approximation is not as good as the similar approximation for temperatures, but it is close. (In fact, the mixture critical pressure may be somewhat above the mole-weighted average.) Using the approximation, a binary mixture critical state would be plotted along the straight line connecting the components. A tertiary mixture critical state would be within the triangle connecting the three substances. The paraffin-type hydrocarbons are grouped so close to a straight line that it is doubtful that a significant difference in critical states could be seen between two or three component mixtures. With the halocarbons, however, there would be a substantial difference. Therefore, an additional degree of freedom results for mixtures of halocarbons, and the critical pressure of the mixture, in addition to critical temperature, could be tailored to the desired requirements. It is felt that three component mixtures of the halocarbons should be investigated to determine if this conjecture is correct.
IV. APPROACH AND ASSUMPTIONS

The system performance for a simple Rankine cycle was calculated using assumptions consistent with those used in References 1, 2, and 4 (the hydrocarbon and ammonia-water analyses). Mixtures from pure R-114 to pure R-22 were used as working fluids. The following subsections describe the cycles, list the assumptions made in the analysis, and then describe the analytical procedure.

1. Binary Geothermal Cycle Descriptions

The working fluid in a binary geothermal electric power plant undergoes the processes of a Rankine thermodynamic cycle. Figure 2, which is a schematic diagram of a simple binary geothermal cycle, illustrates these processes as well as the major components of the plant. Starting at the condensate storage tank, the working fluid is pumped from the condenser pressure to the heater pressure. Heat is transferred from the geofluid to the working fluid in the heater (a shell-and-tube heat exchanger). In most of the cycles analyzed, the heater pressure was above the mixture critical pressure so there was no phase change in the heater. If the pressure is less than the critical pressure, the heater functions as a boiler and superheater. The working fluid is heated to the appropriate turbine inlet temperature. The working fluid vapor then flows through the turbine, producing work at the turbine shaft. The turbine drives the generator, which produces the electrical work. The turbine-exhaust working fluid is then condensed (after being desuperheated, if necessary) in the condenser, and the heat is transferred to cooling water. This heat is rejected, in turn, to atmospheric air using a wet cooling tower. The condensed working fluid is then returned to the condensate storage tank and the cycle is repeated.
Figure 2: Simple Binary Geothermal Cycle
In many instances, there is enough energy in the turbine exhaust at a high enough temperature, to preheat the working fluid going to the heater. A recuperator may be added to the cycle to accomplish this task as is shown in Figure 3. This modification is particularly useful when a limit on the working fluid outlet temperature is imposed. In these applications, the recuperator allows the working-fluid-to-geofluid-flow ratio to be increased in order to increase the geofluid effectiveness. The heat rejected is then reduced, but this is a small effect. In the case where there is no minimum imposed on the geofluid outlet temperature, recuperation is generally not worthwhile because only the heat rejected is decreased which gives a small increment in geofluid effectiveness at the expense of a more complex system.

2. Thermodynamic Assumptions

The assumptions made in this analysis are essentially the same assumptions that were made in previous working fluid studies. The assumptions are:

1. The geofluid supplied to the plant was liquid at 360°F and was slightly subcooled.

2. Cooling water was supplied to the condenser from a wet cooling tower. The wet-bulb temperature was assumed to be 60°F and the tower approach temperature difference was 10°F. Therefore, cooling water entered the condenser at 70°F. The parasitic power requirements were estimated as described in References 1 and 2.

3. Pinch point temperature differences in the heater and condenser were taken to be 10°F. The pinch point in the recuperator was assumed to be 90°F.
Figure 3: Binary Geothermal Cycle with Turbine-Exhaust Recuperator
4. Pump and turbine isentropic efficiencies were assumed to be 80 and 85 percent, respectively. Electrical losses were not included.

5. Geofluid pumping requirements (at a given geofluid flow rate) were assumed to be the same in all cases, and those parasitics were not included.

6. Component, valve, and piping pressure drops were neglected.

7. Geofluid properties were assumed to be those of pure water and were taken from the Steam Tables (Reference 6) as were cooling water properties. The working fluid properties were taken from the DuPont computer codes (Reference 5). Superheated vapor properties were taken from SUPERTABLE, bubble and dew points were taken from SATTABLE (each of which generated a hard-copy table), and the two-phase properties between the bubble point and the dew point were obtained from an interactive program, CYCLE.

Some inconsistencies were noted in the properties of the halocarbon mixtures. First, the isentropic enthalpy change from the saturated liquid (bubble point, pump inlet) to the heater pressure showed some deviation from $V_{bP}$ even though the density of the liquid was approximately constant. The $V_{aP}$ values were used for the pump power calculation, with some additional steps introduced to obtain consistency with heater enthalpy calculations. This is discussed to a greater detail in the appendix, which describes the computer program. Second, there were some discrepancies noted in the dew point properties calculated different ways by the program. These deviations should be resolved by further study of the properties.
3. Method of Analysis

A computer program was written which will perform a thermodynamic cycle analysis using the assumptions listed in the previous section. The program is written in BASIC, and runs on an IBM PC. A listing of the program along with input instructions and the results of a typical run are given in the appendix to this report. Thermodynamic properties (sets of temperature, enthalpy and entropy) are input at the heater pressure and the condenser pressure with temperature ranges to cover the possible operating range of the system. A turbine inlet temperature or entropy is specified, and the program analyzes four cases: no geofluid outlet temperature restriction with and without recuperator, and a specified minimum geofluid outlet temperature with and without a recuperator.

Mixtures from 0 to 100 percent R-114 were analyzed (every 25% from 0 to 75% R-114, and then every 5% to 100%). For each mixture, several heater pressures were chosen, and for each pressure the turbine inlet temperature varied from the point which would give an isentropic turbine outlet state with 10% moisture to the point at which a pinch point occurs at the heater outlet (350°F). At each heater pressure the temperature for maximum geofluid effectiveness was determined for each of the following cases: 1. no minimum geofluid outlet temperature limit (10°F heater pinch point) with an isentropic turbine expansion which avoided the two-phase region (without a recuperator). 2. no minimum geofluid outlet temperature limit with an isentropic turbine expansion which passed through the two-phase region (without a recuperator). 3. 160°F minimum geofluid outlet temperature without a recuperator. 4. 160°F minimum geofluid outlet temperature limit with a recuperator. The initial results showed that the gains in performance achieved by adding a recuperator
to a system with no minimum geofluid temperature limit were generally less than 0.1%, for reasons noted in the previous section. These gains could not offset the added complexity and capital cost of a recuperator. Therefore, recuperators were not considered when there was no geofluid-temperature constraint. Similarly, no system with a 160°F geofluid outlet temperature limit produced an optimum value with an expansion which passed through the two-phase region. In general, the optimum turbines inlet temperatures which were found for each pressure chosen, were different for each of the four cases mentioned above. (This was more optimization than was done in the previous studies of References 1, 2, and 4.)

On the condensing side, the condensing pressure was obtained using the following rules (to avoid a separate optimization of condenser pressure): If the condensing range (difference between the dew point and the bubble point) was less than 20°F, the dew point was taken to be 105°F. If the condensing range was greater than 20°F, the bubble point was taken to be 85°F. These are also the rules that were used in the previous analyses of References 1 and 2. Recent analyses have indicated that optimization of the condenser pressure may change the results to some extent; this behavior should be examined further for the near optimum cases.
V. RESULTS

The results of the analysis discussed in the previous section are shown in Figures 4 and 5. Figure 4 gives the results for a mixture containing 50% by mass R-114, the composition giving the maximum geofluid effectiveness. Figure 5 presents the same results for a mixture containing 95% by mass of R-114.

Notice that there is no curve for expanding through the dome (Case 2) in Figure 4. It was found that unless the fluid properties resulted in a drying effect on expansion, there was no calculated performance gain by going into the dome (even with the optimistic assumption of no turbine efficiency degradation with moisture). At each pressure, the turbine inlet temperature was varied to obtain the maximum geofluid effectiveness under the assumptions of each of the remaining three single-phase-expansion cases: 1) no geofluid outlet temperature constraint, 3) 160°F geofluid outlet temperature constraint without a recuperator, and 4) 160°F geofluid outlet temperature constraint with a recuperator. The turbine inlet temperature at the maximum effectiveness is noted on the figure for each case. Normally, the constrained-outlet-temperature cases optimized at higher heater pressures and turbine inlet temperatures than did the unconstrained cases. The constrained-temperature case without a recuperator optimized at a higher temperature and pressure than the case with a recuperator. Indeed, the unrecuperated, turbine inlet temperature was as high as possible (350°F) giving a pinch point at the heater outlet.

Similar results are shown in Figure 5 for the 95% R-114 case. Here, the turbine expansion is drying so a performance improvement is possible by expanding through the two-phase dome. In general, the maximum geofluid effectiveness is achieved with the isentropic expansion ending on the saturation line; in some cases, however, the outlet state was slightly superheated.
No geofluid outlet temperature constraint:
1 Dry isentropic turbine expansion

160°F geofluid outlet temperature constraint:
3 No recuperator
4 Recuperator

( ) Turbine inlet temperature at optimum effectiveness in °F

Figure 4: Cycle Performance for a 50% R-114/50% R-22 Mixture
No geofluid outlet temperature constraint:
1 Dry isentropic turbine expansion
2 Two-phase isentropic turbine expansion

160°F geofluid outlet temperature constraint:
3 No recuperator
4 Recuperator

( ) Turbine inlet temperature at optimum effectiveness in °F

Figure 5: Cycle Performance for a 95% R-114/5% R-22 Mixture
Figure 6 shows the maximum performance for each of the four cases as a function of mixture composition. Note that the two-phase turbine expansion through the dome shows improvement over a dry isentropic turbine expansion only for compositions with 65% or more R-114. (Pure R-114 dries on expansion while R-22 wets on expansion.) Two relative maxima appear on each curve. Past cycle analyses for hydrocarbon mixtures have not shown this effect. Reference 1, however, only considered a small range of compositions, especially for those mixtures with sharply peaked performance curves such as propane-hexane and isobutane-heptane mixtures. Closer examination of these curves indicates that the slopes of the curves must change and at least an inflection point (if not a lesser maximum) must occur, prior to reaching the pure heavy constituent. With the halocarbon mixtures considered in this report, the pure components have approximately equal performance, while with the hydrocarbon mixtures mentioned above, the performance of the pure heavy constituent is quite a bit lower than that of the pure light component. Therefore, where two maxima appear with the halocarbons, possibly only one exists with the hydrocarbons (or at least the second maximum will be much lower than those shown in Reference 1).

For the R-114/R-22 mixture, the maximum performance occurs at compositions between 30 and 50% R-114. The maximum is very flat and system performance will not be sensitive to changes in composition. The lower maximum occurs at a composition of 90 to 95% R-114 and is considerably more peaked. For the unconstrained-outlet-temperature case, the second maximum is 2.7% lower than the highest maximum if wet isentropic turbine expansion (through the dome) is allowed, and 5.0% lower if the isentropic expansion is forced to remain dry. For the case in which the geofluid outlet temperature is constrained to remain above 160°F, the second maximum is 2.6% lower than the highest maximum. The use of an exhaust gas recuperator with the constrained geofluid-outlet temperature produced an effectiveness curve having a maximum within 1.4% of the unconstrained maximum.
Figure 6: Maximum Cycle Performance as a Function of R-114 Content

- No geofluid outlet temperature constraint:
  1. Dry isentropic turbine expansion
  2. Two-phase isentropic turbine expansion
- 160°F geofluid outlet temperature constraint:
  3. No recuperator
  4. Recuperator
VI. CONCLUSIONS AND RECOMMENDATIONS

The results of the study and the conclusions reached are summarized below:

1. The performance of halocarbon binary geothermal cycles appears to be as good as that of hydrocarbons as measured by the net geofluid effectiveness (watt-hr/lb geofluid flow). The highest values of geofluid effectiveness are in the range from 9 to 10 watt-hr/lb geofluid for both types of working fluids.

2. The incremental increase in performance with halocarbon mixtures, as compared with single-component halocarbons, is at least as large as that for hydrocarbon mixtures: With no geofluid outlet temperature restriction and no recuperation, a 7.8 percent increase in geofluid effectiveness was possible with a halocarbon mixture (relative to a pure halocarbon) for a cycle having a dry turbine expansion, and a 6.0 percent increase resulted for a cycle with expansion through vapor dome. With the 160°F geofluid outlet temperature restriction, an increase of 3.0 percent with no turbine exhaust recuperator was observed for the mixture, and an 8.8 percent increase was predicted with a recuperator.

3. Turbine exhaust recuperation increases the optimum performance with the 160°F geofluid outlet temperature limit to within 1.4 percent of the optimum performance with no limit on outlet geofluid temperature. The unrecuperated case with the temperature limit is 10.3 percent below the unrestricted case. These results are similar to those noted for the hydrocarbon mixtures.

4. There is some indication that tertiary mixtures may give better results than binary mixtures for the halocarbons (whereas this was not the case for the paraffin-series hydrocarbons).
As a result of this preliminary study, the following recommendations are made:

1. Further study of the halocarbon mixtures as working fluids in geothermal power plants should be conducted. This work should include: a. A study to investigate the effect on performance of optimizing the condenser pressure. b. Thermodynamic performance studies of other halocarbon mixtures (including tertiary mixtures). c. A second law (availability) analysis of the systems. d. Studies estimating the cost of electricity for a halocarbon plant relative to a hydrocarbon plant.

2. A more critical look at the thermodynamic properties of the halocarbon mixtures should be taken. This effort might require the use of the National Bureau of Standards (NBS) computer code, EXCST, to evaluate the mixture properties. Preliminary investigations indicate that the NBS code predicts the published thermodynamic properties of pure halocarbons quite well. The DuPont code predicts the thermodynamic properties of binary mixtures only; if tertiary mixtures are to be considered, the EXCST code may be the best method available. Some additional experimental data would be required to determine the interaction parameters for a given mixture if extremely accurate properties are needed. However, for preliminary analyses, an approximation of these properties can be made without the additional experimental results.
VII. REFERENCES


This appendix contains a listing of the computer program used for the cycle analysis in the report, an explanation of the input required to run it, and a sample output for the case shown in the listing. The program is written in BASIC and was run on an IBM PC. The program was run by changing the input data in lines 1100-1200, 5300-5400, and 5550-5600 using the screen editing capability of the PC and then running each case. The program determines the performance and state point data, including availability (exergy) for four cases: a) a fixed heater pinch point and no recuperator, b) a fixed heater geofluid outlet temperature and no recuperator, c) a fixed heater pinch point and a recuperator, and d) a fixed heater geofluid outlet temperature and a recuperator. When there is insufficient difference in temperature between the turbine outlet and the pump outlet for a recuperator with the specified pinch point temperature difference, the message "NOT ENOUGH TEMPERATURE DIFFERENCE FOR RECUPERATION" is printed and the results are terminated after Cases a and b are printed.

Input Description

The input to the program (with the exception of fluid properties) is found in lines 1100-1200:

TG1 = geofluid heater inlet temperature, °F (360°F for this study).
TF1 = working fluid heater outlet temperature, °F (turbine inlet temperature). If this is set to zero, S will be used as the turbine inlet entropy.
PF1 = working fluid heater pressure, psia (turbine inlet pressure).
GPP = pinch point in the heater, °F.
TG2LIM = geofluid outlet temperature limit, °F (150°F for this study).
PF4 = condenser pressure, psia.
TF4 = condenser outlet temperature, °F.
VF4 = condenser outlet specific volume, ft³/lbm (pump inlet).
CF4 = condenser outlet (liquid) specific heat, Btu/lbm °F.
PP = recuperator pinch point, °F.
S  = turbine inlet entropy, Btu/lbm °R. If this is set equal to
zero, TF1 will be used.
TC1 = cooling water condenser inlet temperature, °F.
CPP = condenser pinch point, °F.
M   = number of points in working-fluid heater pressure
property profile.
N   = number of points in working fluid condenser pressure property
profile.
P   = number of points in geofluid property profile.
OPT1 = 1 lists working fluid heater pressure property profile.
OPT2 = 1 lists working fluid condenser pressure property profile.
OPT3 = 1 lists geofluid property profile.

The property profiles are in lines 5300-5400, 5550-5600 and 5710-5730. Each
set of data contains the temperatures (in °F), the enthalpies (in
Btu/lbm), and the entropies (in Btu/lbm °R) for each profile. The working
fluid heater pressure profile is in lines 5300-5400, the working fluid
condenser pressure profile is in lines 5550-5600, and the geofluid profile
is in lines 5710-5730.

Output Description

Following the listing is a sample output for the data in the listing: a
50/50 mixture of R-114 and R-22 at a heater pressure of 1000 psia and a
turbine inlet temperature of 350°F. The condenser pressure was chosen to
follow the condenser dew point and bubble point rules stated in the text.

If OPT1, OPT2, or OPT3 is set equal to 1, a table of the appropriate
property profile is generated as shown in the example output. Then, at the
top of the next page, a data echo reproduces all of the input data as
described in the previous section.
Next, the results of the cases with no recuperator are printed. The results designated "PINCH POINT" refer to Case a, and "GEO OUT LIMIT" refers to Case b. The gross turbine power, pump power, and cooling tower parasitic power are given in units of watt-hr/lbm geofluid. The net power is then given. Note that the net power expressed in these units is the net geofluid effectiveness discussed in the text. The working-fluid-to-geofluid-flow ratio is then given for each case along with the cooling-water-to-working-fluid-flow ratio, which is the same for both cases.

Last, the system state points are given, including pressure, \( P \), in psia; temperature, \( T \), in \(^\circ\)F; enthalpy, \( H \), in Btu/lbm; entropy, \( S \), in Btu/lbm \( ^\circ\)R; and available energy (exergy), \( B \), in Btu/lbm. All corresponding state points for Cases a and b will be the same with the exception of the geofluid pinch point and outlet temperature. For the geofluid, States 2 and 3 refer to Case a, and 2L to Case b. Note that for the working fluid there are two pump outlet states: 5 and 5'. This was necessary because of the inconsistencies in the property tables generated by the DuPont codes. The isentropic pump work was calculated as \( V \cdot P \). Even though the density was approximately constant, the enthalpy change was different by around 1 Btu/lb. Therefore, State 5 uses the \( H \) obtained from \( V \cdot P \), and state 5' the corresponding value from the enthalpy tables. State 5 is used with State 4 to determine the pump work, and State 5' is used with State 6 to determine the heater heat transfer and pinch point.

The next page of data gives the results with a recuperator in place. The "PINCH POINT" results are Case c, and the "GEO OUT LIMIT" results are Case d. The flow ratios and state-point data are given in the same form as for the case with no recuperator as discussed in the previous paragraph. With the recuperator there are state points for the recuperator pinch point, and the turbine outlet and condenser inlet are not the same state, nor are the pump outlet and the heater inlet.

If the geofluid outlet temperature is greater than \( TG2LMT \), the Case d results are set equal to zero and a message "OVERFLOW DUE TO ZERO FLO RATIO" is displayed. In this event Cases c and d are the same because the geofluid limit is a minimum. Note that this was the situation for the output shown in this Appendix. This may also happen for the cases with no recuperator.
PROGRAM LISTING IN
BASIC FOR THE IBM PC
1100 REM************INPUT DATA**************
1105 REM***CONDENSING DATA 5300-5400 HEATING DATA 5550-5600***
1110 TG1=360: TF1=350: PF1=1000: GPP=10: TG2LMT=160
1120 PF4=129.8: TF4=85: VF4=.01236: CF4=.275: RPP=9
1130 MAXS=.1878: S=0
1140 ET=.85: EFP=.8
1150 TC1=70: CPF=10: TWB=60
1190 M=37: N=30: P=17: OPT1=0: OPT2=0: OPT3=0
1200 OPRE=0
1210 GOSUB 3450
1215 GOSUB 5290
1220 REM***********CONTROL PROG*************
1230 IF TF1<>0 AND S<>0 THEN LPRINT"BOTH TF1 AND S CANNOT BE SPECIFIED" ELSE 1250
1240 STOP
1250 IF TF1=0 AND S=0 THEN LPRINT"BOTH TF1 AND S CANNOT BE ZERO" ELSE 1290
1260 STOP
1290 T0=TWB+460
1292 PF2=PF4: PF3=PF4: PF4=PF4: PF8=PF4: PF9=PF4: PF5=PF1: PF6=PF1: PF7=PF1: PF10=PF1
1293 FOR J=1 TO P-1
1294 IF W(1,J)<=TWB AND W(1,J+1)>TWB THEN 1296
1295 NEXT J
1296 FRAC=(TWB-W(1,J))/(W(1,J+1)-W(1,J))
1297 HWO=W(2,J)+FRAC*(W(2,J+1)-W(2,J)): SWO=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
1298 BGO=HWO-T0*SWO
1300 FOR J=1 TO M-1
1301 IF L(1,J)<=TWB AND L(1,J+1)>TWB THEN 1306
1302 NEXT J
1303 FOR J=1 TO M-1
1304 IF L(1,J)<=TWB AND L(1,J+1)>TWB THEN 1306
1305 NEXT J
1306 FRAC=(TWB-L(1,J))/(L(1,J+1)-L(1,J))
1307 HFO=L(2,J)+FRAC*(L(2,J+1)-L(2,J)): SFO=L(3,J)+FRAC*(L(3,J+1)-L(3,J))
1308 BFO=HFO-T0*SFO
1330 GOSUB 1410 : REM TURBINE CALC STATES F1 AND F2
1331 GOSUB 1900 : REM PUMP CALC STATES 4 AND 5
1332 GOSUB 2100 : REM RECUP CALC STATES F3 AND F6
1340 GOSUB 2650 : REM GEO HX CALC STATE G2 AND FLOW RATIO
1350 GOSUB 3110 : REM COND CALC STATE THOT AND FLOW RATIO
1380 GOSUB 3710
1390 GOSUB 3880
1395 LPRINT CHR$(12)
1400 IF OPRE=1 THEN END ELSE OPRE=1 : GOTO 1332
1410 REM***********TURBINE CALCULATION***********
1420 IF TF1=0 AND S<>0 THEN 1510 ELSE 1430
1430 FOR J=1 TO N-1
1440 IF TF1>=H(1,J) AND TF1<H(1,J+1) THEN 1460
1450 NEXT J
1460 FRAC1=(TF1-H(1,J))/(H(1,J+1)-H(1,J))
1470 HF1=H(2,J)+FRAC1*(H(2,J+1)-H(2,J))
1480 SF1=H(3,J)+FRAC1*(H(3,J+1)-H(3,J))
1485 BF1=HF1-T0*SF1
1490 IF FRAC1=0 THEN JF1=J-1 ELSE JF1=J
1500 GOTO 1620
1510 SF1=S
1520 FOR J=1 TO N-1
1530 IF H(3,J)<=SF1 AND H(3,J+1)>SF1 THEN 1550
1540 NEXT J
1550 FRAC2=(SF1-H(3,J))/(H(3,J+1)-H(3,J))
1560 TF1=H(1,J)+FRAC2*(H(1,J+1)-H(1,J))
1570 HF1=H(2,J)+FRAC2*(H(2,J+1)-H(2,J))
1580 IF FRAC2=0 THEN JF1=J-1 ELSE JF1=J

28
```plaintext
GOTO 1620
1600 FOR J TO M-1
1610 IF L(3,J)<SF1 AND L(3,J+1)>SF1 THEN 1670
1620 NEXT J
1630 GOTO 1670
1640 LPRINT "SF1="SF1,"L(3,J)="L(3,J),"L(3,J+1)="L(3,J+1),"L(2,J+1)="L(2,J+1),"L(2,J)="L(2,J),"J="J
1650 FOR J=1 TO M-1
1660 IF L(3,J)<=SF1 AND L(3,J+1)>SF1 THEN 1670
1670 HF2S=L(2,J)+((SF1-L(3,J))/(L(3,J+1)-L(3,J)))*(L(2,J+1)-L(2,J))
1680 DH=ET*(HF1-HF2S)
1700 SPWRG=DH/3.413
1710 HF2=HF1-DH
1720 GOTO 1750
1730 FOR J=1 TO M-1
1740 IF L(2,J)<HF2 AND L(2,J+1)>HF2 THEN 1780
1750 NEXT J
1760 FRAC=(HF2-L(2,J))/(L(2,J+1)-L(2,J))
1770 JF2=J
1780 TF2=L(1,J) + FRAC*(L(1,J+1)-L(1,J))
1790 SF2=L(3,J) + FRAC*(L(3,J+1)-L(3,J))
1800 BF2=HF2-T0*SF2
1810 RETURN
1820 REM *************** COMPRESSOR/PUMP ***************
1830 FOR J=1 TO N-1
1840 NEXT J
1850 IF L(1,J)<TF4 AND L(1,J+1)>TF4 THEN 1950
1860 FRAC=(TF4-L(1,J))/(L(1,J+1)-L(1,J))
1870 HF4 = L(2,J) + FRAC*(L(2,J+1)-L(2,J))
1880 SF4 = L(3,J) + FRAC*(L(3,J+1)-L(3,J))
1890 BF4=HF4-T0*SF4
1900 JF4=J
1910 HF5S = HF4 + (VF*PF5/144)/(778)
1920 DHC = (HF4 - HF5S)/EFP
1930 SPWR=-DHC/3.413
1940 HF51 = HF4 - DHC
1950 SF51=SF4 + CF4*LOG((TF5+460)/(TF4+460))
1960 FOR J=1 TO M-1
1970 IF H(1,J)<TF5 AND H(1,J+1)>TF5 THEN 2070
1980 NEXT J
1990 FRAC=(TF5-H(1,J))/(H(1,J+1)-H(1,J))
2000 HF5 = H(2,J) + FRAC*(H(2,J+1)-H(2,J))
2010 SF5 = H(3,J) + FRAC*(H(3,J+1)-H(3,J))
2020 BF5=HF5-T0*SF5
2030 RETURN
2040 REM *************** RECUPERATOR ***************
2050 IF OPRE=0 THEN 2125
2060 IF TF5<TF2-RPP THEN 2140
2070 LPRINT "NOT ENOUGH TEMPERATURE DIFFERENCE FOR RECUPERATOR" : STOP
2080 TF6=TF5 : HF6=HF5 : SF6=SF5 : BF6=HF6-T0*SF6
2090 TF3=TF2 : HF3=HF2 : SF3=SF2 : BF3=HF3-T0*SF3
2100 RETURN
2110 TF6=TF2-RPP
2120 FOR J=1 TO M-1
2130 IF H(1,J)<TF6 AND H(1,J+1)>TF6 THEN 2180
2140 NEXT J
2150 FRAC=(TF6-H(1,J))/(H(1,J+1)-H(1,J))
2160 HF6 = H(2,J) + FRAC*(H(2,J+1)-H(2,J))
2170 HF3 = HF2 - (HF6-HF5) : TF=TF2 : HFHP=HF2 : SFHP=SF2 : HFLP=HF6
2180 RETURN
```
FOR J=JF2-1 TO 1 STEP -1
HA = L(2,J) : SA=L(3,J)
TB = L(1,J) - RPP
IF TB<TF5 THEN 2350
FOR I=1 TO M
IF H(I,1)<=TB AND H(I,1+1)>TB THEN 2280
NEXT I
HB = H(2,I) +((TB-H(I,1))/(H(I,1+1)-H(I,1)))*(H(I,1+1)-H(2,I))
HF6I = HB + (HF2-HA)
HF3I = HA - (HB-HF5)
NEXT J
TF3I=TF5+RPP
FOR J=1 TO M-1
IF L(1,J)<=TF3I AND L(1,J+1)>TF3I THEN 2390
NEXT J
FRAC=(TF3I-L(1,J))/(L(1,J+1)-L(1,J))
HF3I=L(2,J) + FRAC*(L(2,J+1)-L(2,J))
HF6I=HF5 + (HF2-HF3I)
IF HF1I>HF1 THEN HF1=HF1I : HF4=HF4I : TF=TF3 : HFHP=HF3 : SFHP=SF3 : HFLP=HF5
NEXT J
FOR J=1 TO M-1
IF L(2,J)<=HF3 AND L(2,J+1)>HF3 THEN 2460
NEXT J
FRAC = (HF3-L(2,J))/(L(2,J+1)-L(2,J))
TF3 = L(1,J) + FRAC*(L(1,J+1)-L(1,J))
SF3 = L(3,J) + FRAC*(L(3,J+1)-L(3,J))
BF3=HF3I-TO*SF3
NEXT J
FOR J=1 TO N-1
IF H(2,J)<=HF6 AND H(2,J+1)>HF6 THEN 2520
NEXT J
FRAC = (HF6-H(2,J))/(H(2,J+1)-H(2,J))
TF6 = H(1,J) + FRAC*(H(1,J+1)-H(1,J))
SF6 = H(3,J) + FRAC*(H(3,J+1)-H(3,J))
BF6=HF6I-TO*SF6
NEXT J
TF8=TF : HF8=HFHP : SF8=SFHP : HF10=HFLP
NEXT J
BF8=BF8-TO*SF8
NEXT J
FOR J=1 TO N-1
IF H(2,J)<=HF10 AND H(2,J+1)>HF10 THEN 2590
NEXT J
FRAC=(HF10-H(2,J))/(H(2,J+1)-H(2,J))
TF10=H(1,J)+FRAC*(H(1,J+1)-H(1,J))
SF10=H(3,J)+FRAC*(H(3,J+1)-H(3,J))
BF10=HF10-TO*SF10
NEXT J
RETURN
REM ********FIND PINCH LOCATION BETWEEN GEOFLUID AND WORKING FLUID
FOR J=1 TO P-1
IF W(1,J)<=TG1 AND W(1,J+1)>TG1 THEN 2863
NEXT J
FRAC=(TG1-W(1,J))/(W(1,J+1)-W(1,J))
HG1=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG1=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
BG1=HG1-TO*SG1
TF7=H(1,JF1) : HF7=H(2,JF1) : SF7=H(3,JF1) : TG3=TF7+GPP
NEXT J
IF W(1,J)<=TG3 AND W(1,J+1)>TG3 THEN 2874
NEXT J
FRAC=(TG3-W(1,J))/(W(1,J+1)-W(1,J))
HG3=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG3=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
FR=(HG1-HG3)/(HF1-HF7)
2890 FOR I=JFl-1 TO 1 STEP -1
2891 TG3I=H(1,I)+GPP
2892 FOR J=1 TO P-1
2893 IF W(1,J)<=TG3I AND W(1,J+1)>TG3I THEN 2895
2894 NEXT J
2895 FRAC=(TG3I-W(1,J))/(W(1,J+1)-W(1,J))
2896 HG3I=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG3I=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
2900 FR1=(HG1-HG31)/(HF1-H(2,1))
2910 IF FR1<FR THEN FR=FR1
2920 TF7=H(IJI)
2930 HG3=HG3I
2940 SG3=SG3I
2950 TF6=W(2,J)+FRAC*(W(2,J+1)-W(2,J))
2960 IF TF7>TF6 THEN 2931
2970 FOR J=1 TO P-1
2980 IF W(1,J)<=HG3 AND W(2,J+1)>HG3 THEN 2953
2990 NEXT J
3000 BF7=HG3-T0*SF7 : BG3=HG3-T0*SG3
3010 HG2=HG1-(HF1-HF6)*FR
3020 FOR J=1 TO P-1
3030 IF W(2,J)<=HG2 AND W(2,J+1)>HG2 THEN 2953
3040 NEXT J
3050 FRAC=(TG2LMT-W(1,J))/(W(1,J+1)-W(1,J))
3060 TG2=W(1,J)+FRAC*(W(1,J+1)-W(1,J)) : SG2=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3070 BG2=BG2-T0*SG2
3080 IF TG2>TG2LMT THEN 3010
3090 FOR J=1 TO P-1
3100 IF W(1,J)<=HG2L AND W(2,J+1)>HG2L THEN 2953
3110 NEXT J
3120 FRAC=(TG2LMT-W(1,J))/(W(1,J+1)-W(1,J))
3130 TG2L=W(1,J)+FRAC*(W(1,J+1)-W(1,J))
3140 TG2L=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG2L=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3150 BG2L=BG2L-T0*SG2L
3160 IF TG2L>TG2LMT THEN 3010
3170 FOR J=1 TO P-1
3180 IF W(1,J)<=HG2L AND W(2,J+1)>HG2L THEN 2953
3190 NEXT J
3200 BF7=HG3-T0*SF7 : BG3=HG3-T0*SG3
3210 TG3=W(1,J)+FRAC*(W(1,J+1)-W(1,J))
3220 SC1=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3230 BC1=HG1-T0*SC1
3240 TF9=L(1,JF4+1) : HF9=L(2,JF4+1) : SF9=L(3,JF4+1)
3250 IF HF9>HF3 THEN 3201
3260 TC3=TF9-CPP
3270 FOR J=1 TO P-1
3280 IF W(1,J)<=TC3 AND W(1,J+1)>TC3 THEN 3135
3290 NEXT J
3300 FRAC=(TC3-W(1,J))/(W(1,J+1)-W(1,J))
3310 HC3=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SC3=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3320 FLOR=(HF9-HF4)/(HC3-HC1)
3330 FOR J=1 TO P-1
3340 IF W(1,J)<=HC3 AND W(1,J+1)>HC3 THEN 3135
3350 NEXT J
3360 FRAC=(HC3-W(1,J))/(W(1,J+1)-W(1,J))
3370 HC3=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SC3=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3380 FLOR=(HF9-HF4)/(HC3-HC1)
3390 FOR J=1 TO P-1
3400 IF W(1,J)<=HC3 AND W(1,J+1)>HC3 THEN 3135
3410 NEXT J
3420 IF W(1,J)<=TC3 AND W(1,J+1)>TC3 THEN 3164
3163 NEXT J
3164 FRAC=(TC3I-W(1,J))/(W(1,J+1)-W(1,J))
3165 HC3I=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SC3I=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3170 FLOR1=(HF9I-HF4)/(HC3I-HC1)
3180 IF FLOR1>FLOR THEN FLOR=FLOR1 : TF9=TF9I : HF9=HF9I : SF9=SF9I : TC3=TC3I
       : HC3=HC3I : SC3=SC3I
3180 IF L(1,I+1)>TF3 THEN 3201
3200 NEXT I
3201 TC3I=TF3-CPP
3202 FOR J=1 TO P-1
3203 IF W(1,J)<=TC3I AND W(1,J+1)>TC3I THEN 3205
3204 NEXT J
3205 FRAC=(TC3I-W(1,J))/(W(1,J+1)-W(1,J))
3206 HC3I=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SC3I=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3210 FLOR1=(HF3-HF4)/(HC3I-HC1)
3220 IF FLOR1>FLOR THEN FLOR=FLOR1 : TF9=TF3 : HF9=HF3 : SF9=SF3 : TC3=TC3I
       : HC3=HC3I : SC3=SC3I
3225 BF9=HF9-T0*SF9 : BC3=HC3-T0*SC3
3230 HC2=HC2I+(HF3-HF4)/FLOR
3240 FOR J=1 TO P-1
3241 IF W(2,J)<=HC2 AND W(2,J+1)>HC2 THEN 3243
3242 NEXT J
3243 FRAC=(HC2-W(2,J))/(W(2,J+1)-W(2,J))
3244 TC2=W(1,J)+FRAC*(W(1,J+1)-W(1,J)) : SC2=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3245 BC2=HC2-T0*SC2
3270 RAN=TC2-TC1
3270 PT= (.0618+.00076*RAN)*FLOR
3440 RETURN
3450 REM **************INPUT PRINT STATEMENTS
3460 LPRINT "*************************INPUT DATA CYCLE CALC**************************"
3470 LPRINT
3480 READ FL$: LPRINT "FLUID-----"FL$, DATE$, TIME$ : LPRINT
3490 LPRINT "TG1="TG1, "TF1="TF1, "PF1="PF1, "GPP="GPP, "TG2LMT="TG2LMT
3500 LPRINT "TF4="TF4, "PF4="PF4, "TC1="TC1, "CPP="CPP, "S="S
3505 LPRINT "ET="ET, "EFP="EFP, "RPP="RPP, "VF4="VF4, "CF4="CF4
3510 LPRINT "OPT1="OPT1, "OPT2="OPT2, "OPT3="OPT3
3520 LPRINT
3520 LPRINT
3540 RETURN
3710 LPRINT
3711 IF OPRE=0 THEN LPRINT "*************************WITHOUT RECUPERATOR*****************************************************************
3720 LPRINT "*************************WITH RECUPERATOR*******************************************************************"
3730 LPRINT "**************************PERFORMANCE IN W-H/LB GEOFLUID*****************************"
3740 LPRINT
3760 LPRINT "PINCH POINT","GEO OUT LIMIT"
3770 LPRINT "GROSS TURBINE PWR=" ,SPWRG*FR, SPWRG*FRL
3770 LPRINT "PUMP PWR=" , ,SPWPR*FR, SPWPR*FRL
3780 LPRINT "WET COOLING TOWER=" ,PT*FR, PT*FRL
3790 LPRINT "NET POWER (EFFECTIVENESS)="(SPWRG-SPPWR-PT)*FR, (SPWRG-SPPWR-PT)*FRL
3800 LPRINT
3810 LPRINT "WORKING FLUID/GEOFLUID WT. FLOW RATIO BASED ON PINCH="FR
3820 IF TG2>TG2LMT THEN LPRINT "OVERFLOW DUE TO ZERO FLO RATIO"
3830 LPRINT "WORKING FLUID/GEOFLUID WT FLOW RATIO BASED ON GEOFLUID LIMIT="FRL
3850 LPRINT "COOLING WATER/WORKING FLUID WT FLOW RATIO="FLOR
3860 LPRINT
3870 RETURN
3880 LPRINT "**************************SYSTEM STATE POINTS*******************************"
DATA "R114/22 50/50"
5230 IF OPT1=0 THEN 5320
5300 LPRINT
5310 LPRINT "MATRIX A(I,J) WORKING FLUID CONDENSING DATA @P="PF4;"PSIA" : LPRINT . "(T(F))","H(BTU/LB)","S(BTU/LB R)"
5320 DIM L(3,3)
5330 DATA 60,65,67,69,91,93,95,97,99,101,103,105,107,109,111,113.75,115,120,125, 130,135,140,145,150,155,160,165,170,175,180,185,190,195,200,205,210,215
5340 DATA 24.83,31.53,40.05,47.22,53.42,58.90,63.86,68.41,72.67,76.72,80.62,84.41,88.15,91.86,95.69,99.85
5350 DATA .0526,.0650,.0789,.0908,.1012,.1105,.1191,.1272,.1349,.1423,.1496,.1568,.1641,.1715,.1790,.1865
FOR I=1 TO 3
FOR J=1 TO M
READ L(I,J)
NEXT J : NEXT I
IF OPT1=0 THEN 5520
FOR J=1 TO M
READ L(1,J),L(2,J),L(3,J)
NEXT J
IF OPT2=0 THEN 5550
FOR J=1 TO M
LPRINT L(1,J),L(2,J),L(3,J)
NEXT J
LPRINT CHR$(12)
IF OPT2=0 THEN 5550
LPRINT "MATRIX B(I,J)-WORKING FLUID DATA @P="PFl; "PSIA" : LPRINT "T(F)", "H (BTU/LB)", "S(BTU/LB R)"
DIM H(3,N)
DATA 70,80,90,100,110,120,130,140,150,160,170,180,190,200,210,220,230,240,250,260,270,280,290,300,310,320,330,340,350,360
LPRINT "DATA 27.71,30.23,32.80,35.39,38.03,40.70,43.43,46.21,49.05,51.96,54.94,58.01,61.18,64.47"
DATA 67.69,71.49,75.28,79.32,83.65,88.32,93.29,98.39,103.30,107.83,111.93,116.75,119.14,122.40,125.50,128.48
LPRINT "DATA .0539,.0586,.0633,.0680,.0726,.0773,.0820,.0866,.0913,.0961,.1008,.1057,.1106,.1156,.1208"
LPRINT "DATA .1261,.1316,.1374,.1436,.1501,.1570,.1639,.1705,.1765,.1819,.1867,.1911,.1952,.1991,.2028"
FOR I=1 TO 3
FOR J=1 TO N
READ H(I,J)
NEXT J : NEXT I
IF OPT2=0 THEN 5680
FOR J=1 TO N
LPRINT H(I,J),H(2,J),H(3,J)
NEXT J
LPRINT CHR$(12)
IF OPT3=0 THEN 5705
LPRINT "MATRIX W(I,J)-WATER DATA " : LPRINT "T(F)", "H(BTU/LB)", "S(BTU/LB R)"
DIM W(3,P)
DATA 60,80,100,120,140,160,180,200,220,240,260,280,300,320,340,360,380
LPRINT "DATA 76.249,18.269,73,290.43,311.30,332.35,353.62"
DATA .05555,.09332,.12963,.16465,.19651,.23130,.26311,.29400,.32406,.35335,.38193,.40986,.43720,.46400,.49031,.51617,.54163
LPRINT "FOR I=1 TO 3"
FOR J=1 TO P
READ W(I,J)
NEXT J : NEXT I
IF OPT3=0 THEN 5820
FOR J=1 TO P
LPRINT W(1,J),W(2,J),W(3,J)
NEXT J
LPRINT CHR$(12)
RETURN
PROGRAM OUTPUT FOR THE DATA IN THE LISTING
### Input Data Cycle Calc

**Fluid:** R114/22  
**50/50**

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<th>Parameter</th>
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**Date:** 06-30-1986  
**Time:** 08:09:28

#### Matrix A(I,J) Working Fluid Condensing Data @P = 129.8 PSIA

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**WITHOUT RECUPERATOR**

**PERFORMANCE IN N-H/LB GEOFLUID**

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- **STATE 1** HEATER INLET: 0.0 360.0 332.35 5162 64.75
- **STATE 2** HEATER OUTLET: 0.0 138.6 108.60 1962 5.38
- **STATE 3** HEATER PINCH PT: 0.0 250.0 218.60 3676 28.23
- **STATE 2L** HEATER OUTLET: 0.0 160.0 127.96 2313 8.49

**WORKING FLUID/GEOFLUID WT. FLOW RATIO BASED ON PINCH= 2.463188**

**COOLING WATER/WORKING FLUID WT FLOW RATIO= 2.170561**

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***************PERFORMANCE IN W-H/LB GEOFLUID***************

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WORKING FLUID/GEOFLUID WT. FLOW RATIO BASED ON PINCH= 2.463188

OVERFLOW DUE TO ZERO FLO RATIO

WORKING FLUID/GEOFLUID WT FLOW RATIO BASED ON GEOFLUID LIMIT= 0

COOLING WATER/WORKING FLUID WT FLOW RATIO= 2.170561

***************SYSTEM STATE POINTS*************

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<th>S (BTU/LB R)</th>
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(GEOFLUID TEMP LIMIT)

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| STATE 2 TURBINE OUTLET | 129.8 165.0 109.40 .2037 6.00 |
| STATE 3 CONDENSER INLET | 129.8 111.9 97.05 .1820 4.92 |
| STATE 4 CONDENSER OUTLET | 129.8 85.0 31.53 .0650 0.25 |
| STATE 5' FEED PUMP OUTLET | 1000.0 94.0 34.02 .0695 0.39 |
| STATE 5 FEED PUMP OUTLET | 1000.0 94.0 33.85 .0652 2.47 |
| STATE 6 HEATER INLET | 1000.0 139.9 46.19 .0866 3.70 |
| STATE 7 HEATER PINCH PT | 1000.0 240.0 79.32 .1374 10.39 |
| STATE 8 RECUP PINCH PT | 129.8 113.8 99.85 .1878 4.72 |
| STATE 9 COND PINCH PT | 129.8 97.0 68.41 .1272 4.79 |
| STATE 10 RECUP PINCH PT | 1000.0 104.7 36.64 .0702 2.67 |

(GEOFLUID TEMP LIMIT)

| STATE 1 COND INLET | 0.0 70.0 38.09 .0744 0.18 |
| STATE 2 COND OUTLET | 0.0 100.2 68.27 .1300 1.47 |
| STATE 3 PINCH POINT | 0.0 87.0 55.08 .1060 0.75 |