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

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C. J. Bliem

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Idaho National Engineering Laboratory
EG&G Idaho, Inc.
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ABSTRACT

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.

III. 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.

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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 9°F.

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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 $V\Delta P$ even though the density of the liquid was approximately constant. The $V\Delta P$ 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.

Figure 4: Cycle Performance for a 50% R-114/50% R-22 Mixture

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

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.

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APPENDIX

COMPUTER PROGRAM LISTING AND RESULTS

COMPUTER PROGRAM LISTING AND RESULTS

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 (160°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 $^{\circ}\text{F}$; enthalpy, H , in Btu/lbm; entropy, S , in Btu/lbm $^{\circ}\text{R}$; 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 $V \Delta P$. 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 $V \Delta P$, 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 : CPP=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 TO=TWB+460
1292 PF2=PF4 : PF3=PF4 : PF8=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-TO*SWO
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-TO*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 2850 : 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-TO*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

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1590 GOTO 1620
1600 LPRINT HF1="HF1,"SF1="SF1,"J="J
1620 FOR J=1 TO M-1
1630 IF L(3,J)<=SF1 AND L(3,J+1)>SF1 THEN 1670
1640 NEXT J
1650 GOTO 1670
1660 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
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 LPRINT "HF2S="HF2S,"HF2="HF2,"DH="DH,"PWRG,KW="PWRG,"SPWRG="SPWRG
1750 FOR J=1 TO M-1
1760 IF L(2,J)<=HF2 AND L(2,J+1)>HF2 THEN 1780
1770 NEXT J
1780 FRAC=(HF2-L(2,J))/(L(2,J+1)-L(2,J))
1790 JF2=J
1800 TF2=L(1,J) + FRAC*(L(1,J+1)-L(1,J))
1810 SF2=L(3,J) + FRAC*(L(3,J+1)-L(3,J))
1820 BF2=HF2-T0*SF2
1840 RETURN
1900 REM ***** COMPRESSOR/PUMP *****
1920 FOR J=1 TO N-1
1930 IF L(1,J)<=TF4 AND L(1,J+1)>TF4 THEN 1950
1940 NEXT J
1950 FRAC = (TF4-L(1,J))/(L(1,J+1)-L(1,J))
1960 HF4 = L(2,J) + FRAC*(L(2,J+1)-L(2,J))
1970 SF4 = L(3,J) + FRAC*(L(3,J+1)-L(3,J))
1972 BF4=HF4-T0*SF4
1975 JF4=J
2010 HF5S = HF4 + (VF4*(PF5-PF4)*144)/(778)
2020 DHC = (HF4 - HF5S)/EFP
2022 SPPWR=(-DHC)/3.413
2030 HF51 = HF4 - DHC
2033 TF5=TF4 - DHC/CF4
2036 SF51=SF4 + CF4*LOG((TF5+460)/(TF4+460))
2040 FOR J=1 TO M-1
2050 IF H(1,J)<=TF5 AND H(1,J+1)>TF5 THEN 2070
2060 NEXT J
2070 FRAC = (TF5-H(1,J))/(H(1,J+1)-H(1,J))
2080 HF5 = H(2,J) + FRAC*(H(2,J+1)-H(2,J))
2090 SF5 = H(3,J) + FRAC*(H(3,J+1)-H(3,J))
2092 BF5=HF5-T0*SF5 : BF51=HF51 - T0*SF51
2095 RETURN
2100 REM ***** RECUPERATOR *****
2105 IF OPRE=0 THEN 2125
2110 IF TF5<TF2-RPP THEN 2140
2120 LPRINT "NOT ENOUGH TEMPERATURE DIFFERENCE FOR RECUPERATOR" : STOP
2125 TF6=TF5 : HF6=HF5 : SF6=SF5 : BF6=HF6-T0*SF6
2130 TF3=TF2 : HF3=HF2 : SF3=SF2 : BF3=HF3-T0*SF3
2135 RETURN
2140 TF6=TF2-RPP
2150 FOR J=1 TO M-1
2160 IF H(1,J)<=TF6 AND H(1,J+1)>TF6 THEN 2180
2170 NEXT J
2180 FRAC = (TF6-H(1,J))/(H(1,J+1)-H(1,J))
2190 HF6 = H(2,J) + FRAC*(H(2,J+1)-H(2,J))
2200 HF3 = HF2 - (HF6-HF5) : TP=TF2 : HFHP=HF2 : SFHP=SF2 : HFLP=HF6

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2210 FOR J=JF2-1 TO 1 STEP -1
2220   HA = L(2,J) : SA=L(3,J)
2230   TB = L(1,J) - RPP
2240   IF TB<TF5 THEN 2350
2250   FOR I=1 TO M
2260     IF H(1,I)<=TB AND H(1,I+1)>TB THEN 2280
2270   NEXT I
2280   HB = H(2,I) + ((TB-H(1,I))/(H(1,I+1)-H(1,I)))*(H(2,I+1)-H(2,I))
2290   HF6I = HB + (HF2-HA)
2300   HF3I = HA - (HB-HF5)
2310   IF HF3I>HF3 THEN HF3=HF3I : HF6=HF6I : TP=TB+RPP : HFHP=HA : SFHP=SA : H
FLP=HB
2340 NEXT J
2350 TF3I=TF5+RPP
2360 FOR J=1 TO M-1
2370   IF L(1,J)<=TF3I AND L(1,J+1)>TF3I THEN 2390
2380 NEXT J
2390 FRAC=(TF3I-L(1,J))/(L(1,J+1)-L(1,J))
2400 HF3I=L(2,J) + FRAC*(L(2,J+1)-L(2,J))
2410 HF6I=HF5 + (HF2-HF3I)
2420 IF HF1I>HF1 THEN HF1=HF1I : HF4=HF4I : TP=TF3 : HFHP=HF3 : SFHP=SF3 : HFLP
=HF5
2430 FOR J=1 TO M-1
2440   IF L(2,J)<=HF3 AND L(2,J+1)>HF3 THEN 2460
2450 NEXT J
2460 FRAC = (HF3-L(2,J))/(L(2,J+1)-L(2,J))
2470 TF3 = L(1,J) + FRAC*(L(1,J+1)-L(1,J))
2480 SF3 = L(3,J) + FRAC*(L(3,J+1)-L(3,J))
2485 BF3=HF3-T0*SF3
2490 FOR J=1 TO N-1
2500   IF H(2,J)<=HF6 AND H(2,J+1)>HF6 THEN 2520
2510 NEXT J
2520 FRAC = (HF6-H(2,J))/(H(2,J+1)-H(2,J))
2530 TF6 = H(1,J) + FRAC*(H(1,J+1)-H(1,J))
2540 SF6 = H(3,J) + FRAC*(H(3,J+1)-H(3,J))
2545 BF6=HF6-T0*SF6
2550 TF8=TP : HF8=HFHP : SF8=SFHP : HF10=HFLP
2555 BF8=HF8-T0*SF8
2560 FOR J=1 TO N-1
2570   IF H(2,J)<=HF10 AND H(2,J+1)>HF10 THEN 2590
2580 NEXT J
2590 FRAC=(HF10-H(2,J))/(H(2,J+1)-H(2,J))
2600 TF10=H(1,J)+FRAC*(H(1,J+1)-H(1,J))
2602 SF10=H(3,J)+FRAC*(H(3,J+1)-H(3,J))
2606 BF10=HF10-T0*SF10
2610 RETURN
2850 REM *****FIND PINCH LOCATION BETWEEN GEOFLUID AND WORKING FLUID
2860 FOR J=1 TO P-1
2861   IF W(1,J)<=TG1 AND W(1,J+1)>TG1 THEN 2863
2862 NEXT J
2863 FRAC=(TG1-W(1,J))/(W(1,J+1)-W(1,J))
2864 HG1=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG1=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
2865 BG1=HG1-T0*SG1
2870 TF7=H(1,JF1) : HF7=H(2,JF1) : SF7=H(3,JF1) : TG3=TF7+GPP
2871 FOR J=1 TO P-1
2872   IF W(1,J)<=TG3 AND W(1,J+1)>TG3 THEN 2874
2873 NEXT J
2874 FRAC=(TG3-W(1,J))/(W(1,J+1)-W(1,J))
2875 HG3=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG3=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
2880 FR=(HG1-HG3)/(HF1-HF7)

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2890 FOR I=JF1-1 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-HG3I)/(HF1-H(2,I))
2910   IF FR1<FR THEN FR=FR1 : TF7=H(1,I) : HF7=H(2,I) : SF7=H(3,I) : TG3=TG3I :
HG3=HG3I : SG3=SG3I
2920   IF H(1,I-1)<TF6 THEN 2931
2930 NEXT I
2931 TG3I=TF6+GPP
2932 FOR J=1 TO P-1
2933   IF W(1,J)<=TG3I AND W(1,J+1)>TG3I THEN 2935
2934 NEXT J
2935 FRAC=(TG3I-W(1,J))/(W(1,J+1)-W(1,J))
2936 HG3I=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG3I=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
2937 FR1=(HG1-HG3I)/(HF1-HF6)
2938 IF FR1<FR THEN FR=FR1 : TF7=TF6 : HF7=HF6 : SF7=SF6 : TG3=TG3I : HG3=HG3I :
SG3=SG3I
2939 BF7=HF7-T0*SF7 : BG3=HG3-T0*SG3
2940 HG2=HG1-(HF1-HF6)*FR
2950 FOR J=1 TO P-1
2951   IF W(2,J)<=HG2 AND W(2,J+1)>HG2 THEN 2953
2952 NEXT J
2953 FRAC=(HG2-W(2,J))/(W(2,J+1)-W(2,J))
2954 TG2=W(1,J)+FRAC*(W(1,J+1)-W(1,J)) : SG2=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
2955 BG2=HG2-T0*SG2
2960 IF TG2>TG2LMT THEN 3010
2970 FOR J=1 TO P-1
2971   IF W(1,J)<=TG2LMT AND W(1,J+1)>TG2LMT THEN 2973
2972 NEXT J
2973 FRAC=(TG2LMT-W(1,J))/(W(1,J+1)-W(1,J))
2974 HG2L=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SG2L=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
2975 BG2L=HG2L-T0*SG2L
2980 FRL=(HG1-HG2L)/(HF1-HF6)
3000 GOTO 3100
3010 FRL=0
3100 RETURN
3110 REM *****COOLING WATER PINCH POINT AND RANGE CALC
3120 FOR J=1 TO P-1
3121   IF W(1,J)<=TC1 AND W(1,J+1)>TC1 THEN 3123
3122 NEXT J
3123 FRAC=(TC1-W(1,J))/(W(1,J+1)-W(1,J))
3124 HC1=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SC1=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3125 BC1=HC1-T0*SC1
3128 TF9=L(1,JF4+1) : HF9=L(2,JF4+1) : SF9=L(3,JF4+1)
3130 IF HF9>HF3 THEN 3201
3131 TC3=TF9-CPP
3132 FOR J=1 TO P-1
3133   IF W(1,J)<=TC3 AND W(1,J+1)>TC3 THEN 3135
3134 NEXT J
3135 FRAC=(TC3-W(1,J))/(W(1,J+1)-W(1,J))
3136 HC3=W(2,J)+FRAC*(W(2,J+1)-W(2,J)) : SC3=W(3,J)+FRAC*(W(3,J+1)-W(3,J))
3140 FLOR=(HF9-HF4)/(HC3-HC1)
3150 FOR I=JF4+2 TO M-1
3160   HF9I=L(2,I) : TF9I=L(1,I) : SF9I=L(3,I) : TC3I=TF9I-CPP
3161 FOR J=1 TO P-1
3162   IF W(1,J)<=TC3I AND W(1,J+1)>TC3I THEN 3164

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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
3190 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=HC1+(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
3370 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
3530 LPRINT
3540 RETURN
3710 LPRINT
3711 IF OPRE=0 THEN LPRINT "*****WITHOUT RECUPERATOR*****"
****" ELSE LPRINT "*****WITH RECUPERATOR*****"
3720 LPRINT "*****PERFORMANCE IN W-H/LB GEOFLUID*****"
3730 LPRINT
3740 LPRINT,,"PINCH POINT","GEO OUT LIMIT"
3760 LPRINT "GROSS TURBINE PWR=",SPWRG*FR,SPWRG*FRL
3770 LPRINT "PUMP PWR=",SPPWR*FR,SPPWR*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*****"
3890 LPRINT:LPRINT"          P          T          H          S
B"

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3891 LPRINT "                " (PSIA) (F) (BTU/LB) (BTU/LB R) (B
TU/LB)"
3892 LPRINT
3894 LPRINT "*****GEOFLUID*****"
3900 LPRINT USING "STATE 1 HEATER INLET      ###.##  ###.##  ###.##  .### ##
#.##";PG1,TG1,HG1,SG1,BG1-BG0
3910 LPRINT USING "STATE 2 HEATER OUTLET      ###.##  ###.##  ###.##  .### ##
#.##";PG2,TG2,HG2,SG2,BG2-BG0
3920 LPRINT USING "STATE 3 HEATER PINCH PT    ###.##  ###.##  ###.##  .### ##
#.##";PG3,TG3,HG3,SG3,BG3-BG0
3925 LPRINT USING "STATE 2L HEATER OUTLET     ###.##  ###.##  ###.##  .### ##
#.##";PG2,TG2LMT,HG2L,SG2L,BG2L-BG0
3926 LPRINT "                (GEOFLUID TEMP LIMIT)"
3930 LPRINT "*****WORKING FLUID*****"
3940 LPRINT USING "STATE 1 TURBINE INLET      ###.##  ###.##  ###.##  .### ##
#.##";PF1,TF1,HF1,SF1,BF1-BF0
3950 LPRINT USING "STATE 2 TURBINE OUTLET      ###.##  ###.##  ###.##  .### ##
#.##";PF2,TF2,HF2,SF2,BF2-BF0
3960 LPRINT USING "STATE 3 CONDENSER INLET     ###.##  ###.##  ###.##  .### ##
#.##";PF3,TF3,HF3,SF3,BF3-BF0
3970 LPRINT USING "STATE 4 CONDENSER OUTLET    ###.##  ###.##  ###.##  .### ##
#.##";PF4,TF4,HF4,SF4,BF4-BF0
3980 LPRINT USING "STATE 5 FEED PUMP OUTLET    ###.##  ###.##  ###.##  .### ##
#.##";PF5,TF5,HF5,SF5,BF5-BF0
3982 LPRINT USING "STATE 5 FEED PUMP OUTLET    ###.##  ###.##  ###.##  .### ##
#.##";PF5,TF5,HF5,SF5,BF5-BF0
3990 LPRINT USING "STATE 6 HEATER INLET        ###.##  ###.##  ###.##  .### ##
#.##";PF6,TF6,HF6,SF6,BF6-BF0
4000 LPRINT USING "STATE 7 HEATER PINCH PT     ###.##  ###.##  ###.##  .### ##
#.##";PF7,TF7,HF7,SF7,BF7-BF0
4010 IF OPRE=1 THEN LPRINT USING "STATE 8 RECUP PINCH PT  ###.##  ###.##  ###.
## .### ##.##";PF8,TF8,HF8,SF8,BF8-BF0
4020 LPRINT USING "STATE 9 COND PINCH PT       ###.##  ###.##  ###.##  .### ##
#.##";PF9,TF9,HF9,SF9,BF9-BF0
4030 IF OPRE=1 THEN LPRINT USING "STATE 10 RECUP PINCH PT  ###.##  ###.##  ###.
## .### ##.##";PF10,TF10,HF10,SF10,BF10-BF0
4033 LPRINT "*****COOLANT*****"
4040 LPRINT USING "STATE 1 COND INLET          ###.##  ###.##  ###.##  .### ##
#.##";PC1,TC1,HC1,SC1,BC1-BG0
4050 LPRINT USING "STATE 2 COND OUTLET         ###.##  ###.##  ###.##  .### ##
#.##";PC2,TC2,HC2,SC2,BC2-BG0
4060 LPRINT USING "STATE 3 PINCH POINT         ###.##  ###.##  ###.##  .### ##
#.##";PC3,TC3,HC3,SC3,BC3-BG0
4080 RETURN
5200 DATA "R114/22      50/50"
5290 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,M)
5330 DATA 60,85,87,89,91,93,95,97,99,101,103,105,107,109,111,113.75,115,120,125,
130,135,140,145,150,155,160,165,170,175,180,185,190,195,200,205,210,215
5340 DATA 24.83,31.53,40.05,47.22,53.42,58.90,63.86,68.41,72.67,76.72,80.62,84.4
1,88.15,91.86,95.59,99.85
5350 DATA 100.17,101.09,102.01,102.93,103.85,104.77,105.69,106.62,107.54,108.47,
109.40,110.33,111.27,112.19,113.13,114.07,115.01,115.96,116.90,117.85,119.76
5390 DATA .0526,.0650,.0789,.0908,.1012,.1105,.1191,.1272,.1349,.1423,.1496,.156
8,.1641,.1715,.1790,.1878
5395 DATA .1880,.1899,.1915,.1931,.1946,.1962,.1977,.1992,.2007,.2022,.2037,.205
2,.2067,.2081,.2096,.2110,.2125,.2139,.2153,.2168,.2196

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5440 FOR I=1 TO 3
5450 FOR J=1 TO M
5460 READ L(I,J)
5470 NEXT J : NEXT I
5480 IF OPT1=0 THEN 5520
5490 FOR J=1 TO M
5500 LPRINT ,L(1,J),L(2,J),L(3,J)
5505 NEXT J
5506 LPRINT CHR$(12)
5520 IF OPT2=0 THEN 5550
5530 LPRINT
5540 LPRINT "MATRIX B(I,J)-WORKING FLUID DATA @P="PF1;"PSIA" : LPRINT , "T(F)", "H
(BTU/LB)", "S(BTU/LB R)"
5550 DIM H(3,N)
5560 DATA 70,80,90,100,110,120,130,140,150,160,170,180,190,200,210,220,230,240,2
50,260,270,280,290,300,310,320,330,340,350,360
5570 DATA 27.71,30.23,32.80,35.39,38.03,40.70,43.43,46.21,49.05,51.96,54.94,58.0
1,61.18,64.47
5580 DATA 67.89,71.49,75.28,79.32,83.65,88.32,93.29,98.39,103.30,107.83,111.93,1
15.67,119.14,122.40,125.50,128.48
5590 DATA .0539,.0586,.0633,.0680,.0726,.0773,.0820,.0866,.0913,.0961,.1008,.105
7,.1106,.1156,.1208
5600 DATA .1261,.1316,.1374,.1436,.1501,.1570,.1639,.1705,.1765,.1819,.1867,.191
1,.1952,.1991,.2028
5610 FOR I=1 TO 3
5620 FOR J=1 TO N
5630 READ H(I,J)
5640 NEXT J : NEXT I
5650 IF OPT2=0 THEN 5680
5660 FOR J=1 TO N
5670 LPRINT , H(1,J),H(2,J),H(3,J)
5675 NEXT J
5676 LPRINT CHR$(12)
5680 IF OPT3=0 THEN 5705
5690 LPRINT
5700 LPRINT "MATRIX W(I,J)-WATER DATA " : LPRINT , "T(F)", "H(BTU/LB)", "S(BTU/LB R
)"
5705 DIM W(3,P)
5710 DATA 60,80,100,120,140,160,180,200,220,240,260,280,300,320,340,360,380
5720 DATA 28.08,48.09,68.05,88.00,107.96,127.96,147.99,168.07,188.22,208.44,228.
76,249.18,269.73,290.43,311.30,332.35,353.62
5730 DATA .05555,.09332,.12963,.16465,.19851,.23130,.26311,.29400,.32406,.35335,
.38193,.40986,.43720,.46400,.49031,.51617,.54163
5740 FOR I=1 TO 3
5750 FOR J=1 TO P
5760 READ W(I,J)
5770 NEXT J : NEXT I
5780 IF OPT3=0 THEN 5820
5790 FOR J=1 TO P
5800 LPRINT ,W(1,J),W(2,J),W(3,J)
5810 NEXT J
5811 LPRINT CHR$(12)
5820 RETURN

```

**PROGRAM OUTPUT FOR THE
DATA IN THE LISTING**

*****INPUT DATA CYCLE CALC*****

FLUID-----R114/22 50/50 06-30-1986 08:09:28

TG1= 360 TF1= 350 PF1= 1000 GPP= 10 TG2LMT= 160
 TF4= 85 PF4= 129.8 TC1= 70 CPP= 10 S= 0
 ET= .85 EFP= .8 RPP= 9 VF4= .01236 CF4= .275
 OPT1= 1 OPT2= 1 OPT3= 1

MATRIX A(I,J) WORKING FLUID CONDENSING DATA @P= 129.8 PSIA

T(F)	H(BTU/LB)	S(BTU/LB R)
60	24.83	.0526
85	31.53	.065
87	40.05	.0789
89	47.22	.0908
91	53.42	.1012
93	58.9	.1105
95	63.86	.1191
97	68.41001	.1272
99	72.67	.1349
101	76.72	.1423
103	80.62	.1496
105	84.41001	.1568
107	88.15	.1641
109	91.86	.1715
111	95.58999	.179
113.75	99.85	.1878
115	100.17	.188
120	101.09	.1899
125	102.01	.1915
130	102.93	.1931
135	103.85	.1946
140	104.77	.1962
145	105.69	.1977
150	106.62	.1992
155	107.54	.2007
160	108.47	.2022
165	109.4	.2037
170	110.33	.2052
175	111.27	.2067
180	112.19	.2081
185	113.13	.2096
190	114.07	.211
195	115.01	.2125
200	115.96	.2139
205	116.9	.2153
210	117.85	.2168
215	119.76	.2196

MATRIX B(I,J)-WORKING FLUID DATA @P= 1000 PSIA

T(F)	H(BTU/LB)	S(BTU/LB R)
70	27.71	.0539
80	30.23	.0586
90	32.8	.0633
100	35.39	6.800001E-02
110	38.03	.0726
120	40.7	.0773
130	43.43	.082
140	46.21	.0866
150	49.05	9.130001E-02
160	51.96	.0961
170	54.94	.1008
180	58.01	.1057
190	61.18	.1106
200	64.47	.1156
210	67.89	.1208
220	71.49	.1261
230	75.28	.1316
240	79.32	.1374
250	83.65	.1436
260	88.32	.1501
270	93.29	.157
280	98.39	.1639
290	103.3	.1705
300	107.83	.1765
310	111.93	.1819
320	115.67	.1867
330	119.14	.1911
340	122.4	.1952
350	125.5	.1991
360	128.48	.2028

MATRIX W(I,J)-WATER DATA

T(F)	H(BTU/LB)	S(BTU/LB R)
60	28.08	.05555
80	48.09	.09332
100	68.05	.12963
120	88	.16465
140	107.96	.19851
160	127.96	.2313
180	147.99	.26311
200	168.07	.294
220	188.22	.32406
240	208.44	.35335
260	228.76	.38193
280	249.18	.40986
300	269.73	.4372
320	290.43	.464
340	311.3	.49031
360	332.35	.5161701
380	353.62	.54163

*****WITHOUT RECUPERATOR*****
 *****PERFORMANCE IN W-H/LB GEOFLUID*****

	PINCH POINT	GEO OUT LIMIT
GROSS TURBINE PWR=	11.62	10.52033
PUMP PWR=	1.795939	1.625979
WET COOLING TOWER=	.4763891	.4313058
NET POWER (EFFECTIVENESS)=	9.347668	8.463047

WORKING FLUID/GEOFLUID WT. FLOW RATIO BASED ON PINCH= 2.463188
 WORKING FLUID/GEOFLUID WT FLOW RATIO BASED ON GEOFLUID LIMIT= 2.230083
 COOLING WATER/WORKING FLUID WT FLOW RATIO= 2.170561

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

	P (PSIA)	T (F)	H (BTU/LB)	S (BTU/LB R)	B (BTU/LB)
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*****GEOFLUID*****

STATE 1 HEATER INLET	0.0	360.0	332.35	.5162	64.75
STATE 2 HEATER OUTLET	0.0	138.6	106.60	.1962	5.38
STATE 3 HEATER PINCH PT	0.0	250.0	218.60	.3676	28.23
STATE 2L HEATER OUTLET (GEOFLUID TEMP LIMIT)	0.0	160.0	127.96	.2313	8.49

*****WORKING FLUID*****

STATE 1 TURBINE INLET	1000.0	350.0	125.50	.1991	24.49
STATE 2 TURBINE OUTLET	129.8	165.0	109.40	.2037	6.00
STATE 3 CONDENSER INLET	129.8	165.0	109.40	.2037	6.00
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	94.0	33.85	.0652	2.47
STATE 7 HEATER PINCH PT	1000.0	240.0	79.32	.1374	10.39
STATE 9 COND PINCH PT	129.8	97.0	68.41	.1272	4.79

*****COOLANT*****

STATE 1 COND INLET	0.0	70.0	38.09	.0744	0.18
STATE 2 COND OUTLET	0.0	105.9	73.96	.1400	1.96
STATE 3 PINCH POINT	0.0	87.0	55.08	.1060	0.75

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

	PINCH POINT	GEO OUT LIMIT
GROSS TURBINE PWR=	11.62	0
PUMP PWR=	1.795939	0
WET COOLING TOWER=	.4532218	0
NET POWER (EFFECTIVENESS)=	9.370835	0

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*****

	P (PSIA)	T (F)	H (BTU/LB)	S (BTU/LB R)	B (BTU/LB)
*****GEOFLUID*****					
STATE 1 HEATER INLET	0.0	360.0	332.35	.5162	64.75
STATE 2 HEATER OUTLET	0.0	169.0	137.00	.2457	10.07
STATE 3 HEATER PINCH PT	0.0	250.0	218.60	.3676	28.23
STATE 2L HEATER OUTLET (GEOFLUID TEMP LIMIT)	0.0	160.0	127.96	.2313	8.49
*****WORKING FLUID*****					
STATE 1 TURBINE INLET	1000.0	350.0	125.50	.1991	24.49
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
*****COOLANT*****					
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