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THE KALINA CYCLE AND SIMILAR CYCLES FOR GEOTHERMAL POWER PRODUCTION

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SUMMARY

The Heat Cycle Research Program has as its primary goal the cost-effective production of electric power from moderate temperature hydrothermal resources. Recent work has included the study of supercritical cycles with counterflow condensation which utilize mixtures as working fluids. These advanced concepts are projected to give a 20 to 30% improvement in power produced per unit geofluid flow rate (geofluid effectiveness, w hr/lb). The Kalina cycle is a system which is similar to the cycles being studied in the Heat Cycle Research Program and it was felt that this new cycle should be studied in the geothermal context.

Small performance improvements were noted with the Kalina or Kalina-like cycles for working fluid mixtures having high performance in standard supercritical cycles. These new cycles are considerably more complex than the simple Rankine cycle with a large number of recuperative heat exchangers. The percentage improvement with the Kalina cycle was greatest when working fluid mixtures having low performance in the simpler Rankine cycle were used. The supercritical Rankine cycles with the advanced concepts presently being studied in the Heat Cycle Research Program had efficiencies similar to those quoted in published results for the simple Kalina cycles. Recent discussions with AKT Systems, Inc., the company responsible for commercialization of the Kalina cycle, have indicated that somewhat larger efficiencies may be possible with a modification of the original Kalina cycle using a water/ammonia mixture. The modification involves a more complex heat addition and turbine system. These facts lead to the belief that the limit on performance is being approached with the simple supercritical cycles studied in References 2 and 3 and the Kalina cycle will not improve on that performance appreciably, although the capital cost will be greater because of the additional components for the 360°F hydrothermal application. A new variation of the Kalina cycle is proposed that may have some merits with respect to mixed wet and dry heat rejection (to minimize cooling water usage). Although all systems analyzed at this time have had at most small performance improvements, the proper choice of working fluid might well

show more substantial improvements. This type of cycle and the advanced Kalina cycle should be considered seriously when advanced heat rejection systems are studied.

This report contains a brief discussion of the mechanics of the Kalina cycle and ideas to extend the concept to other somewhat different cycles. A modified cycle which has a potential heat rejection advantage but little or no performance improvement is discussed. Then, the results of the application of the Kalina cycle and the modified cycle to a geothermal application (360^{o}F resource) are discussed. The results are compared with published results for the Kalina cycle with high temperature sources and estimates about performance at the geothermal temperatures. Finally, the conclusions of this scoping work are given along with recommendations of the direction of future work in this area.

ACKNOWLEDGMENTS

The author wishes to thank a number of people for their help with this report. First, the people at INEL, G. L. Mines at EG&G, Idaho, Inc. and K. J. Taylor at DOE's Idaho Operations Office were helpful in their review of the document. The discussions with O. J. Demuth, originally with and now a consultant to the Heat Cycle Research Program, gave insight into the problem and helped to provide a more coherent way to present the results. The review by Dr. D. Y. Goswami of the Mechanical Engineering Department of North Carolina Agricultural and Technical State University gave an outside point-of-view. Last, the information received from AKT Systems, Inc. and discussions with Dr. M. Tribus and Dr. H. M. Leibowitz who conveyed Dr. Kalina's thinking on this subject have helped to shape the final version of the report.

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THE KALINA CYCLE AND SIMILAR CYCLES FOR GEOTHERMAL POWER PRODUCTION

1. INTRODUCTION

The Heat Cycle Research Program has as its primary goal the cost-effective production of electric power from moderate temperature hydrothermal resources. Recent work has included the study of supercritical cycles with counterflow condensation which utilize mixtures as working fluids. These advanced concepts are projected to give a 20 to 30% improvement in power produced per unit geofluid flow rate (geofluid effectiveness, w hr/lb). The Kalina cycle is a system which is similar to the cycles being studied in the Heat Cycle Research Program and it was felt that this new cycle should be studied in the geothermal context.

The Kalina Cycle has recently received a great deal of attention as a possible enhancement to gas turbine power production. The system being considered for this application consists of a conventional unrecuperated gas turbine with Kalina's unique cycle as a bottoming system using the gas turbine exhaust as a heat source. The combined cycle gives thermal efficiencies of around 50 % when combined with gas turbine cycles having efficiencies of 30 %. (see Reference 1). The first-ever Kalina cycle plant is being constructed and tested at the Department of Energy's Energy Technology Engineering Center (ETEC) located at Canoga Park, California. It will use 1050^{o}F gas from a gas-fired waste heat facility as its heat source, cooling the gas to 146^{o}F.

Because of the similarities in the gas turbine exhaust and waste heat sources with a hydrothermal heat source, it was felt that the Kalina cycle might offer a performance improvement in the geothermal application. Although both heat sources are similar (having variable temperature and approximately constant specific heat), the temperature ranges are quite different. The present Kalina cycle heat sources are at 1000 to 1050^{o}F while geothermal resources of interest are at significantly lower temperatures (300 to 450^{o}F). This indicates that different working fluids would be necessary for optimized performance. Accordingly, this scoping study has considered three working fluid mixtures: ammonia/water (the fluid used in the high temperature Kalina applications), isobutane/heptane (one of the best hydrocarbon mixtures with conventional supercritical cycles when used with a hydrothermal source at 360°F[2]) and Refrigerant 22/114 (the fluid studied in the halocarbon study that gave comparable results to those of the isobutane/heptane hydrocarbon mixture [3]). A mixture with a heavier component (Benzene/Propane) was also considered because it was felt that a mixture with a wider boiling range might improve the performance.

2. THE KALINA CYCLE

The Kalina cycle is a modification of the Rankine cycle that uses a mixture for a working fluid. Kalina proposes to use a 70/30 mass percent mixture of ammonia and water. This cycle introduces two areas of improvement over the conventional boiling Rankine cycle used with a variable temperature heat source. The first improvement occurs by heating and boiling of the mixture takes place at a varying temperature and, thereby, matches the cooling curve of the heat source (turbine exhaust or geofluid) reducing the irreversibilities generated in that heat transfer process. This effect is presently being exploited in the geothermal, mixed-hydrocarbon, supercritical, binary cycles used in the Heber plant and being explored at the Heat Cycle Research Facility. In these geothermal applications, the working fluid is heated at pressures above the critical pressure which, like the Kalina cycle, gives a good match between the heating curve of the working fluid and the cooling curve of the heat source and creates little irreversibility. There is a practical concern that the boiling in the Kalina cycle will not be a very effective process. The boiling process must take place in an integral, counterflow arrangement to achieve the maximum thermodynamic benefit. The working fluid will be completely boiled and possibly superheated. Boiling heat transfer coefficients for mixtures are substantially lower than those for pure fluids. The integral boiling would entail use of a once-through boiler with complete evaporation of the working fluid. The tube walls would dry out and there would be an area of quite inefficient heat transfer.

The second area of improvement of the Kalina cycle is the unique heat rejection system. Figure 1 shows a schematic diagram of the entire cycle. The use of the distillation subsystem allows the composition of the working fluid in Condenser 1 to be less volatile than that of the working fluid that goes through the turbine. The cost of the required distillation subsystem is, however, not negligible. In addition, although the total heat duty in condensers 1 and 2 will be less than for the cycle without the Kalina modification because of the increased efficiency, the average

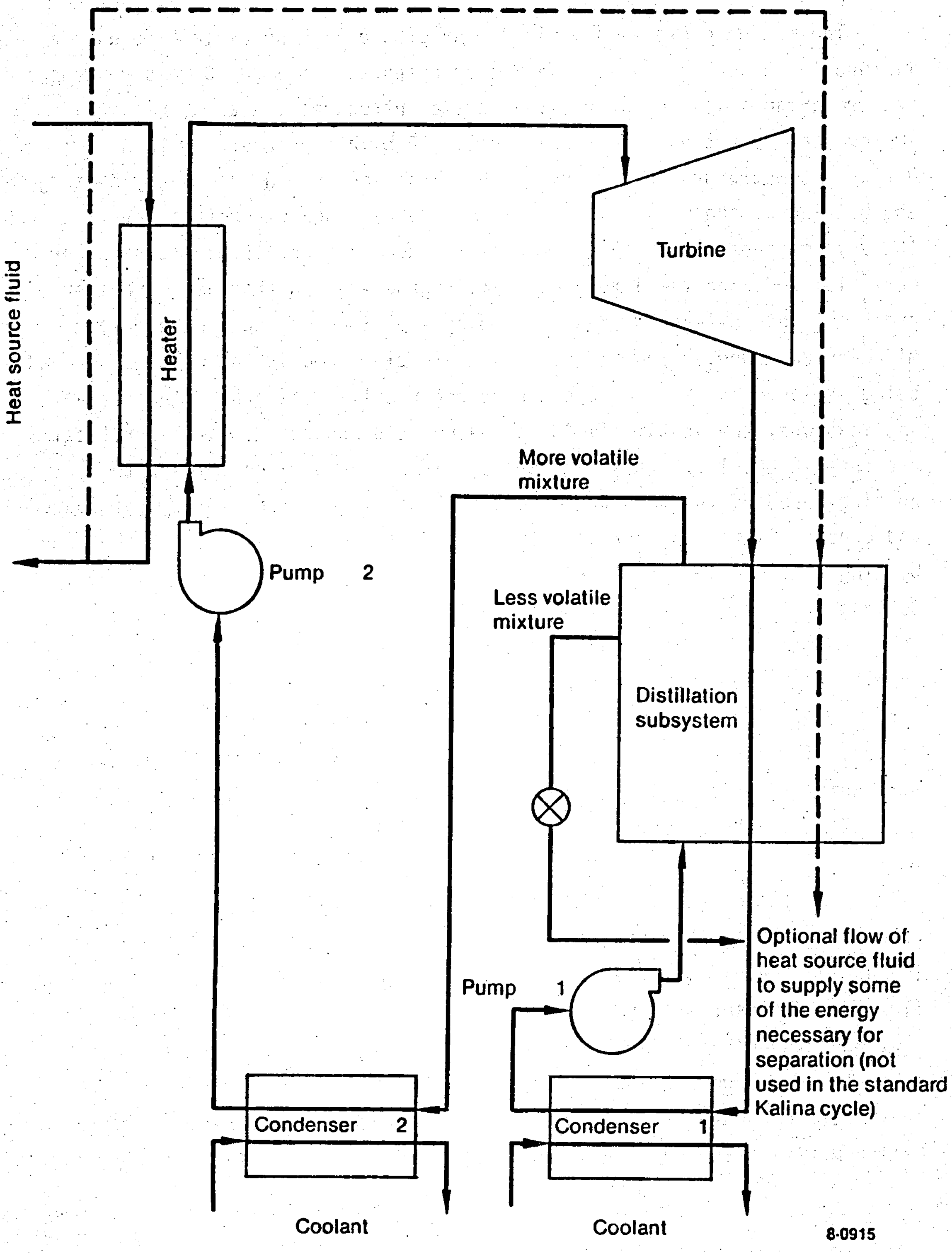

Figure 1. Basic Kalina Cycle

temperature during condensing will be lower. This will result in possible lower cooling water temperature changes in the condenser, for the same cooling water inlet temperature and, therefore, higher cooling water flow rates. This will increase the parasitic power requirement to condense the working fluid. Lower mean temperature difference will result and may possibly increase the size of the condensers over those in a conventional power cycle.

Figure 2 shows a possible configuration of the distillation subsystem. Here, the separation is accomplished by heating the liquid stream that leaves Condenser 1 above its bubble point, and producing a two-phase fluid. The liquid and vapor phases are separated, and if required, some of the liquid is mixed with the vapor. Note that all of the energy required to boil the stream that is to be separated does not necessarily come from the turbine outlet vapor flow; the separated liquid and vapor streams may supply some of the energy. The turbine outlet vapor must supply only the temperature to give adequate pinch points in the recuperative heat exchanger. If the boiling range (difference in dew point and bubble point temperatures) is not large enough, there may not be heat available at an adequate temperature in the turbine outlet vapor to perform the separation. In the geothermal application, the heat source fluid (geofluid) may be used in addition for the distillation. Use of the geothermal energy would improve the power output, but may not decrease the condenser heat load because the power increase results from more heat added to the system rather than from an increase in thermal efficiency.

Recent literature[4,5] published on the simple Kalina cycle applied to the heat sources at 1000 to 1100°F indicate that efficiencies based on the available energy (exergy) in the heat source stream are ~60%. The available energy is referenced to an ambient condition related to cooling water temperature into and out of the cycle. These efficiencies do not include any parasitic power requirements associated with the supply of the cooling water or the heat source fluid. In all of the prior studies made at INEL on geothermal power plants, the cooling parasitic was accounted for because at the geothermal temperatures it is a substantial fraction of the net power (at high temperatures it is insignificant); but the heat source parasitic was not accounted for because it is a site-specific quantity.

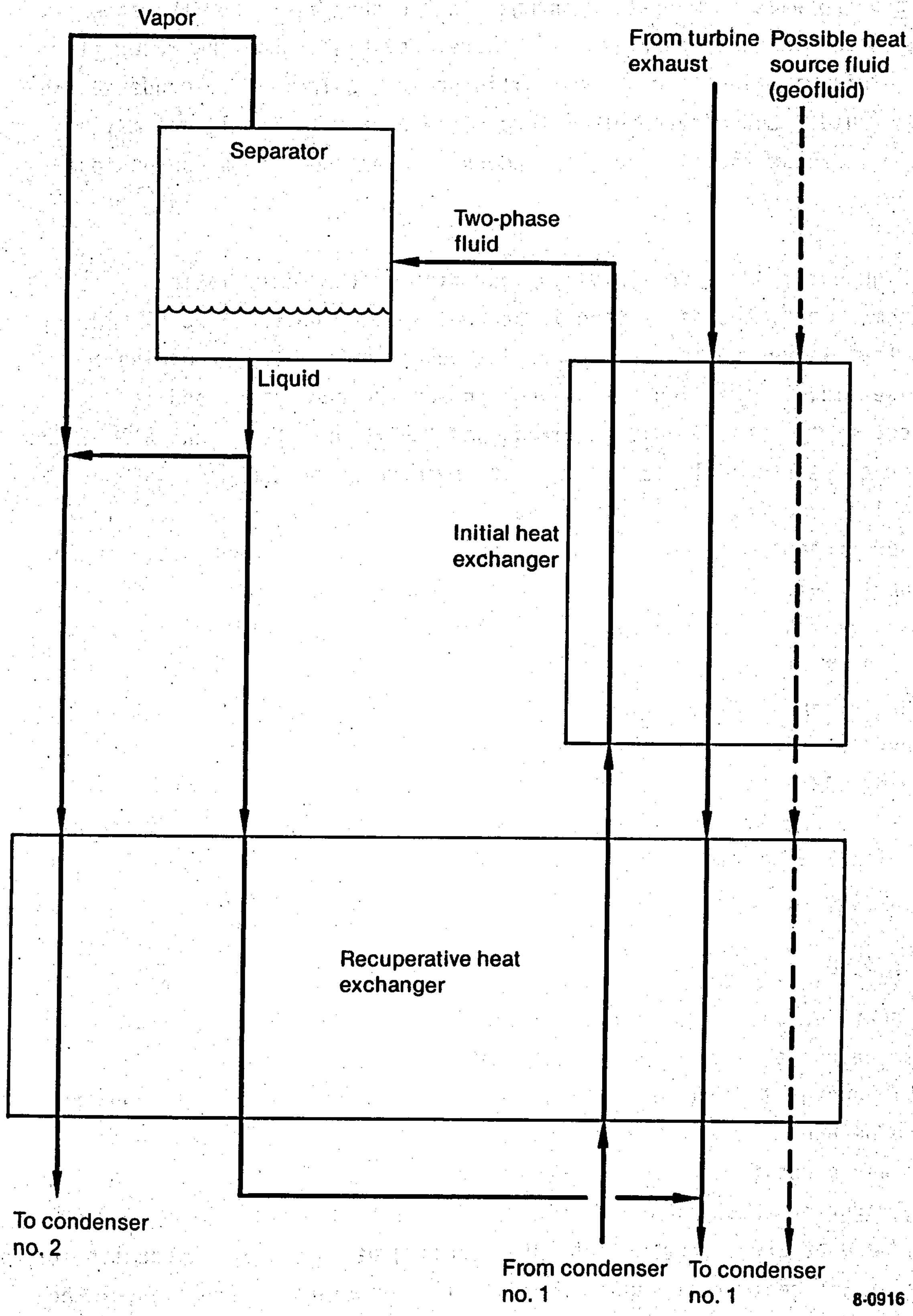

Figure 2. Typical Distillation Subsystem For Simple Kalina Cycle

More recent communications with AKT Systems, Inc. (see private communication in Appendix A) indicate that Dr. Kalina believes that for this geothermal application, second law efficiencies, as defined above, of around 75% are possible. This improvement is attained by modification of the heat addition side of the system. Figure 3 shows the modified cycle. The modifications include:

1. Reheating the working fluid after partial expansion through the first turbine with a parallel stream of source fluid
2. Recooling the working fluid after further expansion through the second turbine and partially heating part of the working fluid
3. Finally expanding through a third turbine.

Earlier in the geothermal Heat Cycle Research Program, some similar heat addition strategies were proposed. These included multiple-boiling cycles. (See Reference 11.) Although not identical to the Kalina modification, multiple boiling cycles do decrease the heat addition irreversibilities by means of more complicated heat exchanger arrangements and the use of multiple turbines. Industrial reaction to this type of cycle indicated that the system was too complex for the geothermal application.

Another variation of the Kalina cycle is shown in Figure 4. In this system, the separation takes place by the partial boiling of the working fluid. The remaining liquid is cooled by regeneratively heating the feed to the boiler. If the demand for combined wet/dry heat rejection is necessary, partial cooling of the liquid may be done by direct heat rejection to the air in an air cooler (the dry part of the wet/dry system). This will decrease the thermal efficiency of the cycle, but the geofluid effectiveness will probably be effected only slightly. If it is desirable to superheat the vapor going to the turbine inlet, a superheater may be added as indicated by the dashed component at the top of the schematic diagram.

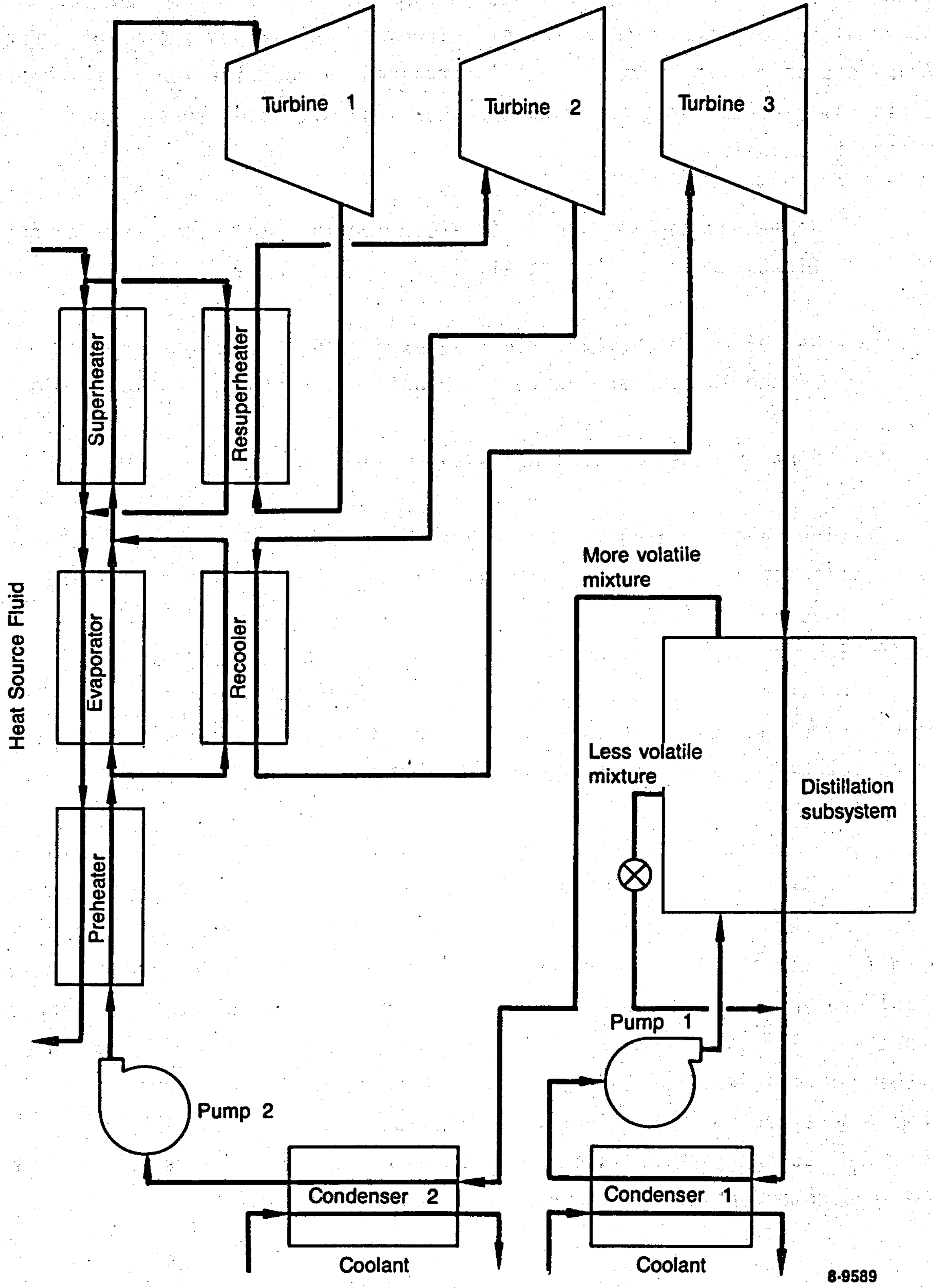

Figure 3. Advanced Kalina Cycle

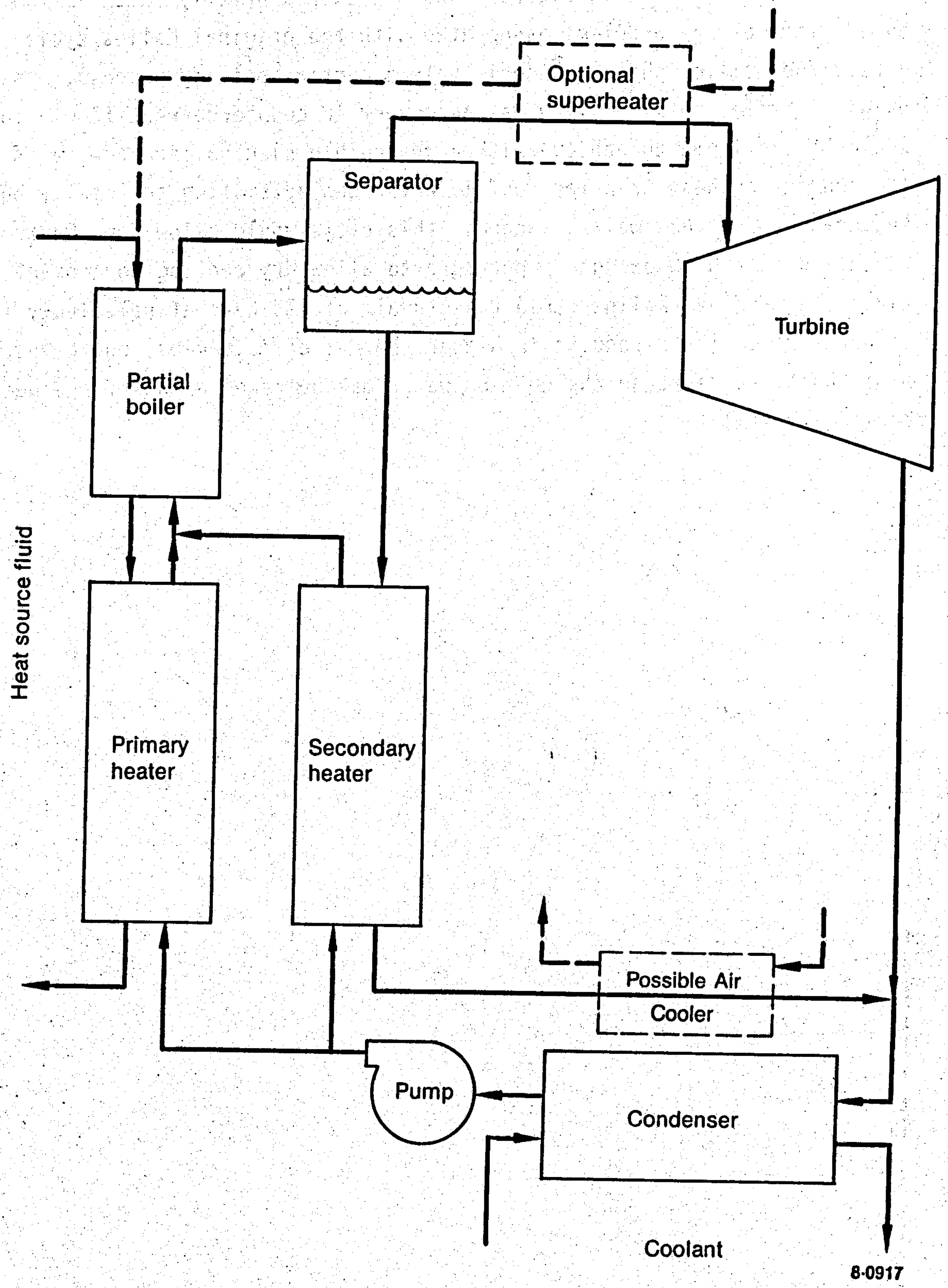

Figure 4. Modification of Kalina Cycle to Allow Dry Cooling

The system shown in Figure 4 was considered briefly in this study; it avoids some of the problems associated with the original Kalina cycle. First, the boiling phase change is only a partial boiling process. In the original cycle, total boiling was necessary in countercurrent flow. This would be difficult to achieve with a reasonable size boiler because of the low convection heat transfer coefficients when attempting to totally boil and dry out the tube walls. Second, this cycle would allow some heat rejection at a high enough temperature to allow dry cooling to ambient air. The original Kalina cycle rejects all of its heat at relatively low temperatures. (This results in higher thermal efficiencies, but gives no opportunity to decrease the cooling water makeup requirements for a wet cooling system).

3. GEOTHERMAL APPLICATION

A preliminary investigation of the use of a Kalina cycle for a geothermal power application was carried out to assess the potential of this new cycle. A hydrothermal resource at 360°F was chosen as the heat source to be consistent with previous analyses. No restrictions on geofluid outlet temperature were considered. Heat rejection was assumed to be with an evaporative condenser because it was felt that this type of heat rejection system would be more favorable to the Kalina cycle with its low heat rejection temperature than would a conventional condenser with a wet cooling tower. (The heat rejection at lower temperatures requires larger condensers and potentially the added capital cost will offset the gains in performance.) This type of heat rejection system will favor the Kalina cycle with its small temperature variation during condensation over the conventional cycle that has a larger change in temperature during condensation. If conventional wet cooling tower and shell-and-tube condensers were used, the amount of cooling water circulated, and therefore, the size of the heat rejection system and heat rejection parasitic power loss would have been so large for the Kalina cycle as to make it noncompetitive with the supercritical Rankine cycle. The wet bulb was assumed to be 60°F and the performance was as outlined in Reference 4. All of the assumptions with respect to cycle component performance, pinch points, turbine and pump efficiencies, etc.; were identical to those used in the previous cycle analysis for the Heat Cycle Research Program.[2,3,6]

Initially, three working fluid mixtures were investigated in this part of the study: a 94/6 mass percent mixture of isobutane and heptane, a 50/50% mixture of Refrigerants 22 and 114 and a 70/30% mixture of ammonia and water. Because the composition of the working fluid changes throughout the cycle, the compositions defined above refer to the fluid flowing through the heater and turbine. The cycle considered in this part of the study was a Kalina-like cycle in which the working fluid mixture was heated at supercritical pressures (with the exception of the ammonia/water system which was boiled as Kalina did with his bottoming cycle for gas turbines). The isobutane/heptane mixture was chosen because it was one of the best mixed hydrocarbons previously studied at this resource temperature (see Reference 2). The fluorocarbon mixture was the best mixture for those two refrigerants in a study reported in Reference 3, and the ammonia/water mixture was that proposed by Kalina for the gas turbine bottoming cycle. The original ammonia/water system was studied in Reference 7.

The thermodynamic properties for the hydrocarbon mixture were obtained from the National Bureau of Standards computer code, EXCST.[8] The refrigerant properties were determined from a package of codes from DuPont described in two Freon Technical Bulletins: CP-1 and CP-2, "Computer Programs for Refrigerant Mixtures".[9] The ammonia/water data was taken from an Institute of Gas Technology Report: Research Bulletin No. 34 "Physical and Thermodynamic Properties of Ammonia-water Mixtures."[10] Entropies and superheated vapor data were extrapolated from the data in this report and property tables for pure water and pure ammonia assuming ideal gas mixtures (see Reference 7).

When no large gain was exhibited by these working fluids, a mixture of propane and benzene was investigated. It was thought that this mixture would have the wide boiling range exhibited by the original ammonia/water mixture of Kalina, but have a suitable critical temperature for this low temperature application.

The second configuration (see Figure 4) was analyzed using normal hydrocarbon mixtures.

4. RESULTS

Table 1 gives a summary of the results for the basic Kalina cycle (and the cycle with supercritical heating) using the original three mixtures. For each mixture, a standard cycle is compared with a Kalina cycle. In the case of both the isobutane/heptane and Refrigerant 22/114 mixtures, there was not enough energy in the turbine exhaust at a high enough temperature to effect the separation. In each of these cases the geofluid, after leaving the heater, was used in addition to the turbine exhaust to vaporize the stream to be separated. This caused the geofluid outlet temperature in the Kalina cycle to be significantly lower than in the conventional cycle. The pinch points in the distillation subsystem for these two working fluids were too low to be practical, 1 to 2^{o}F. If reasonable pinch points had been assumed, the improvement in performance would have been less than is shown in Table 1. The results for these two working fluids may then be thought of as optimistic estimates of the Kalina cycle improvements because in a real situation, the pinch points would be considerably larger. For the ammonia/water mixture, a third column indicates the results that Dr. Kalina predicts can be attained with the modified cycle.

The improvement with the isobutane/heptane mixture is quite small. Utilizing the turbine exhaust and the geofluid leaving the heater as energy inputs to the distillation subsystem result in a possible change in composition that creates a change in turbine back pressure from 56 psia in the standard cycle to 54 psia in the modified Kalina cycle (the turbine pressure ratio increasing from 10.7 to 11.1). This results in an increase in turbine power of <1% and a decrease in thermal efficiency because of the addition of heat at a low temperature. In the geothermal cycle, the thermal efficiency is not the most important parameter, however, and the results are also expressed in terms of geofluid effectiveness (W hr/lb geofluid). These results indicate a less than one percent increase in net geofluid effectiveness. The turbine power is increased, but the cooling parasitic is increased also because of the lower heat rejection temperature and the decrease in thermal efficiency. There are a number of reasons for the small

TABLE 1 - CYCLE COMPARISON WITH EVAPORATIVE CONDENSER

$(T_{\text{Wet Bulb}} = 60^{\circ}\text{F}, T_{\text{geofluid}} = 360^{\circ}\text{F})$

Fluid Mixture		Isobutane/Heptane		Refrigerant 22/114		Ammonia/Water		
Cycle		Standard	Kalina	Standard	Kalina	Standard	Kalina	Advanced Kalina
Composition (%)	Heater/Turbine	94/6	94/6	50/50	50/50	70/30	70/30	70/30*
	Condenser	94/6	92/8	50/50	40/60	70/30	40/69	
Pressure (psia)	Heater	600	600	1100	1100	200	200	350
	Turbine Outlet	56	54	130	118	110	32	21
Temperature (°F)	Geofluid Outlet	142	92	125	95	110	110	
Thermal Efficiency (%)		14.2	11.7	13.5	12.2	4.7	11.8	
Second Law Plant Efficiency (%)		62.9	63.7	64.9	67.3	21.3	60.2	75.0*
Power (Whr/lbgeo)	Turbine	11.21	11.31	12.52	13.07	3.44	9.98	11.95
	Pump	1.18	1.18	2.34	2.34	0.04	0.38	
	Cooling Parasitic	0.96	1.04	0.89	1.19	0.16	0.95	1.36***
	Net	9.07	9.09	9.29	9.54	3.24	8.65	10.59

* Estimates From AKT Systems

** Exclusive of Cooling Parasitic Heat Resection Temperature (70 + 90)/2 = 80°F Based on Performance with Cooling Tower Water 70 to 90°F

*** Extrapolated From Other Cycles

increment in performance in the Kalina cycle with this working fluid. First, the condensing (boiling) range is only around 32°F. For the Kalina cycle to work at its optimum, a large amount of energy should be available in the turbine exhaust at a relatively high temperature to effect the distillation, thereby, requiring a large boiling range (100°F as with the water-ammonia mixture). Second, this system is already optimized in the standard cycle and had a relatively high geofluid effectiveness.

The refrigerant 22/114 mixture shows a slightly larger performance improvement than the hydrocarbon mixture. Here, if energy directly from the geofluid is used to supplement the energy in the turbine exhaust, the turbine back pressure can be reduced from 130 to 118, psia which gives an increase in turbine power of 4.3 %. The cooling parasitic is increased also, for the same reasons as for the hydrocarbon mixture, and a net effectiveness increase of only 2.7% results.

The largest improvement for the Kalina cycle is noted in the water/ammonia mixture. Here, the turbine back pressure decreases from 110 to 32 giving an increase in pressure ratio from 1.8 to 6.2 and a power increase of 190%. With this wide boiling range mixture (~165°F), the Kalina distillation subsystem works with only the turbine exhaust for heat input and 10°F pinch points. The net geofluid effectiveness increases 167% over the corresponding conventional cycle. The effectiveness of the standard cycle chosen was quite low, however, and was probably not the maximum for this fluid. The resulting effectiveness is still lower than for the other working fluids, but only by 5%. Another interesting fact is that the heater pressure with this working fluid is only 200 psia as compared to 600 psia for the hydrocarbon mixture and 1100 psia for the halocarbon mixture.

The last column in the table represents an advanced Kalina cycle as depicted in Figure 3. This is the system described in the Appendix. The second law efficiency of this system is 75% and the advanced heat addition system allows an increase in turbine inlet pressure from 200 to 350 psia. The condenser pressure is reduced from 32 to 21 psia. These effects combine to increase the efficiency from 60 to 75%. Because only the efficiency is given, the turbine work, pump work, and cooling parasitic can not be determined exactly. The efficiency gives the difference in turbine and pump work. The cooling parasitic was extrapolated using the other cycles. If this cycle can be achieved, the net geofluid effectiveness will be ~10.6 w h/lb. This is an increase of 10 to 15% over an advanced supercritical cycle. The heater arrangement and the fact that more than one turbine is required will make the Kalina cycle less acceptable for small systems; especially, well-head units.

Thermal efficiencies and second law efficiencies are given for each system. The thermal efficiency is the standard net power output divided by the heat input. The net work includes the turbine work as well as the working fluid pumping and heat rejection parasitic. The second law efficiency is defined in the same manner as by Kalina.[4,5] This is the net work output (excluding cooling parasitic) divided by the available energy (exergy) in the heat source stream referred to the average coolant temperature as the environmental temperature. This was performed to compare with the reported results for the Kalina cycle. The thermal efficiency is not very meaningful in this application. A high thermal efficiency is obtained if less heat is removed from a unit mass of geofluid (therefore, at a higher average temperature). This would increase thermal efficiency at the expense of geofluid utilization that is not desirable. The second law efficiency incorporates the same ideas as the geofluid effectiveness that was used in the early geothermal studies.[2,3,6]. Note that for the most part the second law efficiency of the isobutane/heptane and R-22/R-114 mixtures that were optimized without the Kalina modification are relatively high. The Kalina modification improves them slightly. The ammonia/water cycle is improved the most, but still falls short of the performance of the original cycles.

The geofluid outlet temperature in all of the Kalina applications investigated is quite low. If a particular resource has an outlet temperature that is limited by precipitation of silica in the geofluid, the Kalina cycle would not be a good choice. Other working fluid cycles may not result in the low geofluid outlet temperatures found in this brief study. The use of the benzene/propane mixture proved to be no better than the other working fluids. It was thought that with the wider boiling range, the fluid would be more favorable for the Kalina cycle application. No composition analyzed produced a cycle as favorable in performance as those already considered. The problem of obtaining energy to effect the separation from the turbine exhaust continued to be the controlling problem. In addition, the wide boiling range working fluid did not show the inherent performance of the hydrocarbon and halocarbon mixtures.

The Kalina-like cycle that partially boils the working fluid and effects the separation leaving the heater was considered briefly. Again, no working fluid initially screened gave performance near that of the standard supercritical cycle (or the Kalina cycle). One important advantage of this system is its ability to reject heat at a higher temperature (to air) as well as to cooling water from a wet tower. This type of system should be investigated in greater detail when considering heat rejection and minimization of cooling water usage.

5. CONCLUSIONS AND RECOMMENDATIONS

Although the study was short and scoping in nature, certain conclusions may be drawn:

1. For the Kalina cycle, the use of geofluid as a heat source for the distillation subsystem is generally not very effective relative to the better binary cycles presently being investigated. Although the turbine power can be increased, the cooling parasitic power increases to partially nullify the gain. The required condenser size may be increased because the condenser heat load will probably be increased.

2. Large increments in performance by the addition of the Kalina cycle have been realized for working fluids with large condensing ranges. Unfortunately, the working fluids studied either have small condensing ranges (hydrocarbon and fluorocarbon mixtures studied) or are not well suited for this temperature range in a simple configuration (ammonia/water mixture). Even the propane/benzene mixture which has a wide boiling range did not produce high performance for this application. The advanced Kalina cycle overcomes the disadvantages of the ammonia/water mixture in this temperature range, but at the expense of a complex heat addition system.

3. The combination of the Kalina cycle with different working fluids will give an extra degree of freedom in determining the best performance. There may be some fluorocarbon or hydrocarbon mixtures which combined with the Kalina cycle will give superior performance to all existing cycles studied, although it is suspected that it will be difficult to surpass the geofluid effectiveness of the standard supercritical systems previously analyzed. There is a certain amount of irreversibility inherent in a cycle and the cycles previously considered are close to that limit. The primary way to decrease the irreversibility is to find a better heat rejection system.

4. The newly devised Kalina type cycle which performs the separation after leaving the heater may be important in cases in which the cooling load is to be switched to partial dry cooling if the appropriate working fluid is found. The main advantage to this cycle will be in its heat rejection abilities rather than its greatly enhanced performance.

It is recommended that further work be initiated that will consider different working fluids to be used in conjunction with the modified Kalina cycle when studies of heat rejection with saving in makeup water is studied. The use of the advanced Kalina cycle with its emphasis on the heat addition system should be postponed until heat addition systems are considered again as a class. At low heat source temperatures, the higher priority item is the heat rejection side.

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APPENDIX A

Description of Advanced Kalina Cycle

The A.K. Texergy Co.
AKT Systems, Inc.

July 18, 1988

Mr. C. J. Bliem
Energy Programs
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, ID 83415

Dear Mr. Bliem:

It was good to talk with you and to learn about your work on the application of the Kalina cycle to geothermal sources. Because Dr. Tribus is traveling extensively, he has asked me to respond to your letter of 30 June 1988.

Over the past two years we have developed six variations on the Kalina cycle, as shown in Table I attached. It is unfortunate that many people only know about one or two of these cycles and assume that a cycle developed for one application will work well in another. For example, as you have found, when our System 1 or 6, which are designed as bottoming cycles, are applied to a geothermal source, they may perform poorly.

Because our limited resources are completely committed to design support for the demonstration power plant and certain follow-on business ventures, we are unable, at this time, to provide you with a design specifically tailored to your application.

We can, however, outline for you with a broad brush, what is required. Your Table I shows the turbine operating on a 70% mixture between 200 and 32 psia. After briefly reviewing your brine conditions, Dr. Kalina estimated that a well-designed geothermal plant (System 2), using the same 70% mixture, would operate between pressures of 350 psia and 21 psia, respectively. At this expansion ratio the second law efficiency would rise from 52.8% to 75%. We have several suitable designs in conceptual form but at this moment have not the time to demonstrate them to you. If you examine the data we have presented for System 6 (ref. 4) you will find that with a 70/30 mixture and an exhaust pressure of 21.9 psia it has a second law efficiency of 80%. This figure is more characteristic of Kalina type cycles when they are optimized.

Our demonstration plant is based on KCS1D2 (Kalina Cycle System 1 Distillation subsystem 2) which is not a very efficient system. This system meets two criteria:

1) It is the least expensive we can build.
2) It is the most we can afford.

Unfortunately, it only has a second law efficiency of 60%. That value should not be used as the basis for an extrapolation.

We were especially pained to read the next to last paragraph on page 4, when you wrote...

> " Recent literature published on the Kalina cycle.... indicate that efficiencies based on exergy .... are about 60%. Exptrapolating these results to lower temperature sources .... will probably lower the efficiency to around 56 percent ...""

We are confident that when we have the opportunity to work with you, we shall be able to demonstrate to your satisfaction, that the more typical second law efficiency to use is 80% and that it remains high, independent of temperature level.

It is extremely important to us that studies from prestigious organizations like yours be as accurate as possible. Off-hand comments can cause serious problems for a small company trying to bring a significant change into a large, well established industry which is not known for its rapid adoption of new ideas.

Depending on your timetable, let me suggest one of two approaches. If your schedule permits, we will send you the results of our System 2 design by year's end. If not, let's find some way that we can cooperate together to get you the proper information needed for your study.

Thank you again for allowing us to comment on your study.

Very truly yours,

Hank Leibowitz

H. M. Leibowitz
Vice President

HML:spo

Enclosure

TABLE I

	System	Application
1	BOTTOMING CYCLE FOR A SOURCE OF WIDELY VARYING TEMPERATURE	BOTTOM OF A COMBINED CYCLE OF LOWEST POSSIBLE COST
2	SPLIT CYCLE WITH SOURCE OF NARROW RANGE OF TEMPERATURE	HIGH TEMPERATURE GEOTHERMAL SOURCE
3	SOURCE OF MODEST PEAK TEMPERATURE, NARROW RANGE OF VARIATION	SOLAR SOURCE WITHOUT A CONCENTRATOR, E.G., A SOLAR POND
4	MULTIPLE HEAT SOURCES, EACH WITH A DIFFERENT TEMPERATURE BUT SERVED WITH A SINGLE TURBINE AND DCSS	INDUSTRIAL CO-GENERATION FROM SEVERAL HEAT SOURCES AT THE SAME TIME.
5	DIRECT FIRED, HIGH TEMPERATURE SOURCE WITH LARGE RANGE OF TEMPERATURE VARIATION	POWER PLANTS BURNING COAL OR SOLID BIOMASS FUELS
6	GAS OR OIL FIRED SYSTEMS OF HIGHEST POSSIBLE EFFICIENCY.	BOTTOMING PORTION OF A COMBINED CYCLE.