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21855

BINARY CYCLE PERFORMANCE IMPROVEMENT FROM REAL TIME PROCESS CONTROL

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KEY WORDS

binary power cycles, performance improvements, working fluid mixtures, real time control

PROJECT BACKGROUND AND STATUS

Relative to fossil fuels, the liquid-dominated hydrothermal resources are a relatively low grade energy source. As such, the performances of the energy conversion systems using these resources are very dependent upon the temperature of both the heat source and heat sink. As the difference between the source and sink temperature increases, the amount of power that can be produced increases; conversely, as the temperature difference decreases so does the amount of power produced. Although the temperature of the hydrothermal resource (heat source) is usually considered to be constant, it will decrease with time as the resource declines. The heat sink for these energy conversion systems is the ambient air, for which the temperature can vary significantly annually, as well as daily. In designing these energy conversion systems and sizing the equipment a constant heat source and heat sink temperature are typically assumed. Given the variation in the ambient air temperature, the resulting plant will not be operating at the design point most of the time.

Studies conducted at the INEL have shown that a supercritical cycle with optimized turbine inlet conditions and working fluid selection would have a performance approaching a practical thermodynamic maximum. INEL investigators are attempting to incorporate the performance improvements identified for the supercritical cycle using mixed hydrocarbon working fluids into a fixed configuration power plant to minimize the impact of changes in the air temperature. By continually adjusting the turbine inlet conditions and the composition of the working fluid mixture to account for the variation in the ambient conditions, the performance of the plant can be maximized. Both continuous and seasonal adjustments of the composition are being examined.

The initial design of an energy conversion system is being evaluated to determine the degree of flexibility necessary to allow the maximum performance to be obtained. A value analysis will establish whether the addition of the flexibility is cost effective. This analysis will examine the impact of different power sales agreements on the cost effectiveness of the various design configurations.

The initial effort examined a fixed plant designed using a pure working fluid (isobutane) to determine the improvements obtained when adjusting the process conditions (including working fluid composition) in the real-time. If this study suggests a cost effective improvement is possible, binary plant operators will be contacted to determine the feasibility of operating an existing facility in this mode.

PROJECT OBJECTIVES

The objective of the Heat Cycle Research Project is to develop technologies that will reduce the cost of generating electricity from those hydrothermal resources considered marginally feasible for economic development. This investigation examines whether the real-time adjustment of the power cycle process conditions (including the composition of the working fluid) can improve the performance of the energy conversion system.

Technical Objectives

- Establish the improvement in the performance of a fixed configuration power plant obtained by the real-time adjustment of the power cycle process conditions in response to variations in the ambient air temperature.
- Define systems that can be used for the on-line adjustment of the composition of the working fluid.
- Establish the level of flexibility in the plant design necessary to obtain the maximum benefit of the real-time control of the process conditions.
- Determine whether the real-time control scheme is cost effective.
- Evaluate the impact of different power sales terms on the cost effectiveness of the real-time control scheme.

Expected Outcomes

- The continuous adjustment of the process conditions will minimize the impact of variations in the ambient air temperature on the performance of binary cycles.
- Cost effective real-time control methods will be identified.
- By combining a real-time control scheme with flexibility in the plant design, a power cycle can be defined that allows the power sales revenues to be increased.
- The real-time adjustment of process conditions can be incorporated into existing power plants to improve their performance.

APPROACH

To evaluate the effect of the ambient air temperature on the performance of a binary power plant, a plant has been modeled utilizing the ASPEN software. This model was used to optimize plant performance for assumed heat source and heat sink temperatures, and then size the equipment for the corresponding process conditions. A parametric study was made using the ASPEN model to optimize the performance of this fixed configuration plant at various ambient conditions and working fluid compositions. This study identified the process conditions providing the optimum performance for the set of conditions assumed. Air-cooled condensers were used in the ASPEN model. The design heat sink condition is an average annual air temperature for a representative site.

The ASPEN software allows different schemes for adjusting working fluid chemistry to be incorporated into the binary plant model. Once the process conditions are established, the model is used to size the equipment required for a particular scheme.

The ASPEN software allows changes in the required equipment sizes to be established for different plant designs. The value analysis technique used previously by INEL investigators is used to determine the relative impact of the cost of power. Different power sales agreement scenarios are assumed to determine the conditions under which the different real-time control schemes would be cost effective.

RESEARCH RESULTS

In 1996, investigators obtained the ASPEN software and developed the binary plant model that allowed the different process conditions to be simulated. The assumed temperature of the hydrothermal resource was 350°F. The baseline plant was designed using a pure isobutane working fluid and an ambient air temperature of 45°F. The plant utilizes a supercritical cycle. The performance of the baseline plant was then optimized over a range of ambient air temperatures using a pure isobutane working fluid. This optimization indicated the plant output for a given brine flow would be at a maximum when the turbine inlet condition was at the highest pressure possible for the design working fluid pump size. As the air temperature increased, the turbine inlet pressure giving the optimum performance also increased.

The performance of this fixed plant was then simulated over the same ambient air temperature range after adding different amounts of hexane to the working fluid. Hexane was selected instead of heptane as the minor component because optimum performance levels would be obtained with larger amounts of hexane. It was anticipated that this would provide better control of the working fluid composition with air temperature. Initial studies suggested that if only a small amount of the minor component was used at the higher air temperatures, that it might be necessary to completely remove this component at the lower air temperatures. The complete removal of the minor component would be equipment intensive, especially if done on a continuous basis.

The projected improvement of adding hexane in 2-$^1/_2$% increments is shown in Figure 1 for an air temperature range of 0° to 100°F. The addition of hexane improves performance over the temperature range, however, at air temperatures below the design value of 45°F the amount of hexane has to be decreased or a performance penalty may be incurred. Concentrations of hexane greater than 5% required that the working fluid pump flow be throttled; the modeling with pure isobutane suggested that performance decreased when flow had to be throttled. The results shown in Figure 1 are for a plant originally designed for a single component working fluid; pure isobutane.

These results were applied to a representative (Basin and Range) annual ambient air temperature profile to determine how much additional power could be generated from a nominal 5 MW_e (net) plant. As indicated in Figure 1, the addition of the hexane would allow the power from the plant to be increased during the summer months. In the winter, the increase in power relative to the base plant would be small. The additional power that could be produced over a one year period is shown in Figure 2. Four scenarios were considered; operating with a mixture containing 2.5% hexane, operating with a mixture containing 5% hexane, continuously adjusting the composition as the ambient air temperature changed, and making a seasonal adjustment of the composition (operating from November to March with the 2.5% hexane content and the remainder of the year at the higher hexane level). As would be expected, making a continual adjustment of the fluid chemistry provides the highest incremental increase in the power from the plant. It is projected that an additional 1.23 million KW-hr of power would be produced by the plant. This represents ~3% increase in the amount of power generated over the year. The projected power increase when seasonally adjusting the composition was only slightly less, 1.2 million KW-hr. This small difference suggests that seasonally adjusting the working fluid composition would be the most cost effective of these alternatives.

FUTURE PLANS

During the coming year, the analytical studies will be completed and reported. Members of industry will be contacted to solicit interest in continuing these activities. If interest exists, the feasibility of modifying an operating plant to operate with a varying working fluid composition will be examined.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Mammoth Pacific has indicated an interest in this activity as a potential means of improving the performance of existing facilities. It is anticipated that if the results are positive, it could be applied to a number of existing binary facilities, as well as new plants.

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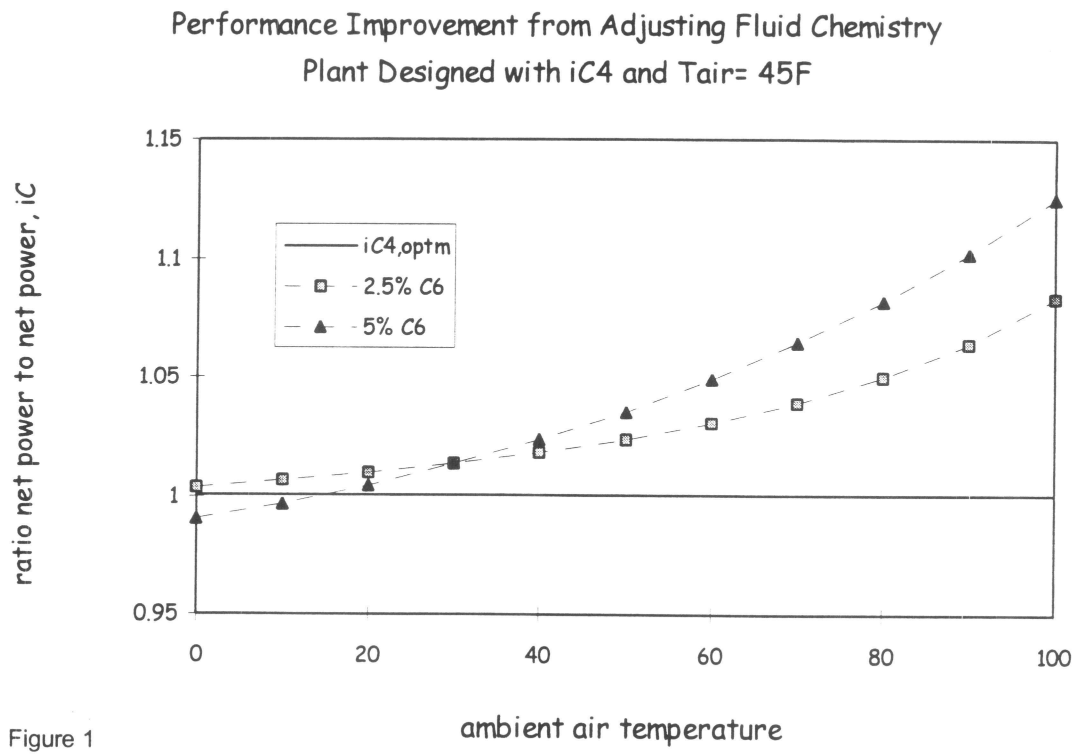

Figure 1

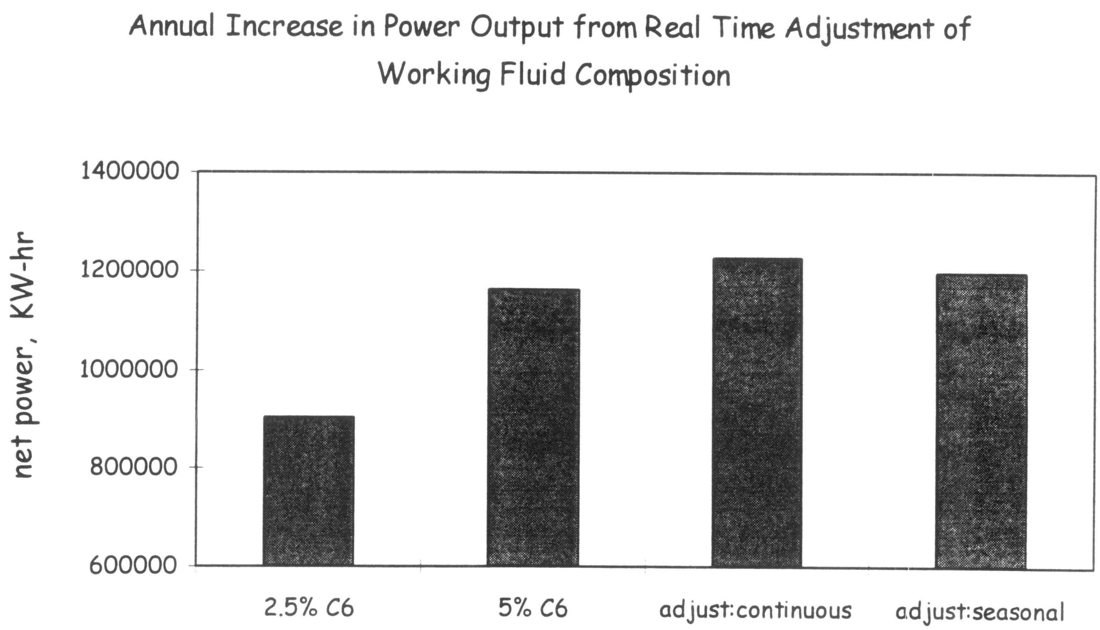

Figure 2