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21850

MODEL DEVELOPMENT AND ANALYSIS OF ADVANCED BINARY CYCLES

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KEY WORDS

computer-aided model, binary cycle, geothermal power plant, heat rejection system, economic evaluation, thermodynamic evaluation, off-design, performance, mixed hydrocarbon fluid, binary working fluid

PROJECT BACKGROUND AND STATUS

The development of geothermal energy in the U.S. depends in part on the exploitation of low-temperature, liquid-dominated sites. The most promising technology for these resources is a binary cycle that uses a hydrocarbon working fluid, pure or mixed. Because of the low temperatures of these resources, the amount of heat rejected to the environment is high relative to the heat input to the cycle. The optimization of the heat rejection system, therefore, can result in large increases in cycle efficiency and decreases in levelized cost of electricity (LEC).

During the past three years, a computer model has been developed at NREL to represent binary cycles with different types of heat rejection systems. The change in the levelized cost of producing electricity from a base case was determined based on the changes in the cycle thermodynamic attributes. This modeling used Value Analysis, similar to that used by Demuth and Whitbeck early in the Heat Cycle Research Program. Baseline configurations were determined from some low temperature systems conceived by Barber Nichols Engineering and have also been determined from the *Next Generation Geothermal Power Plants* (NGGPP) study conducted by CE Holt Company. The model used at NREL consists of a computer program to do the cycle thermodynamics and equipment sizing, a database of thermodynamic properties of various working fluids, and a spreadsheet to do the economic evaluation.

In FY1994, NREL began the development of the computer model and made some initial studies using a dry heat rejection system and a number of different working fluids. A program to evaluate the thermodynamic performance of a basic Rankine cycle was written and a spreadsheet for economic analysis was developed. A limited database of working fluid properties was developed. Economic information was based on studies conducted by Barber-Nichols Engineering for small power plants at low temperature (less than 300°F) resources. A number of studies were made using the computer model, and the results were compared to the base line data from Barber-Nichols.

In FY1995, the computer model was enhanced by including the ability to model different types of heat rejection systems and temperatures, and to determine cycle performance during "off-design" operation. These modifications allowed NREL to conduct a number of studies of the effect of heat rejection system type and temperature on cycles under different environmental conditions.

In FY1996, further enhancements were made to the computer model and new economic information was incorporated into the model. The thermodynamic performance program was modified to allow the uninterrupted running of multiple cases over a range of heater pressure, condenser bubble point temperature, and air-cooled condenser and heater pinch points. The database of working fluid properties was expanded significantly by the use of a new program. This program, based on the NIST14 software, was developed to generate quickly all the data files necessary to describe a working fluid, and allowed NREL to explore many new fluids. In addition, detailed economic information from CE Holt Company, which performed the NGGPP study, was obtained for a number of large (50 MW) power plants at four low-temperature resources. This economic information was incorporated into the spreadsheet tool and became the new base line cases for a series of cycle optimizations using dry cooling and a variety of working fluids. The results showed that the use of mixed hydrocarbon working fluids, in plants optimized for their use, could significantly reduce LEC.

In FY 1997, NREL will continue its studies of the effect of type of working fluid on the performance of cycles located at different resources, and will explore operating strategies that involve the use of different working fluids as resource and environmental conditions change. The use of recuperation will also be studied.

PROJECT OBJECTIVES

The objectives of this project are twofold. The first objective is to develop a model for the comparative thermodynamic and economic evaluation of different cycle designs that use a variety of heat rejection systems and working fluids. This goal was achieved by the development of a program for cycle thermodynamic performance and a spreadsheet for economic evaluation. The database of working fluids was expanded significantly, allowing NREL to study a large variety of mixed and pure working fluids. Recuperation and different types of heat rejection systems could also be studied. New economic information was obtained from CE Holt Company and included in the model.

The second objective is to analyze the performance of cycles using different working fluids and heat rejection configurations. This objective includes studies to determine the optimum working fluid for a plant using a particular resource, and to determine cycle performance when the environmental and resource conditions change. Strategies to improve cycle performance by altering the working fluid as resource conditions deteriorate will be examined. Different types of heat rejection systems will be studied, and the effect of using recuperation will be determined.

Technical Objectives

- This project will produce a computer model with flexibility in the types of cycles it can analyze. The model will rank the relative performance, based on LEC, of cycles that use different types of heat rejection systems and working fluids, with and without recuperation. The minimization of water consumption can also be a goal in the ranking of plant performance. A large number of different working fluids will be able to be used in the program. The latest economic information for large plants, from the NGGPP study, will be the basis of the economic evaluation.

- Studies will be conducted that will determine the optimum working fluid for a plant using dry cooling at a number of low temperature resources. Strategies that involve changing the working fluid composition as resource and environmental conditions vary will be evaluated. The use of recuperation will be explored.

Expected Outcome

- A computer model will be produced that will be the main tool used to evaluate advanced systems.
- Optimal working fluids for different plant configurations and resources will be determined.
- Operating strategies to cope with changing resource and environmental conditions will be evaluated.
- The effect of including recuperation on LEC will be determined.

APPROACH

The studies outlined above will be conducted using the computer model described in the Background section. This model uses, as a base line case, the cycle configuration and economic information from the NGGPP study. The model allows one to see what effect changing the plant configuration or working fluid has on LEC, and permits the relative ranking of different plants. The results of these studies will direct research into the most promising technologies for improving binary cycle, geothermal plant performance.

In past years, the model was developed and incrementally improved. It has now reached a point where it can accommodate cycles, with or without recuperation, that use a variety of heat rejection systems. The database of working fluids now includes a large number of pure and mixed hydrocarbons. The latest economic information from CE Holt Company has been included.

In the future, the model will be used extensively for the studies outlined above.

RESEARCH RESULTS

The results of the study to determine the optimum working fluid for a given resource show that large reductions in LEC are possible. As an example, in Figure 1 are shown the results for the resource at Thermo Hot Springs. This resource provides geofluid at a temperature of 265°F, and is the lowest temperature resource studied. The base line plant used commercial isobutane with a dry cooling heat rejection system. The LEC for the base line plant is 10.22 ¢/kWhr. In addition to pure fluids, mixtures of propane and isopentane, and isobutane and hexane were studied. The mixtures are designated with an "M" and the last two digits in their names indicate the percent mass fraction of the heavier component. Commercial grade isobutane was also included.

The results show that the use of mixed hydrocarbon working fluids has a large effect on LEC at Thermo Hot Springs. Using a mixture of 90% isobutane/10% hexane reduces the cost of electricity to 7.6 ¢/kWhr, a 26% reduction in LEC from the base case. A mixture of 98% propane/2% isopentane reduces it slightly more to 7.4 ¢/kWhr.

The simplified model, when duplicating the base case of CE Holt for this resource, delivered cycle performance results that compared favorably with the base case.

FUTURE PLANS

In FY1997, studies will be made on the selection of working fluids to fit a particular resource, operating strategies for varying environmental and resource conditions, and the effect of using recuperation.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

The computer model will be made available to industry when it has been completed and the user interface improved. The model will give the user an accurate idea of the relative performance of an advanced system relative to the NGGPP base line cases.

The results of the working fluid, operating strategies, and recuperation studies will be immediately useful to industry as ways to decrease operating costs and improve plant performance are sought.

The preliminary results of the working fluid and off-design studies, using Barber-Nichols data, were presented at the Geothermal Session of the 1996 World Renewable Energy Conference, and during the Geothermal session of the IECEC 96. Industrial attendees showed great interest in the current and future results of the program.

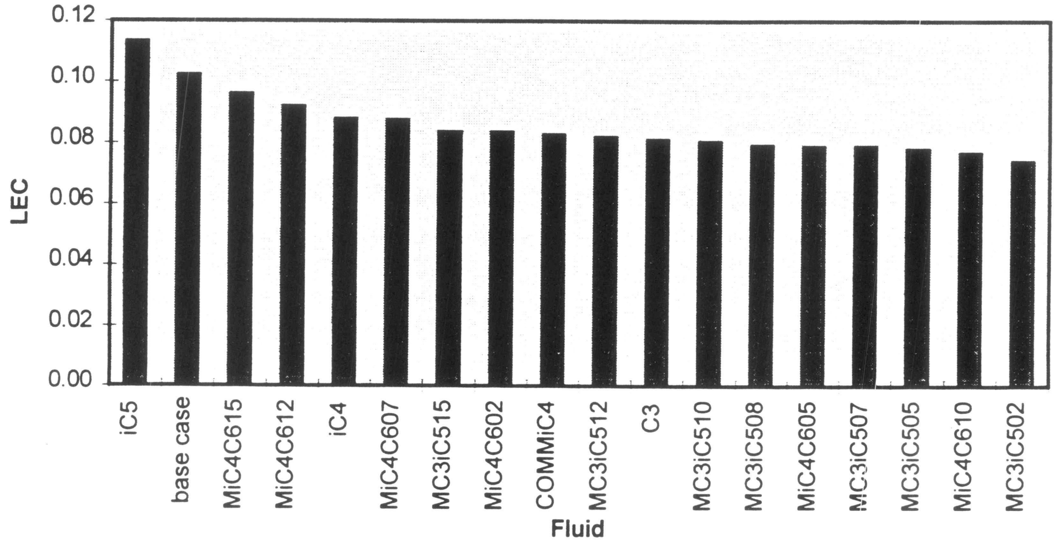

Figure 1. Results of study to determine optimum working fluid at Thermo Hot Springs.