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OPERATING RESULTS FROM A HYBRID CYCLE POWER PLANT ON A GEOPRESSURED WELL

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ABSTRACT

The U.S. Department of Energy and Electric Power Research Institute are co-funding a demonstration of the hybrid cycle power concept on a geopressured resource. The power plant was constructed at the Pleasant Bayou geopressured test facility in Texas and has been operational since August 1989. This paper presents an overview of the design and construction and a detailed discussion of plant operation and performance.

INTRODUCTION

In the hybrid cycle power conversion concept, electricity is generated from two or more sources of energy. From a geopressured resource, energy can be recovered from high temperature brine, from dissolved methane, and from hydraulic energy of the high pressure brine. In the demonstration plant, gas is burned in a gas engine to generate electricity directly. Exhaust heat from the gas engine is then combined with heat from the brine to generate additional electricity in a binary cycle. Heat from the gas engine is available at high temperature, thus improving the efficiency of the binary portion of the hybrid cycle.

The Ben Holt Co., under contract to EPRI, refurbished equipment from DOE's Direct Contact Heat Exchange facility in East Mesa, California for use at Pleasant Bayou. In addition, Holt purchased new heat exchangers and other equipment required for a hybrid cycle plant. Construction and operation are under a separate contract funded by DOE. For this work, Holt teamed with Eaton Operating Company (Houston, Texas) and Institute of Gas Technology (Chicago, Illinois).

The primary objective of this project is to demonstrate the hybrid concept for electricity generation. Other objectives include demonstrating electricity generation from a geopressured resource and obtaining data from operating a power plant using geopressured fluids.

SYSTEM DESCRIPTION

Figure 1 is a flow diagram of the hybrid power cycle which was installed at Pleasant Bayou. The system is designed to operate on 10,000 BBL/day of geopressured brine containing 22 SCF of gas/BBL. This flow is approximately one half of the total flow from the Pleasant Bayou well. The gas is approximately 87 percent methane with the balance mostly carbon dioxide.

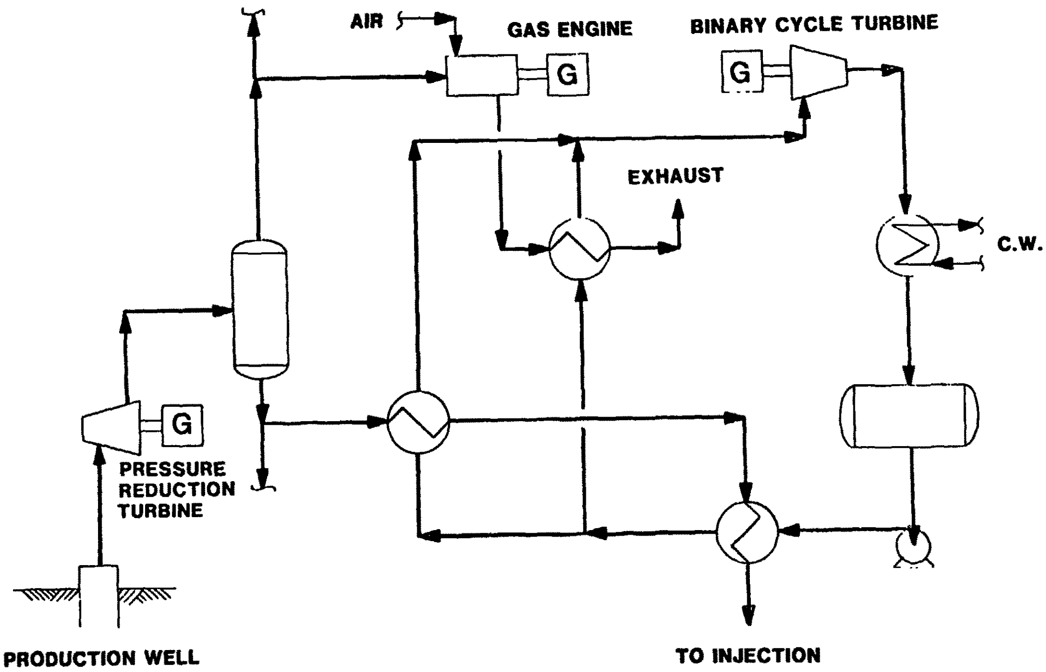
Power can be produced from three forms of energy in the cycle as shown. The first form is hydraulic energy, which can be recovered in the pressure reduction turbine. A pressure reduction turbine was not included in the Pleasant Bayou experiment.

The second form of energy is chemical energy, recovered by burning the methane in a gas engine. A gas turbine could be used instead with minor changes to the process. Two gas engines, each with fifty percent capacity, are used at Pleasant Bayou.

The final form of energy recovered is heat. The high temperature engine exhaust gas and the hot geothermal brine provide heat to a binary cycle.

Design power generation from the system without the pressure reduction turbine is:

HYBRID CYCLE FLOW DIAGRAM



Gas Engine	650 kW
Binary Cycle Turbine	540 kW
Parasitic Power	(210 kW)
Net Power	980 kW

DESIGN AND CONSTRUCTION

Beginning in 1984, The Ben Holt Co., under contract first to EPRI and later to DOE, completed the system design and procured equipment.

Much of the equipment for the binary cycle was furnished by DOE from the Direct Contact Heat Exchange (DCHX) test facility at East Mesa, California. Isobutane, used as the working fluid in the DCHX, was also selected for use in the hybrid experiment. Operating conditions were chosen to allow reuse of existing equipment with minimum modifications. Equipment from the DCHX facility was dismantled, refurbished, and shipped to Pleasant Bayou. New equipment, including three heat exchangers, firewater pump, gas-freeing compressor, electrical switchgear, and several instruments were purchased to complete the system.

During construction, the major problems encountered were with corrosion of equipment from the DCHX facility. All equipment was cleaned and put into operating condition during the construction period. The evaporative condensers were in the worst condition, with leaks occuring in approximately 12% of the tubes. Leaky tubes were sealed off to prevent the loss of isobutane during operation. Sealing off the tubes decreased the condenser surface area, but the range of operating conditions to be encountered at Pleasant Bayou allowed the objectives of this test program to be met anyway.

An area of concern for operation on a geopressured resource is corrosion of the tubes in shell-and-tube heat exchangers. Testing has shown that corrosion is most severe in areas of high turbulence. Therefore, ferrules were inserted into the inlets of heat exchanger tubes which have brine flowing through the tube side. These ferrules are in the area of highest turbulence and are exposed to the highest corrosion. By the time the brine leaves the ferrule, the velocity profile has smoothed out and corrosion should be reduced.

SYSTEM PERFORMANCE

System check-out was performed in September 1989, and the turbine and gas engines have been operational since October 26, 1989. As of February 28, 1990, the Geopressure Hybrid Power System has been on line over 2600 hours and exported nearly 1770 MW/hrs to Houston Lighting and Power. The plant has been reliable as have commercial binary cycle power plants.

Typical power generation from the system at design flows is:

Gas Engines	690 kW
Binary Cycle Turbine	535 kW
Parasitic Power	(270 kW)
Net Power	955 kW

The gas engines and turbine are meeting their predicted design performance. However, parastic loads are higher than predicted due to higher pumping power and higher incidental power loads.

Maximum net power is generated at maximum isobutane flowrate. The brine flow required to heat the isobutane has not changed over the life of the test. At 60°F, 3.8 kW are produced by the turbine for every 1000 lb/hr of brine circulated. This is greater than the design value of 3.2 kW per 1000 lb/hr of brine. The primary reason for this high performance is that the brine temperature at 290°F is 12°F higher than the design temperature of 278°F.

The table below compares system performance with and without the gas engines running.

	Engines Off	Engines On
Brine Flow (lb/hr)	139,000	159,000
Isobutane Flow (lb/hr)	118,900	118,900
Turbine Output (kW)	520	520
Gas Engines Output (kW)	680	0
Net Sale (kW)	920	305

A significant portion of the power is produced by the gas engines. Also, by using the energy available from the exhaust 15% more energy is produced per pound of brine.

COMPONENT PERFORMANCE

GAS ENGINES

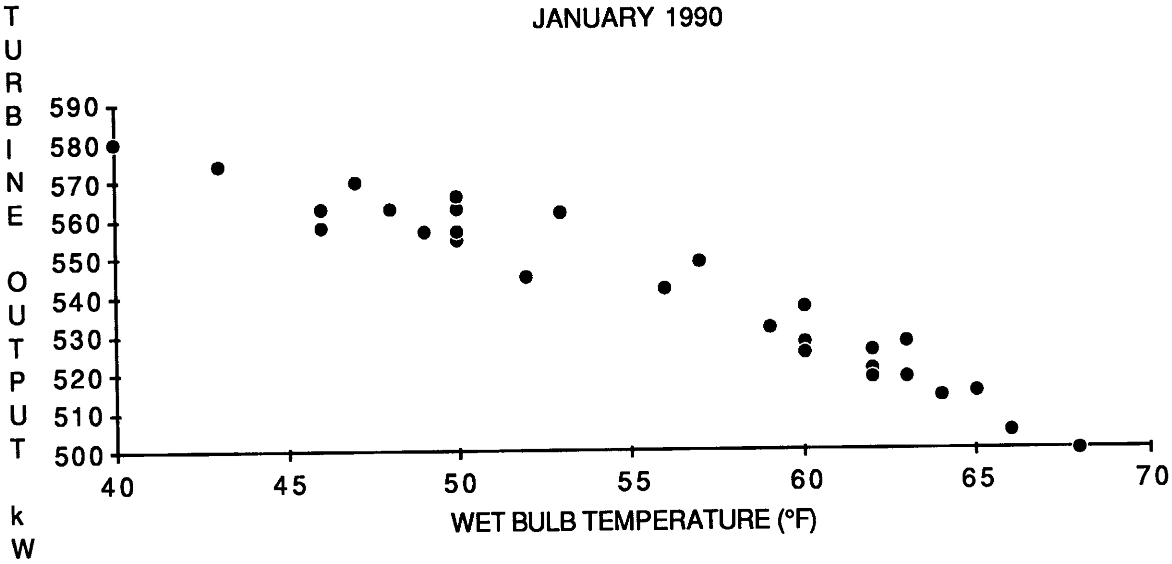
The engines have operated at their rated output over 2400 hours with only routine maintenance. Gas utilization has remained constant at the design value of 1.38 kW each per lb/hr of gas flow. Gas utilization is optimized at maximum gas flow. Gas utilization per engine decreases at lower gas input to that engine. There have been no operational difficulties associated with operating on impure wellhead gas.

TURBINE

A major source of problems during operation of the DCHX test facility was the turbine. In an attempt to avoid similar problems in the geopressured program, a finite element analysis was made of the turbine rotor. Results of this analysis showed that the existing rotor may be overstressed and would be operating close to critical frequencies. As a result, a new rotor was designed and fabricated for operation in the existing housing. A finite element analysis of the design showed the new rotor to be well designed with respect to strength and critical frequencies. Over 1300 hours of successful turbine operation validated the new rotor design.

Late in February, during a roll-down after an electrical outage the turbine seal overheated due to a loss of seal oil. An automatic monitoring system had been installed as part of the Pleasant Bayou test facility. This system shut down the turbine and prevented serious damage to the turbine seal, bearing and rotor. The

FIGURE 2
GEOPRESSURED HYBRID POWER SYSTEM
TURBINE-GENERATOR OUTPUT VERSUS WET BULB TEMPERATURE
JANUARY 1990



automatic high vibration shutdown of the turbine was the only indication of the overheated seal.

Turbine output varies with wet bulb temperature as shown in Figure 2. At the design back pressure of 55 psig, the design output of 540 kW is produced by the turbine. Since an evaporative condenser is used in this system, the isobutane condensing temperature and consequently the turbine back pressure are set by the wet bulb temperature.

HEAT EXCHANGERS

Geopressured resource utilization requires that problems due to corrosion and scaling be overcome. The brine has approximately 130,000 ppm of total dissolved solids and has shown severe scaling tendencies when untreated. In addition, carbon steel in untreated brine has been corroded at rates as high as one inch per year. Eaton Operating Company and the Institute of Gas Technology worked together to come up with a combination of scale and corrosion inhibitors which was successful at production temperatures with heavy-walled carbon steel pipe. This combination also appears to be effective at preventing scaling and corrosion at lower brine temperatures in thin-walled carbon steel heat exchangers.

Heat transfer coefficients have been closely tracked to monitor scaling. Isobutane is heated to its bubble point in a brine-to-isobutane heat exchanger. This is a shell-and-tube exchanger with single tube and shell passes with true counter current flow. 90% of the isobutane is vaporized in the brine-to-isobutane boiler. This heat exchanger is a reboiler with isobutane on the shell side and brine on the tube side. Exhaust gas from the gas engines is used to vaporize the remaining portion of isobutane.

No appreciable fouling with time has been noted in either of the brine to isobutane exchangers. At design flow, the overall heat transfer coefficient is consistently slightly better than design.

The exhaust gas-to-isobutane boiler has shown consistently lower overall heat transfer than expected. Visual inspection during a shutdown showed significant fouling. Cleaning this exchanger lowered the calculated fouling resistance from 0.025 hr-sq ft-^{o}F/Btu down to 0.003 hr-sq ft-^{o}F/Btu. The primary cause of fouling is thought to be thick soot created by backfiring of the gas engines during start-up. Additional operating data is required to determine if overall heat transfer will again degrade.

CONCLUSIONS AND RECOMMENDATIONS

The geopressured hybrid power system at Pleasant Bayou has demonstrated the viability of the hybrid concept for electricity generation from a geopressured resource. The turbine has operated over 1300 hours and has met its specified design performance. The gas engines have operated over 2400 hours and have met their specified design performance. No evidence of scaling or corrosion problems were found in the brine exchangers. Additional operation is recommended to characterize the performance of the exhaust gas-to-isobutane exchanger. No difficulties were related to operation on a geopressured resource. The success of this program indicates that commercial utilization of geopressured resources is attainable.