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WELLHEAD POWER PLANTS AND OPERATING EXPERIENCE AT WENDEL HOT SPRINGS

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ABSTRACT

Modular wellhead power plants, based on the organic Rankine cycle, have proven reliability with high utilization of the available resource. The power cycle is adaptable to water or steam temperatures of 180°F to 350°F. The power plant working fluid is a halogenated hydrocarbon refrigerant that is selected to provide high overall performance. The working fluid is nontoxic and nonflammable. These features reduce system cost and provide safer operation. Each power plant consists of one module which contains all of the heat exchangers, power turbine, alternator and controls. The power plant can generate from 300 kW to over 1000 kW. The larger size plants utilize additional heat rejection modules. Multiple plants can be located at the wellhead, producing several megawatts. These plants can be on line in approximately six months from project initiation. Operating experience at the Wineagle Power Project, located at Wendel Hot Springs, has demonstrated a plant availability greater than 95% since commencing commercial operation in September of 1985. Module performance features and operating experience are discussed in the paper.

PRINCIPLE OF OPERATION

The wellhead power plant is referred to as a "Power Generation Module" or PGM. The principle of operation is described as follows:

Water is used for the working fluid in large utility power plants. The low molecular weight of water requires multi-stage turbines to obtain high efficiency. For Rankine engines with heat source temperatures below 800°F, organic fluids with molecular weights greater than that of water can provide high cycle efficiency and result in simpler and less costly expanders. The working fluid used in the PGM is a halocarbon-type refrigerant that is nontoxic, nonflammable and readily available.

The main components of the PGM are shown in the schematic of Figure 1. It consists of heat exchangers (the preheater/evaporator) which transfers energy from a heat source (such as geothermal hot water or steam) to the working fluid. The heat supplied is sufficient to completely vaporize the working fluid which is at a relative high pressure. The vaporized working fluid is expanded through a turbine where shaft power is produced to drive a generator. The working fluid then flows to the condenser where heat is rejected to a heat sink (such as the evaporation of water or ambient air) and the working fluid is condensed. The liquid working fluid is pumped from the condenser back to the preheater/evaporator, thus completing the cycle. The PGM also contains a control system for automatic and unattended startup and operation of the PGM. The major components, including controls, are all assembled into one module and then shipped to the site for installation. This approach maximizes the factory work done under well-equipped conditions and minimizes expensive field work. The PGM is tailored to match the resource temperatures and flows in order to provide the maximum utilization of that resource.

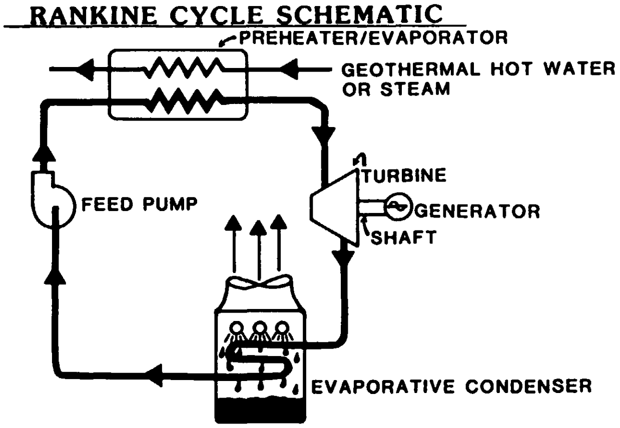

FIGURE 1

POWER POTENTIAL

The generating potential of a geothermal resource for various geothermal hot water temperatures and flow rates is shown in Figure 2. Knowing the geothermal water temperature and flowrate, one can use this figure to estimate the potential power output. As an example, assume a geothermal resource has a liquid temperature of 250°F and flows at 300 gpm. From Figure 2, the resource could generate 330 kW of electrical power. It should be noted that the power output in this figure is net output power, i.e., the PGM parasitic loads such as the condenser and feed pump power have been accounted for; geothermal pump requirements, if any, have not been accounted for. Single PGM's can handle flow rates up to 1000 gpm. Multiple PGM units can accommodate greater flow rates and produce proportionately larger output powers. The output power from two-phase water-steam or steam alone is much greater than the curves shown for liquid. Temperatures above 350°F can also be accommodated with high efficiencies by making minor modifications to the PGM.

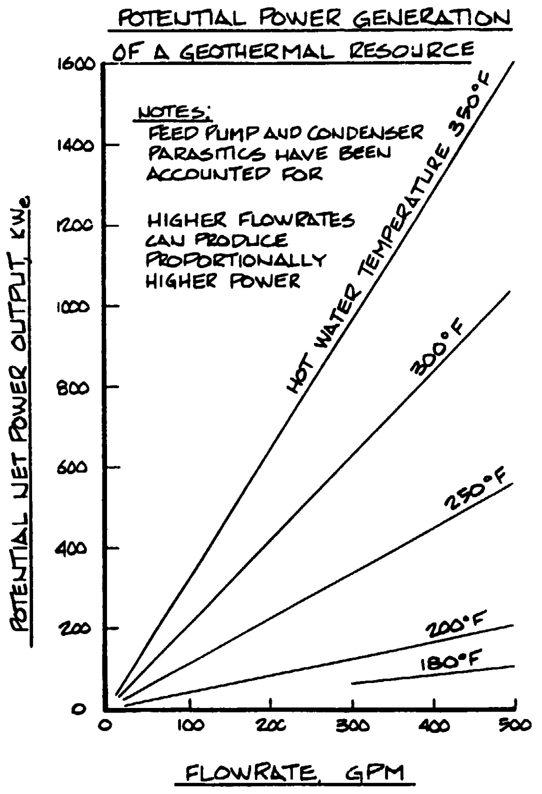

FIGURE 2

COMPONENT DESCRIPTION

The preheater and evaporator are tube-and-shell heat exchangers incorporating heavy walled tubing for long life. The geofluid is on the tube side to facilitate cleaning.

Heat is rejected from the PGM's by an evaporative condenser. The evaporative condenser combines, into one unit, the functions of a cooling tower and a separate condenser. The condensing takes place inside a tube bundle. Water is sprayed over the exterior of the tubes, and air blowing through the tube bundle evaporates the water required for cooling. The evaporative condenser requires less total power than a separate cooling tower and a tube-and-shell condenser. The water flow rate in the evaporative condenser is much less than required for a tube-and-shell condenser supplied by a cooling tower or cooling pond and large water pumps with their high power usage are not needed. This approach improves the efficiency of the PGM and it is less costly in most cases.

The rotating machinery includes the turbine, generator and the feed pump. The turbine is a high efficiency, single stage design, direct-coupled to the 3600 rpm generator. This eliminates the requirement for a speed-reducing gearbox. The turbine blading and nozzle design is based on the results of aerospace research program. The blading uses a highly refined contour and a manufacturing process that provides extremely good surface finishes. Turbine efficiencies of 80% in a single stage have been achieved. The feed pump is mechanically driven by the turbine output shaft.

This approach eliminates the number of energy conversions and improves overall efficiency. The feed pump drive is designed to provide high efficiency and low maintenance.

The PGM can be supplied with either an induction or synchronous generator which is directly connected to the turbine by a drive shaft. Standard electrical output is 480 volt, 3-phase, 60 Hertz. Induction generators are usually provided because of their ease in synchronizing to the line.

CONTROLS

The PGM controls provide for automatic system startup and operation. The PGM operation is self-monitored and, in the event that selected operating parameters are out of limits, the modules will automatically shut down. Automatic telephone notification of a problem to an operator is provided. A full-time operating staff is not required. When the condition that caused a shutdown is cleared, the unit will automatically restart and properly reconnect to the power line.

PGM PACKAGE

The rotating equipment, controls, preheater and evaporator are packaged in a structural steel frame. The structure also supports the evaporative condensers which are located above the other equipment. The structure is enclosed within a lockable, weatherproof, metal enclosure to provide environment protection and security. The module size is approximately 40 feet long, 23 feet high and 10 feet wide, and is arranged as shown in Figure 3.

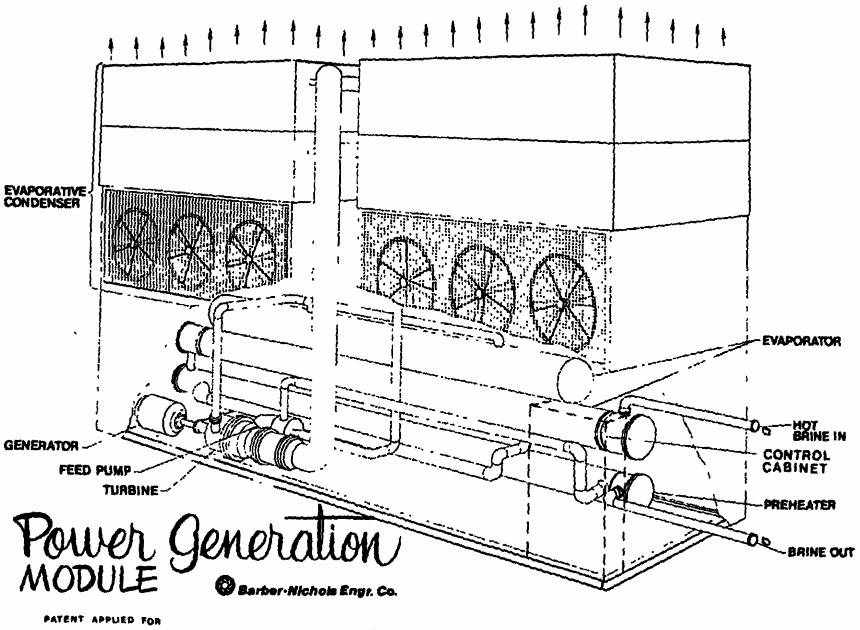

FIGURE 3

OPERATING EXPERIENCE

The Wineagle Power Project is located at Wendel Hot Springs, approximately 24 miles east of Susanville, California. The plant consists of one well producing 800 gpm of hot water at 228°F and two binary power modules (PGM's) producing a nominal 600 kWe net after all plant parasitics. The PGM's generate power at 480 volts which is then transformed to 34.5 kV and delivered to PG&E via C. P. National's transmission line. The well is produced by means of a line shaft downhole pump. The pump is driven by a 50 hp motor powered by the output from the PGM's. The PGM's were designed, built and installed by Barber-Nichols Engineering Company. The module installation was completed in the summer of 1985 and commercial operation commenced on September 21, 1985. Between September 21, 1985 and January 31, 1986, the PGM's operated 3007 hours out of a possible 3141 hours or 95.7% of the time. The project has been very successful and plans are underway to drill additional wells and add more PGM's in the near future.

The plant is completely automated. The entire plant, including the well pump, is controlled by either PGM. By pushing one button on the PGM control panel, the plant will start, synchronize to the power line and continue operation. If the power line goes "down", the PGM's and the downhole pump immediately shut down, since no power is available for its operation. When the power line is re-energized, the PGM's restart the downhole pump, then bring themselves on line.

Other operating parameters can cause either PGM to shut down, and after the fault has cleared, the PGM will restart. The control logic and switching functions are accomplished by a solid-state micro processor. The program can be easily modified on location or set up to be reprogrammed via telephone from Barber-Nichols offices in Denver. If the PGM's shut themselves down and are unable to restart within a reasonable time, a telephone dialer calls a predetermined contact and notifies that person the modules are down and require additional attention.

The PGM control panel is shown in Figure 4. The top portion of the panel contains an annunciator light group. When the PGM shuts down, one or more lights turn on indicating the reason for the shutdown. The faults may be in the power line or within the module itself.

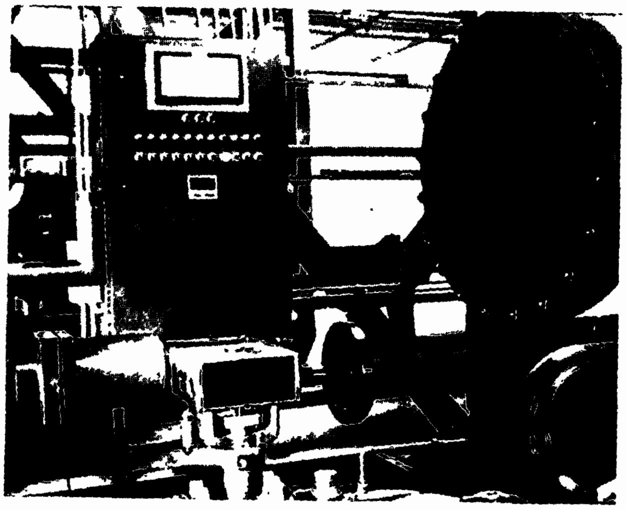

FIGURE 4

FIGURE 5

The two Wineagle Power Plant PGM's are shown in Figure 5. The electrical power distribution cabinet and the transformer also appear in this photo. The electrical power distribution cabinet receives power from each PGM and also supplies power to the downhole pump. A motor starter at the well receives a signal from either PGM that causes the pump to operate. Output power from the distribution cabinet passes through the transformer to the power grid. Power metering by PG&E is on the power side of the transformer.

The Wineagle well is approximately 400 feet from the PGM's. The hot water is transferred by an 8" pipe, which is covered by dry earth for protection and insulation. A view of the power plant from the well is shown in Figure 6.

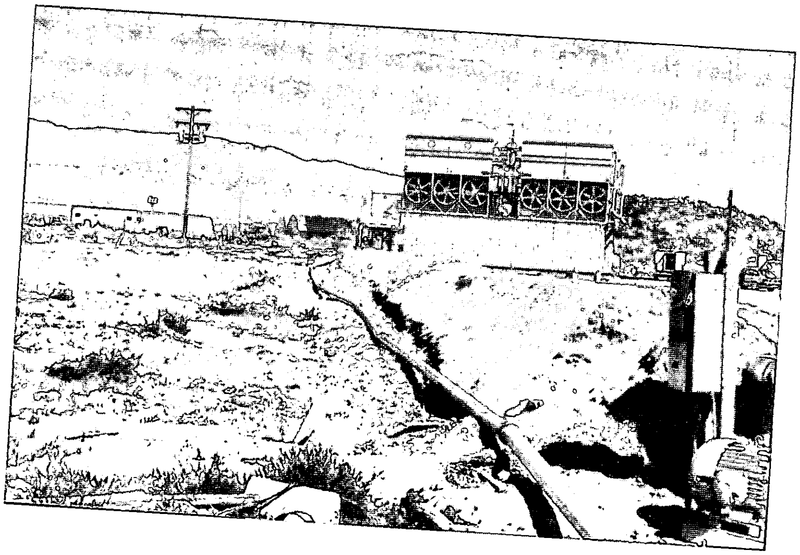

FIGURE 6

PLANT INSTALLATION AND STARTUP

Installation of the PGM's takes about 3-4 weeks. Site preparation prior to arrival of the PGM need be only a satisfactory road base for the trucks and cranes, and a concrete pad to support the PGM. Figures 7 and 8 show the PGM's being placed on the concrete pads at the Wineagle site and the condenser assembly being placed on top of the frames. Metal siding is then added to the frame enclosing the turbine, generator, controls and heat exchangers providing protection for these components. After installation of the power modules and completion of the geothermal fluid piping, makeup water supply and electrical lines to the modules, the system is ready for startup. This process, including debugging of the total system and training of local personnel, will take 2-4 weeks. Due to the fully automated control system, full-time operators are not required. Personnel from the adjacent greenhouse complex are utilized to provide a once-a-day, 20-minute walk-around inspection to ensure that everything is functioning normally.

The startup of the Wineagle plant took about eight weeks since this was the first installation of units of this design. The downhole pump was not delivered for the first six weeks of this eight-week period so we could not run the units with the proper geothermal flow. The shakedown problems encountered were associated with the working fluid feed pump seals and bearings, and several pressure and level switches used in the control logic. The problems with the switches were corrected by changing the type of switch used or changing the location of the switch in the system. The feed pump problems were solved by incorporating our own bearing and seal design. The feed pumps have accumulated over 12,000 hours of operation since these modifications were made.

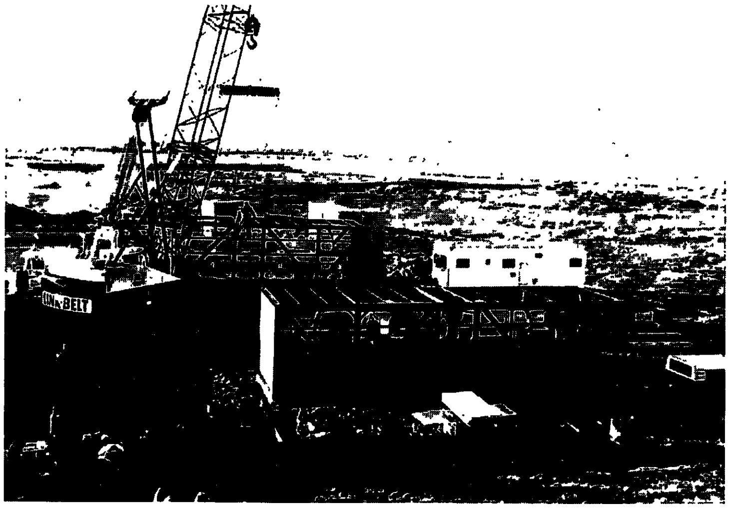

FIGURE 7

FIGURE 8

FIELD PERFORMANCE

The downhole pump was installed and became operational on August 15, 1985. The power modules operated approximately 70% of the available time from August 15 to September 21 when they commenced full-time commercial operation. Table I shows the operating time and the time available that the modules could operate on a monthly basis from September 21, 1985 to March 31, 1986. The ratio of actual PGM operating hours to maximum hours the unit could run is called the plant "availability". The availability is averaging above 95%. We feel this is very good considering the limited time the plant has been in operation. Plant capacity factor is defined as the ratio of total kW-hr of electrical energy delivered to the anticipated kW-hr over a specified time period. The plant capacity factor for this same period has averaged 109%.

The lower availability that occurred during October reflects problems encountered when the ambient temperatures fell below freezing. The problem was freeze up of the air lines that supply control air to the evaporator level controller. The problem was identified and corrected by heat tracing the air lines. Problems occurred with the feed pumps in both units during March. The pump shaft failed in Unit No. 1 and the shaft bearing wore out in Unit No. 2. The feed pumps have been retrofitted with a new Barber-Nichols design shaft and bearings.

TABLE I

POWER PLANT AVAILABILITY

TIME PERIOD	MODULE HOURS (2 MODULES)	POWER GRID HOURS	*POWER PLANT AVAILABILITY*
9/21/85 10/1/85	469.6	239	98.2%
10/1/85 11/1/85	1345.5	733	91.8%
11/1/85 12/1/85	1344.2	717	93.7%
12/1/85 1/1/86	1460.4	739	98.8%
1/1/86 1/31/86	1394.7	713	97.9%
1/31/86 2/28/86	1260	1340	94%
2/28/86 3/31/86	1054	1368	77%
3/31/86 4/15/86	716	719	99.6%

ACKNOWLEDGEMENT

The power plant is owned by Wineagle Developers, a Limited Partnership. Carson Development of Sacramento, CA is General Partner. The Wineagle Power Project is successful and plans are underway to drill additional wells and add PGM's to increase the plant capacity.