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Advanced power plants for use with HDR/enhanced geothermal technology

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ABSTRACT

The issues inhibiting, the future commercialization of the Hot Dry Rock (HDR) or Enhanced Geothermal System (EGS) technologies are both technical and economic. The costs of drilling wells and the pumping and supply of water are still the major cost barriers to commercializing HDIUEGS technologies. Since drilling costs are related both to the geological formations and to well depth, power plants, which can effectively use lower temperature fluids from shallower wells can reduce power production costs. In addition power plants which do not consume any water, regardless of fluid temperatures, and which are insensitive to water chemistry, are desirable for HDR/EGS applications. **ORMAT's** Organic Rankine Cycle (ORC) binary based technology allows for the effective utilization of air cooled condensers with EGS produced fluid temperatures from 100°C to 315°C. The basic binary cycle system operates with the produced fluid continuously under high pressure and in contact only with the power plant piping and the heat exchanger tubes. Thus there is no loss of water circulating in the EGS system, no corrosion and no scaling of the plant or well bore. The use of modular power units allows for increasing the plant size as more EGS fluid production is developed. This presentation describes tbe binary and steam/binary geothermal combined cycle systems, and presents case histones of operating plants successfully employing these technologies.

KEYWORDS

Hot Dry Rock, enhanced geothermal system, geothermal energy, binary-cycle, combined-cycle

Introduction

The issues driving, or inhibiting, the future commercialization of the Hot Dry Rock (HDR) or Enhanced Geothermal System (EGS) technologies are both technical and economic. The costs of drilling injection and production wells and the pumping and supply of water are the major cost barriers to commercializing HDIUEGS. Since drilling costs are related both to the geological formations and to well depth, power plants, which can effectively use lower temperature fluids from shallower wells reduce power costs. In addition power plants which do not consume any water, regardless of fluid temperatures, and which are insensitive to water chemistry, are desirable for HDREGS applications, since even the loss of 5 to 10% of the water injected into the geological structure of an HDR system imposes a serious requirement for make up water. This presentation will describe the field proven advanced technology power plants which optimize effectiveness of an HDREGS system over the widest range of fluid temperatures and characteristics.

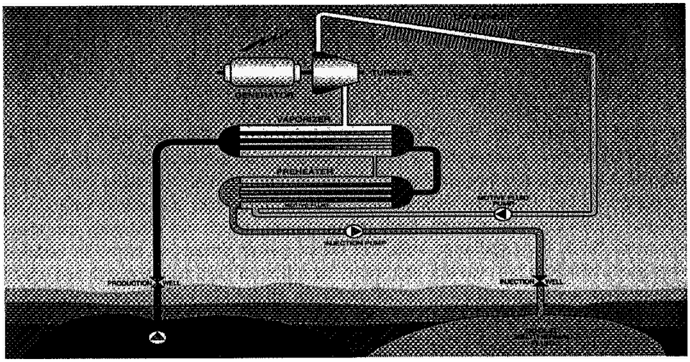

Figure 1: Process diagram: air cooled binary geothermalpower plant.

ORMAT's Organic Rankine Cycle as incorporated into its ORMAT Energy Converter or OEC binary based technology allows for the effective utilization of air cooled condensers in power plant applications with geothermal fluid temperatures to 315°C. The basic OEC geothermal air cooled binary power plant cycle is shown schematically in figure 1. In this cycle the geothermal fluid heats the organic motive fluid in the vaporizer, which is a tube and shell heat exchanger with the geothermal fluid flowing in the tubes and the motive fluid in the shell side. The vaporized motive fluid, typically iso-pentane, drives a specially designed slow speed turbine, which is direct coupled to the generator. Grid compatible power is generated and fed to the plant sub-station. The spent motive fluid vapors leave the turbine at a positive pressure above one bara, are condensed in the finned tube air cooled condenser and pumped hack into the vaporizer to repeat the cycle. No EGS produced geothermal fluid is consumed or lost and 100% of the fluid is injected.

Modular binary power plants

The basic binary cycle is most effective when used with geothermal (or EGS fluids) below 175°C. For EGS or HDR applications the binary system operates with the produced fluid continuously under high pressure and in contact only with the power plant piping and the heat exchanger tubes. Thus there is no loss of water circulating in the EGS system, no corrosion and no scaling of the plant or well bore. The use of modular OEC power units allows for increasing the plant size as more EGS fluid is produced. For EGS systems where the geological structure can produce fluids at the surface at temperatures above 175°C, it is usually more effective to flash a portion of the produced fluid into steam and use geothermal combined cycle technology.

Geothermal combined cycle power plants

The ORMAT geothermal combined cycle power technology can accommodate lower pressure flashed steam, at pressures as low as 1.2 bara, as well as higher pressure steam, at pressures up to 100 bara. For lower pressure steam, depending on the steam wetness and characteristics, the two phase binary cycle, as shown in figure 2, may be employed.

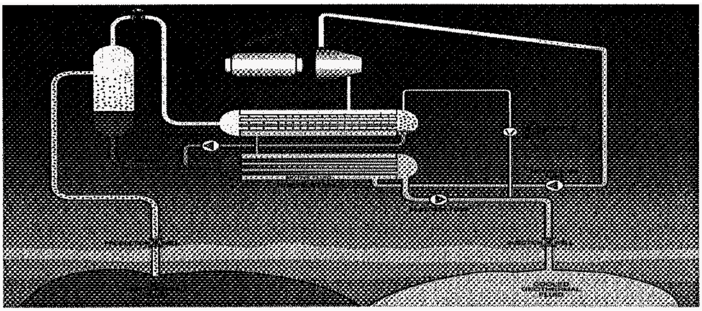

Figure 2: Process diagram: two-phase binary geothermal power plant.

In the two-phase binary system the low pressure steam from the flash tank is condensed in the vaporizer of the binary system, and the hot brine is used to preheat the organic motive fluid. As in the basic binary system the motive fluid vapors drive the slow speed turbine, and are subsequently condensed in the air cooled condenser. The use of air cooled condensers with organic motive fluid vapors is more effective than with steam under vacuum, as in condensing steam turbines, because the organic vapors under positive pressure have a much smaller volume than the low pressure steam during the condensing cycle. As a result the piping and heat transfer surfaces for the organic vapors are much smaller than would be required for air cooled steam condensers.

Benefits of modular binary based technology

The Ormat modular binary and steam/binary combined cycle power plants are thus designed to optimize EGS/HDR power system performance as follows:

- geothermal fluid temperatures between 100°C and 315°C may be efficiently utilized;
- corrosive steam or geothermal fluids only come in contact with internal piping and heat exchanger tube surfaces, which may be of titanium or other special metals;
- corrosion and scaling are all but eliminated;
- by the use of air-cooled condensers and closed loop systems, no **EDS** produced water is consumed by the plant and 100% injection of all geothermal fluids is possible;
- the power plant may be matched to the resource to effectively optimize the initial resource condition, and allow **for** future changes in the water produced by the EGS;
- the overall project achieves a minimal environmental impact with near zero operating emissions, and a low visual profile;
- the power plant may be expanded as more EGS fluids are produced.

Case histories of power plants suitable for EGS/HDR use

Binary power plants

NAGQU GEOTHERMAL POWER PLANT, TIBET, PRC

The Nagqu geothermal power plant, located approximately 200 kilometers north **of** Lhasa, Tibet, is the highest geothermal plant in the world at 4,500 meters ASL. This plant is the only completely stand alone, off grid geothermal power project. The project, funded by the UNDP, is owned and operated by the Nagqu Power Bureau. It includes two production wells and one 1.3 MW air cooled OEC modular binary power plant, installed and commissioned in 1993 (figure 3). The wells *are* pumped and produce 4,200 liters **per** minute of geothermal fluid at 110°C.

The plant initially operated for 6,400 hours and was shut down following failures of the down-hole pumps. A cable failure occurred after 15 days and a pump seal failed after 7 months of operation. The wells were temporarily operated without the pumps and the subsequent severe scaling resulted in the plant being shut down.

The down bole pumps were subsequently replaced and the plant was re-commissioned in August 1998. It is currently operating properly.

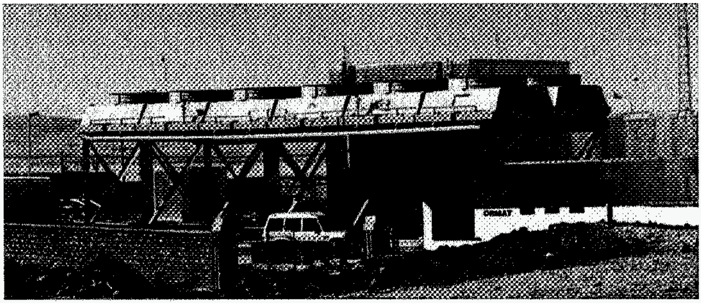

Figure 3: Nagqu 1.3 MW air cooled binary geothermal plant

BAY OF PLENTY GEOTHERMAL POWER PLANTS, KAWERAU, NEW ZEALAND

The Bay of Plenty Electric Power Board, services a wide variety of domestic, farming, commercial and industrial installations, including some of New Zealand's major paper, timber and dairy product manufacturers. This area encompasses the Kawerau geothennal field, with a total tested capacity of 200MW$_e$, and 31 drilled wells, with a maximum depth of 1611 meters and a maximum bottom hole temperature of 310°C.

The New Zealand Ministry of Energy sells geothermal process steam to Tasman Pulp and Paper. The process was surface discharging the separated brine at 174°C, both as steam into the atmosphere and brine into the Tarawera River. Bay of Plenty Electric obtained the rights to the spent geothermal fluid and installed two 1.3 MW air cooled modular binary OEC units in 1989 and one 3.8 MW air cooled modular binary OEC in 1993, for a total of 6.4 MW capacity. The figure 4 shows a photograph of the 3.8 MW unit.

These OEC units utilize the 174°C brine, cooling it to 110°C, in the first two 1.3 MW units, and to 80°C in the 3.5 MW unit. The total electricity generated from a total flow of some 550 tons/hr of geothermal fluid, is 7.1 MW. The benefits from this project are as follows:

- the projects provide the local electricity supplier, Bay of Plenty Electric, with an otherwise wasted, reliable, clean natural resource for generating electricity for the local communities;
- the OEC modular binary power plants have proven to be very cost effective. They were installed in less than 15 months from purchase awards and are operated efficiently;
- the air-cooled plants, which have near zero environmental impact, have also solved the environmental problem of the surface discharge of potentially hazardous geothermal brine.

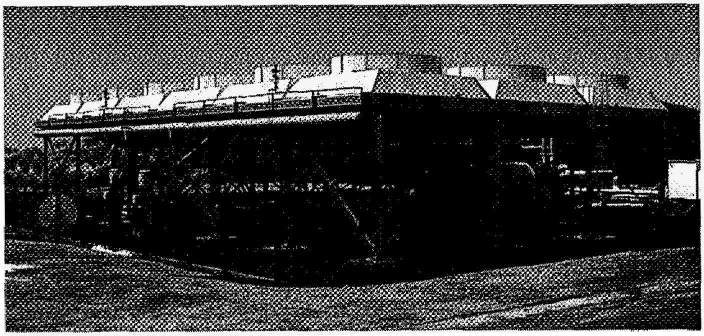

Figure 4: Kawerau 3.8 MW air cooled binary geothermal plant.

At this time, and after nearly 10 years of continuous operation the Kawerau Geothermal Power Plants are operating at over 98% availability, with the Bay of Plenty Electric estimating its operations and maintenance expenses as not exceeding US$0.02/kWh.

Two phase steam/binary combined cycle

SAO MIGUEL, GEOTHERMAL POWER PLANT, AZORES, PORTUGAL

The privately owned Sao Miguel power plant, consisting of two dual air cooled OEC modules, commissioned in 1994, and two dual modules commissioned in late 1998, generates 14 MW which is sold to Electricity of the Azores, Ltd. This project utilizes free flowing production wells providing 128 t/h of 5.1 bara steam and 412 t/h of 153°C geothermal fluid.

The two phase flow is used in a modular binary system, which also makes **use** of the steam condensate to dilute the injected brine so as to lower the injection temperature and thus extract more heat ftom the produced geothermal fluids.

The frst phase plant operated continuously, producing a significant portion of the Island of Sao Miguel's base load power, with an availability factor of 98%. Air cooling and 100% injection of all geothermal fluids and gases has resulted in a very low (near zero) environmental impact. With the development of additional production wells the construction of the second 9 MW phase, bringing the total generation capacity to 14 MW, was completed in late 1998 (figure 5).

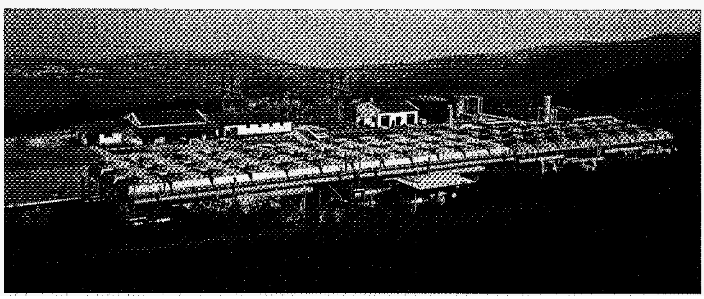

Figure 5: Sao Miguel 14 MW air cooled binary two phase geothermal plant.

Integrated geothermal combined cycle

ROTOKOWA GEOTHERMAL POWER PLANT, ROTOKAWA, NEW ZEALAND

The Rotokawa Geothermal Power Plant has been erected on land owned by the Tanhara North No. 2 Mauri Trust. The power plant, which is owned by Rotokawa Generation Ltd., a Join Venture between Power New Zealand (the second largest utility in New Zealand) and a Mauri Trust corporation, is an integrated geothermal combined cycle plant comprised of one 25 MW (gross) Ormat Combined Cycle Unit (OCCU) and one 5 MW binary OEC Module, for a total 30 MW installed capacity. The power plant was constructed and commissioned in 1997, and utilizes 2 production and 3 reinjection wells (figure 6).

The air cooled combined cycle unit (OCCU) utilizes 304 t/h of steam at an inlet pressure of 23.2 bara with the steam from the Level I back pressure turbine exiting at 1.3 bara. The net power produced by the OCCU is 23.5 MW. The OEC modular binary unit utilizes 304 t/h of 219°C brine, with a high content of corrosive and hostile constituents resulting in an exit temperature of 150°C, to generate approximately an additional 4 MW.

The use of the air cooled Integrated Geothermal Combined Cycle technology has resulted in a power plant which consumes no geothermal fluid or other water, makes efficient use of a high temperature resource, with virtually no environmental impact and with the ability to accommodate changes in the resource characteristics, which are anticipated in the fnture.

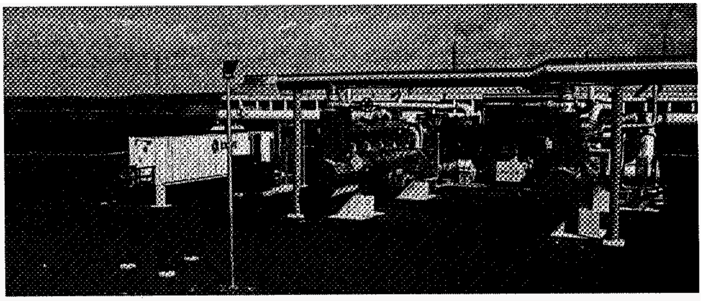

Figure 6: Rotokawa 27 MW air cooled integrated geothermal combined cycle plant.

Conclusions

The use of field proven binary based advanced power cycles has particular advantages for the future commercialization of EGS/HDR technology. The case histones have demonstrated that:

- a wide range of geothermal fluid temperatures, from 100°C upwards may be efficiently utilized;
- corrosive steam or geothermal fluids may be utilized, since they only come in contact with internal piping and heat exchanger tube surfaces;
- by the use of air-cooled condensers and closed loop systems, no **EDS** produced water is consumed by the plant and 100% injection of all geothermal fluids is possible;
- the power plant may be matched to the resource to effectively optimize the initial resource condition, and allow for future changes in the water produced by the **EGS;**
- the overall project achieves a minimal environmental impact with near zero operating emissions, and a low visual profile;
- the power plant may be expanded **as** more **EGS** fluids are produced