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IMPROVING GEOTHERMAL POWER PLANT PERFORMANCE WITH TOPPING AND BOTTOMING CYCLES, CASE HISTORIES IN ICELAND, NEW ZEALAND AND THE PHILIPPINES

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1. ABSTRACT

In many cases, additional generating capacity may be obtained in a cost effective manner by re-powering existing geothermal power plants utilizing otherwise-untapped geothermal energy, without drilling additional wells. Often this repowering also provides concommittant environmental benefits. This presentation examines several repowering applications, including the 9.1MW exhaust steam recovery binary power plant at Svartsengi in Iceland, the 6.4 MW brine recovery binary power plant at Kawerau in New Zealand and the Leyte geothermal power plant optimization project. The four (4) Leyte optimization plants added a total of 64 MW of geothermal power and improved environmental and power plant operating conditions, without any additional well field costs. With geothermal power plant owners and operators concerned with costs and competition, increasing plant output by re-powering is a highly desirable and cost effective option.

2. INTRODUCTION

Unlike fossil fuels, which are delivered to a power plant at a per-unit price, geothermal energy fuels the power plant for the life of the project at a high up-front cost. Therefore for cost effective power generation, the extraction of heat from geothermal fluids must be maximized. The growing sustainability demand, along with competitive pressures continues to increase the incentives for optimizing existing facilities. Re-powering is thus viewed favorably by plant owners, the public and governmental agencies, since it conserves energy while reducing environmentally hazardous waste. Geothermal energy, by the nature of the power plant technologies commonly employed, offers unique pportunities for re-powering. Specifically the use of the following power plant technologies usually results in untapped energy which may be recovered by topping or bottoming cycles.

2.1 Non Condensing Geothermal Steam Turbines

Non-condensing geothermal steam turbines often release exhaust steam into the atmosphere at temperatures above 100^{o}C. This wastes heat energy and has a serious negative environmental impact.

2.2 Geothermal Brine

The steam flow from steam/brine separators is usually 10 to 30 percent of the total flow, resulting in large amounts of brine injected into the reservoir or surface discharged. This brine, at temperatures of 110 to 180^{o}C, contains a significant percentage of untapped or otherwise wasted energy.

2.3 Excess Steam Inlet Pressure

The condensing steam turbines in wide use are usually designed for inlet pressures below 8 Bara. Geothermal steam is often at much higher pressures and must be reduced in pressure to the required turbine inlet conditions. Condensing steam turbines usually have a specified capacity, and where the well field produces more steam than required, this excess steam represents an untapped source of energy.

3. CASE HISTORIES

ORMAT® Energy Converter (OEC) modular units are specifically designed to match the resource conditions. OEC units may be located near the heat source, away from the space constraints of the main plants. Since the OECs are designed for automatic operation and remote monitoring, they may be operated either as part of the main plant or as free standing power plant units.

These case histories, which include projects of different sizes and ownership structure, have been selected to illustrate the technical, economic and environmental benefits of re-powering existing geothermal power plants, as well as the applications of topping and bottoming cycles.

3.1 The Svartsengi Geothermal Project, Reykjanes Peninsula, Iceland

The Svartsengi Geothermal Power Plant is owned and operated by the Sudurnes Regional Heating Corporation (Sudurnes), which supplies geothermal heat and electricity to the Reykjanes Peninsula in southwestern Iceland. The geothermal system at Svartsengi is a water-dominated reservoir with a steam cushion at the top. Shallow wells have produced dry steam from a boiling zone in the eastern most part of the drilled area. Deeper wells in the west have produced geothermal fluids with temperatures over 290^{o}C. The original power plants built in 1978 and 1980 utilized three backpressure steam turbines to generate 8 MW; some of the power was provided to the local grid. Some of the exhaust steam from these turbines was used to heat water for district heating, while some of it was discharged into the atmosphere.

Sudurnes installed three 1.3 MW water-cooled OEC binary modules, generating 3.6 MW, in 1989, as the first re-powering phase. These OECs use steam turbine exhaust as the heat source. In 1993 four more 1.3 MW air cooled OEC binary modules, generating 4.8 MW were added, bringing the total OEC capacity to 9.1 MW and the total power station production capacity to 16.4 MW. The re-powered plant is operated with essentially the same staff since the new equipment was integrated into the existing facility. Shown in Figures 1 and 2 are the process diagram and a photograph of the first re-powering phase. (Elovic, 1992)

After 10 years of continuous operation the OEC units are operating at over 97% availability, and this project has the following major benefits:

- The waste steam is utilized to produce an additional 8.4 MW of power, more than doubling the installed power of the Sudernes power plant from 8 to 16.4 MW.
- The re-powering was implemented in two steps, thus reducing investment risk.
- The overall thermal efficiency of the plant, including the use of geothermal energy for both district heating and electricity generation, has been increased.
- The availability factor of the plant has been increased, and the power costs have decreased.
- Environmental damage, caused by acid rain from the exhaust steam droplets spreading over a wide area, has been eliminated.
- The non-condensable gases in the steam are now collected in one pipe as the steam is condensed in the OEC. These gases, mostly CO_2, were previously a source of corrosion and are now available for beneficial industrial use in making dry ice and liquid CO_2.
- The cooling water from fresh water wells, at 4°C is pre-heated in the process to 22°C, heated to 100°C and pumped as district heating water to the communities on the Reykjanes Peninsula.

3.2 Bay of Plenty, Geothermal Power Plants, Kawerau, North Island, 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 manufacturers. This area encompasses the Kawerau geothermal field, which is one of the most explored and proven geothermal fields in the world. With a total tested capacity of 200 MW_e, the Kewarau field has 31 drilled wells, with a maximum depth of 1611 meters and a maximum bottom hole temperature of 310°C.

Since the early 1960s, the New Zealand Ministry of Energy through its Gas and Geothermal Trading unit was selling 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 this partially spent geothermal fluid and in two phases 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 of installed capacity. Figures 3 and 4 are the process diagram of the first re-powering phase and a photograph of the second phase power plant 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 technical, economic and environmental 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 operate efficiently and have proven to be very cost effective. They were installed in less than 15 months from purchase awards.
- 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.

After nearly 10 years of continuous operation of the first installation, the OEC Kawerau Geothermal Power Plants are operating at over 98% availability. the Bay of Plenty Electric estimates its operations and maintenance expenses as less than US$0.02/kWh.

3.3 The Leyte Geothermal Optimization Project, The Philippines

In March 1995, the Philippine National Oil Company – Energy Development Corp. (PNOC-EDC), solicited competitive proposals for converting otherwise untapped geothermal energy into electricity at four (4) major operating geothermal projects on Leyte. ORMAT won the 50 MW Leyte Geothermal Optimization Project award, which has the form of a ten-year energy conversion agreement between ORMAT and PNOC-EDC. The project was awarded in July 1995 and financing was closed only 10 months later. Project equity was provided by ORMAT and long term debt was obtained from U.S.Ex-Im Bank. EPC turnkey construction activities started shortly thereafter. (Hennagir, 1997)

PNOC-EDC, as owner, made the decision to use the otherwise untapped geothermal energy produced by existing capitalized facilities. This modification generated 49 MW, *adding almost 10%* in cost effective power. The Project consists of 4 individual power plant units, as follows, as in Table 1 below:

Tongonan Topping Unit

The main Tongonan Power Plant has a capacity of 112.5 MW and requires 1,008 tons/hr of steam at 6.83 bara at the plant inlet. The resource pressure is 11.14 bara, and the topping unit is to generate maximum power while reducing the pressure 6.83 bara. The ORMAT topping turbine is a backpressure turbine characterized by simple construction, with high efficiency and reliability. The specially designed unit utilizes technology proven by the continuous reliable operation, since 1993, of the 30 MW Puna Hawaii plant. It consists of two 3.25 MW turbines, each direct coupled to opposite sides of a common generator. The Tongonan Topping Plant is comprised of 3 topping units producing 16.95 MW net power.

Mahanagdong A and Mahanagdong B Topping Units

The main Mahanagdong Power Plants have a combined capacity of 180 MW, and require 6.83 bara steam flows at 817 tons/hr (for Mahanagdong A, producing 120 MW) and 410.4 tons/hr (for Mahanagdong B, producing 60 MW). The resource pressure was a nominal 10.8 bara, with the mission of the topping units to generate maximum power and reduce the pressure to 6.8 bara. Using 2 topping units the Mahanagdong A Topping Plant produces 12.45 MW net output (see figure 5) and with one topping unit the Mahanagdong B Topping Plant produces 6.25 MW net.

Malitbog Bottoming Unit

The main Malitbog Power Plants have a capacity of 231 MW (77 MWx3), utilizing steam at 5.85 bara. The well field facility produces 109 tons/hr of second flash steam, which is used by a condensing steam turbine Bottoming Cycle to generate 13.35 MW net. The bottoming plant utilizing water-cooled condensers, with a cooling tower, is shown in Figure 6.

4. CONCLUSIONS

Re-powering of existing geothermal power plants has proven to be technologically viable as well as economically and environmentally beneficial. Both large and small projects enjoy the benefits of re-powering and OEC modular topping and bottoming cycle units have been field proven as reliable and easily maintained power plants These plant retrofit additions have been purchased directly by facility owners and have also been financed as independent power projects. Re-powering has, in fact, been proven as the most cost-effective way to generate additional geothermal power.

5. REFERENCES:

1. Elovic, A. (1992). Repowering Geothermal Power Plants, *Geothermal Resources Bulletin,* pp. 252-257.

2. Hennagir, T. (1997). Philippines Fast Track, *Independent Energy*.

TABLE 1. Summary of Leyte Geothermal Optimization Project

Name of Plant	No. Units	Output (MWnet)	Comm. Operation	Plant Type	Main Plant Cap. (MW)	Total Cap. (Mwnet)
Mahanagdong A	2	12.45	Sept. 25, 97	Topping	120	132.45
Mahanagdong B	1	6.25	Sept. 25, 97	Topping	60	66.25
Tongonan	3	16.95	Sept. 25, 97	Topping	112.5	129.45
Malitbog	1	13.35	Dec. 31, 97	Bottoming	231	90.35
Total	**7**	**49 MW**			**502.5 MW**	**551.5 MW**

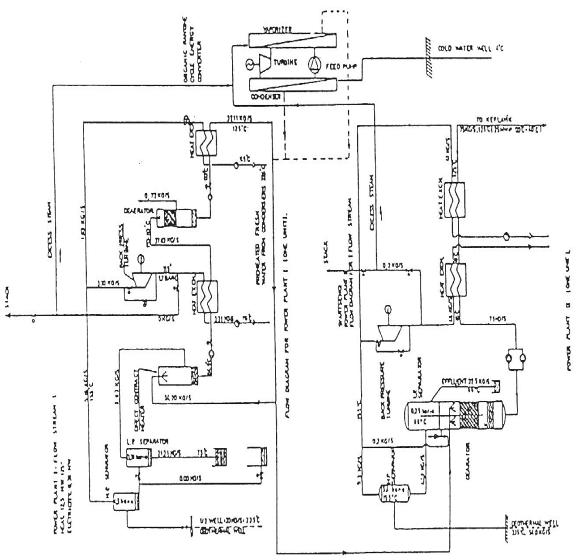

Figure 1. Svartsengi Process Diagram

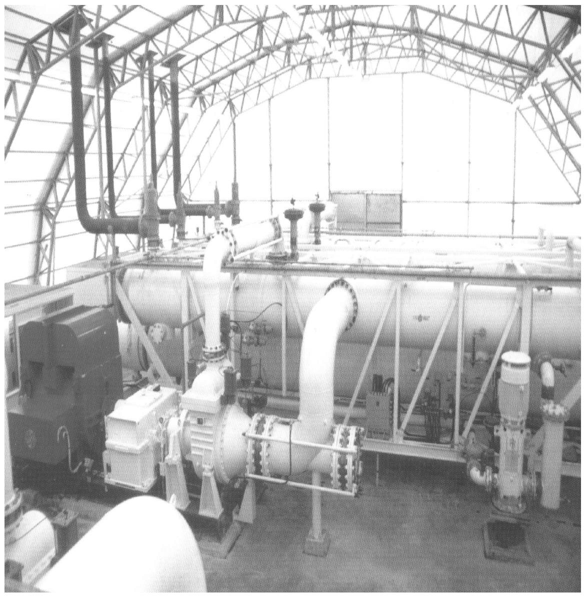

Figure 2. Svartsengi First Repowering Phase

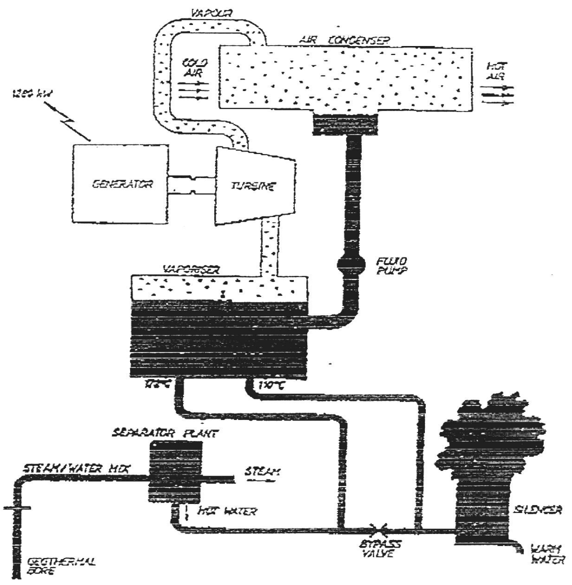

Figure 3. Bay of Plenty Process Diagram

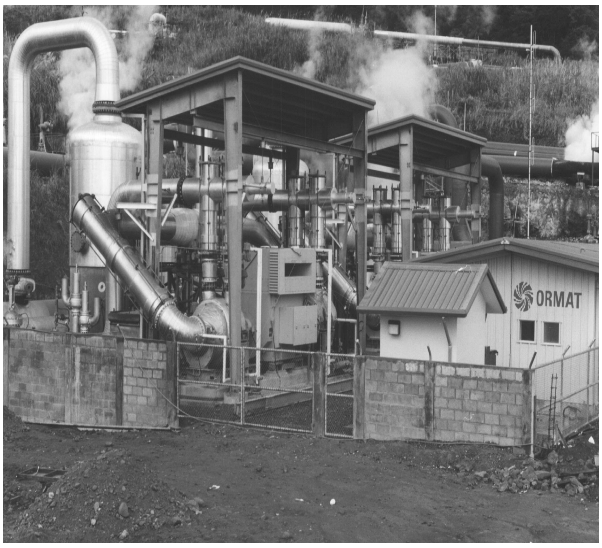

Figure 5. Mahanagdong A, Topping Unit

Figure 4. Bay of Plenty First Repowering Phase

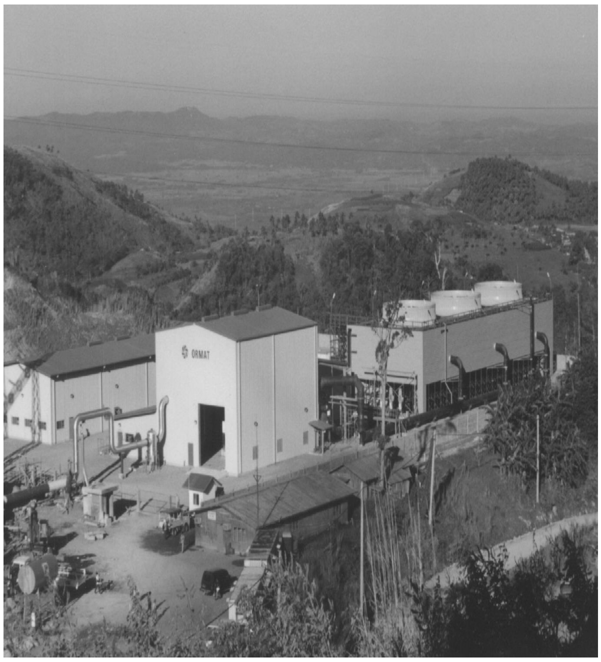

Figure 6. Malitbog Bottoming Unit