CASE HISTORIES OF IMPROVING GEOTHERMAL POWER PLANT PERFORMANCE WITH TOPPING AND BOTTOMING CYCLES

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ABSTRACT

The most cost effective way to develop additional generating capacity is by re-powering of existing geothermal paver plants utilizing untapped, and otherwise wasted, geothermal energy without any additional drilling or resource development costs, and often with environmental benefits. This presentation deals with the case histories of several such applications: (a) the 9.1MW exhaust steam recovery binary power plant at Svartsengi in Iceland; (b) the 6.4 MW brine recovery binary power plant at Kawerau in New Zealand; (c) the 17 MW excess pressure inlet steam topping turbine at Tongonan in the Philippines; (d) the 19 MW excess steam topping turbines at Mahanagdong A&B in the Philippines, and (e) the 13 excess steam condensing steam turbine bottoming unit at Malitbog in the Philippines. These re-power plants have 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 paver plant developers and operators very concerned about competitive costs, increasing plant output by re-powering without additional well field development is a highly desirable and cost effective option

1.0 INTRODUCTION

Unlike fossil fuels, which are delivered to a power plant at a per unit price, geothermal energy, which fuels the power plant for the life of the project, involves a high up front cost. Therefore for the most cost effective power generation, geothermal fluids should be utilized with a minimum of unused or otherwise wasted energy. The growing demand for clean, sustainable electricity from renewable energy sources, along with the competitive pressure from low cost fossil fuels, has increased the incentives for optimizing power production from existing facilities. Re-powering of existing plants, to utilize otherwise untapped energy, is thus viewed favorably by the plant owners, as well as by the public and the governmental agencies, since it conserves energy while reducing environmentally hazardous waste products.

Geothermal energy, by the nature of the power plant technologies commonly employed, offers unique opportunities for repowering, which are quite different from other methods used in the electrical power industry. Specifically the use of (a) back pressure steam turbines with atmospheric exhaust, (b) separated steam from two phase steam/brine mixtures to run steam turbines, and (c) low pressure condensing steam turbines, usually results in untapped energy which may be recovered by topping or bottoming cycles.

In the case of non-condensing geothermal steam turbines, the exhaust steam is generally released into the atmosphere at temperatures above 100°C. This not only wastes energy, but also has a serious negative environmental impact. The steam flow fiom 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°C, contains a significant percentage of untapped or otherwise wasted energy. 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.

Ormat's experience in repowering geothermal plants has been based on the use of its ORMAT Energy converter (OEC) modular units, with each application specifically designed and optimized to the actual resource conditions. The OEC modular units may be located near the heat source, away fiom 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 fee** 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 repowering existing geothermal power plants, **as** well **as** the applications of topping and bottoming cycles.

2.0 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 fiom** 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°C.** The original power plants built **by** Sudurnes in **1978 and** ***1980*** utilized *three* backpressure ***steam*** turbines to generate **8** MW, **with** some of the power provided **to** the local grid. Some of the exhaust ***steam*** from **these turbines was** used ***to*** heat water for district **hating,** while **some** of it **was** discharged into the atmosphere.

Sudurnes installed **three 1.3 MW** water-cooled **OEC** binary power modules, generating 3.6 MW, in ***1989,* as the first** repowering phase. **These OECs** use the ***steam*** turbine **exhaust as** the heat **source.** In **1993** four additional **1.3** MW **air** cooled **OEC** binary modules, generating **4.8** MW were added, bringing the total **OEC** installed 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.

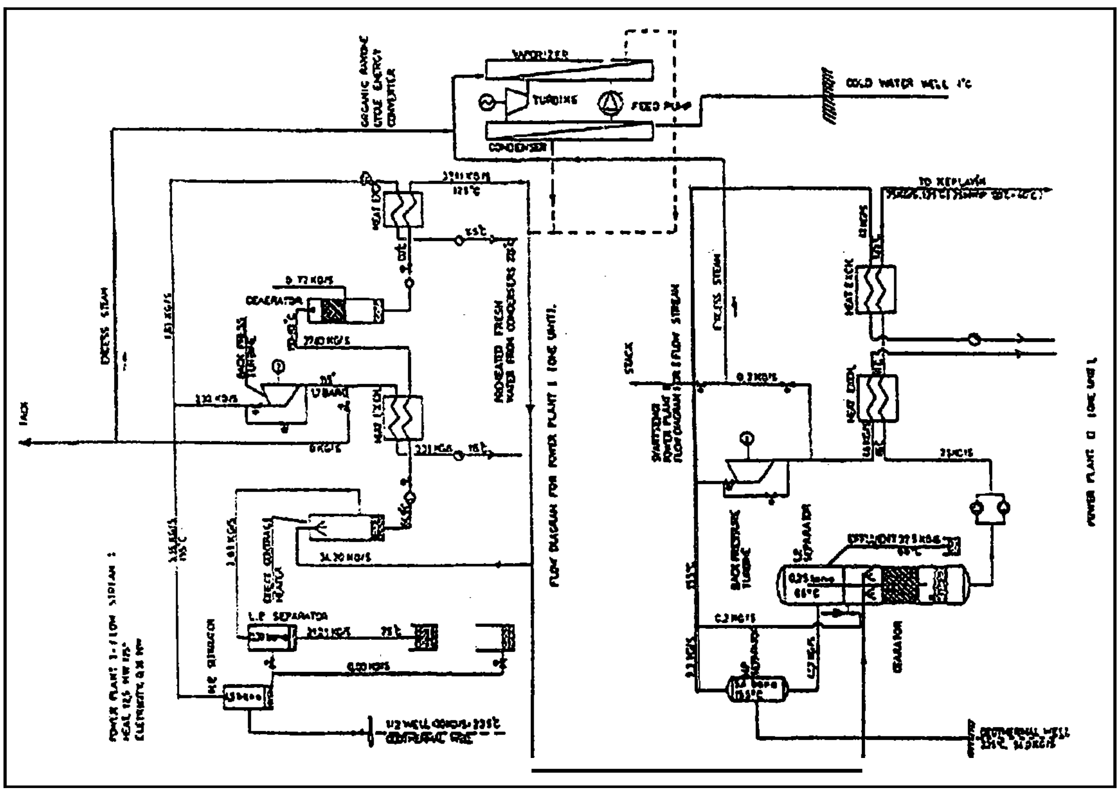

Figure 1. Process diagram, **Svartsengi geothermal power plant, first-phase repowering by condensing exhaust steam.**

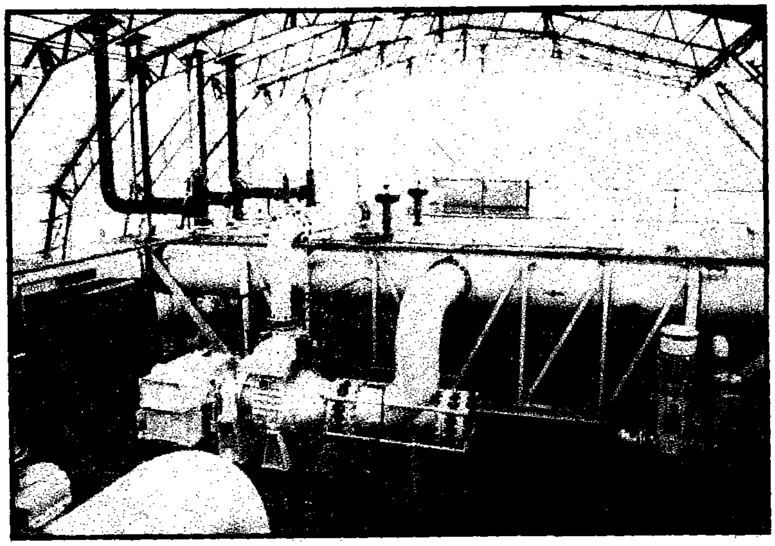

Figure 2. Photograph of water cooled OEC binary module first-phase repowering of Svartsengi geothermal plant.

After 10 years of continuous operation the OEC units are operating at over 97% availability, this project has had 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 Sudemes power plant fiom 8 to 16.4 MW.
- The repowering 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 fiom 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, containing mostly CO_2, and previously a source of corrosion, are now available for beneficial industrial use in making dry ice and liquid CO_2.
- The cooling water fiom fresh water wells, at 4°C is preheated in the process to 22°C, and then heated to approximately 100°C and pumped as district heating water to the communities on the Reykjanes Peninsula.

3.0 THE BAY OF PLENTY TARAWERA GEOTHERMAL POWER PLANTS, Kawerau, North Island, NEW ZEALAND:

The Bay of Plenty Electric Power Board, with a supply area of 8,400 km^2, 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 geothermal field, which is one of the most explored and proven geothermal fields. 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 brme into the Tarawera River. Bay of Plenty Electric obtained the rights to this partially spent geothennal 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 secund phase power plant unit.

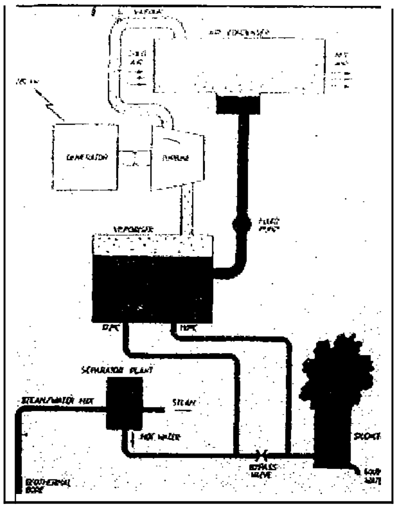

Figure 3. Process diagram, Tarawera first phase OEC installation.

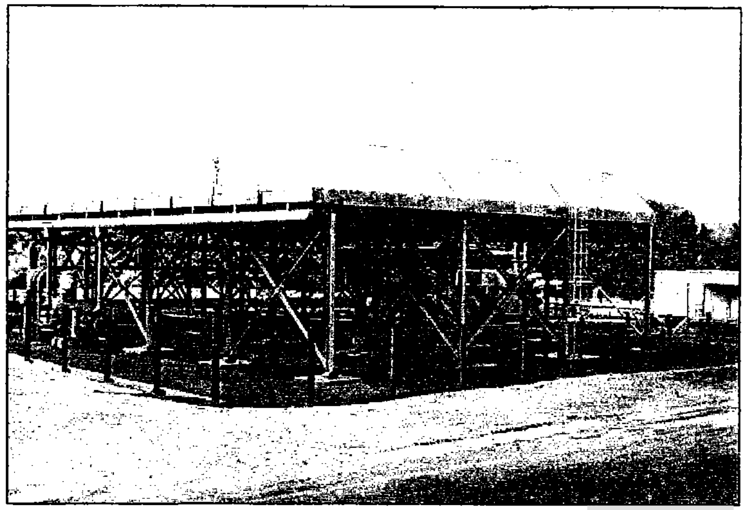

Figure 4. Photograph of air cooled Tarawera 3.5 MW OEC geothermal power plant.

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 have proven to be very cost effective. They were installed m 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.

At *this* time, and after nearly 10 years of Continuous operation of the fist installation, the OEC 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.

4.0 THE LEYTE GEOTHERMAL OPTIMIZATION PROJECT, Leyte, 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 m July 1995 and financing was closed only 10 months later, with project equity provided by ORMAT and long term debt from U.S.Ex-Im Bank. EPC turnkey *construction* activities *started* shortly thereafter.

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

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**

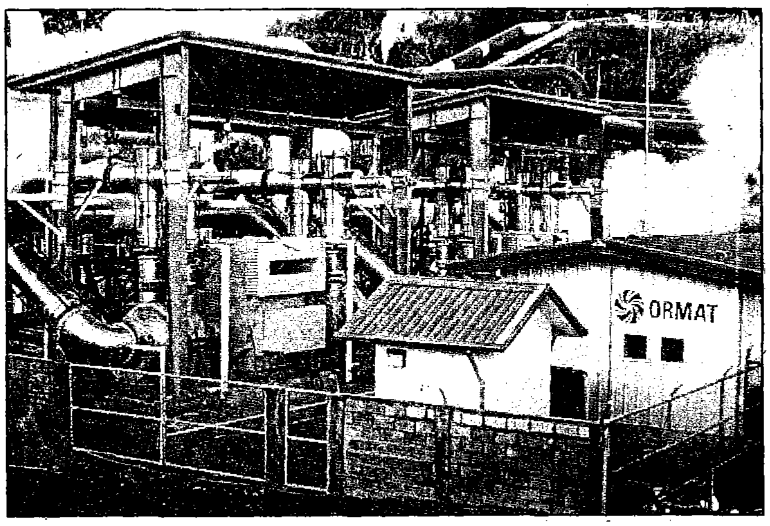

Figure 5. Photograph of 12.45 MW Mahanagdong A geothermal topping plant.

4.1 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 especially designed unit utilizes technology proven by the Continuous reliable operation, since 1993, of the 30 MW PUNA Hawaii plant, and 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.

4.2 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.

4.3 Malitbog Bottoming Unit

The main Malitbog Power Plants have a capacity of 231 MW (77 MW x 3), utilizing *stem* 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.

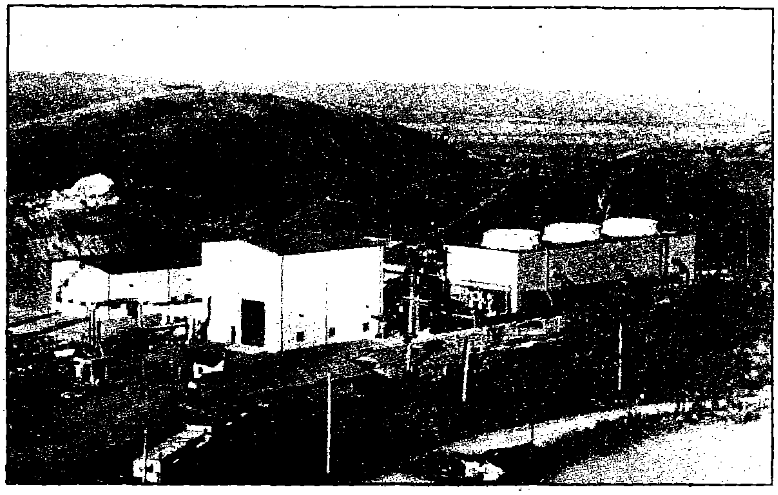

Figure 6. Photograph of 13.35 MW Malitbog geothermal bottoming plant.

5.0 CONCLUSIONS

Repowering 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 repowering 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. Repowering has, in fact, been proven as the most cost-effective way to generate additional geothermal power.