The Wairakei Binary Power Plant: First Eight Years of Operation

Ted Montague¹, Wayne Christi¹, and Hilel Legmann²

¹Contact Energy
²Ormat Technologies, Inc.

Keywords
Wairakei Geothermal Field, geothermal power plant, Organic Rankine Cycle, air-condensing, low temperature resource

ABSTRACT

Investors are increasingly cautious about geothermal generation. In North America, financial commentators lament the low capacity factors associated with low temperature binary plants and corresponding decreases in shareholder value.

Concurrently, in Indonesia, geothermal operators with steam flash plants are considering installing binary facilities to extract additional value from the separated geothermal exiting the final flash.

This paper summarises the experience of a recent, lower temperature binary plant and concludes that such facilities can be constructed and operated in a way that meets investment requirements.

Background

The Wairakei Geothermal Field resides in the central North Island of New Zealand, close to the city of Taupo (Figure 1). The original development featured a tiered series of steam turbines housed in two stations. The first plant was commissioned in 1958 and the second in 1962. The development has run continuously for over 50 years and set a production record in its 40th year.

Development & Construction

After the turn of the 21st century, electricity prices in New Zealand began to increase as natural gas prices rose and hydro-electrical production fell (due to dryer climate conditions). Contact Energy’s Wairakei engineers reformulated a binary project to increase the plant output while retaining the same level of geothermal fluid take.

Contact secured the environmental permits to construct the plant in 1999. These contained onerous noise requirements and gave a five-year window to begin construction. In 2003, after completing a performance specification, the development team conducted a competitive bid for the supply of a binary plant.

Location Map

Engineers first considered binary technology at Wairakei’s inception but rejected the option as too uncertain. Since 1980, Wairakei staff formulated a number of binary schemes to utilise the energy contained in the low pressure, separated geothermal fluid. None of these projects proceeded due to low electricity prices resulting from the availability of inexpensive natural gas.
Ormat Industries won the tender and the parties signed an EPC contract in October 2003.

The EPC scope included the design and construction of the binary plant and grid connection, plus pipework connecting the plant to the existing re-injection system. The operator’s scope included new pipework linking existing flash plants into the re-injection main (supplying the binary plant) and new injection wells.

Construction was completed on time and on budget. The construction time from site establishment through the reliability run was 18 months (Table 1).

Table 1. Development Timeline.

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental permits issued</td>
<td>1999</td>
</tr>
<tr>
<td>Tender released</td>
<td>May 03</td>
</tr>
<tr>
<td>EPC signed</td>
<td>Oct 03</td>
</tr>
<tr>
<td>Site established</td>
<td>Jan 04</td>
</tr>
<tr>
<td>Commissioning starts</td>
<td>May 05</td>
</tr>
<tr>
<td>Reliability run complete</td>
<td>June 05</td>
</tr>
</tbody>
</table>

The construction team faced several site-specific challenges. The most difficult was managing the interface between the operating plant and the construction site. Other site issues included tomos (subsurface voids), noise restrictions and safety.

Plant Description

Design & Configuration

The power generation equipment installed at the Wairakei power plant two includes two Integrated Two-Level Unit (ITLU) modules and additional accessories such as controls and monitoring required to convert the hot geothermal brine into useful electric power.

The major components of each ITLU consist of preheaters, vaporizers, turbines, generator, lubrication and sealing systems, air-cooled condenser and motive fluid cycle pumps. The module also includes automatic and manual control valves, instrumentation (gauges, switches and transmitters), internal piping, and power and control boards.

Operation process of the ITLU is based on the Organic Rankine Cycle, in which an organic motive fluid absorbs heat from a heat source, causing the motive fluid to vaporize; it then expands in the turbine, producing rotational shaft power by transforming kinetic energy gained by the vapor’s expansion process.

The geothermal brine flows through the level I vaporizer tubes and then enters the tube section of the level II vaporizer. After exiting the vaporizers, it flows in parallel to the level 1 and level 2 tube sides of the preheaters, while organic fluid flows through the shell side. The organic motive fluid thermal cycle is a closed-loop cycle. The ITLU extracts heat from the geothermal fluid in a simple and highly efficient way without the complication of using mixtures of working fluids or operating in super critical cycles.

A feed pump transfers the organic fluid from the condenser into the preheater tube section. The fluid is heated in the preheater to a temperature close to the boiling temperature and in the vaporizer the organic fluid reaches the boiling point and vaporizes. The organic vapor passes through the vapor inlet assembly, then enters the organic turbine and expands, thus dropping in pressure and temperature and producing rotational shaft power. The low-pressure vapor flows to an air-cooled condenser, condenses and then is pumped back into the preheater.

The organic motive fluid used in the thermal cycle is Iso-Pentane, selected for optimal utilization of available heat source.

Components Description

The OEC is comprised of the following main components:

Vaporizer

The vaporizer is a horizontal shell-and-tube heat exchanger, manufactured of carbon steel with a tube bundle, sheet metal shell and fixed tube sheets. Heating fluid flows through the tube side and motive fluid through the shell side. A bellow type expansion joint is provided to compensate for any differential thermal expansion of the tubes and shell.

The separator is installed on the top of the vaporizer. The separator is designed to retain the droplets of liquid carried in the vapor, thus preventing impinging droplets on turbine blades.

Preheater

The preheater is a horizontal shell-and-tube heat exchanger manufactured from carbon steel with a tube bundle, metal shell and fixed tube sheets. Heating fluid flows through the tube side and motive fluid through the shell side. A bellow type expansion joint is provided to compensate for any differential thermal expansion of the tubes and shell.

Power Skid

Each of the two OEC power skids consists of a dual shaft extension generator, two turbines and associated oil system.

(a) Synchronous Generator

The generator is a synchronous type, air-cooled, three-phase machine, brushless and weather protected. It is built to NEMA WP type II enclosure specifications and rated at 9,500 kW, 0.8 PF, 11 kV and 50 Hz. The generator and two turbines are directly coupled.
(b) Turbine

Each of the two OEC turbines consist of a single casing, multi-stage axial unit. The turbine is directly coupled to the end of the generator shaft. No speed-reducing gearbox is required because the properties of the organic fluids produce favorable aerodynamic matching at relatively low blade and rotational speeds. A shaft seal is used to prevent leakage of the working fluid into the atmosphere or lube oil.

Air-Cooled Condenser

The condenser is an induced draft, air-cooled heat exchanger. The tubes are arranged in a one-pass configuration where motive fluid vapor is fed from the inlet box to the tubes. The motive fluid is cooled and condensed, inside the tubes, by forced air flowing outside of the finned tubes in a cross-flow pattern. The condensed motive fluid accumulates in the hot well collector from where it flows by gravity to the motive fluid filters and pumps.

Additional Components

Additional components include feed pumps, the Organic Motive Fluid Piping system, the purge system, the geothermal brine piping system, controls and protections.

Design Conditions and Performance Specifications

Site Conditions

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design max. temperature for electrical equipment in control shelter</td>
<td>40ºC</td>
</tr>
<tr>
<td>Altitude</td>
<td>360 m asl</td>
</tr>
<tr>
<td>Wind</td>
<td>Per NZS 4203</td>
</tr>
<tr>
<td>Seismic zone</td>
<td>UBC Zone 4</td>
</tr>
</tbody>
</table>

Performance Specification

At Design Conditions:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator rated power</td>
<td>2 x 9,500 kW at power factor 0.8</td>
</tr>
<tr>
<td>Generator rating (each of 2)</td>
<td>2 x 11,875 kVA</td>
</tr>
<tr>
<td>Design ambient temperature</td>
<td>11 ºC</td>
</tr>
<tr>
<td>Net system output at design conditions, (After deducting for plant internal use, but before well field pump use.)</td>
<td>14,380 kW</td>
</tr>
<tr>
<td>Voltage</td>
<td>11 kV</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Geothermal fluid inlet temperature</td>
<td>127º C</td>
</tr>
<tr>
<td>Geothermal fluid flow</td>
<td>2,800 t/h</td>
</tr>
</tbody>
</table>

Plant Performance

From take-over through 2011, the plant has produced over 810 GWh, at an average of 123 GWh per year (Figure 2). While maximum plant output has declined, on an annual basis there is no evidence of plant degradation. The load factor has remained relatively constant, influenced mainly by scheduled outages and the supply of geothermal fluid. Since 2010, plant output has fallen due to external outages related to the reconfiguration of the Wairakei steam field and low voltage system.

On a seasonal basis, the air-cooled condensers lift their performance (compared to design conditions) markedly during the winter (Figure 3). The corresponding decline in summer is modest. Major surveys are normally scheduled in November, resulting in a statistically lower output during that month over the eight years of production. This seasonal output profile matches New Zealand’s electricity consumption.

Monthly plant availability typically rates over 95% (Figure 4). The notable decreases from this trend reflect major plant surveys.

![Figure 2. Plant Production by Month (GWh). Note: the baseline reflects the nameplate output at design conditions](image)

![Figure 3. Average Plant Production by Month. Note: The plant capacity at design conditions is 10.3 MWh per month.](image)

![Figure 4. Monthly Plant Availability (%).](image)
and full station outages. Smaller deviations reflect the periodic planned, three-day outages to clean the heat exchange tubes and forced outages.

Load factors show that Wairakei binary performs at similar levels to other binary plants of a similar vintage and size (Table 2). The very high (100%) load factor appearing in some years results from the additional production during the cold winter months. In this respect, binary plants in New Zealand will have higher load factors than plants in continental climates due to the cooler summers.

<table>
<thead>
<tr>
<th>Plant</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRK Binary</td>
<td>100.3</td>
<td>94.6</td>
<td>100.8</td>
<td>101.7</td>
<td>94.0</td>
<td>88.1</td>
</tr>
<tr>
<td>Galena I</td>
<td>88.8</td>
<td>87.0</td>
<td>100.2</td>
<td>91.3</td>
<td>94.4</td>
<td></td>
</tr>
<tr>
<td>Ngawha</td>
<td></td>
<td>84.6</td>
<td>98.5</td>
<td>93.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Contact’s O&M philosophy is adaptive, with annual maintenance planning based on plant operating conditions and corrosion monitoring. In the first year, the maintenance team worked through a number of teething problems, such as:

- Pump motor bearing and seal failures: The feed pumps tripped on a number of occasions due to bearing failures or leaking mechanical seals. These defects were remedied.
- Strainer blockages: Initially the separated geothermal fluid carried enough debris to clog the strainers and trip the plant. Over time, staff minimised the impact of well work-overs to reduce debris in the system.
- Tube defects: A small number of tubes in the vaporiser were found to be leaking. These were converted to baffles without any loss in plant performance.
- Fan defects: A number of the condenser fan motors were damaged in transport and these were replaced.
- Pentane purging: For the first turbine survey, maintenance staff had to work out procedures for draining and purging pentane from the motive circuit so that turbine inspections could proceed safely.

Since the first year, maintenance staffs have kept plant availability steady (Figure 4). On-going maintenance and operating issues include:

- Scaling in the heat exchangers: Even a few millimetres of silica precipitation in the primary (geothermal) heat exchanger tubes can affect plant performance. Staff elected to clean the primary tubes by water blasting three times per year. With experience, tube cleaning has been reduced to twice per year.
  - System flow: Plant operators have to manage the pressure drop across the plant and its effects on the steam separators upstream and the re-injection pressures downstream. This is an on-going art form.
  - Hazardous substance management: The motive fluid represents a significant hazard for the site. Wairakei staff has drafted and implemented detailed safety plans to prevent and manage any spills.

The Wairakei Binary plant runs within its environmental requirements. Most notably, the plant meets the mandated noise levels and oil-pentane spillage allowances.

Conclusion

The Wairakei binary plant demonstrates that low-temperature binary projects can meet their investment objectives. The project was constructed on time and on budget. Since commissioning, the plant has met or exceeded its production targets.

The project has not suffered from fluid supply problems experienced by some geothermal projects. The plant was appropriately sized and configured so that sufficient separated geothermal fluid would be available during planned outages to the flash plants.

The project also has benefited from the temperate climate of New Zealand, where air cooling does not induce a seasonal output penalty. In addition, the incremental nature of the investment means that capex costs were reduced (no drilling) and that no new O&M staffs were required to operate the plant.

The bottoming cycle application of binary technology thus constitutes a credible investment option for existing flash turbine plants.

1 High pressure, intermediate pressure and low pressure. The high pressure turbines were removed in 1968 as planned due to field pressure declines.
2 During the coldest days
3 The southern hemisphere winter is June, July and August
4 New Zealand’s mild climate tempers electricity consumption in summer
5 Situated on the vaporizer geothermal inlet