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A REVIEW OF THE GUNUNG SALAK GEOTHERMAL EXPANSION PROJECT

R. SOEPARJADI[1], G.D.HORTON[2], E. BRADLEY AND P.E. WENDT[1]

[1]Unocal Geothermal of Indonesia Ltd.,Indonesia
[2]Unocal Corporation, USA

SUMMARY - In December 1997, Unocal Geothermal of Indonesia, in partnership with PT Nusamba Geothermal, Pertamina, and PT PLN (Persero), completed the first private geothermal power build-operate-transfer (BOT) project in Indonesia. Unocal installed three 55 MW and PLN installed one 55 MW Power Generation Facilities (PGF) to bring the total power generation at Salak to 330 MW, making Salak the largest geothermal project in Indonesia. UGI also expanded the Resource Production Facilities (RPF) to increase steam delivery for six units. The project challenges included handling a liquid-dominated resource, environmentally sensitive protected forest, difficult surface conditions, and coordinating on-going power generation operations and a three rig drilling program with new construction efforts. Unocal's power plants feature three identical Fuji turbines and generators, shell and tube surface condensers, concrete cross-flow air-induced cooling towers, and a hybrid gas removal system. Drilling, engineering, procurement and construction were accomplished within 28 months. Plant operators were locally hired and trained within the construction period, and are now operating all the project facilities. The plants have been generating at demand with up to 340 MW capacity since start-up.

1. INTRODUCTION

The Gunung *Salak* Contract Area is located in West Java, Indonesia, 60 km south of Jakarta. The contract area was formed February 11, 1982 when Unocal Geothermal Indonesia (UGI) entered into a Joint Operating Contract with the Indonesian National Oil Company (Pertamina) and the national electrical utility of the Indonesian government, PT PLN. Exploration drilling resulted in the discovery of the Awibengkok field in 1983. Steam production to the first 110 MW (2 X 55 MW) power plant commenced in March 1994 (Mosby, et al., 1997).

The facilities were expanded by adding a third power generating facility adjacent to Units 1 and 2 (engineered and installed by Ansaldo for PLN), and installing three new turbines operated by Unocal. To meet the steam supply requirement for the four new units, 36 additional production and injection wells were drilled and associated surface facilities were installed. The total installed capacity of the field was brought to 330 MW by November 1997, making Awibengkok one of the largest operating geothermal fields in the world.

Unocal overcame many challenges to meet the objectives of the expansion project, including:

- Rough hilly terrain, limiting available sites for drilling pads, transmission towers, and surface facilities.
- Volcanic soils that become structurally unstable when disturbed.
- A narrow access road to transport the turbine and generator sets, drilling rigs and construction material.
- A tropical rain forest with 4000 mm of annual rainfall.
- Environmentally sensitive protected forest.
- Financing.
- Technology transfer and training of an inexperienced local work force.

Despite these hurdles, the expansion project was completed in 28 months and within budget. Construction was completed with over five million man-hours without a lost time accident. Unocal received the Patra Adikriya Bhumi Pratama, an environmental award from Pertamina for its commitment and quality of implementation to environmental protection at the project site. The Project also received the Project Finance International Asia Pacific **Award** 1996 for the unique and creative financing of the expansion project.

2. RESOURCE DEVELOPMENT STRATEGY

The Awibengkok reservoir is a high temperature liquid-dominated reservoir containing relatively benign fluid.

Resource Characteristics:

Temperature	221 - 312 °C (430 - 593 °F)
Steam Flash	17% - 100%
Permeability	up to 1,000,000 md-ft
Chemistry	NaCl Brine, TDS = 13,000 ppm
NCG	average 1.0% by wt. in steam

The basic development strategy for Awibengkok was to produce from the relatively shallow, high permeability interior areas and inject deep towards what is currently perceived to be the edge of the reservoir (Ganefianto and Shemeta, 1996).

Figure 1 shows the areas for injection and production for the Salak Expansion Project. Twenty-four production wells and 12 injection wells were drilled in 1995-1997.

During the initial Unit 1 and 2 operation, Awi 7 and 8 brine was gravity fed to Awi 9 wells and Awi 11 brine to Awi 10. The Awi 9 wells encountered deep permeable zones, reducing risk of early injection returns (Noor et al., 1992). Since Awi 10 wells had both larger magnitude and shallower permeability, greater potential for injection breakthrough was anticipated. Slug tracer and geochemical monitoring confirmed rapid returns of Awi 10 brine to the Awi 11 production wells located one km northeast. Therefore, the Awi 10 wells were converted to producers as part of the 220 MW expansion strategy which otherwise followed the initial pattern of interior production and peripheral injection.

3. FINANCING

Unocal's unique financing structure led to it being the first Indonesian Geothermal Independent Power Producer (IPP) to achieve financial closure. Several firsts were achieved as stated by Asia Pacific Project Financing International (Barek and Kenna, 1997):

- the first time banks accepted geothermal risks in Asia;
- the first financially closed privately owned geothermal power project in Indonesia;
- the first project financing loan in Indonesia that has no political risk coverage or export credit support;
- the first time an Asian grass roots project obtained financing in commercial debt ;
- it achieved financial closure in about nine months from the time representatives were appointed to close.

Asia Pacific indicated that the banks accepted the financial structure primarily based on Unocal's record as a geothermal developer.

Unocal and Nusamba established a vehicle for financing the project by creating a contractual joint venture and separate project company, Dayabumi Salak Pratama Ltd. The structure limited recourse of lenders to the project and raised financing off the balance sheet. A joint operation contract (JOC) between Pertamina and Unocal/Nusamba and an energy sales contract (ESC) whereby Pertamina sells electricity to PT PLN formed the equivalent of the power purchase agreement (PPA) for Dayabumi (Figure 2).

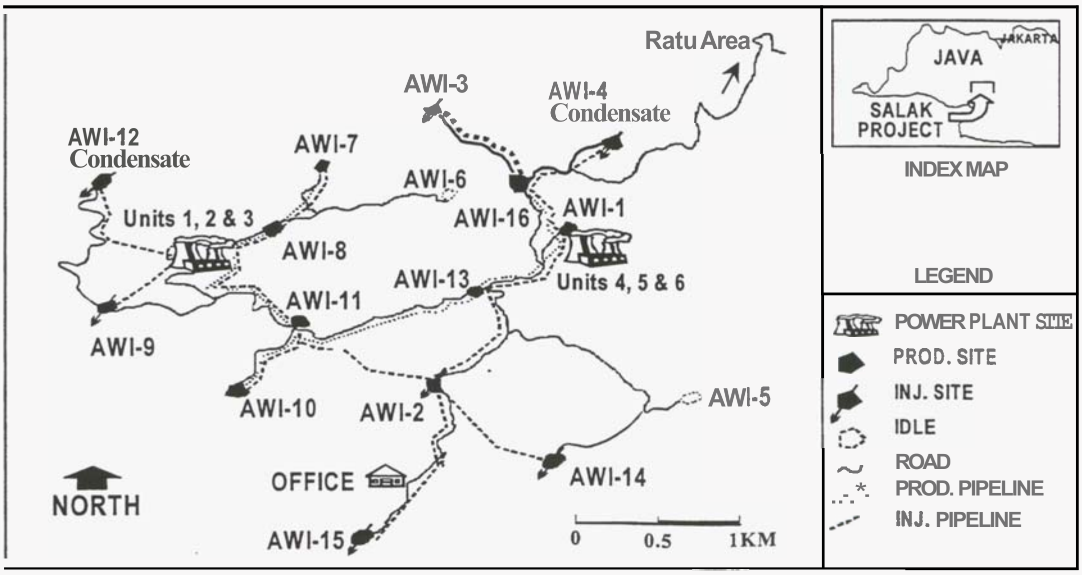

Figure 1 - Awibengkok Field Plot Plan

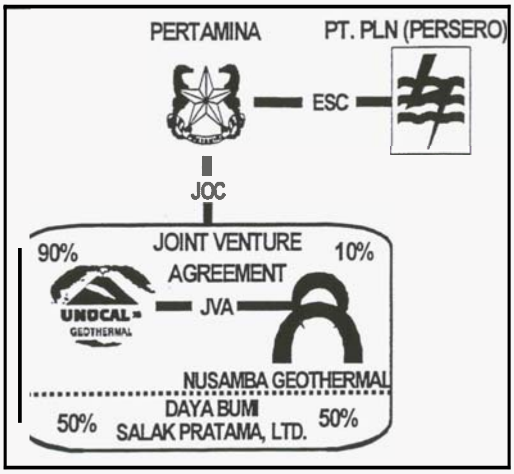

Figure 2 - Gunung Salak Contracts

4. DRILLING

Thirty-six wells were drilled during the expansion program, including 24 production wells and 12 injection wells.

Unocal reduced the drilling costs significantly through innovation and a dedicated team effort among the operations, geoscience, reservoir and drilling groups. Factors in improving drilling performance included:

- proactive management
- use of top drive vs. kelly
- rig skidding on individual well pads
- innovative casing designs
- frequent injection tests to determine the permeability structure

The results were an 11% decrease in costs per megawatt produced, and a 16% decrease in the dollar per foot drilled from early 1996 to late 1997. The average number of feet drilled per day increased by 58%, and seventeen percent of the wells were drilled in less than 30 days. The best effort was 17 days! The cost of the production wells dropped 27% and the injection well cost decreased by 10% on average.

Strategic surface drilling locations were limited due to the rough hilly terrain. As such, wells were drilled in clusters (up to seven on one pad) using directional drilling techniques. This had the added advantage of minimizing footprint area, which reduced land acquisition, pipeline, road and location construction costs. It also minimized the effect on the forest and reduced the number of trees to be cut.

During the peak of the drilling schedule, three rigs were utilized to drill the wells. The drilling operations used sumpless drilling to minimize the run-off into the rain forest and to protect the environment. This eliminated effluent disposal problems for operations but large quantities of drill cuttings and residual mud were still generated. Using innovative soil stabilization techniques, drill cuttings and drilling waste products were converted to road base and structural bricks for lining drainage canals and building components.

5. RPF DESIGN AND CONSTRUCTION

The RPF is designed to supply steam to the power plants and dispose of the brine and condensate. For operational purposes, the field is divided into the West and East sides. The West side steam production is from Awi 7, 8, 10 and 11, supplying Units 1, 2, and 3. The East-side steam production is from Awi 1, 13 and 16 which supply steam to Units 4, 5, and 6. The East and West systems are interconnected at Awi-13. Brine reinjection occurs at Awi 2, 3, 9, 14, and 15 (Figure 1).

The production wells and separators are generally remotely located from the power plant. Large diameter cross-country pipelines ranging from 24 to 42 inch (61-107 cm) traversing up to 4 km of hilly terrain are used to gather the steam. Brine disposal pipelines are generally 16-36 inch (40-91 cm) diameter. The total pipe installed at Salak for the 330 MW operation is:

- Steam Pipelines 9.5 km
- Brine Pipelines 17.2 km
- Condensate Pipelines 5.4 km
- Water Distribution System 12.0 km

The expansion of the RPF by 220 MW required a phased approach. Phase 1 included the activities necessary to shift steam production to maintain an adequate steam supply to Units 1 and 2 while modifying existing wellsites to increase the steam production to support Unit 3. Phase 2 involved the work activities necessary to increase steam production and brine and condensate disposal to support Unit 3. The third phase of the expansion program involved bringing the new wellsites on-line as needed to support the operations of Units 4, 5 and 6.

6. PGF DESIGN AND CONSTRUCTION

The Units 4, 5, and 6 PGF consists of three identical, 55 MW (gross) steam turbine-generators in one building.

The design effort began in June 1995 and was essentially complete by October of the same year. Contractors broke ground in August 1995 during the rainy season. Nearly 750,000 m^3 of volcanic tuff was excavated and disposed of in nearby valleys. Handling the material became particularly difficult due to the unstable condition

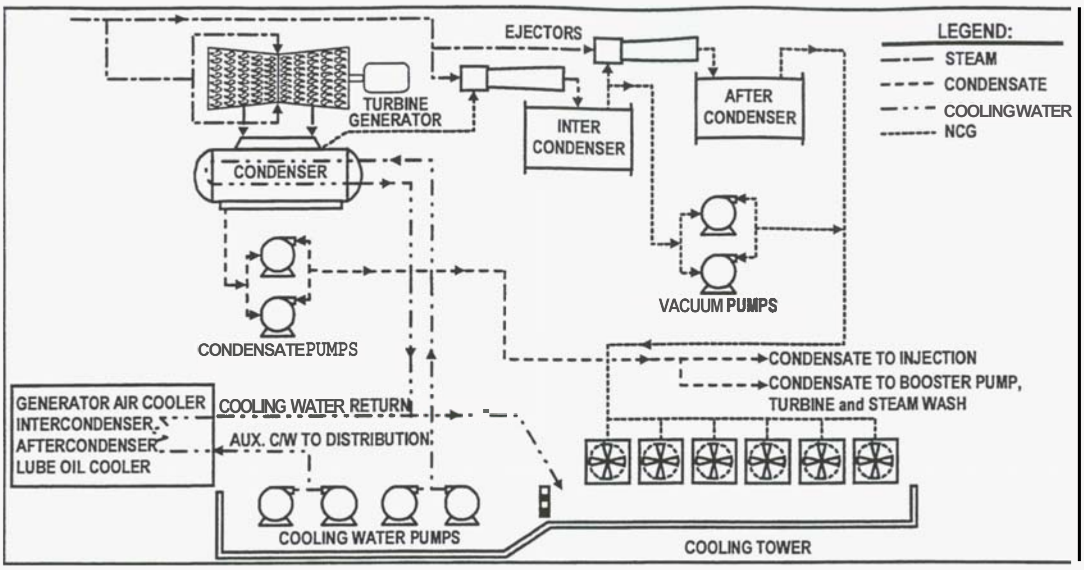

Figure 3 - PGF Major Equipment and Process Flow

of the soil after being disturbed. It turned into soupy mud that required constructing about 25,000 m^3 of gabion dams to contain it and prevent it from flowing into streams. The disposal areas were later replanted with native plants. The reforestation effort gained Unocal the Patra Adikriya Bhumi Pratama environmental award from Pertamina.

The power plant foundation and turbine pedestals were built just before the arrival of the turbine-generators (TG's). Unit 4 TG arrived October 1996 followed by Units 5 and 6 TG's, staggered by two-month periods. Meanwhile, the cooling tower erection, mechanical and piping system installation and electrical installation commenced. Mechanical completion and turnover to the start-up team was July, August and November 1997 for Units 4, 5 and 6, respectively.

Five million man-hours without a lost time accident was achieved during the construction effort.

7. PGF MAJOR FEATURES

Major features of the PGF include the turbine-generator, surface condensers, hybrid gas removal system, concrete cross-flow cooling towers and provisions for future hydrogen sulfide gas abatement equipment if needed (Figure 3). The plant design placed emphasis on reliability, flexibility to operate under a variety of conditions, and ease of maintenance.

The turbine-generator was manufactured, supplied and installed by Fuji Electric Company. The turbine is a single cylinder, double flow, and dual entry condensing type unit. The rotating turbine blades are all reaction style. There are nine stages of blading on each end of the turbine.

A Digital-Electro-Hydraulic Governor Control System (DEH) controls the turbine speed and load. The turbine control and supervisory panel (TCP) is located in the main control room. The TCP sends signals to the governor to control speed, load, and turbine inlet pressure. The turbine coupled to the generator rotates at 3,000 rpm.

The generator is a 64.7MVA gross (equivalent to 55 MW at a .85 power factor), 50 Hz, three phase, totally enclosed water to air cooled, two pole, synchronous generator with an 11.8 kV voltage rating. Although the generator is officially rated at 55 MW, it is fully capable of operating at 70 MW at unity power factor should PLN's system demand, or economic considerations require, additional generation.

Downstream of the turbine, a tube-in-shell surface condenser is provided to create a turbine back pressure of 0.083 bara (6.2 cmHgA) by condensing steam and removing non-condensable gases. The condenser is an in-line two pass divided unit. Cooling water enters the upper water box and tube bundle, and flows to one end of the condenser, makes a "U" turn, and returns through a second tube bundle installed below the first pass. The surface condenser, as opposed to direct contact condenser, is provided to minimize entrainment of non-condensible gases in the condensate in anticipation that hydrogen sulfide abatement may be required at some later date.

Each unit has a six cell, mechanically-induced draft, double cross-flow cooling tower. The cooling tower is designed to cool 19,500,000 kg/hr of circulating water composed of steam condensate from 38.1°C to 27.2°C, with air entering at a wet bulb temperature of 21°C.

The non-condensible gas removal system removes non-condensable gases (NCG) and residual water vapor from the condenser and delivers the gases to the top of the cooling tower where they are dispersed to the atmosphere. The non-condensible system is designed as a hybrid system consisting of both steam jet gas ejectors (SJGE) and liquid ring vacuum pumps. This hybrid system represents the optimal configuration by balancing the greater efficiency of the vacuum pumps with the lower capital and maintenance costs of the ejectors.

Liquid ring vacuum pumps are used as the primary second stage component since they are more energy efficient than a second stage SJGE under the given steam conditions. After leaving the vacuum pumps, the gases and a small amount of vapor are routed through a moisture separator and then to the top of the cooling tower. In the event one liquid ring vacuum pump is inoperable and the gas rate is above 60% of the design rate, a second stage SJGE is provided in parallel with the vacuum pumps as a back-up. The stand-by SJGE is installed for back-up use since its expected operation is infrequent and the capital cost is considerably less than that of a stand-by liquid ring vacuum pump. Gases and vapor exiting the second stage SJGE pass through an after condenser and are then routed to the top of the cooling tower fan cylinders.

8. TRAINING

Unocal management strategically planned for a lean operation. Only 30 additional technical people, representing a 50 percent growth in the operating and maintenance work force, were hired to handle the additional responsibilities of the 200 percent expansion. The challenge was to find and train people from the local labor pool, who had limited experience and skill levels. Complicating the efforts was the lack of English language skills necessary to transfer technology effectively to the young operators and craftsmen.

A team-based approach was used to establish and implement a training program for the operators and craftsmen, allowing the safe and timely start-up of the RPF and PGF without major upsets. The objective of the team was to systematically develop and implement a training program for the start-up, which could be transferred to future Unocal geothermal projects.

The core elements of the training system consisted of Operation Fundamentals and English language training, Task Specific Training for skills and knowledge, On-the-Job task performance auditing and a certification program.

Over two hundred lesson plans were developed for the RPF and PGF training programs. Each lesson plan took 30 minutes to three hours to teach. In addition to in-house training, Unocal provided training from the vendors for the Programmable Logic Controllers, Distributed Control System, turbine and generator and other systems.

Proprietary computer learning and performance-support-system software was used as a training and administrative tool. The software aids in conducting task analysis, developing performance standards and preparing effective training objectives. It has embedded instructional help and templates for training and provides document control and administration capabilities.

9. START-UP

During the start-up of Units 4, 5, and 6, the operators applied what they learned in class and at the same time received on-the-job training in operating the power plant equipment. Six weeks were scheduled to start each unit from the initial turnover of the 150 kV electrical system for power distribution to first synchronization. The first unit, Unit 4 took longer, but the experience permitted Units 5 and 6 startups to be completed progressively faster, with Unit 6 taking only 5 weeks.

Due to some construction delays, Unit 4 synchronization was achieved 3 months after the originally scheduled date. However, with improvements gained by experience in both construction completion and startup, Unit 6 synchronization was achieved only 10 days after its originally scheduled date. This was followed by the Lender's required reliability test. with all three units in operation at full load continuously for 25 days. This was achieved on December 19, ahead of Unocal's self-imposed December 31 deadline. The Commercial Date for Units 4, 5, and 6 was therefore set on December 19, 1997.

Electricity produced is transmitted to PT PLN and integrated with power from PT PLN's Units 1, 2, and 3. Integration of generation from Unocal to PLN has been set-up to supply the electrical grid "island" of Bogor in times of emergency. Additional generation capacity above the official nameplate rating can be made available to PLN should their transmission system demand or economic dispatch require additional generation. This increased output flexibility is available to PLN during circumstances such as when one of the three units is out for scheduled maintenance or when PLN may have several units out for unscheduled or scheduled outages.

10. CONCLUSIONS

Despite the obstacles and challenges encountered during field development and construction periods, the Gunung Salak Geothermal Expansion Project was successfully completed and started commercial operations in December 1997. Unocal Geothermal of Indonesia, in partnership with PT Nusamba Geothermal, Pertamina and PT PLN completed the first private geothermal power build-own-transfer project in Indonesia. The locally hired and trained operators are now operating all the project facilities, which generate power into the Java-Bali Grid. The field generation has been up to 340 MW and availability is nearly 100 percent for Units 4/5/6.

11. ACKNOWLEDGEMENTS

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