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FUJI ELECTRIC REVIEW

4

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Geothermal Power Generation

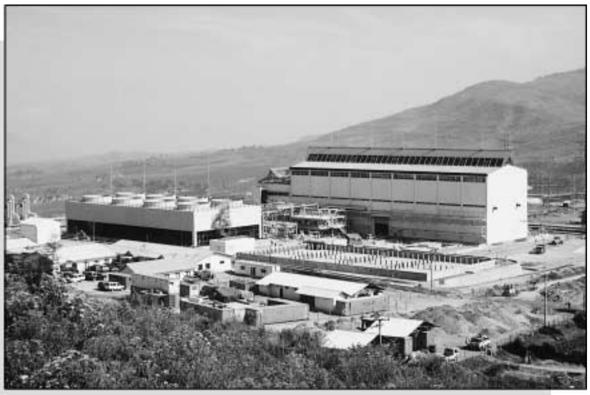
FUJI ELECTRIC

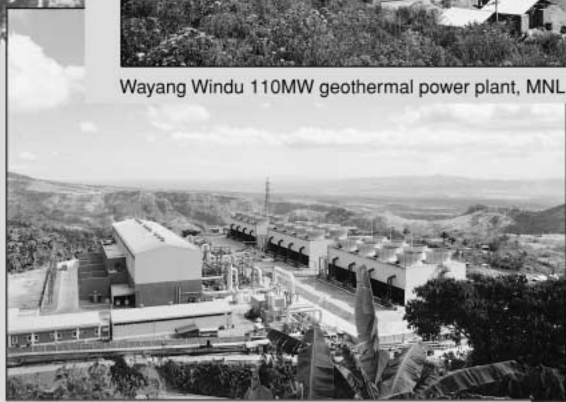
Creating a Better Tomorrow with Trustworthy Technology

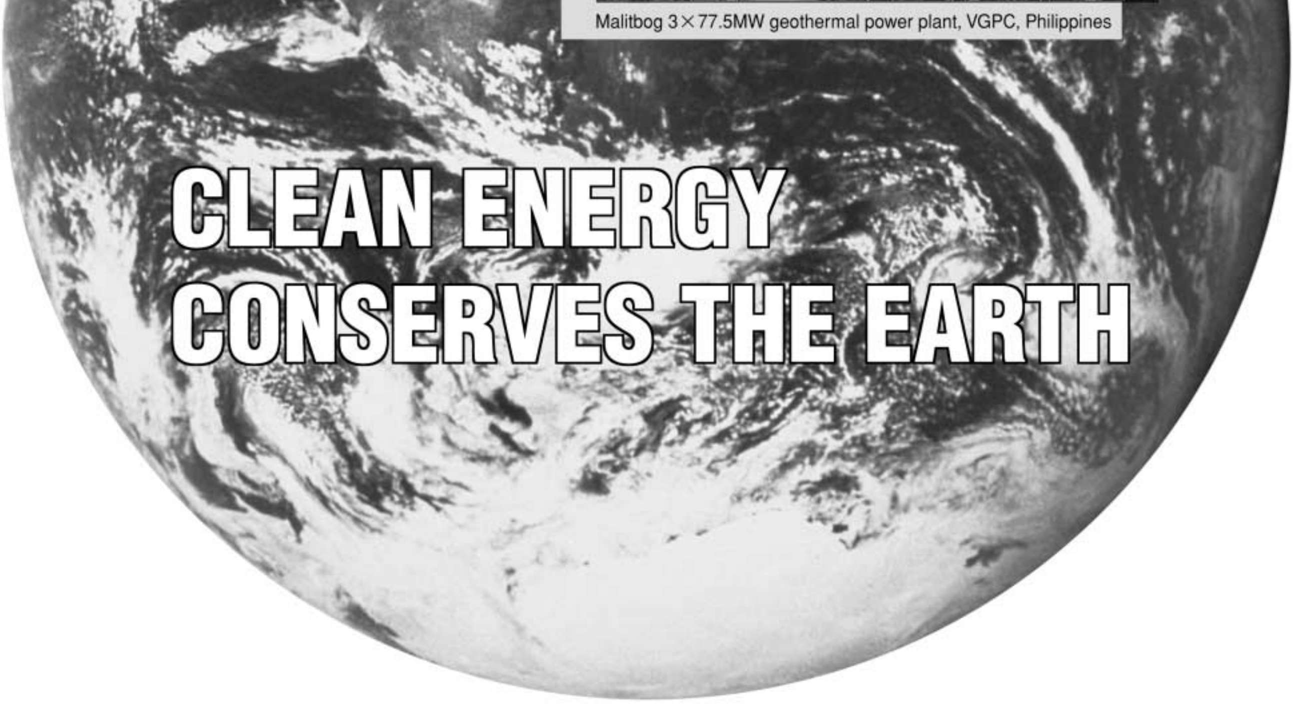
FUJI ELECTRIC'S GEOTHERMAL POWER PLANTS

It is known that geothermal power plants emit no oxides of nitrogen or sulfur and the emission of carbon dioxide in question because of the earth warming is one-tenth as much as oil-burning power plants. In addition, there is no fear of geothermal energy exhaustion.

Fuji Electric has supplied about 1,700MW of geothermal power plants ranging from large-scale utility use to small and medium industrial use and is ready to propose an optimum power plant meeting the needs.


Wayang Windu 110MW geothermal power plant, MNL, Indonesia


Malitbog 3×77.5MW geothermal power plant, VGPC, Philippines



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REVIEW

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Geothermal Power Generation

CONTENTS

Cover Photo:

Geothermal energy is receiving widespread attention as a source of clean and renewable energy. Geothermal power plants are being constructed throughout the world in those countries which have geothermal resources.

Fuji Electric has supplied geothermal power units capable of producing a cumulative output of 1,700MW, ranging from small capacity units such as for a hotel to large-capacity 110MW units, depending on customer needs. The units supplied by Fuji Electric are favorably regarded for their high reliability.

The photograph on the front cover shows a complete view of the Wayang Windu Geothermal Power Plant in Indonesia and its 110MW geothermal steam turbine. The turbine is the world's largest single-casing-type geothermal turbine.

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Fuji's Activities in Geothermal Power Generation

Shigeto Yamada

1. Introduction

Geothermal power generation was first experienced in Italy in 1904 as a water-binary cycle system that used a reciprocating steam engine, very different from the flash cycle systems of today. In 1923, also in Italy, a system which introduces geothermal steam directly into a steam turbine was tested for the first time.

Since then, this system has become the major means of geothermal power generation. Many geothermal power plants which use flash cycles (natural steam, single flash or double flash) have been built in countries where geothermal resources are abundant such as New Zealand, the Philippines, the USA and Japan. According to presentations at the World Geothermal Congress of May, 2000 in Beppu and Morioka, Japan, the total capacity of geothermal power plants in the world is about 8,000MW at present. Of that number, Fuji Electric has supplied equipment that produces about 1,700MW in total.

2. Current Status

Features of geothermal power generation, that it is clean and recyclable, are widely known. Since there is no combustion of fossil fuels which emit carbon dioxide and nitrous or sulphurous oxides, geothermal power generation contributes to the conservation of the environment. Geothermal steam was originally rain water which penetrated deep underground and then was heated by magma. After being separated from steam, hot water is also returned from wells to the earth. This completes a natural recycling system. Although geothermal energy cannot be transported like a fossil fuel, it is actively being developed in countries where geothermal resources are abundant. Figure 1 shows geothermal zones throughout the world and the capacity of geothermal unit installed by Fuji Electric. Table 1 shows the capacity of countries in both 1995 and 2000, and a forecast for 2005. As you can see from this table, the development of geothermal power generation is particularly active in those countries which have no petroleum resources such as the Philippines, New Zealand and Italy. In the USA which has the largest installation of geothermal power plants in the world, and at the same time is a major oil producing country, geothermal power generation is recognized as an economical and environmentally benign means of power generation, and geothermal resources are abundantly distributed in the western states, especially in California. Although Indonesia is blessed with fossil fuels such as oil and natural gas, it is aggressive in the development of geothermal resources. All geothermal energy development plans in Indonesia have been suspended ever since the economical crisis, however, those plans will be revived soon. If present development plans are realized, Indonesia will become one of the largest geothermal power generation countries in the world as shown in Table 1.

In the Philippines and Indonesia, geothermal power plants used to be built by national utilities such as NPC (the Philippines) and PLN (Indonesia). However, it is becoming more popular to build a plant under BOT (build, operate and transfer) type contract where a foreign developer and the national utility sign an ECA (energy conversion agreement) or PPA (power purchase agreement). This system helps accelerate the construction of power plants by attracting foreign developers, particularly American developers who have vast domestic experiences. In this system, either a governmental body such as PNOC-EDC (the Philippines) or PERTAMINA (Indonesia) develops and maintain geothermal fields to supply steam and developers build power plants, or a private developer does everything from drilling wells and constructing pipelines to building the power plant. In either case, the main tendency is for the developer to enter into an EPC (engineering, procurement and construction) type contract with a supplier, where the supplier is solely responsible for completion of the power plant. In order to receive financing from monetary institutions, it is essential to have a single responsible entity as the main contractor rather than having multiple contractors.

Fuji Electric, a leading manufacturer of geothermal steam turbines, recognizing the needs of geothermal developers, has become increasingly focussed

Fig.1 Worldwide geothermal zones and power plants supplied by Fuji Electric

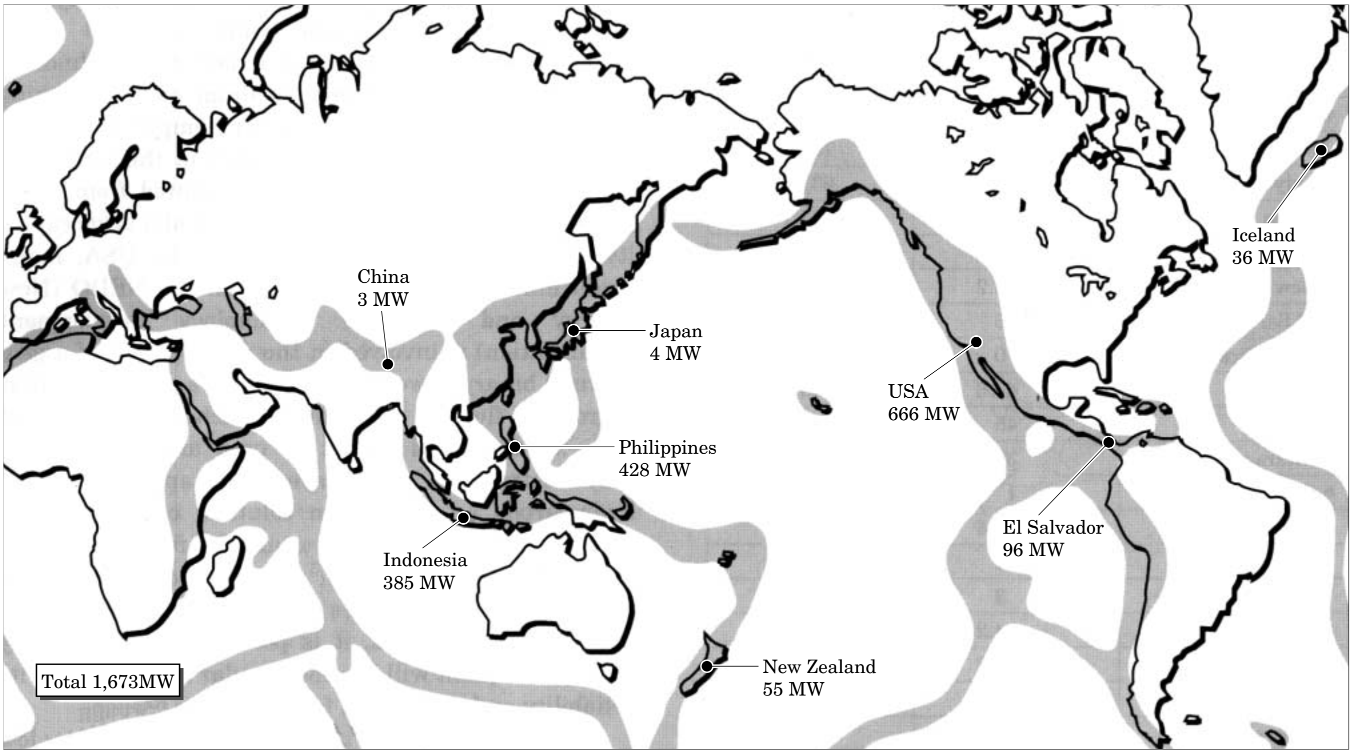


Table 1 Worldwide capacity of geothermal power plants (Source : IGA NEWS, July to September 2000)

Countries	Capacity (MW)		
	Year 1995	Year 2000	Year 2005 (forecast)
* USA	2,817	2,228	2,376
* Philippines	1,227	1,909	2,637
Mexico	753	755	1,080
Italy	632	785	946
* Japan	414	547	567
* Indonesia	310	589	1,987
* New Zealand	286	437	437
* El Salvador	105	161	200
Nicaragua	70	70	145
Costa Rica	55	142	161
* Iceland	50	170	170
Kenya	45	45	173
* China	29	29	NA
Turkey	20	20	250
Russia	11	23	125
Portugal	5	16	45
France	4	4	20
Argentina	0.7	0	NA
Thailand	0.3	0.3	0.3
Australia	0.2	0.2	NA
Ethiopia	0	9	9
Guatemala	0	33	33
Total	6,833	7,974	11,398

Note : * shows the countries where Fuji Electric supplied geothermal power plants.

toward total plant engineering. In the recent construction of Malitbog Geothermal Project in Leyte, Philippines, Fuji Electric (along with a trading company as the main contractor) worked on the project to provide a full turnkey solution, including construction, civil engineering work, manufacturing, procurement, installation and commissioning of the plant which consists of three 77.5MW units. In this case, the only data supplied to Fuji Electric was given were the steam conditions at the plant boundary, the site meteorology, and the customer's required net plant output. Fuji started the engineering work by determining the design wet bulb temperature, which has a large influence on the plant economy and performance. Then, design conditions were determined for the main equipment and each sub-system. The ultimate goal of plant engineering is to realize a geothermal power plant which is reliable, highly efficient, economical, and at the same time has a minimum influence on the environment.

More recently in 1999, Fuji Electric provided equipment to the Wayang Windu Geothermal Power Plant located in West Java, Indonesia also under an EPC contract. The power plant is equipped with a 110MW geothermal steam turbine, the world's largest single casing turbine for geothermal service.

Another recent example, in contrast to Wayang Windu in terms of its size, is the Hachijo-jima Geothermal Power Plant also inaugurated in 1999. The power plant, whose output is 3.3MW replaced distributed diesel power plants in Hachijo-jima island which is a remote volcanic island in eastern Japan about 300km from Tokyo.

3. Technological Aspects

3.1 Large capacity geothermal steam turbines

In the latter half of the 1980's, several large scale 110 to 150MW capacity units consisting of two 55MW class turbines coupled in tandem, were constructed in the Geysers area of northern California to lower the cost per kWh of generating power. These large units can certainly help reduce the plant construction cost per kilowatt, but they run the risk of causing a shortage of steam to generate the rated capacity. In fact, the last 150MW unit was manufactured and delivered in 1989 but never installed because of the shortage of resources. A large unit is especially unsuited for an IPP (independent power producer), which sometimes rely on only a single unit for revenue, use of a large capacity unit is inappropriate because of possible shut downs of the total power plant due to scheduled maintenance or trouble. Therefore, if the developer has enough steam to support 150MW, it is wiser to install three 50MW units or two 75MW units to increase the flexibility of plant operation.

3.2 Packaged type geothermal steam turbines

On the other hand, there are increasing demands to shorten the period of site work. Responding to this demand, Fuji Electric has standardized so-called skid mounted type turbines and has delivered several of them. To minimize the onsite installation work, steam turbines and generators in the 20 to 40MW range are completely pre-assembled on separate beds at Fuji Electric's Kawasaki Factory prior to shipment. For smaller units, it is possible to assemble both the turbine and the generator on one common bed. However a skid mounted configuration is impossible for larger units such as the ones manufactured for the Philippines and Indonesia due to transportation restrictions, Fuji's design aims to reduce the number of assembled blocks per shipment in order to shorten the installation period. Since most geothermal sites are in remote mountainous areas, and the majority of available labor cannot always be expected to be well experienced, reducing the number of blocks in the shipment becomes even more important from the point of view of both the site schedule management and the preservation of reliability.

3.3 Titanium alloy last-stage blades

Geothermal steam contains hydrogen sulphide, and in such an environment, the internal stress of turbine parts such as blades and rotor should be within the appropriate limit value for each material to avoid cracking due to stress and corrosion. The maximum centrifugal force is exerted at the base of the low pressure blade in the last stage. For this reason the length of the stainless steel blade of the last stage is limited to 26 inches at 60Hz (nominal) or 30 inches at 50Hz. However, since the enthalpy of geothermal steam is low, the turbine exhaust loss cannot be ignored as a portion of the heat drop across the turbine. By using longer last-stage blades, costs can be lowered by reducing the exhaust loss or by implementing a single flow design rather than a dual flow design for the same steam flow. A last-stage blade longer than current limit must be made of a titanium alloy which is lighter than stainless steel and has excellent erosion- and corrosion-resistant characteristics. Fuji Electric has successfully tested long titanium alloy blades and is prepared to supply turbines that use such blades. The physical dimensions of turbines will inevitably increase as longer blades are employed. While contrary to the concept of above mentioned skid mounted design, this technology may be used in the near future for a very big geothermal field if enough steam to support multiple 100MW class units is confirmed.

3.4 Utilization of low temperature geothermal resources

Most geothermal power generation is in the form of a flash cycle that introduces steam, separated from geothermal brine, directly into a steam turbine. To use low temperature geothermal resources for power generation, binary cycle technology employs a suitable thermal medium as the working fluid according to the hot water temperature. This technology has been utilized mainly in the USA. The capacity of a single binary unit is limited from several hundred kW to 4MW maximum. To build a large capacity plant such as a 40MW plant in the USA, many small units are combined. In Japan, NEDO (New Energy and Industrial Technology Development Organization) is involving in the development of a geothermal binary power plant. One problem is that a group of fluorine compounds, which were often used as the working fluid, can no longer be used anymore because they destroy the ozone layer. The application of a hydrocarbon or ammonium solution, or discovery of a new thermal medium is very important for further development of binary cycle power plants. Since medium and low temperature resources are more common than high temperature resources, it is possible that the binary cycle power plants will become popular in Japan once their reliability and economical feasibility are proven.

Other technologies that utilize medium and low temperature geothermal resources for power generation are the total flow turbine and the low pressure flash cycle. The total flow turbine directly intakes geothermal brine, which is either hot water or a mixture of steam and hot water. Fuji Electric designed and manufactured a small scale total flow turbine and carried out a series of factory tests and an onsite test of approximately 1,000 hours using a geothermal fluid. One possible application of the total flow turbine is to utilize hot water from the separator for power generation, before the hot water is re-injected to compensate for plant parasitic loads.

The low pressure flash cycle is similar to an open cycle OTEC (ocean thermal energy conversion). It simply generates low pressure steam by flashing hot water, and guides that steam into the steam turbine. This method does not require the development of new technology because the turbine is an application of the low pressure part of the existing dual flash steam turbine. The characteristic features of this system are that no special working fluid is necessary and that the plant parasitic load is small compared to a binary cycle.

3.5 New technologies

There have been several proposals to use heat from magma or volcanoes directly for power generation, and some basic research has been carried out. The hot dry rock (HDR) technology is probably the most advanced new technologies under development for geothermal power generation. In Japan both NEDO and the CRIEPI are working on HDR projects and have succeeded in retrieving injected water as steam. The next step will be improvement of the percentage and temperature of retrieval. An HDR power plant must be a closed cycle so that the flow of injected water can be reduced. One possibility to solve this problem is to employ a dry type cooling tower instead of the commonly used wet type. The application of a binary power plant is another possibility.

4. Conclusion

This year, the total installed capacity of geothermal power generation in Japan is 580MW, and some additional developments are planned. The Philippines increased their capacity during the 5 years from 1995 to 2000 by 680MW, which includes the construction work of geothermal power plants in Leyte and Mindanao, and still has further development plans. In such Central American countries as El Salvador and Costa Rica, several new geothermal projects,each being 50 to 60MW in size, were completed in late 1990s. Indonesia once had many plans for large capacity geothermal power plants, but these have been suspended ever since the country's economy crisis. However the already signed BOT or BOO (build, operate and own) contracts are still valid, and these projects are expected to resume soon. In addition to these big projects, installations of small wellhead units in remote communities which will allow more people to access to electricity are another possibility as a local energy source in a country like Indonesia.

Coping with the continuously increasing demand for energy while striving for harmony with the global environment is a serious issue for the entire world.

Geothermal power generation, however small a percentage of the total energy output, can be a major source of power in regions or communities where geothermal resources exist. Fuji Electric, through the construction of geothermal power plants based upon its many proven global technologies, as well as new technologies, will contribute to solving the global energy problem.

Wayang Windu Geothermal Power Plant

Hiroshi Murakami

1. Introduction

Throughout the world, development of geothermal power plants has been promoted to utilize clean and renewable energy with low carbon dioxide emissions. The country of Indonesia has the fifth largest development of geothermal energy, following the USA, Philippines, Italy and Mexico in the world.

In June 1997, Fuji Electric of Japan, together with a trading company, entered into an engineering, procurement and construction (EPC) contract with Magma Nusantara Limited (MNL) of Indonesia to supply equipment for the Wayang Windu Geothermal Power Plant (rated capacity : 110MW), including a power station and a steamfield above ground system (SAGS). As an independent power producer (IPP), MNL will operate the plant and sell electricity to Persahaan Listrik Negara (PLN) for 30 years.

The geothermal steam turbine manufactured at Fuji Electric's Kawasaki Factory, has the world's largest single casing capacity of 110MW with 27.4 inch long last-stage blades (LSB).

The plant was put into commercial operation in June 2000. One year after commencing operation, the turbine was disassembled, inspected and checked. Visual inspection revealed neither damage nor contamination. Thus far, plant operation has continued with no reported problem.

2. Overview of the Plant

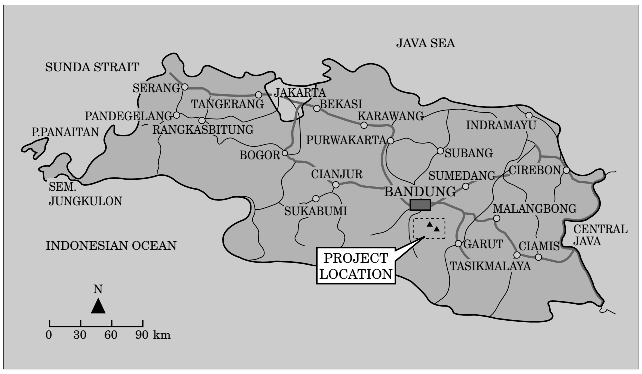
2.1 Plant location

Wayang Windu Geothermal Power Plant is located in Pangalengan approximately 40km south of Bandung, West Java in Indonesia, as shown in Fig. 1. The plant is named after nearby Mt. Wayang and Mt. Windu. A tea plantation surrounds the site and its altitude is approximately 1,700m above sea level.

2.2 Distinctive characteristics

Since the plant is an IPP project, low capital cost and reliable operation with high efficiency are essential from an economical point of view. The plant has several distinctive characteristics including large capacity turbine, two-phase fluid pipelines with central separators, and integrated pressure control designated to meet such requirements.

Fig.1 Project location



(1) Large capacity turbine

It is well known that larger capacity turbines are more efficient for geothermal as well as conventional power plants. The largest single casing capacity geothermal turbine of 110MW is utilized at this plant.

(2) Two-phase fluid pipelines

A mixture of steam and water from production wells is led to a central separator station as two-phase fluid. Use of smaller bore piping can reduce piping material and construction costs, comparing to the conventional steam flow piping

(3) Integrated pressure control system

Stable separator pressure is essential for maintaining steam quality. The integrated pressure control system uses turbine governor valves to maintain steam quality by varying pressure at the same time as controlling flow at the production wells. Consequently, the release of geothermal steam to the atmosphere can be minimized.

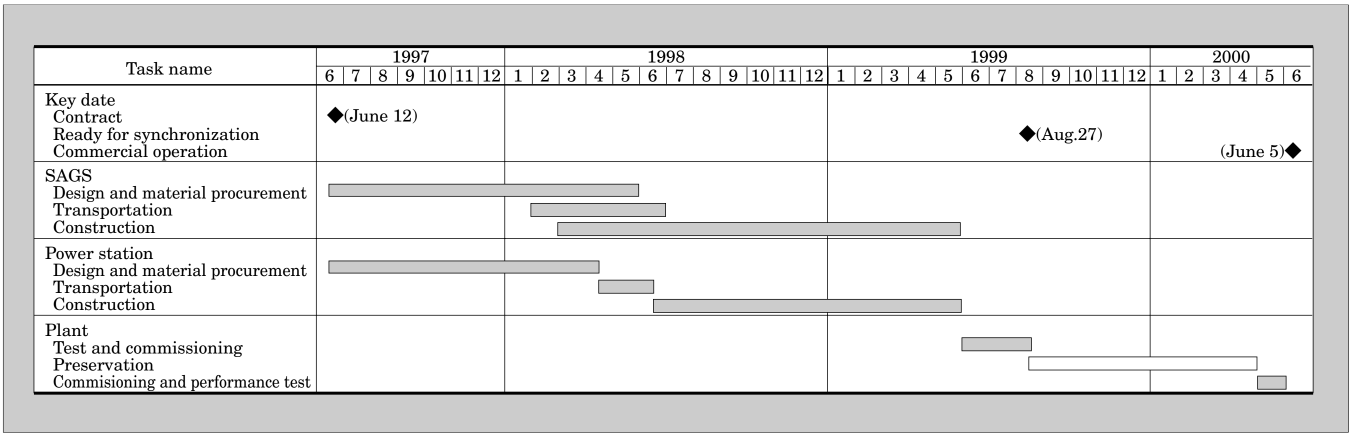
(4) Local architecture

In consideration of harmony with surrounding tea plantation, locally traditional roof and color are incorporated in the architectural design of the power plant.

3. Project Schedule

Figure 2 shows the project schedule, which includes

Fig.2 Project schedule



engineering, design, manufacturing, transportation, construction and commissioning. The contract began in June 1997 and the plant was ready for synchronization in August 1999. After 8 months preservation, the plant went online in June 2000.

3.1 Engineering, design and manufacturing

Critical equipment such as the turbine, generator and condenser were shipped from Fuji Electric's Kawasaki Factory 12 months after notice to proceed was given by MNL. Major auxiliary equipment such as hotwell pumps, the cooling tower, gas removal system, main transformer and distributed control system (DCS) were shipped from Japan, USA, Australia, Singapore, etc., 12 to 16 months after signing of the contract. SAGS piping materials designed by Kingston Morrison Limited (KML) were shipped in stages from Japan, USA, Korea, etc., 8 to 16 months after signing of the contract.

3.2 Construction and commissioning

Civil and construction work was delegated to local subcontractors. Proposals for that work were thoroughly evaluated in terms of technical, commercial and financial perspectives. Onsite work for power station started in June 1997.

SAGS onsite works started in December 1997. A local engineering company, which is a subsidiary of a New Zealand engineering company, has been hired for managing and supervising such subcontractors.

3.3 Preservation

Because the transmission line constructed by PLN was not completed in August 1999, the plant was put on preservation for 8 months.

Mechanical equipment such as the turbine and hotwell pump were disassembled and anti-corrosive measures were taken. Space heaters were put into operation for electrical equipment where necessary. Control and instrument equipment such as DCS and the monitoring system were operated normally.

SAGS pipelines were steam-capped at low pressure steam from production wells.

Fig.3 Power station overview

4. Power Station

Figure 3 shows an overview of the power station. The area is almost square, having 230m E-W and 210m N-S. Civil and architecture for Units No.1 and 2 and the power plant for Unit No.1 are completed at present.

The turbine is of the single flash and double flow type. The cooling water system is a closed circuit consisting of a direct contact condenser and wet cooling tower. The gas removal system is a hybrid system consisting of a steam ejector and vacuum pump.

Figure 4 shows a schematic diagram of the power station and Fig. 5 shows the power station layout after completion of Units 1 and 2.

4.1 Steam turbine

Major specifications are listed below.

Type : single cylinder, double flow and condensing type
Output : 110MW (MCR 115MW)
Inlet steam press. : 1.02MPa
Inlet steam temp. : 181°C
Exhaust press. : 0.012 MPa

Fig.4 Power station schematic diagram

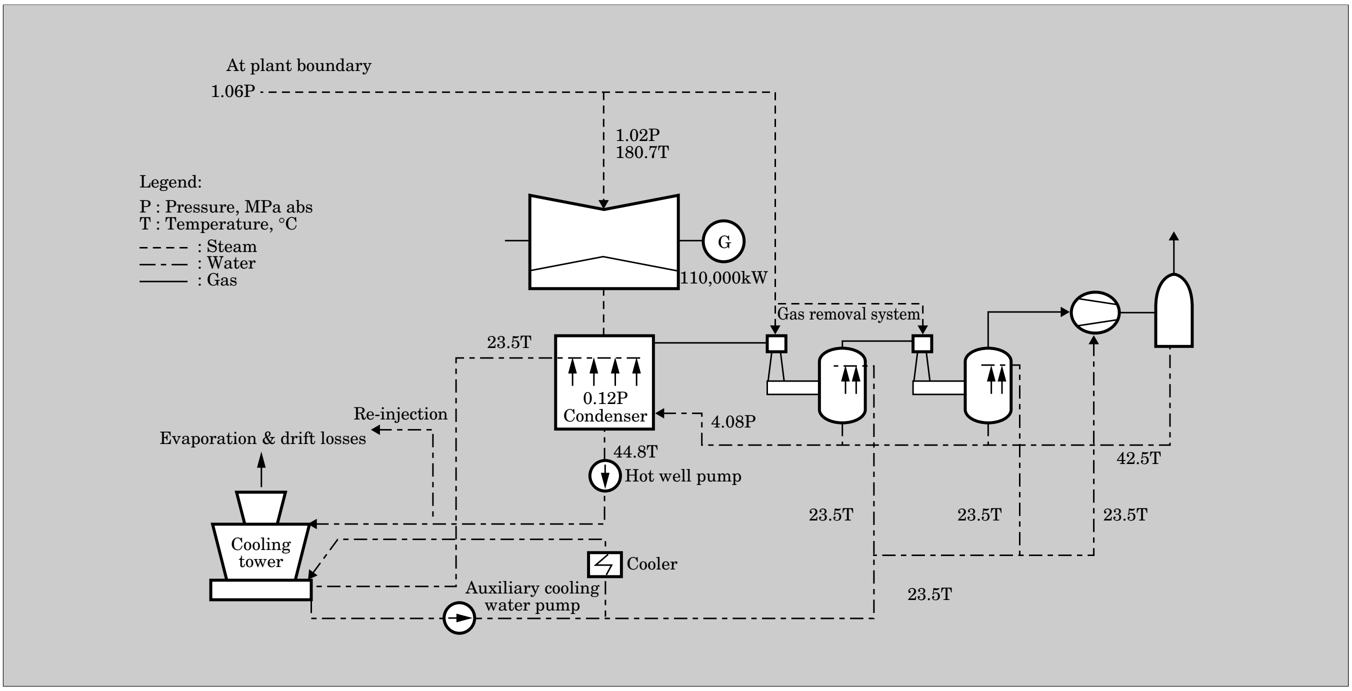
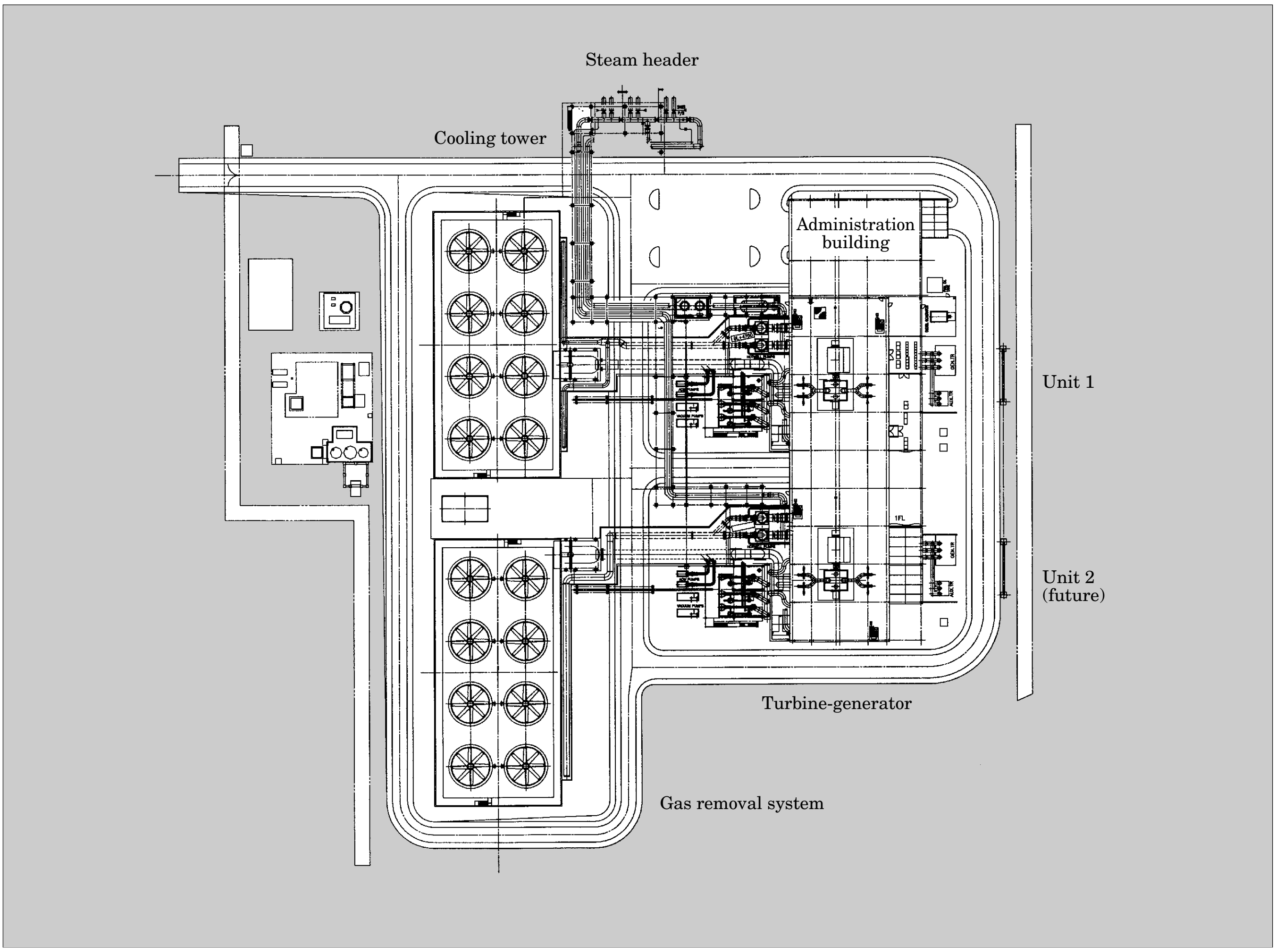


Fig.5 Power station layout



Number of stages : 2 (flows) × 8
Length of LSB : 697 mm (27.4 inch)
Bearing span : 5,800mm
Speed : 3,000 r/min

Figure 6 shows a cross section of the turbine.

(1) High efficiency LP blade

Advanced LP blades are employed in the last three stages, which are designed using the fully three-dimensional (3-D) flow calculation method. The last stationary blades are angled in the radial direction to reduce losses at the root area. The airfoils near the tip of the LSB form the so called convergent-divergent channel that minimizes the shock wave losses. By employing these advanced LP blades, efficiency at the LP blades can be improved by 3%.

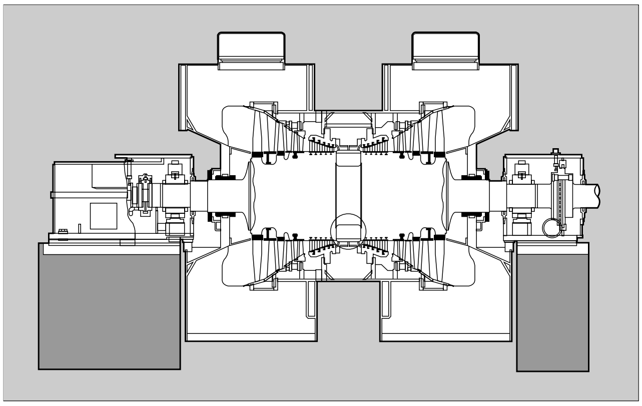
(2) Reaction blade

The turbine blades of Fuji Electric's geothermal steam turbines are all reaction type blades. Blades in the first through fifth stages are integral shroud blades, each of which is machined from one piece of material. These blades are assembled in the rotor and/or the stationary blade holders so that the shroud and root have compression stress on each surface that contacts the adjoining blades at both sides. With this type of assembly, high vibration damping due to dry friction will be produced, but no gaps will form between the adjoining blades under any operational conditions . The moving blades of the sixth stage have a integral shroud with zigzag contour that assures good damping.

(3) Casing

The turbine casing has a single shell construction and is composed of two blocks in the axial direction, i.e. the front and rear parts. The upper half of the casing is shipped as one block, bolted at the vertical joint flange of the front and rear parts assembled with the upper half of stationary holder and/or stationary blade rings, so as to decrease the work at job site. The lower half is also designed as one block in the factory. The casing is directly supported by foundation at both sides of the exhaust. The bearing pedestals are independent from the casing and directly fixed on the foundation. This construction secures the vibration stability of the turbine rotor.

Fig.6 Turbine cross section



(4) Corrosion protection

The turbine uses reaction blades and therefore the turbine rotor has a drum type construction. Due to the flat configuration, stress concentration and deposition of corrosive components are eliminated and the possibility of stress corrosion cracking (SCC) is avoided. Because the rotor has the longest LSB for geothermal use, its maximum diameter is quite large and stresses on the blade groove are large. To reduce the maximum stress on the blade groove, the newly designed low stress groove is employed.

(5) Erosion protection

Stellite shields are brazed to the L-0 and L-1 moving blades on the tip to protect against erosion by water droplets. Also to reduce the erosion by water droplets, drainage is provided at the inlet chamber, fifth stage outlet, and inter-stage of LP-blade row, whereby water droplets will be discharged to the condenser.

(6) Scale protection

A blade wash system is provided as another countermeasure against scaling. This blade wash system washes the turbine blades during normal operation by injecting condensate water.

4.2 Generator

The air cooled turbogenerator for this plant is the largest capacity unit developed by Fuji Electric for geothermal power plants.

(1) Major specifications are as follows:

Type : three-phase horizontal cylindrical revolving field total-enclosed type synchronous generator.
Ventilation : self-ventilation
Cooling : totally enclosed water-to-air cooled (TEWAC)

(2) Rating

Output : 137,500kVA
Voltage : 13.8kV
Power factor : 0.8 (lag)
Frequency : 50Hz
Number of phases : 3
Speed : 3,000r/min
Insulation class : F
Excitation : brushless excitation

5. Steamfield Above Ground System (SAGS)

Steamfield above ground system (SAGS) is the generic name for facilities other than the power station in a geothermal power plant, such as the steam pipeline, brine/condensate pipeline, separator, scrubber, rock muffler, etc.

Figure 7 shows a schematic diagram of SAGS.

5.1 Production and injection wells

The production and injection wells were developed

Fig.7 SAGS schematic diagram

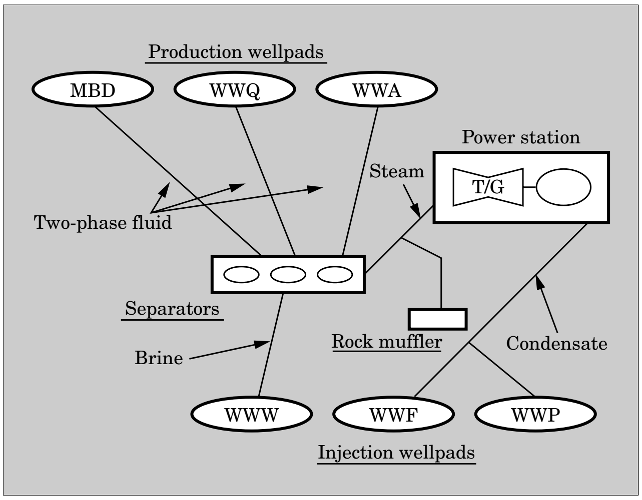


Fig.8 Production wellpad (WWQ)

by MNL prior to commencement of the work for the power station and SAGS. There are three production wellpads and three brine/condensate injection wellpads. Each production wellpad has three or four wells ranging from 1,800m to 2,500m.

The altitude of the production wellpads is approx. 1,850m above see water level (aswl), being higher than that of the power station by 150m. On the other hand, the altitude of the injection wellpads is approx. 1,500m aswl, being lower than the power station by 200m.

Figure 8 shows a production wellpad (WWQ).

5.2 Pipeline

Geothermal steam and fluid from production wells are piped downhill to the separators as two-phase fluid. Pipelines from each wellpad to the separators are made of carbon steel with a 36-inch nominal bore. The distance between the wellpads and separators is approx. 4km. The steam pipeline from the separators to the power station has a 40-inch nominal bore and is approximately 1km long. The brine pipeline from the separators to the injection wellpads has a 30-inch nominal bore and approximately 8km long. The condensate pipeline from the cooling water piping to the injection wellpad has a 28-inch nominal bore and is approximately 9km long.

The necessary pipe loops are provided on those pipelines to absorb thermal expansion.

5.3 Separator, scrubber and rock muffler

Three cyclone type separators are used to separate steam from the two-phase fluid that comes from production wells. Steam is fed to the power station while brine is fed to the injection wells.

Two corrugate type scrubbers are provided just in front of the power station to eliminate further moisture.

Surplus steam is released to the atmosphere through vent valves. Two rock mufflers are provided near the separator station to reduce the noise level of released steam.

Figure 9 shows an overview of SAGS.

6. Power Generation

Since the commencement of commercial operation in June 2000, the plant has been operating stably as a base load power supply for the West Java region. In consideration of recent power demand, the plant is controlled to generate 110MW of power during the daytime and 105MW during the nighttime by the PLN load dispatch center in Bandung.

Figure 10 shows the monthly power generation since June 2000.

7. Other Issues

7.1 Environmental protection

A tea plantation and villages surround the plant. During the construction and commissioning periods, storm water discharge, soil disposal, dust, and water quality have been controlled to ensure minimal environmental impact. Periodical monitoring reports in accordance with AMDAL (Indonesian environmental regulation) were submitted to the government office every 3 months.

7.2 Weather

The period from May through October is usually the dry season. Civil works such as excavation, concrete pouring and backfilling were planned to take place during the dry season. However, there was no dry season in 1998 due to the so called “La Nina phenomenon” which was a consequence of “El Nino phenomenon” in 1997. The progress of civil and structural works was significantly affected. Unanticipated environmental protection works were implemented accordingly.

7.3 Economic crisis in Indonesia

In Indonesia as well as other Southeast Asian countries, an economic crisis occurred in 1998. The difficulty that local subcontractors had in raising funds

Fig.9 Bird's-eye view of SAGS

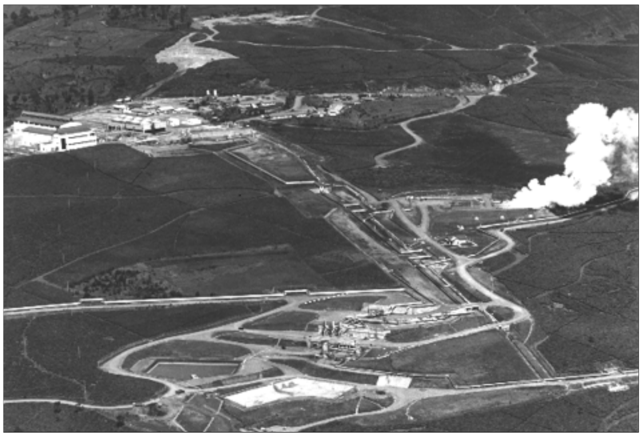
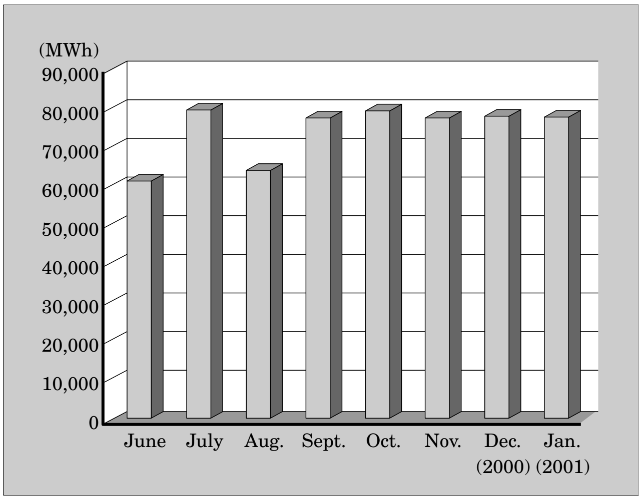


Fig.10 Monthly power generation



resulted in the delay of work progress. Local subcontractors faced difficulty in purchasing materials from foreign countries because foreign companies did not accept letters of credit issued by Indonesian banks.

As a countermeasure, we offered improved terms of payment to the subcontractors so as to assist in solving their finance problem and we purchased necessary materials from foreign companies and supplied them to the subcontractors.

8. Conclusion

The world's largest capacity geothermal turbine was manufactured at Fuji Electric's Kawasaki Factory in Japan, based on extensive experience in both the geothermal and conventional power generation businesses.

The Wayang Windu Geothermal Power Plant unit No.1 has been successfully completed in cooperation with MNL and local subcontractors. We sincerely hope that the electricity generated at this plant will contribute to the development and improvement of life for local people in this area.

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Berlín Geothermal Power Plant

Tadao Horie

1. Introduction

The Berlín Geothermal Power Plant is located in the province of Usulután, an eastern vicinity in the Republic of El Salvador, Central America. The plant area consists of 15km^2, is 107km away from the capital city of San Salvador (See Fig. 2), and is at an altitude of 645 meters above sea level. Geothermal resources at the Berlín area were originally explored in 1970's, but actual project development activities only began in the early 1990's. El Salvador has two existing geothermal complexes. One is Ahuachapán, located in the western vicinity of the country and consisting of three units with 95MW net capacity in total. The other is Berlín, where two 5MW wellhead units have been operational since 1992. This project is the second phase of development of Berlín Geothermal, following construction of the wellhead units. This is also the second project for Fuji Electric to provide equipment to El Salvador, more than 20 years after completion of the Ahuachapán Unit 3 (35MW, dual pressure unit) in 1980.

A turnkey contract was signed with the owner, Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL) in November 1996. After overcoming some natural obstructions, steam was successfully produced, and continuous power generation began in April 1999, The two units were officially put into commercial operation in November 1999.

After more than one year of continuous operation, the first major inspection was carried out in September and October 2000 for each unit respectively. During the inspection, no major problems were found in any of the plant systems and principal equipment.

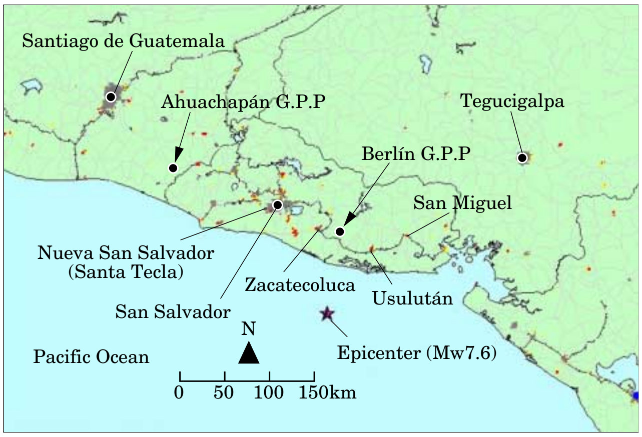
2. Summary of Contract Scope of Work

The basic contract scope includes the engineering, design, supply, procurement, construction and commissioning of 2 units of 28MW for the condensing power generation plant and its associated steam production system. This project involved the expansion of an existing geothermal plant with further future expansion possibilities, however since the new plant is located mostly in a remote field area, infrastructure related works were also included in the scope of work. To summarize, the following geographical area are in our scope of work:

(1) Power generation facility, consisting of 2 × 28.12MW units (Units 1 and 2)
(2) Grading/landscaping of area of future units
(3) 1.2km of access road from the junction of national road (Mercedez Umaña - Berlín Road) to the power plant
(4) Accumulation tank for condensate overflow from the cooling towers

Fig.1 Overview of Berlín Geothermal Power Plant, El Salvador

Fig.2 Map of El Salvador and location of Berlín



(5) Steam separation system and fire water tank at Production wellpads TR-3, TR-4 and TR-5
(6) Cross-country cable ductworks between power plant, production wellpads and CEL's resource office at existing backpressure units
(7) Remote monitoring system of reinjection wellpads TR-1, TR-8 and TR-11
(8) 115kV switchyard equipment at Berlín and remote substations, 15 de Semtiembre S.S. and San Miguel S.S.

In conjunction with the engineering work, Fuji Electric supplied its own steam turbine and condenser units and procured all other equipment and material from various countries. The construction work was subcontracted to and carried out by local firms. For example, earthmoving and foundation works for the power plant, access road and accumulation tank (cold water condensate pond) were performed by Piassa, SA de CV, architectural and electromechanical works for the power plant were performed by Prinel SA de CV, and the steam production system was constructed by Monelca SA de CV.

3. Description of Each Plant Subsystems

3.1 Steam production system

In addition to existing production wellpads TR-2 and TR-9 which has been supplying steam to existing backpressure units (2 × 5MW), new production wells were drilled by CEL at wellpads TR-4 and TR-5. Our contract includes construction of 4 steam separators and associated piping systems at TR-4 and TR-5, which have a total of 8 production wells. The two phase fluid piping at the wellhead was designed to be routed through an underground channel so that future re-drilling or repairing of existing wells can be executed without removing large quantities of wellpad piping, and with minimum disturbance of production to that wellpad (See Fig. 3). The two-phase fluid is routed to separators (See Fig. 4) and separated steam is transported by 28-inch cross-country steam piping, one from the wellpad TR-5 to steam collector unit 1 located at the south boundary of the power plant at a distance of approximately 2.2km, and the other one from the wellpads TR-4, TR-2 and TR-9 to steam collector unit 2, at a maximum distance of approximately 1.7km. On the other hand, hot water from the separators is fed to reinjection wellpads TR-1, TR-8 and TR-11 also through miles of cross-country pipeline.

Located immediately downstream of each separator is a ball valve that protects the plant from water induction in case the separator should carry over hot water into the steam lines. At the power plant side, there are two steam collectors at the boundary, each equipped with pressure control valves, safety valve and rupture disc which connects downstream to a vent silencer.

The intent of this steam collector design is to maintain, to the extent possible, a constant steam flow in the cross-country pipeline, even if the steam flow to the turbine is interrupted due to tripping of the plant or load rejection.

3.2 Power generation plant systems

3.2.1 Steam turbine

The power plant has two identical steam turbine generator units each of which produce a total output of 28.12MW. The steam turbine has a single-flow top exhaust reaction type skid mounted design. It is also equipped with a blade washing system, allowing the injection of condensate water into the wheel chamber to remove deposits during load operation. The turbine is controlled by a triple-redundant microprocessor based Woodward Governor 509DCS, which has speed, load and inlet pressure control functions. It is also equipped with features that enable a quick response to runback and vacuum unloading situations. Main specifications of the turbine generator unit are summarized below.

(1) Steam turbine:

Fig.3 TR-5 wellhead

N68-443-54

Fig.4 TR-5 wellpad separators

N68-443-50

Type : single cylinder single flow, reaction condensing
Rated output : 28,120kW (condition A)
Maximum output : 31,490kW (condition B)
Steam pressure : 0.95MPa abs (condition A)
1.06MPa abs (condition B)
Steam flow : 180t/h (condition A)
200t/h (condition B)
NCG in steam : 0.4% in weight
Exhaust pressure : 0.01MPa abs (3 inch Hg A)
Speed : 3,600r/min
Number of stages : 9 × 1
Length of last stage : 581mm (22.9 inch)

(2) Generator:
Type : 3 phase synchronous, TEWAC
Rated output : 37,050kVA
Voltage : 13.8kV
Power factor : 0.85 lagging
Excitation : brushless with PMG

3.2.2 Condenser and NCG removal system

The condenser is a low level direct contact type and its pressure is maintained at 0.01MPa abs by the non-condensable gas (NCG) removal system. The NCG removal system consists of two stages, two 100% capacity ejectors and two 100% capacity ejector cooling water pumps. The extracted NCG from the after-condenser and gland steam ejector condenser is led to the cooling tower.

3.2.3 Circulating water system

The circulating water system consists of two 60% capacity circulating water pumps which discharge condensate from the condenser hotwell to the cooling towers. The cooling towers have 3 cells per unit and are of the counter flow type with splash fill design.

3.2.4 Auxiliary, fire and potable water system

The plant's internal cooling water, the secondary cooling water, is fed to all of the internal subsystems, such as the turbine lube oil cooler, generator air cooler, compressed air system, air conditioning system, etc., and is cooled by the primary cooling water system through a plate type heat exchanger. While the source of water for the primary system is cooling tower water, potable water is used for the secondary cooling water system. Due to the local climate, with its clearly separated rainy and dry seasons, the city water supply from the foothills of Berlín area becomes critical during the dry season and may potentially be interrupted. To offset such risks, a 400 cubic meter capacity fire water tank was installed at a vacant space near production wellpad TR-3, whose elevation is 300m higher than that of the power plant. The power plant fire protection water and potable water are supplied from this tank through an underground pipeline.

3.3 115kV substation

The Berlín Power Station is connected to two transmission lines, one is routed to the 15 de Septiembre Substation and the other is routed to the San Miguel Substation. The Berlín Substation consists of two circuit breakers at the main transformer side, two circuit breakers at the line side, and one tie circuit breaker. Each circuit breaker, except the tie circuit breaker, has line and bypass disconnect switches.

Fig.5 Turbine and generator

N68-443-92

Fig.6 Turbine sectional view

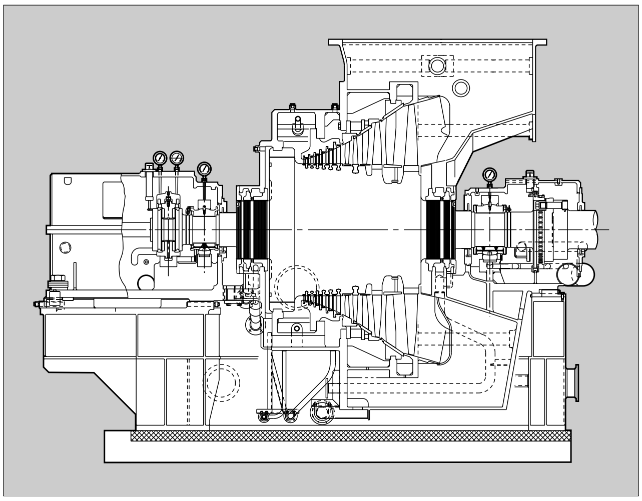


Fig.7 Spray jet condenser

N68-443-62

Redundant protection from transmission line failure is provided by conventional protection relays and a teleprotection system.

All operational conditions and status of the generator's main circuit and substation are also transmitted via the remote terminal unit to a national dispatch center in San Salvador.

Fig.8 Berlín Substation


N68-443-70

3.4 DCS and plant operation/control system

All plant operational conditions including those of the production and reinjection wellpads are monitored by DCS. The DCS itself is a fully double redundant configuration, but in addition to DCS, a PLC-based auxiliary service panel is also provided as a backup in order to realize bumpless transfer of all critical control functions. In other words, operation can be continued without tripping of the plant even if the entire DCS system fails. Pressure control of the steam/water separator and level control of the water tank at production wellpads can be controlled by either the plant's DCS, or by the backup PLC located at each wellpad, which also has the function of providing bumpless transfer whenever DCS control fails. The DCS system also consists of six operating stations: three in the control room, one in the superintendent's room, one in the operation chief's office (both of these rooms are located in the administration building in the power plant), and one in CEL's resource office (located at the 2 × 5MW pilot plant approximately 1km away from the power station).

Fig.9 Power generation plant layout

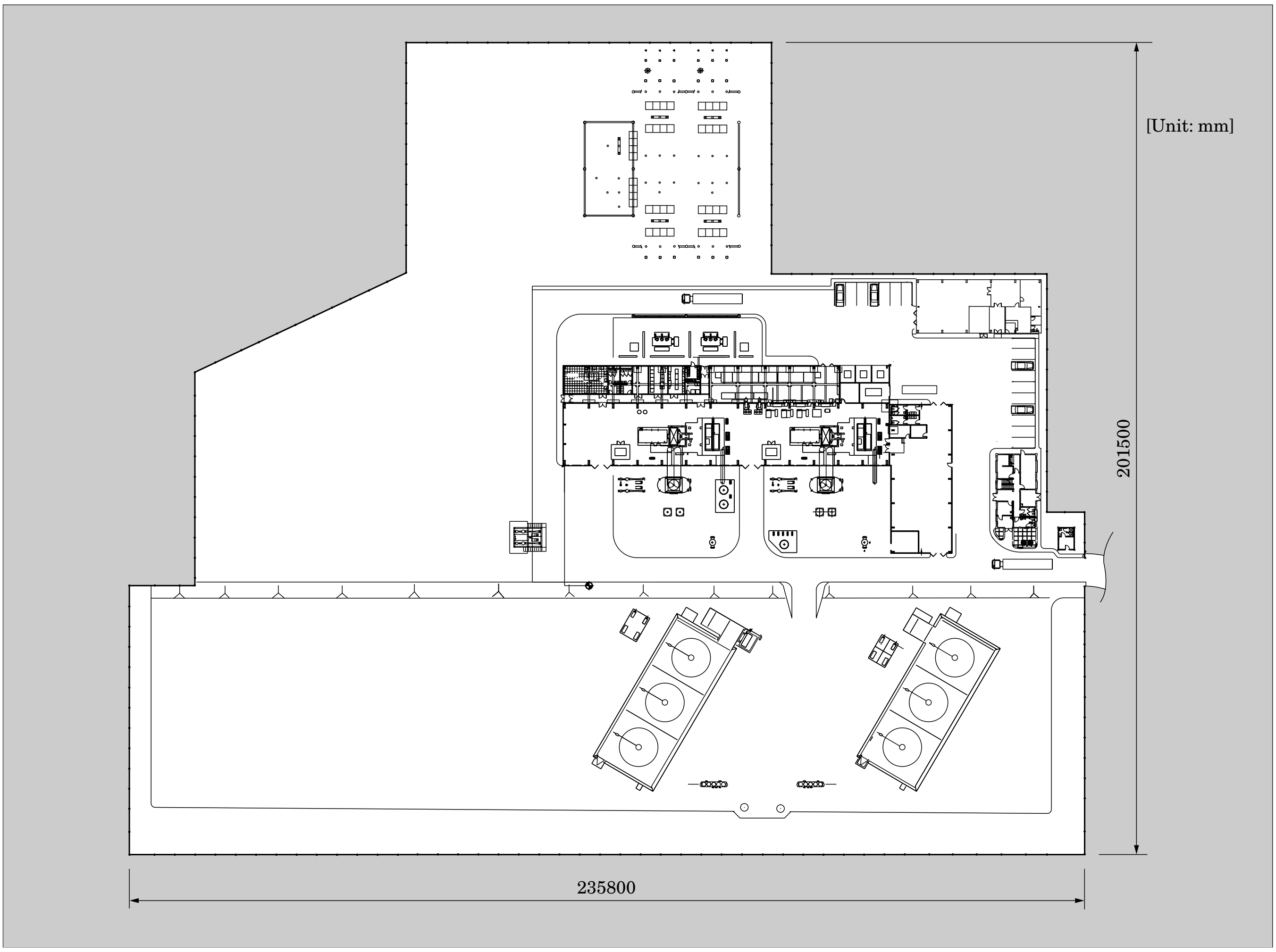


Fig.10 Plant control room

N68-443-5

Fig.11 Reinjection wellpad

N68-443-11

3.5 Reinjection system

All hot water from the 4 wellpad separators is led to reinjection wellpads through a cross-country water pipeline and is continuously reinjected. To confirm secure operation of the production wellpads, the flow and pressure of the reinjection line at each reinjection wellhead are continuously monitored. Because of the remoteness of the reinjection wellpad area, the monitoring panels at reinjection wellpads are powered by solar panels and all data is transmitted to the DCS in the plant control room via a radio frequency system. On the other hand, monitored data at production wellpads is transmitted to the plant's DCS via hard-wired lines.

4. Construction and Commissioning

The construction work was subcontracted to local firms. Other contractors were also working throughout the Berlin geothermal area, such as cross-country piping installation contractors, transmission line construction contractors, O&M personnel camp facility building contractors, etc. All of the interfaces and potential conflicts between the parties were well coordinated by CEL field personnel.

During execution of the construction work, we had to overcome several natural difficulties.

First was the rainy season in 1997. Civil works such as ground breaking work in the power plant area and the access road were started in early 1997, the year remembered for the "El Niño phenomenon". Although the rainy season in El Salvador normally ends in October or November, the rainy season in 1997 was extremely severe and long, lasting until the beginning of the following year.

Second was the discovery of an enormous underground layer of solid rock in the power plant area, whose volume was approximately 21,000m^3 just in location of the plant building and equipment foundation area.

During the excavation work, a tremendous amount of dynamite was used to blast this solid rock layer.

Third was the assault of Hurricane "Mitch" in November 1998. This hurricane killed hundreds of people nationwide in El Salvador, and plant construction work was forced to slowdown due to water/electricity outages, the non-availability of transportation for worker commuting, etc. Physical damage to the construction site was minimal, however.

All of these difficulties were overcome minimum impact on the schedule, due to the coordination and determined effort by CEL and local subcontractors.

The schedule also had to be coordinated with drilling activities. The new production wells at TR-4 was drilled in mid-1998, and wells at TR-5 were drilled from late 1998 to early 1999. Accordingly, the construction work at wellpad TR-4 was started after the completion of drilling and flow testing in late 1998. When the Unit-1 commissioning test was completed in May 1999, TR-5 construction had not yet started. Therefore, Unit-1 was halted and the steam from TR-4 was then diverted to Unit-2 for commissioning. TR-5 construction work finally started in July 1999 and TR-5 began producing steam in November 1999, when the two units became operational.

5. Conclusion

Geothermal power generation is one of the most proven, reliable and environmentally safe alternative energy sources. Fuji Electric continues to contribute its efforts in providing efficient and reliable geothermal power plants throughout the world. In the course of constructing the Berlín Geothermal Plant, we received tremendous and professional support from the owner, CEL, and from geothermal division company GESAL (Geotérmica Salvadoreña S.A. de C.V.) personnel, to whom we sincerely indebted. Fuji Electric looks forward to opportunities for participation in the next phase of the Berlín geothermal project or in other geothermal projects in El Salvador.

Hachijo-jima Geothermal Power Plant

Takashi Murakami

1. Introduction

Hachijo-jima Geothermal Power Plant, the first-ever geothermal power plant to be built on a remote island in Japan, was constructed in the Nakanogo district of Hachijo-jima. Hachijo-jima is an island located approximately 400km south of Tokyo, with a circumference of 58.9km and area of 65.9km^2. The island is gourd-shaped, and has two volcanic mountains, Miharayama (or Eastern Mountain, located in the south eastern part of the island) and Hachijo Fuji (or Western Mountain, located in the northwestern part).

In 1989, New Energy and Industrial Technology Development Organization (NEDO) selected the island as a site to survey for the promotion of geothermal development. A drilling survey confirmed the existence of promising geothermal resources in the southern part of the Eastern Mountain.

In 1992, The Tokyo Electric Power Co., Inc. started geothermal development on the site and performed production well drilling, blow-off tests, an environmental survey, and the basic planning and design for a power generation plant. After having completed various pre-construction procedures, The Tokyo Electric Power Co., Inc. started construction of the Hachijo-jima Geothermal Power Plant in June 1998. After trial runs, the plant began commercial operation on March 26, 1999 and continues its operation today.

This paper presents an overview of the Hachijo-jima Geothermal Power Plant.

2. Overview of the Project

Before the geothermal power plant was constructed, electric power was supplied only from diesel generator units, and demand for electricity was approximately 10,000kW at the maximum and 3,000kW at night.

This geothermal power plant has the capacity to supply 1/3 of the total electricity demand in the island. The plant was projected to serve as a stable power supply, and to reduce fuel cost and hence the cost of power generation compared to the existing diesel generator units.

Fig.1 Overview of Hachijo-jima Geothermal Power Plant

In July 1998, Fuji Electric was awarded an order to supply a turnkey system for the project. Fuji Electric manufactured, procured, installed and commissioned all of the equipment and system, such as a turbine and generator rated at 3,300kW, a steam gathering system, a steam scrubbing system, and an H_2S abatement system.

Since only a short, 3-month installation period was scheduled, components of the plant were designed to be skid-mount type or package-mounted to the extent possible.

Since the steam contains high content of H_2S gas and H_2S gas emission is limited by local regulation, an H_2S gas abatement system was installed.

This plant also provides the hot water supplying system to neighbor facilities through plate-fin heat exchangers utilizing the hot water from the condenser.

Figure 1 shows an overview of Hachijo-jima Geothermal Power Plant.

3. Power Plant

3.1 Basic planning

The plant was planned with consideration for environmental preservation, cost effectiveness, reliability, maintainability, and in accordance with Tokyo metropolitan government regulations.

3.2 Heat cycle

Production wells are steam-dominated and are provided with a single flash cycle system because of the extremely low hot water content in the steam.

3.3 System configuration

Figure 2 shows the main piping diagram. Two-phase flows from the production wells, HT-1 and HT-2, are combined along their way to a steam separator. After being separated from hot water in the steam separator, the steam enters the turbine via the steam scrubbing system, expands in the turbine and then turns into condensate in the condenser. Hot water returns underground via a re-injection pump pit, re-injection pumps and a re-injection well.

With the exception of the two re-injection pump units, the two steam ejector units and some auxiliary machines, the plant is not provided with standby equipment.

3.4 Plant layout

Figure 3 shows the overall plant layout. There are mountains to the north and east of the power plant, and private houses to the south and west. The plans called for machines and equipment to be installed in the eastern part of the plant.

4. Overview of Facilities and their Features

4.1 Steam gathering system

Geothermal fluid is fed as a two-phase flow to the steam separator. There, the fluid is separated into steam and hot water by centrifugal force. Lengths of the two-phase flow piping and steam piping are very short, approximately 30m from the master valve of the production well to the steam separator and approximately 70m from the steam separator to the steam turbine via the steam scrubbing system. Diameters of the pipes are designed to be larger than usual in order to reduce velocity to protect the sand erosion which will be caused by solid impurities and tiny rock.

Figure 4 shows an exterior view of the steam separator. Its specifications are as follows:

(1) Steam separator

Type: vertical cyclone, top-outlet type

Fig.2 Main piping diagram

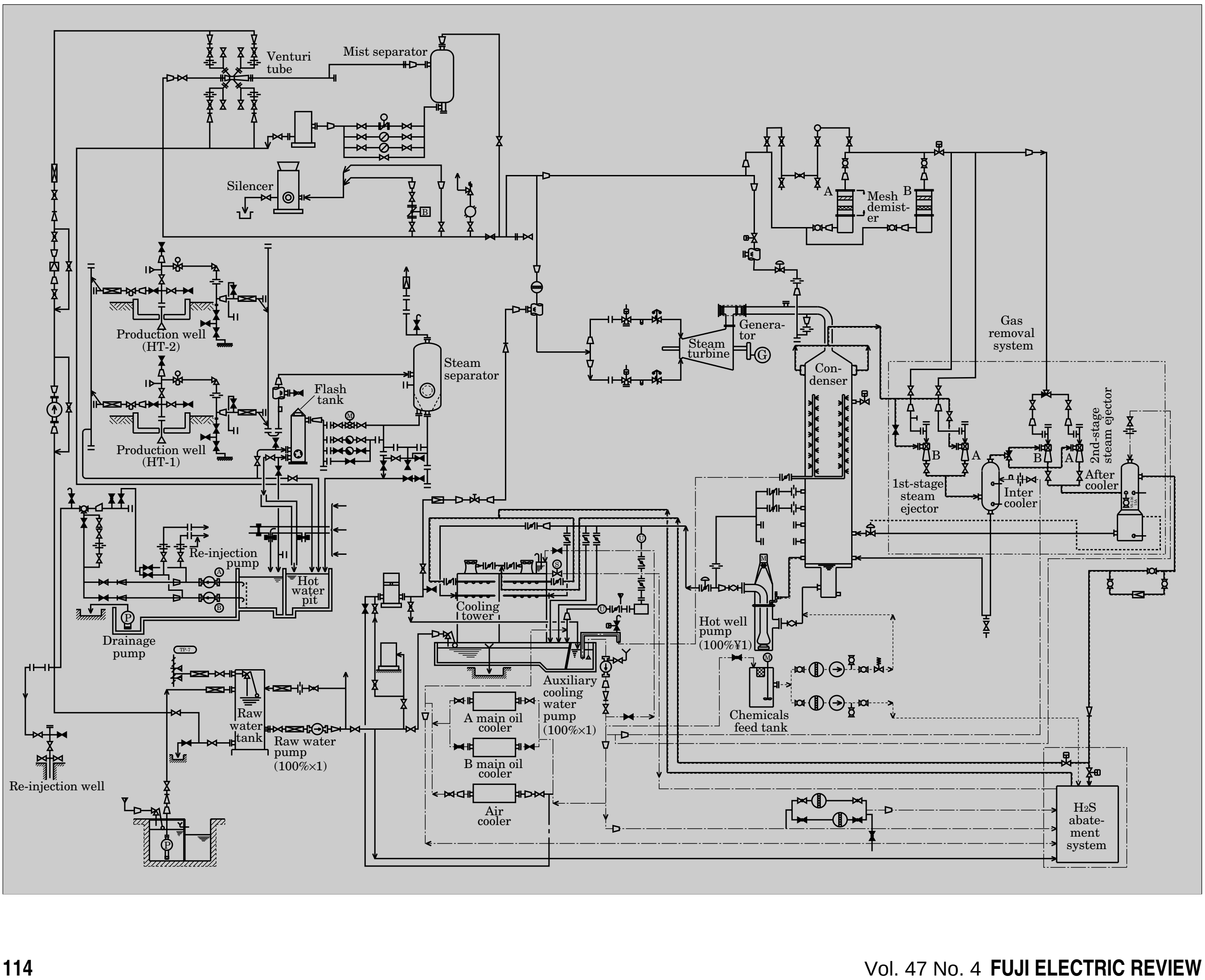


Fig.3 Overall plant layout

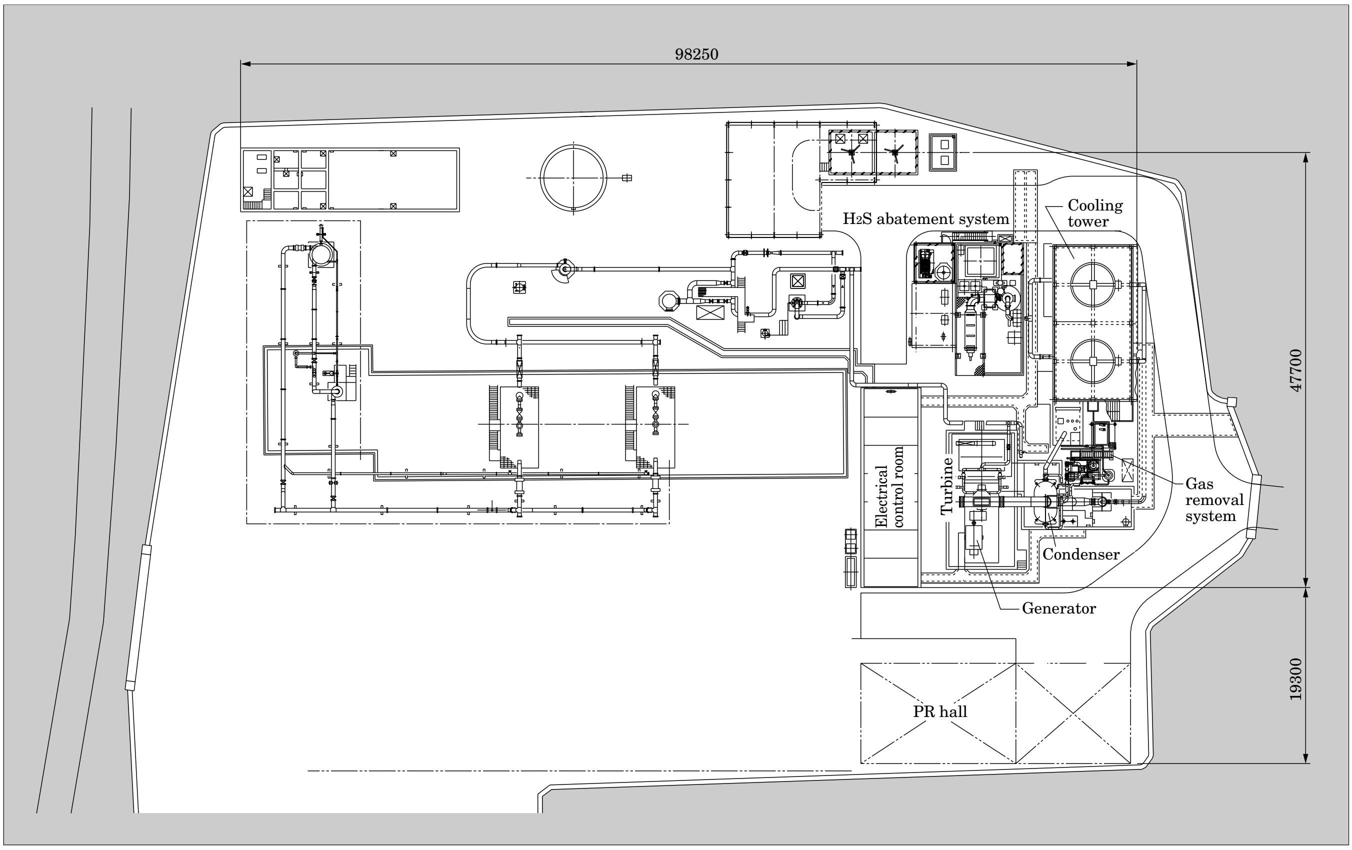


Fig.4 Exterior view of the separator

Number of units : 1
Separated steam : 40t/h
Separated hot water : 4t/h
Design pressure : 1.07MPa
Design temperature : 200°C
Separation efficiency: 99.9%

4.2 Steam scrubbing system

Steam from the steam separator contains a fine mist of sprayed-off hot water. The power plant is provided with a steam scrubbing system to trap the mist and to improve steam quality.

The system consists of a venturi tube, which injects water into the main steam and mixes and collides the injected water drops with mist, and a mist separator, which separates such mist from steam and drainage after water injection.

Figures 5 and 6 show an exterior view of the venturi tube and mist separator. Their specifications are as follows:

(1) Venturi tube
Steam : 40t/h
Number of nozzles: 4 × 50A (A: nominal diameter)
Injection water : 3.7t/h

(2) Mist separator
Type: vertical cyclone, top-outlet type
Number of units : 1
Separated steam : 40t/h
Separated hot water: 4t/h
Design pressure : 1.07MPa
Design temperature : 200°C

4.3 Turbine and auxiliary equipment

A high-speed turbine is adopted based on the results of an assessment to optimize steam conditions,

Fig.5 Exterior view of the venturi tube

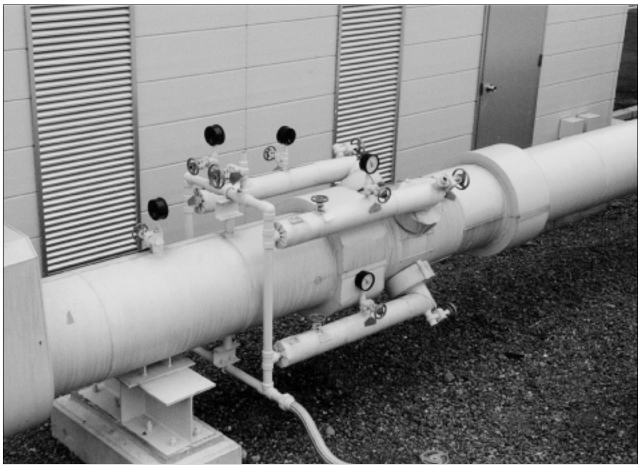


Fig.6 Exterior view of the mist separator

Fig.7 Cross-sectional view of the turbine

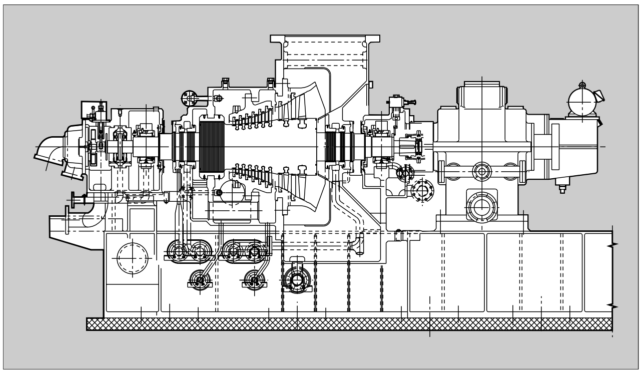


Fig.8 Exterior view of the condenser

plant efficiency and cost of the turbine and its related equipment.

Upward exhaust and skid-mount construction are employed in consideration of the short installation period. In the skid-mount construction, a reduction gear assembly and a generator are mounted on a common bed.

The turbine and generator were installed with an outdoor cover.

A drum-type rotor, reaction-type blading, high pressure blades with an integral shroud and free-standing low pressure blades, all standard features of Fuji Electric's geothermal turbines are utilized. In addition, the turbine includes a skid-mount type oil console with a main oil tank, an oil pump and lubricating oil filters mounted on the skid.

Figure 7 shows a cross-sectional view of the turbine. Its main specifications are as follows.

Type: single cylinder, single flow, top exhaust condensing, high-speed turbine
Output: 3,300kW
Steam conditions
Pressure: 0.79MPa
Temperature: 170°C
Exhaust pressure : 143kPa
Gas content in steam: 2.7% (wt%)
Revolution speed : 7,266 r/min
Number of stages : 8

4.4 Condenser and gas removal system

A spray-jet, direct-contact-type condenser is employed. Fuji Electric has supplied many condensers of this type, which have reliable operational experiences.

To resist corrosion by the geothermal fluid, stainless-clad steel is used for the shell and stainless steel is used for all internal components.

Figure 8 shows an exterior view of the condenser. Specifications of the condenser and gas removal system are as follows:

(1) Condenser
Type: spray jet, direct-contact low-level type
Internal pressure: 133kPa (4 in. Hg)
Cooling water : 1,032m^3/h

Cooling water temperature: 33.2°C

(2) Non-condensable gas removal system

Type: 2 × 100% 2-stage steam ejector
Number of units: 2 (including one standby unit)
Capacity : 1,181kg/h
Driving steam
Pressure : 0.71MPa
Flow rate: 3.9 t/h

4.5 H_2S abatement system

The content of H_2S gas in the plant's geothermal steam is very high. To comply with the maximum permissible emission of 10ppm specified by the Tokyo metropolitan government, dilution of the exhaust gas only with exhaust air from the cooling tower would require an extremely large cooling tower and impractical. Thus, an H_2S abatement system was introduced. In introducing the system, a flue gas desulfurization method was selected based on consideration of the particular circumstances for an island, raw material cost and maintainability. In this method, H_2S gas is mixed with LPG, combusted, converted into SOx and then desulfurized with injected magnesium hydroxide. The H_2S abatement system consists of combustion equipment which combusts the H_2S gas, a desulfurizer which produces harmless magnesium sulfate by sprinkling magnesium hydroxide on the generated SOx, and a sludge processing unit to remove suspended solid (SS) content from the powdered magnesium hydroxide raw material.

Figure 9 shows an exterior view of the H_2S abatement system. Its main specifications are as follows.

(1) Combustion equipment

(a) Combustion furnace
Type: fixed horizontal, cylindrical combustion furnace
Number of units : 1
Design pressure : 108.7kPa
Design temperature: 1,200°C

Fig.9 Exterior view of the H_2S abatement system

(b) Combustion air blower
Type: centrifugal type
Number of units: 1
Capacity : 3,000 Nm^3/h × 170.0kPa
Motor output : 11kW

(c) LPG supply equipment
Type: LPG cylinder (50kg)
Number of cylinders: 18 (9 × 2 lines)
Supply pressure : 116 to 121kPa

(2) Desulfurizer

(a) Absorber
Type: vertical, cylindrical filling type
Number of units: 1
Dimensions : 800mm × 2,000mm (diameter × height)

(b) Oxidation air blower
Type: root type
Number of units: 1
Capacity : 1,140 Nm^3/h × 150kPa
Motor output : 30kW

(3) Sludge processing equipment

(a) Filter press
Type: hydraulic automatic clamping type
Number of units: 1
Capacity : 300 liter

4.6 Cooling water system

Cooling water is fed to the condenser by the pressure difference and elevation difference (head) between the cooling tower cold water basin and the condenser.

After being mixed with cooling water, geothermal steam turns into condensate, and is fed to the cooling tower by a hot well pump. After being cooled at the cooling tower it returns to the cooling tower cold water basin and is again fed to the condenser.

To reduce the noise generated by the splashing of water droplets, the body of the cooling tower is made of concrete. In addition, to prevent ventilation noise from disturbing the local community, the cooling tower employs a single suction type ventilation system in which air intake vents are provided only on the east side of the cooling tower at a considerable distance from private houses.

The height of the cooling tower is limited to within 13m by environmental regulation.

Figures 10 and 11 show exterior views of the hot well pump and cooling tower, respectively. Their main specifications are as follows:

(1) Hot well pump
Type: vertical mixed flow type
Number of units: 1
Capacity : 1,300t/h
Total head : 23m
Motor output : 110kW

(2) Cooling tower
Type: induced draft, counter flow, single suction type
Number of units: 1

Fig.10 Exterior view of the hot well pump

Fig.11 Exterior view of the cooling tower

Water quantity : 1,262m^3/h
Inlet water temperature : 46.6°C
Outlet water temperature : 33.2°C
Design wet-bulb temperature: 21°C
Fan: 2 × 55kW

5. Electric and Control Systems

5.1 Electric system

Figure 12 shows a single line diagram. Electric power generated in the geothermal power plant is supplied to the transmission line of the diesel power station. Even if a failure should occur on the transmission line, the electric system is designed so that isolated operation can be performed by disconnecting the circuit breaker for transmission and instead using in-house auxiliary power.

To protect the generator, digital duplex protective relays are employed for redundancy.

Figure 13 shows an exterior view of the generator. The electric system's main specifications are as follows:

(1) Generator
Type: horizontal cylindrical, air cooled type
Capacity: 3,660kVA
Voltage : 6.9kV
Power factor : 0.93, leading
Revolution speed: 1,500 r/min
Frequency : 50Hz
Excitation : brushless type

(2) House transformer
Type: molded type
Capacity: 600kVA
Voltage : R6.9-F6.6-F6.3kV/460V

5.2 Instrumentation and control systems

Plant starting and stopping is performed at the electrical control room of the plant.

After the system is brought up to a steady condition, all necessary monitoring and control of the voltage or load are performed by the ITV at the remote central control room of the diesel power station about 12km far from this plant.

In parallel operation, turbine is usually operated under power control as base load using turbine bypass system, which controls constantly turbine inlet steam pressure by releasing the surplus steams to the condenser.

A hydraulic blow down control valve is provided downstream from the steam separator. This valve rapidly discharges steam when the turbine trips, and also serves as a backup in case of malfunction of the turbine bypass control valve.

A digital governor named "TGR", which has necessary functions such as turbine automatic start up, power control, inlet steam pressure control, load limiting, and AVR, operates this plant.

TGR consists of the digital voltage source, I/O devices and has redundancy. Generator protection relays also have redundancy.

Electrical and control panels are installed in the packaged type electrical and control room.

5.3 Package-type electrical control room

The electrical control room is a compact package-type housing, comprised of seven modules.

As the countermeasures against H_2S gas corrosion to the electrical and instrumentation equipment in the packaged type electrical and control room, H_2S gas absorption filter is installed at air intake of air conditioner.

In addition, the corrosion protection measures such as tin plating, epoxy coating, and special greases are taken to the electrical and instrumentation apparatus.

Figure 14 shows a view of the package-type electrical control room.

Fig.12 Single line diagram

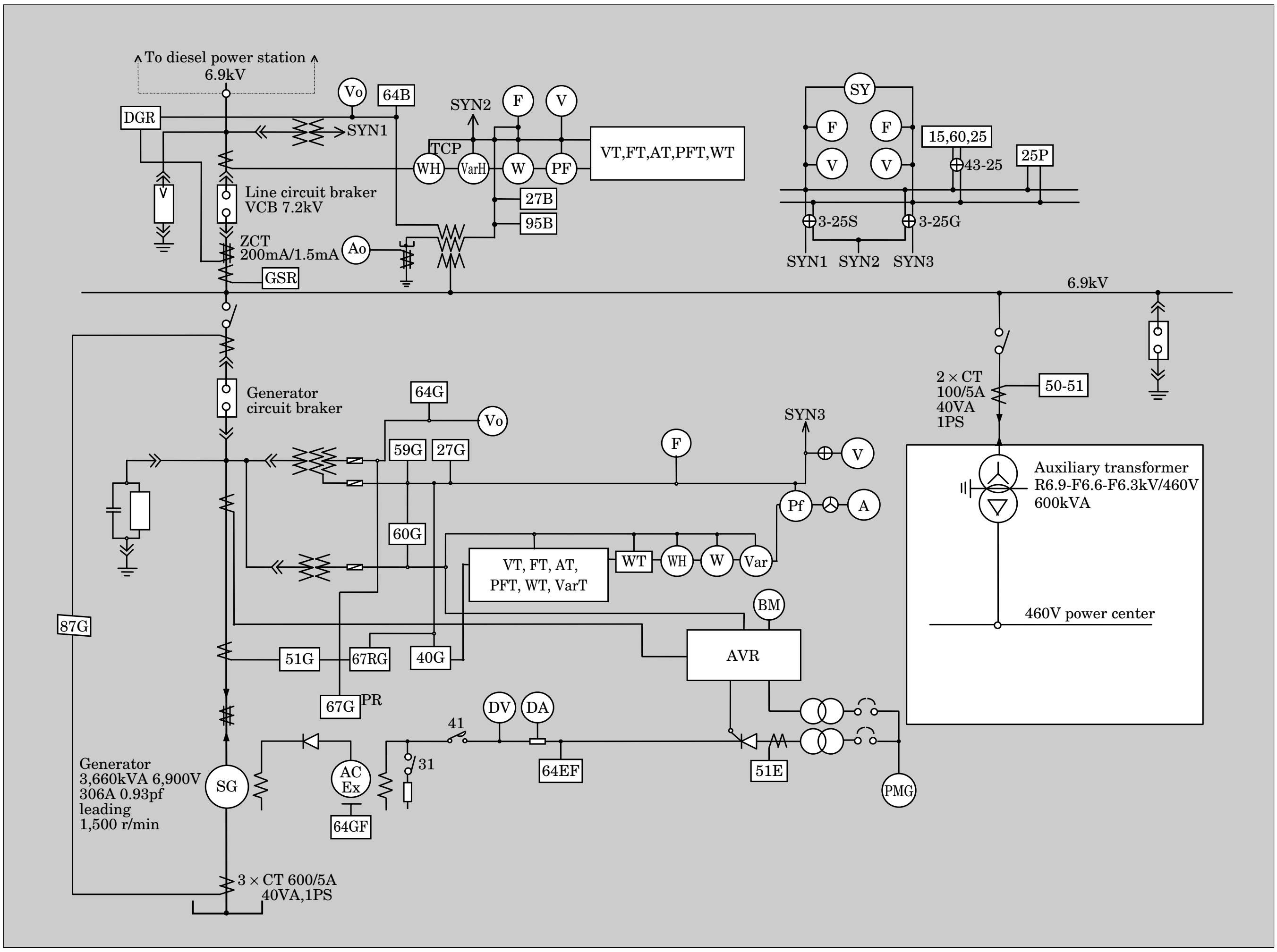


Fig.13 Exterior view of the generator

Fig.14 View of the package-type electrical control room

6. Conclusion

This paper has presented an overview of Hachijo-jima Geothermal Power Plant. At present, the power plant is playing an important role in supplying base power in Hachijo-jima.

It is hoped that this paper will provide useful information for future similar geothermal power plants.

Geothermal Steam Turbines for Various Purposes

Shigeto Yamada

1. Introduction

Geothermal power generation was first experimentally developed in Italy in 1904, and commercial power generation also commenced in Italy in 1913. At first, geothermal power generation utilized natural steam from production wells. The first flash system was went online in 1958 in New Zealand, and the subsequent installation of geothermal power plants spread throughout the world.

As of 2000, the total installed capacity of geothermal power generation units worldwide is about 8,000MW (Fig. 1). Most plants utilize flash cycle technology and are constructed only for power generation.

In cases where the resource temperature is not high enough to generate steam efficiently above atmospheric pressure, binary cycle technology has been utilized. Even for such low temperature geothermal resources, it is possible to plan for steam turbines that utilize flash cycle technology. Although binary cycle technology offers the greatest benefit, that is, it does not emit non-condensable gases including hydrogen sulfide gas into the atmosphere, it uses working fluids other than water, which makes system operation and maintenance more sensitive and costly compared to flash cycle technology.

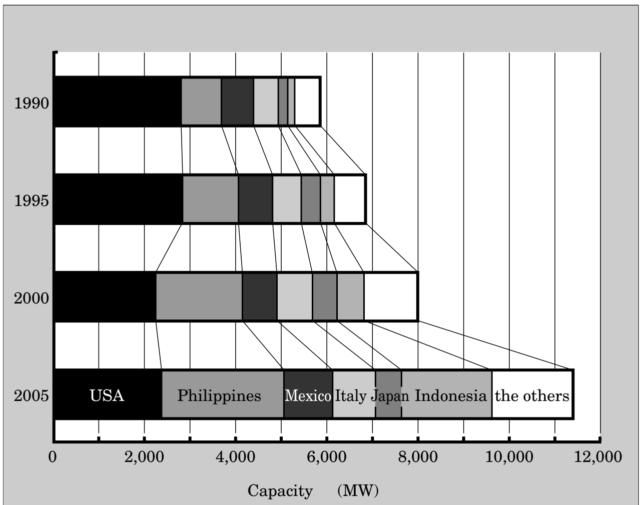
Here, two samples of geothermal power plants having other functions in addition to power generation are introduced. One is the Svartsengi Unit 5 in Iceland, which has two extractions pipes for the heating steam used in district heating. The other is Salton Sea Unit 5, which has two intake pipes from a mineral recovery plant. Also a plan for a geothermal steam turbine for use with a very low pressure (VLP) flash system is introduced.

The proprietary technology Fuji Electric employs in its geothermal steam turbines will contribute to satisfying the various requirements for the efficient utilization of geothermal energy.

2. Svartsengi Unit 5 (30MW)

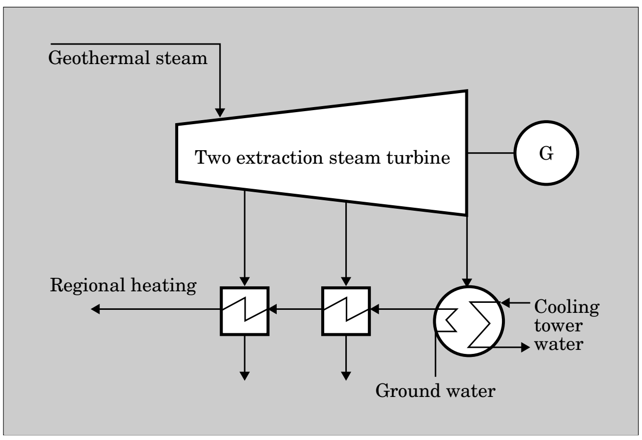
Iceland has been utilizing the geothermal resources for district heating. Sudurnes Regional Heating Corp. (SRH), a company that supplies hot water to its local community, operates the Svartsengi Geothermal Power Plant consisting of the back pressure turbine unit, binary units and a condensing turbine unit. Unit 5 is of the condensing type, and has two output ports to supply the heating steam for the district heating water. Unit 5 was delivered to the plant in 1998 and

Fig.1 Installed capacity of geothermal power plants



Data from IGA homepage (http://www.demon.co.uk/wrtab.html) as of 27 May 1996

Fig.2 Svartsengi Unit 5 system



went online in 1999. Figure 2 shows a schematic of the Unit 5 system.

Geothermal steam is supplied to the turbine for generating 30MW and for heating fresh water. The turbine has an exhaust pipe leading to the condenser as well as two extraction pipes. Exhaust steam is condensed in the condenser by the cooling tower water. The condenser is divided into two sections, one is a normal condensing zone, and the other is a condensing zone that functions also as a pre-heater for the district heating water. Ground water is first fed to the condenser. Two steam pipes are used for heating the ground water. Then the heated water is supplied to the particular region. Table 1 lists major technical specifications of the Unit 5 turbine.

The extracted steam pressure is externally controlled to maintain the heated water temperature. By changing the ground water flow and by the controlling the extraction pressure, four season operation patterns are planned as shown in Table 2.

Figure 3 shows the section of the Svartsengi Unit 5 turbine.

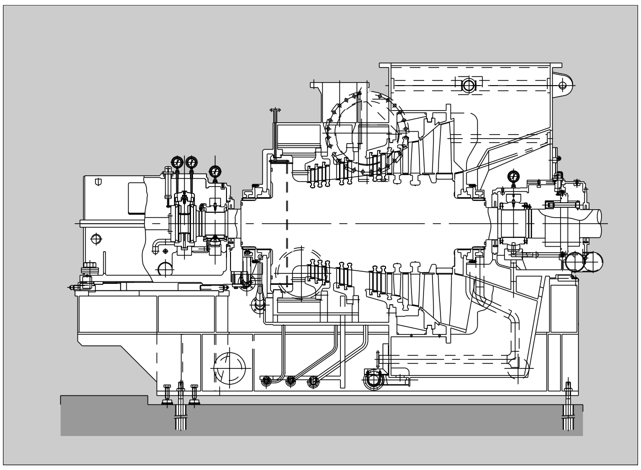
Table 1 Features of Svartsengi Unit 5 turbine

Output	30,000 kW	
Main steam	0.65 MPa abs	262,800 kg/h
No.1 extraction	0.29 MPa abs	14,400 kg/h
No.2 extraction	0.16 MPa abs	97,200 kg/h
Exhaust	0.01 MPa abs	
Speed	3,000 r/min	

Table 2 Four season operation patterns

Item	Summer normal	Spring Autumn	Winter	Winter peak
No.1 Extraction (kg/h)	0	18,000	14,400	39,600
No.2 Extraction (kg/h)	54,000	57,600	97,200	108,000
Hot water supply (kg/h)	432,000	432,000	864,000	864,000

Fig.3 Section of Unit 5 turbine



3. Salton Sea Unit 5

Salton Sea is located in Imperial Valley California, and it is one of the largest geothermal power generation area in the world. Table 3 lists the power generating units currently in operation.

Unit 5, introduced here, is located in the Region 1, where four level of steam pressure are utilized: high pressure (HP), standard pressure (SP), low pressure (LP) and very low pressure (VLP). Unit 1 is a simple straight condensing unit and Unit 2 is a turbo expander from HP to SP. Unit 3 intakes SP and LP steam, and Unit 4 intakes SP steam and extracts LP steam. Unit 5 intakes SP, LP and VLP steam. Usage these four levels of steam pressure is coordinated in the Region 1 area to optimize the steam usage and power generation.

Unit 5 was delivered to the plant in 1999 and went online in 2000. Table 4 lists major technical specifications of Unit 5.

Unit 5 contains not only a power generation unit but also a mineral recovery plant. The LP and the VLP steam for Unit 5 are generated in the mineral recovery plant. Figure 4 shows the rough schematic of the Unit 5 system.

The SP steam supplied to Unit 5 is delivered from Unit 3 and 4 located next to Unit 5. SP brine is also fed from Units 3 and 4 areas to the mineral recovery plant., LP and VLP steam is generated in the mineral recovery plant, and fed to the Unit 5 turbine.

Figures 5 and 6 show the Unit 5 turbine.

Table 3 Power generating units in Salton Sea Area

Region 1	Unit 1	10 MW
	Unit 2	4 MW
	Unit 3	54 MW
	Unit 4	49 MW
	Unit 5	58 MW
Region 2	Vulcan (HP)	27 MW
	Vulcan (LP)	9 MW
	Hoch	36 MW
Region 3	Elmore	36 MW
	Leathers	36 MW
Total		319 MW

Table 4 Features of Salton Sea Unit 5 turbine

Output	58,320 kW	
SP steam inlet	0.86 MPa abs	16 kg/s
LP steam inlet	0.37 MPa abs	73 kg/s
VLP steam inlet	0.14 MPa abs	65 kg/s
Exhaust	0.0096 / 0.013 MPa abs	
Speed	3,600 r/min	

Fig.4 Salton Sea Unit 5 system

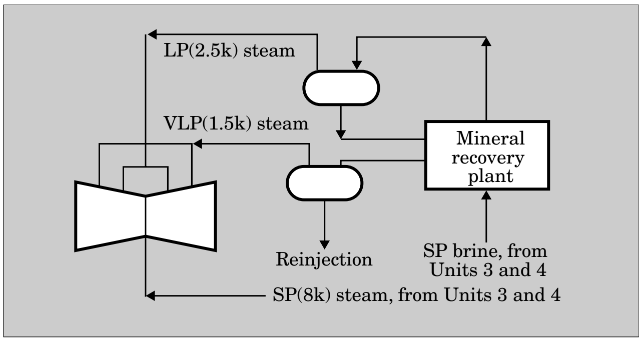


Fig.5 Section of Salton Sea Unit 5 turbine

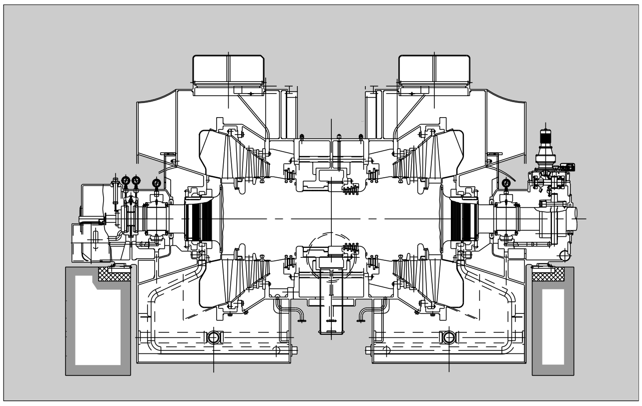
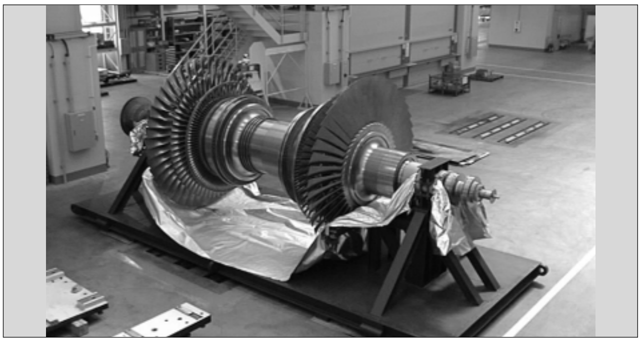


Fig.6 Salton Sea Unit 5 turbine rotor



Because the amount of the SP steam is very small compared to LP and VLP steam as shown in Table 4, the SP steam section is single-flow. After being mixed with LP steam, both LP and VLP sections are double-flow. Some of the SP steam flow is branched to the other side at the LP steam inlet so that the exhaust steam flow on both sides is equal. The turbine exhausts are connected to the condenser, which is divided into two independent condensing zones with different vacuum to increase the unit efficiency compared to a conventional single vacuum condenser.

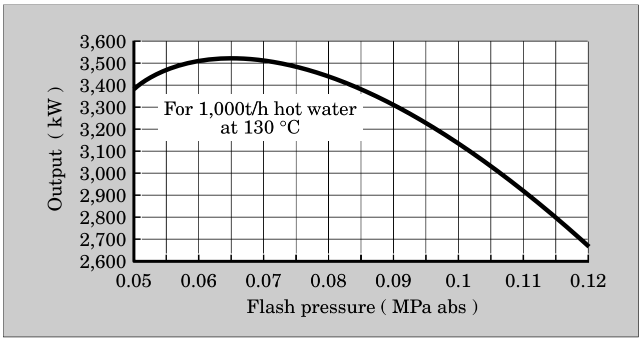
4. Very Low Pressure (VLP) Flash System

When low temperature geothermal resources are used for the power generation, binary cycle technology is normally used. For such geothermal resources,

Table 5 Basis of sample VLP system

Hot water temperature	130°C saturated water
Hot water flow	1,000 t/h
Ambient wet bulb temperature	20°C

Fig.7 Flash pressure vs. output



steam turbines can be utilized by flashing the geothermal brine to very low pressure such as atmospheric or even sub-atmospheric pressure. The binary cycle has a superior to the flash cycle in that the geothermal fluid can be circulated from the production wells to the reinjection wells without emitting gases and impurities from the brine into the atmosphere. However the binary cycle normally requires larger parasitic loads compared to the flash cycle. The working fluid normally used in a binary system is flammable or toxic. The VLP system is planned as one solution that allows utilization of low temperature geothermal resources ranging about 100 to 120°C.

An example of the VLP system plan is show below.

The sample plan is based on the conditions shown in Table 5.

The flash pressure is usually optimized to obtain maximum output. Figure 7 is an example of the optimization for the 130°C saturated hot water. As shown in Fig. 7, maximum output can be achieved at approximately 0.065MPa abs of flash pressure in this example.

Figure 8 shows an example heat and mass balance diagram for this system. Although the maximum output would be achieved at 0.065MPa abs based on Fig. 7, the flash pressure of 0.07MPa abs is selected since the steam flow at 0.065MPa abs does not fit with the selected turbine model for this example. The selected turbine model is a single-flow skid mounted type with 467mm last-stage blades. Figure 9 shows the cross-sectional view of the turbine. As shown in Fig. 9, the turbine is quite similar to a conventional geothermal steam turbine except that the number of stages is only three.

A liquid ring vacuum pump is considered to extract small quantities of leaked air and accompanying steam.

This example has the following parasitic loads; hotwell pump (110kW), auxiliary cooling water pump

Fig.8 Example heat and mass balance of the VLP flash system

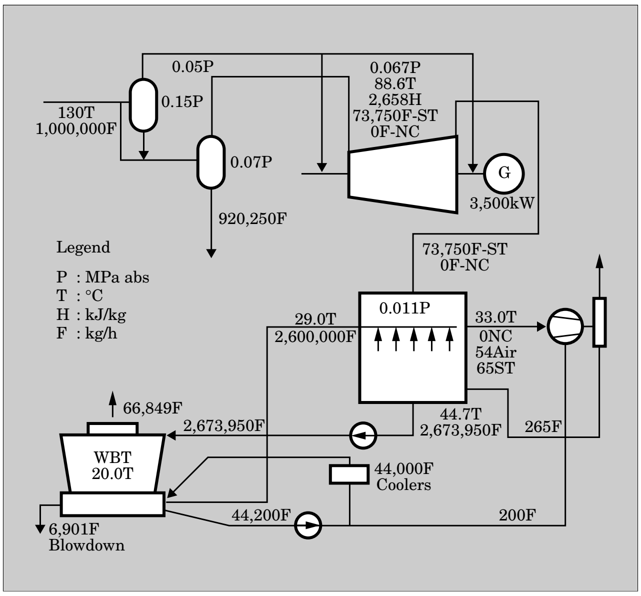
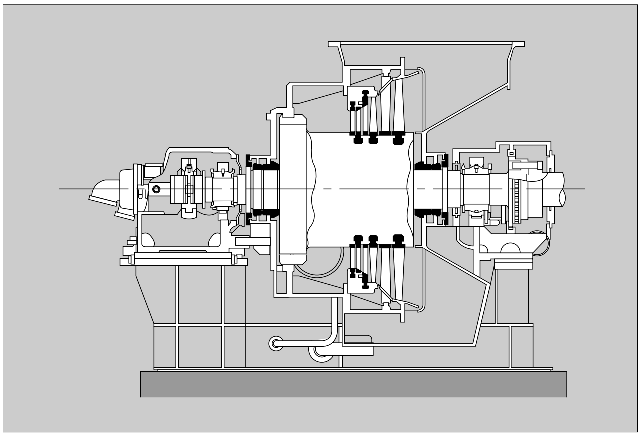


Fig.9 Cross-sectional view of the turbine for very low pressure



(5.5kW), cooling tower fans (110kW), vacuum pump (15kW) and power for the control system (Ca. 10kW) such as an air compressor; totaling approximately 250kW which is roughly 7% of the gross output.

There may be a various other cases in addition to the example described in the previous section. If geothermal hot water contains some percentage of steam, the turbine inlet pressure can be raised, for example, to 0.09MPa abs, thereby increasing the gross output; however in such cases, more power must be consumed for gas extraction because non-condensable gases are usually contained in steam. Condenser pressure plays a very important role in determining the output since the heat drop across the VLP turbine is quite low compared to that of an ordinary geothermal turbine. With a VLP flash system, compared to ordinary geothermal power generation, it is more effective to lower the design condenser pressure to increase the output under the same brine consumption.

5. Conclusion

Geothermal energy is regarded as renewable and domestic energy source, and continuous development is expected in all geothermal countries. In order to utilize geothermal energy more effectively, it is anticipated that geothermal power plants having additional functions, as introduced here, will be planned. Fuji Electric's geothermal steam turbines will contribute as key components to such plans for multi-purpose geothermal plants.

Low temperature geothermal resources are plentiful. In addition to low temperature geothermal resources, hot water that is being re-injected can be a resource for a VLP flash system, if lowering the re-injection temperature is allowed. Nature characteristics of geothermal resources vary area to area, and site conditions also differ. The important consideration is to select the most suitable system under the given conditions. The VLP flash cycle will contribute to expanding the range of selections available for geothermal power generation with low temperature resources.

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Recent Technology of Geothermal Steam Turbines

Yoshifumi Kato

1. Introduction

The cumulative capacity of geothermal power plants constructed worldwide has reached 7,974MW, which is a 16.6% increase in the last 5 years[1]. The cumulated capacity of the geothermal turbines Fuji Electric has manufactured increased from 1,253MW as of 1995 to 1,566MW as of September 2000, which is a 25% increase in terms of capacity. This reveals that increased international environmental awareness has resulted in a larger total geothermal capacity and that throughout the world, users have appreciated the reliability and performance of Fuji's geothermal steam turbines.

The evolution of geothermal steam turbine technology was introduced in a previous paper[2]. Development of the geothermal steam turbine has continued to make progress over the past 5 years. This paper introduces the recent technology of geothermal steam turbines, and also presents the features of two typical geothermal steam turbines that were put into commercial operation in 2000.

Decreasing production well pressure is an inevitable consequence of geothermal power generation. Two solutions to maintain the output of geothermal power plants in cases of decreasing production well pressure will be described.

2. Recent Technology of Geothermal Steam Turbines

Geothermal steam turbines have been developed based upon fossil fueled steam turbines, and therefore several new technologies employed by geothermal steam turbines are the same as those used in fossil fueled steam turbines. This section describes those technologies which are shared with fossil fueled steam turbines as well as specific technology for the geothermal steam turbine.

2.1 Advanced reaction blade airfoil having higher efficiency

An advanced reaction blade airfoil (Fig. 1) was developed to reduce the number of stages in fossil fueled steam turbines by increasing the heat drop per stage. Through employing the new reaction blade airfoil, stage efficiency will be increased by 1.5%.

2.2 Advanced low pressure (LP) blade

A sudden increase in the cross sectional area of the steam line in the last few stages of a condensing steam turbine is necessary due to the huge steam expansion that occurs in a vacuum. Long LP blades are employed for the last three stages.

Progress in computational fluid dynamics (CFD) has enabled the development of advanced LP blades.

Following the development of a 38.5-inch LP blade for use at 3,000 r/min in the latter half of 1980s, a series of advanced LP blades has been completed,

Fig.1 Comparison in efficiency of reaction blade airfoil N1 and T4

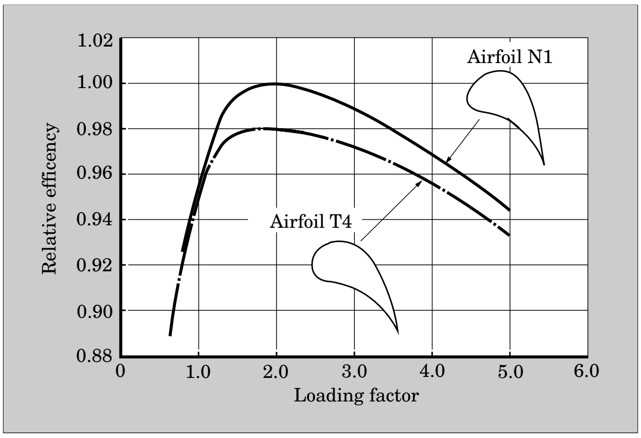
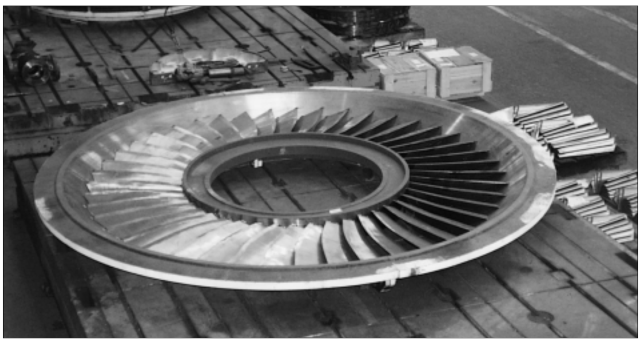


Fig.2 Last stage stationary blade ring



spanning the entire output range.

The last (L-0) stationary blades are radially angled in order to increase reaction degree near the root and to reduce secondary losses (Fig. 2). Airfoils near the tip of the last stage blades (LSB) are contoured to form a so-called convergent-divergent passage that prevents the generation of normal shocks which cause large losses in the transonic cascades (Fig. 3).

By employing the advanced LP blades, stage efficiency will be improved by approximately 3%.

2.3 Large bore sized, triple eccentric butterfly valves

Liquid dominated geothermal power plants tend to employ double flash technology to increase generator output.

In a double flash system, the separated hot water in an HP flasher is fed to an LP flasher to generate low pressure steam. The low-pressure steam is then supplied to the intermediate stage of the steam turbine. The bore size of stop valves and steam control valves for LP steam is normally very large, since the specific volume of the low pressure inlet steam is large.

Double eccentric butterfly valves were employed for the low pressure inlet steam as general stop valves. However, opening a double eccentric butterfly valve usually requires a large torque from an actuator due to the large wedge force generated by the point contact on the sealing surface between the disk and the sheet.

A feature of the triple eccentric buttery valve is that its sealing surface is contoured in the shape of a cone whose center does not coincide with the disk center (Fig. 4). The seal rings installed in the disk are pushed into the disk when the valves closed. As the result, sealing is achieved through surface contact instead of point contact. A comparably small actuator force is sufficient to open these valves smoothly.

Fig.3 Mach number distribution at tip airfoil of LSB

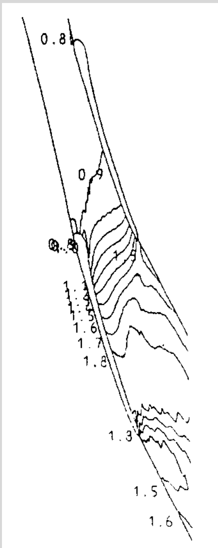
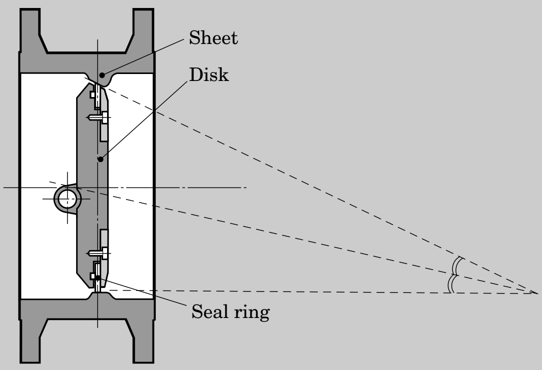


Fig.4 Triple eccentric butterfly valve



3. Recent Geothermal Steam Turbines

Fuji Electric has two types of geothermal steam turbines, a packaged type and a dual exhaust flow type. Packaged type turbines range up to 40MW in capacity, and dual exhaust flow types range from 55MW on up.

The packaged type turbines are completely pre-assembled at the factory and are delivered as a single package in order to reduce the onsite installation work.

The dual flow exhaust turbine is inspected at the factory and then dissembled into parts, which are small enough to be readily transported to the site, such as the rotor and the upper and lower half of the casing.

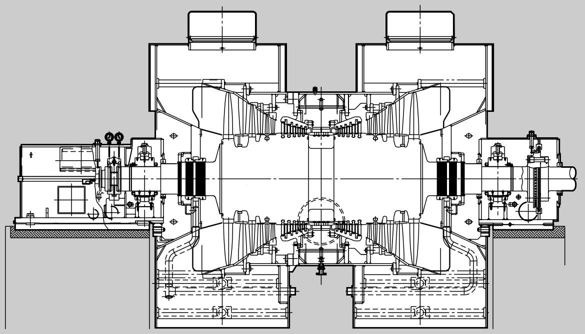
The following describes geothermal steam turbines recently put into the commercial operation.

3.1 Wayang Windu 110MW geothermal steam turbine[3]

Figure 5 shows the cross section of the steam turbine for the Wayang Windu Geothermal Power Plant in Indonesia, which was put into the commercial operation in June 2000. The turbine is of a single flash, dual exhaust flow and single casing type. Major specifications of the geothermal turbine are as follows:

(1) Inlet steam pressure: 1.02MPa
(2) Inlet steam temperature: 181°C

Fig.5 Cross section of 110MW geothermal steam turbine for Wayang Windu Geothermal Power Plant (Indonesia)



(3) Condenser vacuum: 12kPa
(4) Speed: 3,000 r/min
(5) Rated output: 110MW

The rated output of 110MW is the largest in the world for a single casing geothermal steam turbine. Previously, all installed geothermal turbines rated at more than 100MW had been of the dual casing, tandem compound type.

The advanced LP blades with a 27.4-inch LSB enable the realization of a single casing 110MW geothermal turbine.

Moving blades in the last 2 stages are free standing, without lacing wires on the airfoil. Absent of bosses for lacing wires, the airfoil is free from any stress concentrations and deposits of corrosive components. Furthermore, the vibration modes of free standing blades are so simple that natural frequencies of the blades can be precisely predicted by calculation. As the result, the LP blades can operate without limitation within ±5% of the 50Hz rated frequency.

The blade row is composed of 8 double flow stages. The 1st through 5th stages are equipped with reaction blades with an integral shroud. The blades with integral shroud are free from any residual stresses that tend to be generated on riveted shroud blades. This is an advantage of the integral shroud blades. Another advantage of the integral shroud blades is their good damping characteristics.

The 1st through 5th stage stationary blades are installed in a stationary blade holder, which is divided into upper and lower halves. The upper and lower halves of the stationary blade holders are bolted to the respective upper and lower halves of the outer casing. The upper and lower halves of the stationary blade holders are also tightened by bolts at the horizontal joint flange in order to prevent steam leakage and erosion of the horizontal joint flange.

The turbine rotor is of the non-concave, drum type, so that no stress concentrations will be generated. The shaft is formed from CrMoNiV forged steel, consisting of relatively low nickel content in order to prevent stress corrosion cracking (SCC). The large inertia weight of the drum type rotor ensures stable operation.

3.2 Salton Sea 58.32MW geothermal steam turbine

Figure 6 shows a cross section of the 58.32MW geothermal steam turbine for the Salton Sea Unit 5 geothermal power plant in the USA, which began commercial operation in August 2000. The plant employs a triple flash system, that is, standard pressure steam (SP), low pressure steam (LP) and very low pressure steam (VLP) are supplied to the steam turbine. The Salton Sea Unit 5 geothermal steam turbine is the first unit having triple inlet pressure.

The plant employs a dual vacuum condenser, in which one exhaust pressure differs from that of another one.

(1) SP steam pressure : 0.86MPa
(2) SP steam temperature : 174°C
(3) LP steam pressure : 0.367MPa
(4) LP steam temperature : 141°C
(5) VLP steam pressure : 0.137MPa
(6) VLP steam temperature: 110°C
(7) High vacuum side exhaust pressure: 9.6kPa
(8) Low vacuum side exhaust pressure : 13kPa
(9) Speed : 3,600 r/min
(10) Rated output: 58.32MW

The SP steam enters the steam turbine from the bottom of the lower half casing through the stop valve and the steam control valve. The LP steam enters the intermediate stage of the steam turbine from both sides of the lower half casing through two steam control valves branched from a single stop valve. The VLP steam enters from four inlet ports located on the upper half of both exhaust sides, through four steam control valves branched from two stop valves (Fig. 7).

The SP stop valve is a swing-check-type valve with a 14-inch bore size. The LP and VLP stop valves are triple eccentric butterfly valves with 44-inch bore sizes. The 44-inch bore size is the largest size in the world for butterfly valves of geothermal use. The SP steam control valve is a butterfly type valve with a 14-inch

Fig.6 Cross section of 58.32MW geothermal steam turbine for Salton Sea U5 (USA)

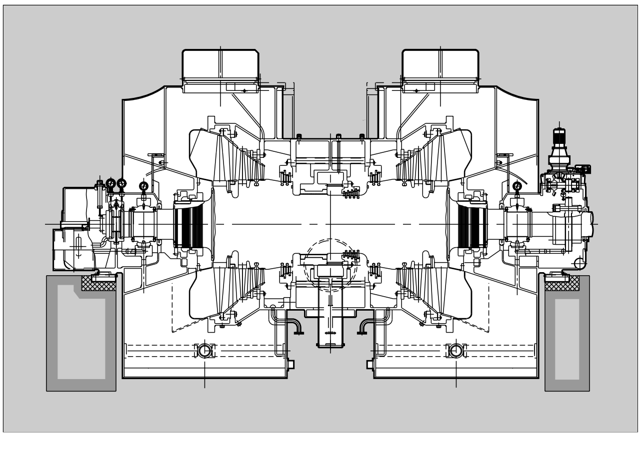
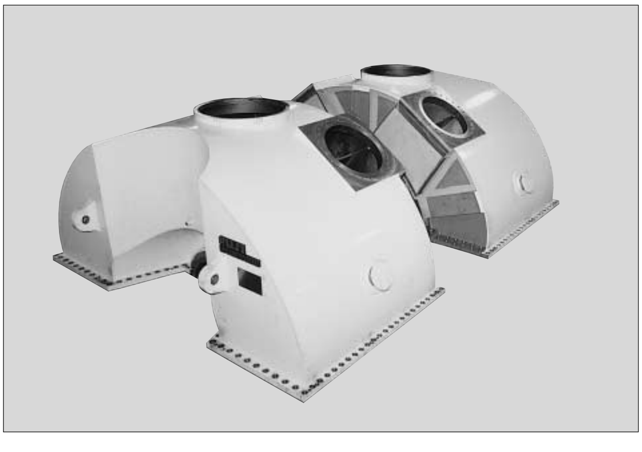


Fig.7 Casing upper half of geothermal steam turbine for Salton Sea U5



bore size, and the LP and VLP steam control valves are butterfly type valves with 30-inch bore sizes. During normal operation, the SP and VLP steam control valves are used to control the corresponding inlet steam pressure, and the LP control valves are used to control the turbine load.

The blade row is composed of 4 single-flow stages, followed by 5 dual-flow stages. The four single-flow stages and the next two dual-flow stages are equipped with integral shroud blades. The last three stages are equipped with advanced LP blades with a 26.2-inch LSB.

4. Solutions for Decreased Production Well Pressure

Geothermal resources generally decline over a long-term operation, even when employing a re-injection system in which surplus hot water is injected back to the reservoir underground.

Two solutions where Fuji geothermal steam turbines have employed are described below:

4.1 NCPA U2

The plant was put into commercial operation in 1983. After more than 10 years of operation, the pressure of the production well had decreased. Original specifications of the steam turbine are as follows:

(1) Inlet steam pressure : 0.799MPa
(2) Inlet steam temperature: 169°C
(3) Inlet steam flow: 107.65kg/s (NCG content: 0.4%)
(4) Condenser vacuum : 10.2kPa
(5) Number of blade rows : 2 (flow) × 8 stages
(6) Speed : 3,600 r/min
(7) Rated output: 55MW

The steam turbine was modified so that the generator output can be maintained despite decreasing well pressure.

Specifications of the steam turbine after modification are as follows.

(1) Inlet steam pressure : 0.572MPa
(2) Inlet steam temperature: 157°C
(3) Inlet steam flow: 124kg/s (NCG content: 0.4%)
(4) Condenser vacuum : 10.2kPa
(5) Number of blade rows : 2 (flow) × 8 stages
(6) Speed : 3,600 r/min
(7) Rated output: 55.6MW

As a result of increasing the steam generation of the production well, the generator output of the modified unit became greater than the original output, despite the pressure decrease.

In the re-powering modification, the original turbine casing and the bearing pedestals are used as is, with no modification. The original rotor was employed after exchanging the blade rows. The 1st through 5th blade rows (double flow) are replaced with new blade rows re-designed conforming in accordance with the specifications; the remaining LP blade rows of the last three stages (L-0 through L-2) are unchanged.

Table 1 shows the major modified and replacement parts.

In this modification, future decreases in the well pressure was took into account.

The new specifications taken the future decrease in pressure into account are the following:

(1) Inlet steam pressure : 0.434MPa
(2) Inlet steam temperature: 143°C
(3) Inlet steam flow: 124kg/s (NCG content: 0.4%)
(4) Condenser vacuum : 10.2kPa
(5) Number of blade rows : 2 (flow) × 7 stages
(6) Speed : 3,600 r/min
(7) Rated output: 51.4MW

The generator output decreases from 55.6MW to 51.4MW due to the decreasing pressure of the production well while the steam generation remains unchanged.

A future modification is simply to remove the 1st stage blade row from the rotor and the casing. This can be performed quickly and at low cost.

4.2 Palimpinon Ⅱ

Four geothermal steam turbines for Palimpinon Ⅱ in the Philippines were put into commercial operation in 1993 and 1994. Palimpinon Ⅱ consists of Nasuji Unit 1, Okoy Unit 1 and Sogongon Units 1 and 2.

Table 2 shows the specifications of these power

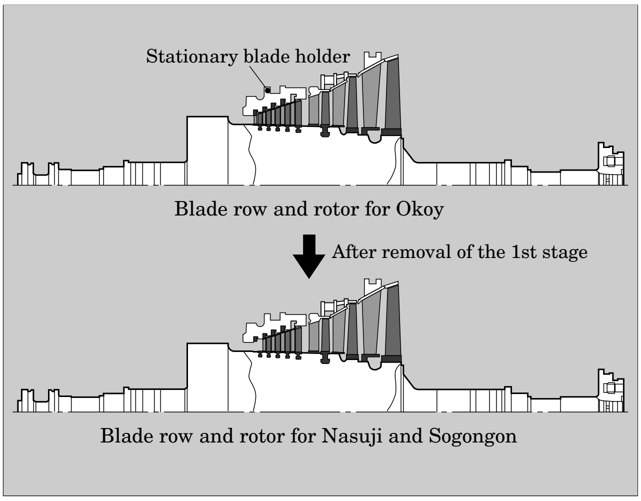
Table 1 Renewed and/or re-constructed parts and their details for NCPA U2

Parts	Details
Blade	1st to 5th stationary and moving blades, stationary blade rings were renewed.
Rotor	The original rotor is applied, being milled for 1st to 5th stage blade root.
Main stop & control valves	Stop valve and steam control valve were replaced.
Steam strainer, inlet steam piping	Replaced steam strainer as well as inlet steam piping with larger size are employed.
Governor	An actuator of steam control valves is modified.

Table 2 Major specifications of the geothermal steam turbines in Palimpinon Ⅱ district

Item / Plant name	Rated output (MW)	Number of unit (unit)	Main steam pressure (MPa)	Main steam temperature (°C)	Exhaust steam pressure (MPa)	Number of stage (stage)	Main steam flow (kg/s)
Nasuji	20	1	0.57	162	0.0137	8	43.89
Okoy	20	1	0.77	174	0.0127	9	40.56
Sogongon	20	2	0.57	162	0.0137	8	43.89

Fig.8 Geothermal steam turbine blade row as well as rotor for Palimpinon II district



plants.

The turbine inlet pressure of Okoy is higher than that of the other two plants, and the turbine for Okoy has 1 more stage than the other units.

The design philosophy is to maintain the generator output of Okoy by removing the 1st stage blade row in case there is a future decrease in production well pressure (Fig. 8).

By removing (machining off) the 1st stage blade row of the Okoy turbine, the turbine rotor will be common among these three geothermal power plants. A spare rotor can be used in any of the four units.

4.3 Selection of the appropriate solution

As described above, two solutions are available to maintain the generator output in case of a decrease in production well pressure, removal of the 1st stage and modification of the blade rows.

Selection of the appropriate solution depends on the characteristics of the production well.

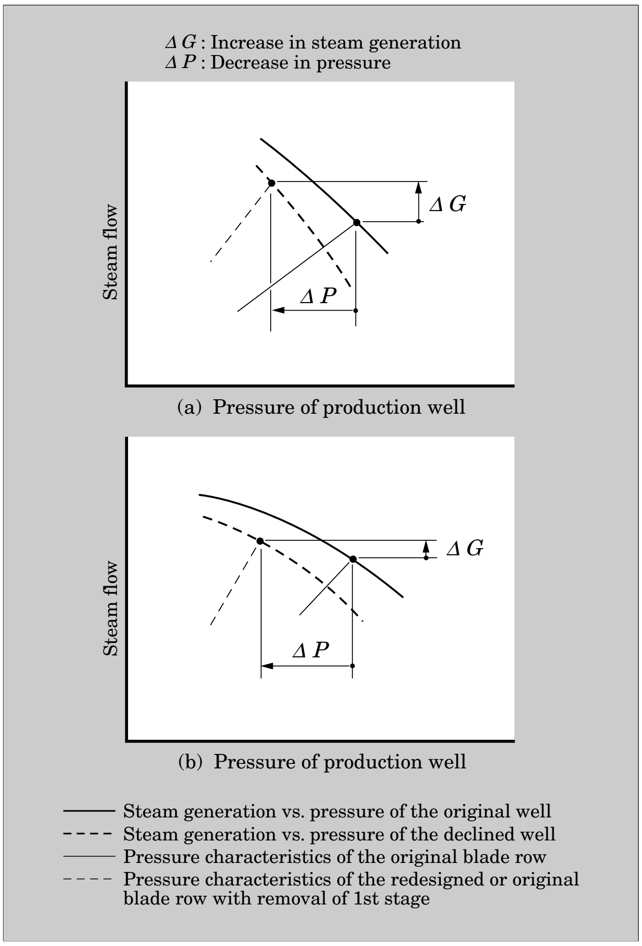
Figure 9 shows the pressure versus steam generation in the production well with inlet pressure versus steam flow of the turbine blade rows.

When the pressure versus steam generation characteristic of the production well is similar to that shown in Fig. 9 (a) in which steam generation simply increases with decreasing pressure, the large capital investment would pay off due to the increase in output despite the decrease in well pressure.

In this case, modification of the blade rows is selected to obtain greater output than that obtained by just removing the 1st stage.

However, the large capital investment might not pay off if the steam generation increases only moderately as the pressure decreases [Fig. 9 (b)]. In such a case, removal of the 1st stage may be selected to maximize the generator output.

Fig.9 Reduction of production well and pressure characteristics of turbine blade row



5. Conclusion

Fuji's geothermal steam turbines have consistently evolved through employing state-of-the-art technologies developed for fossil fueled steam turbines as well as through improvements base on our wealth of experience with geothermal steam turbines. Should production well pressure decrease in the future, two solutions are available to maintain generator output of Fuji Electric's geothermal steam turbines.

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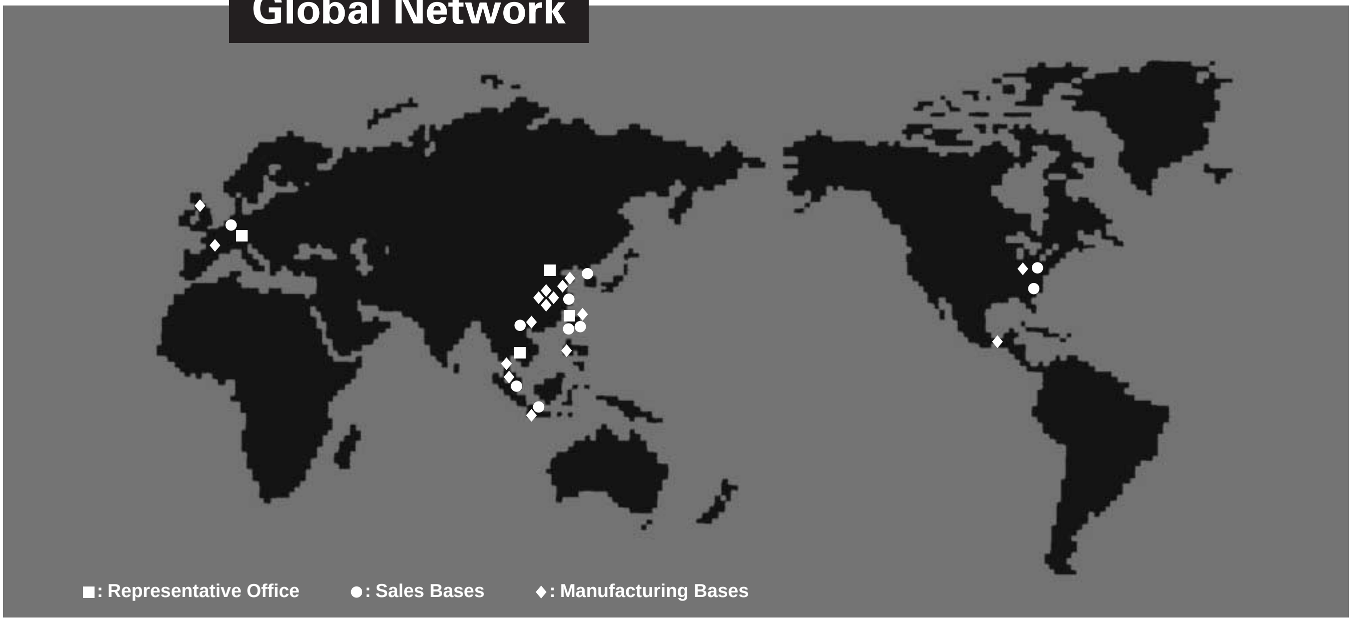

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