RECENT EXPERIENCES IN GEOTHERMAL POWER PLANTS DEVELOPED IN JAPAN

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Though Japan is a volcanic country, the geothermal power plants constructed by the end of 1980 were only 9 units with a total capacity of 215 MW.

Then geothermal development was accelerated by "Sunshine Project" policy of the Japanese government and another 7 geothermal power plants will be completed by 1997, increasing the geothermal power generating capacity of Japan twofold. For six of these plants, modular type turbine was adopted which can be constructed in a short time and which is superior in economics.

The largest capacity modular turbine in the world, of which capacity range is 50 to 70 MW, was recently developed and will start operation in Sumikawa in March 1995.

Key words; Modular-50, Sumikawa, Yamagawa, No scale nozzle, Dry and wet type C/T

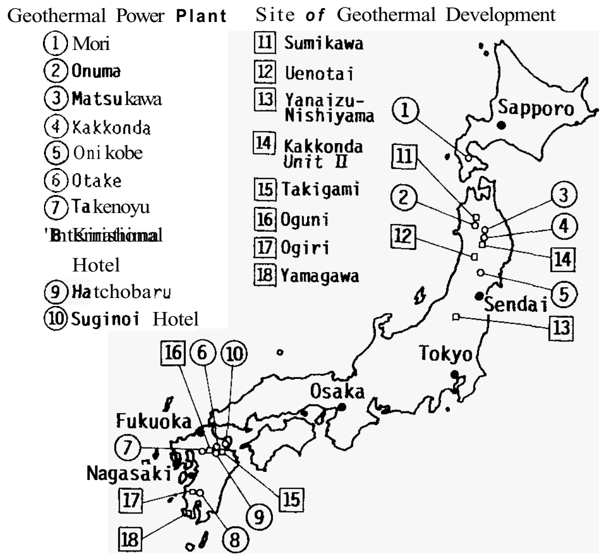

Figure 1 Geothermal Power Plants and Sites of Geothermal Development in Japan

1. INTRODUCTION

1.1 Development History and Forecast of Geothermal Power Plant in Japan

Though there is enough geothermal energy potential in Japan to generate 22.000 MW of electric power for 30 years even when geothermal fields are limited to those of steam dominant and high temperature hot water types which can be developed with current technology, only nine plants with a total output of 215 MW are in operation as shown in Figure 1.

The reason for this is as follows.

(1) Most geothermal fields exist within national parks and siting power plants in national parks is restricted.
(2) High exchange rate of Japanese Yen resulted in a glut of oil and lower oil prices.
(3) Risk of initial investment for well development was high because of the cost of geothermal exploration.

On the other hand, the first oil crisis in 1973 raised oil prices and encouraged geothermal power development and in 1974, a national "Sunshine Project" was inaugurated to accelerate alternative energy development including geothermal energy.

Furthermore, the Government took the following measures to reduce the risk of investment for well development. One is an investment of 2.3 billion dollar to promote research on geothermal fields and development of exploration technology. The other is the introduction of a compensation system for interest on bank credits to support developers undertaking well drilling in a process which requires a large investment at an early stage.

Based on these positive incentives, development of new geothermal fields was started in mid-1970's and seven geothermal power plants with a total output of 260 MW will be constructed in the new geothermal fields in Tohoku and Kyushu districts and will go into operation from 1994 to 1996. (See Table 1.)

Some projects are planned after 1997 but geothermal power plant development is expected to decelerate considerably as compared with development up to 1996. However, since there are positive factors as mentioned below, the geothermal power generating capacity of Japan will continue to increase in the long run.

(1) Fossil fuel resources are finite and public opinion is growing that development of alternative energy is important.

Table 1 Development Status of Geothermal Power Plants in Japan

Name of Power Plant	Output (MW)	Electric Power Company	Geothermal Developer (Well Owner)	Start of Construction / Start of Operation
Uenotai	27.5	Tohoku Electric Power Co., Inc.	Akita Geothermal Energy Co., Ltd.	Apr. 1992 / Mar. 1994
Sumikawa	50	Tohoku Electric Power Co., Inc.	Mitsubishi Materials Corp.	Apr. 1993 / Mar. 1995
Yanaizu-Nishiyama	65	Tohoku Electric Power Co., Ltd.	Okuaizu Geothermal Co., Ltd.	Jun. 1993 / May 1995
Kakkonda II	30	Tohoku Electric Power Co., Inc.	Tohoku Geothermal Energy Co., Ltd.	Apr. 1994 / Mar. 1996
Yamagawa	30	Kyushu Electric Power Co., Inc.	Japex Geothermal Kyushu Co., Ltd.	Jul. 1993 / Mar. 1995
Ogiri	30	Kyushu Electric Power Co., Inc.	Nittetsu Kagoshima Geothermal Co., Ltd.	Jul. 1994 / Mar. 1996
Takigami	25	Kyushu Electric Power Co., Inc.	Idemitsu Geothermal Co., Ltd.	Mar. 1995 / Nov. 1996

(2) Global warming and other environmental problems have come to the fore.

(3) IPP (Independent Power Producer) projects are being approved; the electric power supply business, which was limited to utility companies, is expected to be liberalized.

(4) Increased interest in the binary cycle and development of hot dry rock, which increases the number of geothermal fields which can be utilized.

1.2 Features of Recently Developed Power Plant

The fact that civil and erection costs can be reduced by adopting modular type turbines was first proved in Beowawe, Coso and East Mesa geothermal power plants etc. in the U.S. To achieve the same results, modular type turbines have become popular in Japan, too.

Particularly, 6 plants of 7 plants which will be commissioned from 1994 to 1996 adopt modular type top exhaust turbines. The modular type turbine was first developed for well head power generation of several hundred kilowatts but to obtain the same merits for large capacity central power generation units, unit capacity of modular type turbines has increased year by year, reaching 50 ∿ 70 MW in Modular-50 for Sumikawa Geothermal Power Plant.

2. ADVANTAGE OF MODULAR TYPE TURBINE

Generally speaking, as unit capacity becomes smaller, the investment per unit capacity (kW) increases. So for a small capacity unit, it is necessary to improve economics by packaging the turbine unit and minimizing civil and erection costs. For large and medium capacity units, too, packaging and standardizing, if technically possible, can greatly improve the economics.

Mitsubishi Heavy Ind., Ltd. (MHI) has developed large capacity modular turbines, going through the process as shown in Figure 2, so that advantages of small capacity modular units can be applied to large capacity units. As the result, Modular-25 was applied to Yamagawa 30 MW Power Plant and Modular-50 to Sumikawa 50 MW Power Plant. The advantages of modular units are as follows.

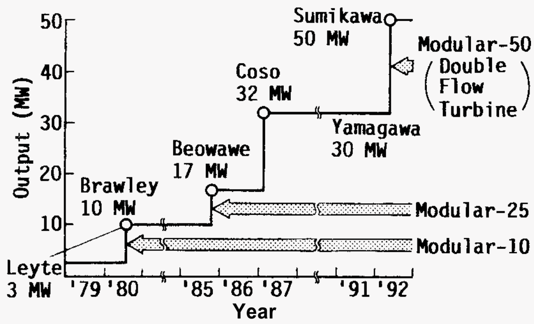

Figure 2 Capacity Increase of Modular Turbines

2.1 Civil and Erection Work at Site

Since all portable types of units are designed to have top exhaust, such high (5 ∿ 7 meters) concrete turbine pedestals as required for conventional units are not required, and modular units can be installed on concrete foundations at the ground level.

This results in a great saving on costs of civil work and obviates the necessity of lifting up to the high turbine pedestal equipment weighing close to 100 tons, making erection very easy.

As for modular units, casing, rotor, diaphragm and oil piping are pre-assembled and flushed in the shop, and only final adjustment and connection with other pipes and electric wires are to be done at the site, contributing to reduction in costs of erection work and shortening of erection schedule. This also minimizes the needs for skilled workers for erection and assembly work of the turbine at the site.

2.2 Quality

Since most parts of modular units are pre-assembled in the shop which is well equipped with manufacturing facilities, high quality can be assured from the view-point of preventing entry of foreign matter and the like.

3. INTRODUCTION OF YAMAGAWA GEOTHERMAL POWER PLANT

Yamagawa Geothermal Power Plant is situated in Yamagawa Town, Kagoshima Prefecture in Kyushu. Power generation is managed by Kyushu Electric Power Co., Inc. and steam is supplied by JAPEX Geothermal Kyushu Co., Ltd. Exploration of the geothermal field was started in 1977 and a test conducted in 1986 confirmed a potential of steam equivalent to 15,000 kW of electricity.

In 1990, a steam flow capable of stable electric supply of 30,000 kW was confirmed. Above-ground equipment including turbine and generator was manufactured and supplied by MHI and the power plant is under construction to start operation in March 1995.

Features of this power plant are described below. Main particulars of Yamagawa Power Plant are given in Table 2.

Table 2 Design Specification of Yamagawa and Sumikawa Geothermal Power Plants

	Item		Unit	Yamagawa	Sumikawa
Turbine	Type		-	Single Pressure Single Flow Impulse-Reaction Condensing Turbine	Single Pressure Double Flow Impulse-Reaction Condensing Turbine
	Rated Output		kW	30,000	50,000
	Maximum Output		kW	30,000	50,000
	Speed		rpm	3,600	3,000
	Steam Condition at MSV Inlet	Press.	bara	10.8	4.9
		Temp.	°C	183.2	151.1
		Gas Content	wt.%	0.5	0.17
	Exhaust Pressure		bara	0.15	0.11
	Steam Consumption at Rated Output		t/h	215.5	389
	No. of Stage		-	6	5 x 2
	Last Stage Blade		mm	635	584
Generator	Type		-	Air Cooled	Air Cooled
	Capacity		kVA	34,000	55,600
Condenser	Type		-	Spray Type Jet Condenser	Spray Type Jet Condenser
	Shell Pressure		bara	0.13	0.10
	Cooling Water Temp.		°C	33.6	22
	Hot Water Temp.		°C	49.4	43.5
	Water Quantity		m^3/h	6,550	9,100
Gas Extraction System	Type		-	Two Stages of Steam Jet Ejector	Two Stages of Steam Jet Ejector
	Suction Pressure		bara	0.12	0.09
	Discharge Pressure		-	Atmosphere	Atmosphere
	Steam Consumption of Ejector		kg/h	4,800	10,740
Cooling Tower	Type		-	Wet Type Counter Flow Mechanical Draft	Dry and Wet Type of Cross Flow Mechanical Draft
	No. of Cell		-	2	4
	Water Quantity		m^3/h	7,000	9,650
	Hot Water Temp.		°C	49.4	43.5
	Cold Water Temp.		°C	33.5	22
	Design Wet Bulb Temp.		°C	26.0	14
	Fan Motor Power		kW	270 x 2	175 x 4
Hot Well Pump	Type		-	Vertical Centrifugal Double Suction	Vertical Centrifugal Double Suction
	No. of Set		-	2	2
	Capacity		m^3/h	3,600	5,100
	Motor Capacity		kW	380	650

3.1 Steam Conditions

Hot water in Yamagawa is high in silica content, so a main steam pressure (10.8 bar abs.), higher than the optimized pressure to produce the maximum output, was selected to prevent silica precipitation in the injection line from the steam separator.

Vacuum was optimized on the basis of wet bulb temperature of 26 °C and 0.13 bar abs. was adopted.

3.2 Cycle

Single flash cycle was adopted for the following reasons.

- Prevention of silica from depositing in the injection well by keeping temperature of injection line from separator above silica saturation temperature
- Hot water ratio* is low and merits of double flash are small.

$$* \textbf{Hot water ratio} = \frac{\text{Separated hot water flow rate}}{\text{Separated steam flow rate}}$$

3.3 Operation

Remote control system from Sendai fossil power station 80 km away from the plant site is introduced because the plant is basically for base load operation and to minimize operation costs.

Start-up is performed at Yamagawa Power Station but monitoring and load changing during operation and shut-down can be done from the remote place, too.

3.4 Major Equipment

Modular-25 top exhaust modular turbine was adopted which is mounted on the ground level foundation. For moving blades in 6 stages, integral shroud blades with high reliability were adopted.

Considering a relatively high concentration of chloride in hot water in Yamagawa, titanium (Ti-6Al-4V) which showed a good result in a field material test was used for the first stage blades which are subject to the most severe corrosive atmosphere. Figure 3 shows a section of the turbine.

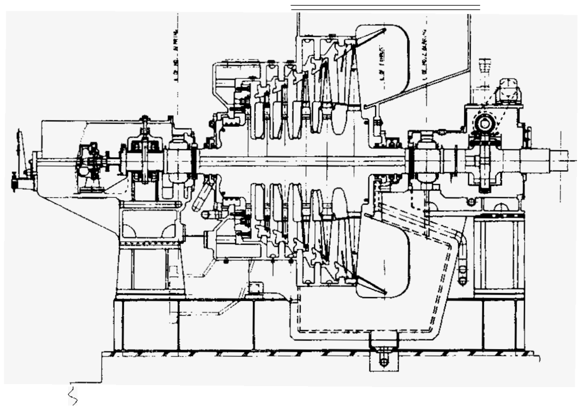

Figure 3 Cross Section of Yamagawa Turbine

Turbine exhaust is connected to the condenser with exhaust pipe of 3.2 m in diameter. The condenser is installed outdoor at the ground level. Two-stage ejector which is simple and highly reliable was used for the gas extraction system since motive steam pressure is sufficiently high.

4. INTRODUCTION OF SUMIKAWA GEOTHERMAL POWER PLANT

Sumikawa Geothermal Power Plant of Tohoku Electric Power Co., Inc. is situated in Akita Prefecture in Tohoku district and is under construction to start operation in March 1995, the same as the Yamagawa Power Plant. Figure 4 shows an expected view of the plant at completion.

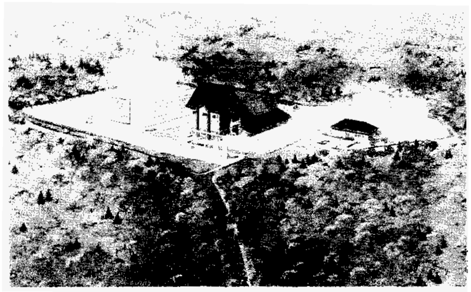

Figure 4 Appearance of Sumikawa Geothermal Power Plant

Exploration and research of the geothermal field was started in 1981 by Mitsubishi Materials Corp. and in 1990 a test confirmed the production of 420 tons/hr of steam at 4.9 bar abs. pressure.

Features of this plant are as follows. Main particulars of Sumikawa Power Plant are given in Table 2.

4.1 Steam Conditions

On the basis of the production well characteristics, 4.9 bar abs. was selected as the optimum pressure to develop the maximum output.

4.2 Cycle

Since merits of double flash cycle could not be expected because of low hot water ratio, single flash cycle was adopted which is advantageous in costs of equipment such as separator and transmission pipe.

4.3 Operation

The plant is remote controlled from a remote supervising station in Kazuno City. which is 10 km away, in the same way as Yamagawa Power Plant.

4.4 Major Equipment

Turbine
Modular-50 was adopted which has the world's largest output range (50 ∿ 70 MW) as a modular unit.

Modular-50 is the first unit to adopt top exhaust for double flow geothermal turbine, making ground level installation possible.

A section of the turbine is shown in Figure 5. Turbine exhaust is led by two 2.8 m diameter exhaust pipes to the condenser which installed outdoor at the ground level. Figure 6 shows arrangement of turbine and condenser.

Adoption of Modular-50 produces the same merits in 50 MW class geothermal power generation as the merits obtained with medium and small capacity modular units of Modular-25 and smaller. Shipping weight and size in case of Sumikawa are shown in Figure 7. The configuration for shipping was based on the inland transportation restriction.

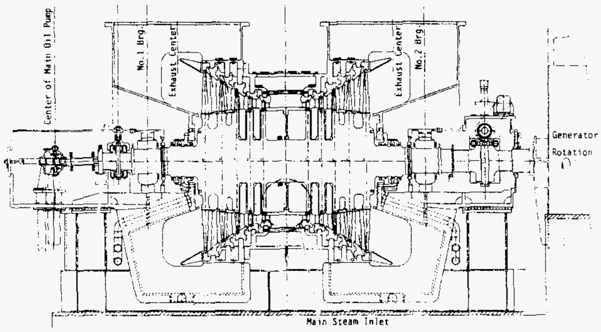

Figure 5 Cross Section of Sumikawa Turbine

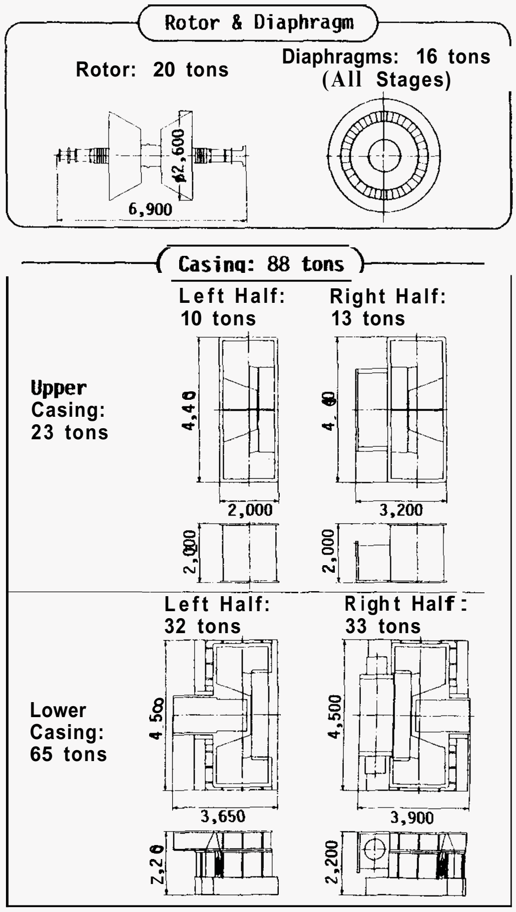

Figure 7 Shipping Weight and Size in case of Sumikawa

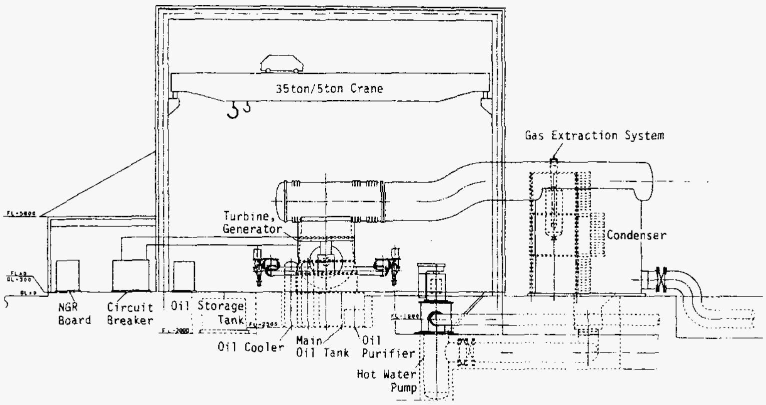

Figure 6 General Arrangement of Major Equipment

"No scaling nozzle" was adopted for the first stage nozzles of Modular-50 turbine for Sumikawa. All nozzles are provided with holes in profile for clean and cool water to pass through to reduce nozzle metal temperature below steam saturated temperature and thereby prevent plugging of flow area due to scaling on the first stage nozzles.

For details of mechanism and field test condition and results, please refer to Figure 8, Table 3 and Figure 9.

As for blading, integral shroud is adopted for moving blades and fully 3-dimensionally designed "Bow Nozzle" was adopted for nozzles to improve reliability and performance individually.

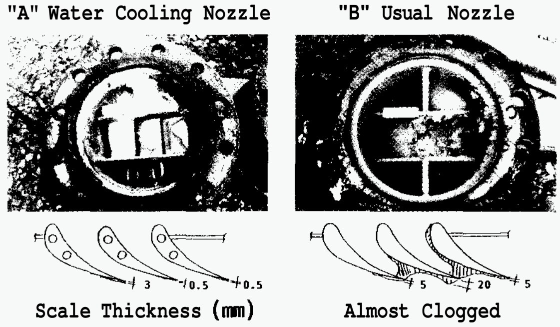

Figure 9 Field Test Result of Water Cooling Nozzle (after 40 Days Operation)

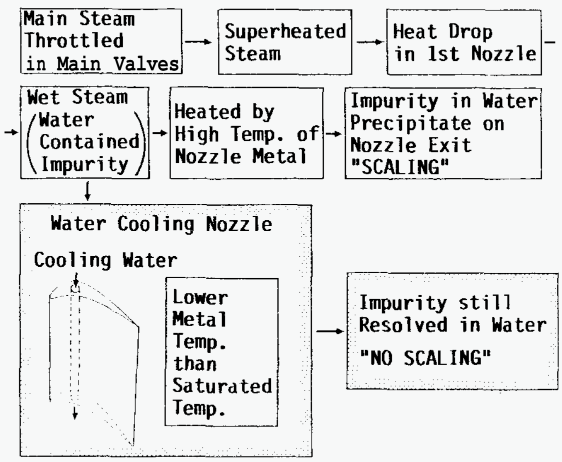

Figure 8 No Scale (Water Cooling) Nozzle

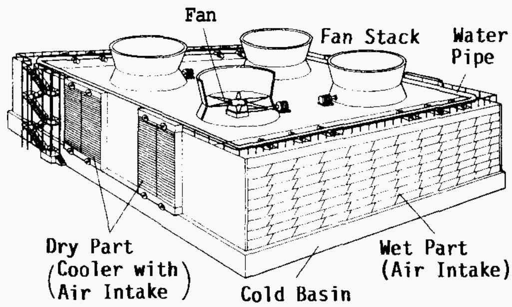

Figure 10 Dry and Wet Type Cooling Tower

Table 3 Test Condition

Item	Unit	Data					
Inlet Pressure	bara.	4.7					
Inlet Temperature	°C	150					
Exit Pressure	bara.	1.9					
Cooling Water Flow Rate	ℓ/min.	6.7					
Impurities in Steam	ppm	Na	Ca	Cℓ	B	SiO_2	TS
		0.1	<0.5	<0.01	6.4	0.17	9

Cooling Tower

The minimum atmospheric temperature in winter is expected to be -20 °C, and with a normal wet type cooling tower, visible plume discharge from the tower will stick to surrounding trees and freeze, producing adverse effects on ecology of trees and causing problems of sunshine shortage and freezing of the ground and structures.

These problems were solved by adopting a dry and wet type cooling tower, which consists of a conventional wet type cooling part, a dry type air cooling part and common fans, performs air heating in the dry air cooling part and delivers dry air to the atmosphere from the fan outlet. Figure 10 shows an outline of the dry and wet type cooling tower.

5. CONCLUSION

In view of the fact that of the seven plants, six plants will adopt modular type turbines, it may be understood that the contribution which the modular type turbine makes to a reduction in total construction costs of plants and to improvement in quality has been recognized in Japan, as have the merits of medium and small capacity modular type turbines such as Modular-25 been recognized in the U.S.

Modular-50 for Sumikawa Power Plant, which has increased the capacity range of modular turbine to 50 ∿ 70 MW, is believed to demonstrate the advantages of modular turbines in 50 ∿ 70 MW geothermal power plant projects.

6. REFERENCES

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