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SHORT CUT TO ECONOMICAL GEOTHERMAL POWER GENERATION WITH WIDE RANGE PORTABLE TURBINES

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ABSTRACT

The 32,000 kW Coso Geothermal Power Plant was put into operation in August, 1987, using a packaged type large capacity portable turbine.

And two other geothermal power plants, Freeport Resources Co. 11,000 kW x 2 Bear Canyon and 14,350 kW x 2 West Ford Flat Plants, will start operation at the end of this year, using portable turbine generators.

This concept for constructing geothermal power plant is aiming at economical geothermal power generation and starting operation in a short period. It is applicable today up to 30,000kW class, using several standardized kinds of turbine generator.

INTRODUCTION

Geothermal power generation has entered a steady growth period. The total capacity of geothermal power plants in the world including those under construction is more than 5,000 MW, and its annual growth rate is dramatic at 16%.

In the U.S. and Mexico, the unit capacity of geothermal power plants has increased and a 150,850 kW plant has come to be planned as PG & E Geysers Unit 21.

On the other hand, there are still great needs for small capacity geothermal power plants, which are constructed not only as wellhead plants but also in developing countries and islands where electric power demands are not so high, and as in-house power plants for hotels in hot spring areas of Japan.

Fig.1 shows the number of units for each generating capacity class in the world.

About 70% of all geothermal power plants are of capacity less than 30,000 kW and there seems to be increasing needs for portable turbines.

Generally, the smaller the capacity of a power plant, the higher the unit cost of construction. Therefore, in constructing a small capacity geothermal power plant, it is necessary to achieve economic viability by packaging the equipment to minimize civil work cost and erection cost.

In the U.S., there are great needs for modularization or shop assembly of equipment because of high erection cost, and geothermal power plants of 10,000 kW - 30,000 kW class are being constructed, using the merits of portable turbine generators.

To meet this needs, Mitsubishi produced various types of portable turbine generators. Mitsubishi manufactured and delivered 56 geothermal turbine generators, of which 21 are of a portable type.

This paper introduces the portable turbine generators Mitsubishi has manufactured and the geothermal power plants recently constructed in the U.S. using large capacity portable type turbines.

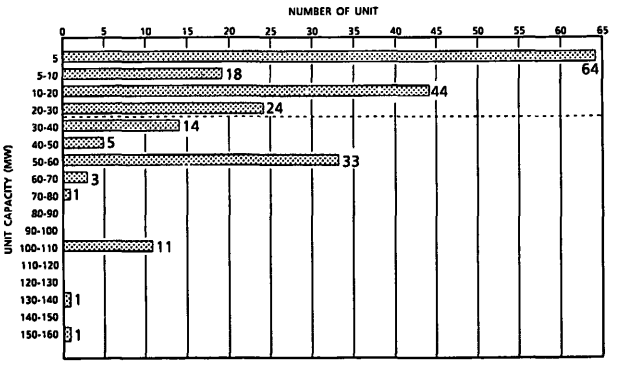
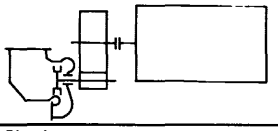
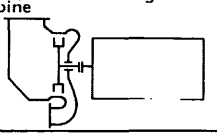
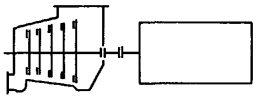
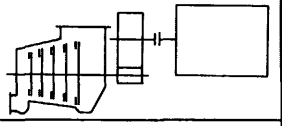
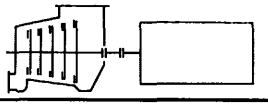


Fig.1 Unit Capacity Distribution of Geothermal Power Plants

PORTABLE TURBINE GENERATOR

Portable turbine generators are classified into back-pressure type and condensing type. Features of different types of portable turbines manufactured by Mitsubishi are shown in Table 1.

Table 1 List of Mitsubishi Portable Turbines

		Type of Turbine & Generator	Characteristics
Back-Pressure Type	MPT-4G	Single-stage back-pressure geared turbine, 4 pole generator 	1. Low cost 2. Small package 3. Suitable output range: 500 kW 3,000kW 4. With reduction gear
	MPT-2L	Single-stage back-pressure turbine, 2 pole generator 	1. Low cost 2. Small package 3. Suitable output range: 1,000 kW 3,000 kW
	MODULAR-5	Multi stage back-pressure turbine, 2 pole generator 	1. Large output and high efficiency 2. Suitable output range: 3,000 KW - 10,000 kW
Condensing Type	MPT-4GC	Multi-stage condensing geared turbine, 4 pole generator 	1. High efficiency 2. Lower cost and shorter erection period than conventional geothermal condensing turbine 3. Small package 4. Suitable output range: 1,000kW - 3,000 kW
	MODULAR-5,10,25	Multi-stage condensing turbine, 2-pole generator 	1. Large output and high efficiency 2. Lower cost and shorter erection period than conventional geothermal condensing turbine 3. Suitable output range: 3,000 kW - 30,000kW

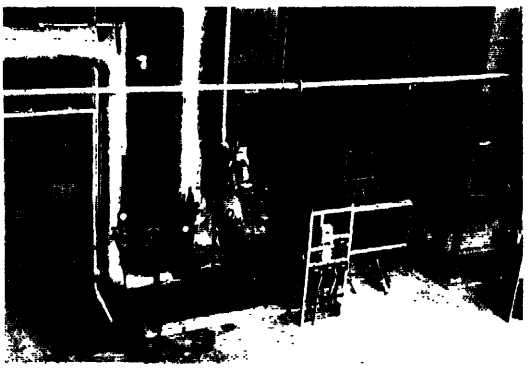


Photo 1 External View of MPT-4G

Back-pressure type turbine

The first back-pressure type portable turbine is a 1,300 kW turbine delivered to Ahuachapan Geothermal Power Plant in El Salvador, and is a single stage back-pressure turbine called MPT-4G, coupled with a 4-pole generator by a reduction gear.
Photo 1 shows its external view.

Designed to supply start-up power source when the main plant is shut down, this portable power plant is provided with a steam turbine driven auxiliary oil pump and an air cooled oil cooler so that it can be started up without external power source or cooling water. Therefore, it can be used as a wellhead power plant without any modification.

A total of three MPT-4G turbines have been supplied, including those for 1,300 kW start-up power plant for Makiling Banahaw Geothermal Power Plant (55,000 kW x 6) and a 3,000 kW wellhead power plant in Leyte in the Philippines.

Aimed at reduced cost and improved performance of portable power generating equipment, MPT-2L model was developed, and a 3,000 kW turbine was delivered to Azores Geothermal Power Plant in Portugal.

Longitudinal section of MPT-2L turbine is shown in Fig 2.

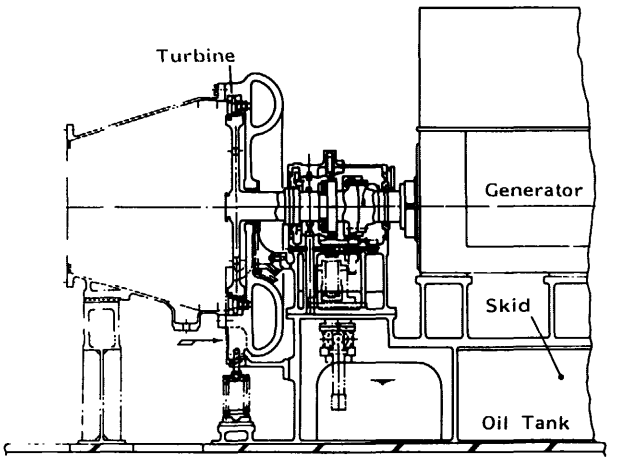


Fig.2 Longitudinal Section of MPT-2L

Features of MPT-2L model are that the turbine disc is directly coupled to the 2-pole generator shaft, thus deleting the reduction gear, and that the generator cooling fan doubles as the air-cooled oil cooler fan.

The second unit of MPT-2L model was delivered to Suginoi Hotel in Beppu, a famous hot spring resort, in Japan.
It was operated as a back-pressure turbine for the first eight months, but a condensing system was provided later, and it has been operated as a condensing turbine since March, 1981.

The average annual availability factor of Suginoi Geothermal Power Plant using a portable turbine generator is as high as 97.8%, which testifies to the high reliability of Mitsubishi portable turbine generators.

Condensing type turbine

All portable turbine generators had been of the back-pressure type, but to realize portable condensing turbine generators of a comparable performance, Mitsubishi developed multiple-stage, portable packaged turbine generators called modular series.

The modular series include standardized module of Modular-5, and -10. The first Modular-10 unit was delivered to Brawley Power Plant in Imperial Valley, Calfornia, and the following four Modular-10 were delivered to Bear Canyon and West Ford Flat Power Plants in the Geysers.

The turbine is of a single-flow, 5 or 6-stage condensing type, and exhausts upward as it is mounted on a ground level.

The oil cooler is water-cooled as cooling water is available from the condensing plant. While Modular-10 was intended for 10,000 kW class power plants, Modular-5 was developed for 5,000 kW class power plants.

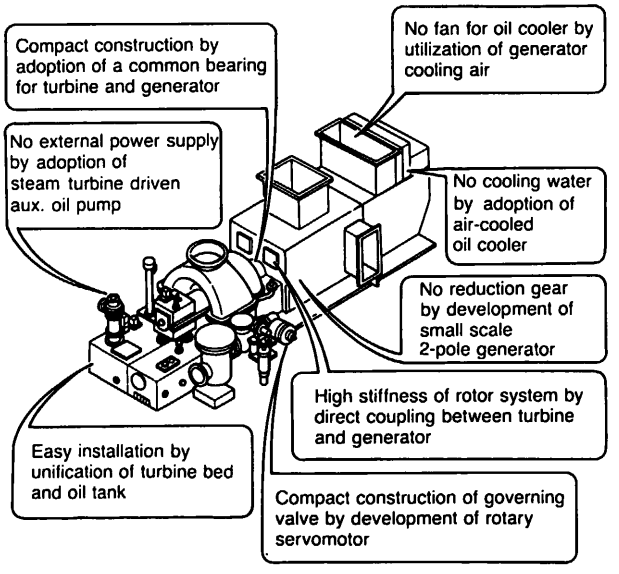


Fig.3 Features of Modular-5

Modular-5 was initially designed as a condensing type, but was later modified for back pressure wellhead power generation, using steam turbine driven auxiliary oil pump and air-cooled oil cooler.
Five Modular-5 back-pressure turbines were delivered to Los Azufres in Mexico.

Features of Modular-5 delivered to Los Azufres are shown in Fig. 3.

Photo 2 shows a Modular-5 units awaiting shipment to Los Azufres.

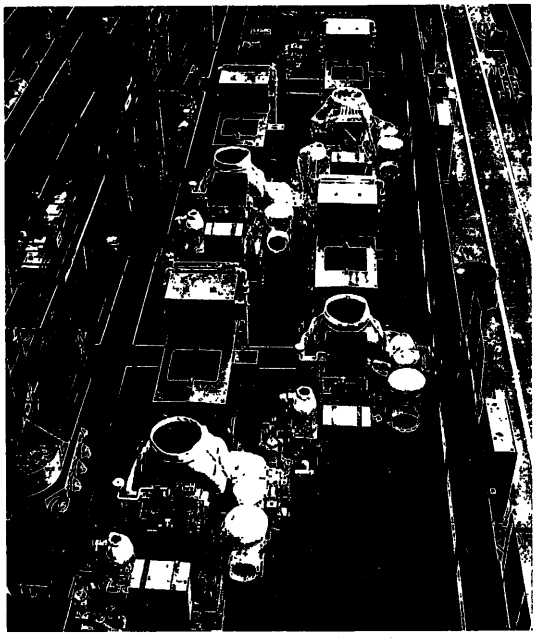


Photo 2 Modular-5 Turbine Generators before shipping

The five Modular-5 turbine generators were successively put into operation with about two month erection periods.

The first Modular-10 condensing portable turbine generator delivered to Brawley Geothermal Pilot Plant in Imperial Valley, had been operated by Southern California Edison and Union Oil from 1980 to 1985.

As the Brawley unit was a prototype, a oil unit was not assembled with turbine module.
Afterward each two Modular-10 were delivered to Bear Canyon and West Ford Flat Geothermal Power Plants in the Geysers.
Design of these units was modified to assemble the oil unit with turbine module from a prototype. Though the weight for transporation was increased to 90 metric tons by this modification, the erection work was made more simplified.
Fig 4 shows a configuration of new Modular-10.

DEH turbine control system was also developed for Modular-10 as standard to comply with recent customer's requirement.

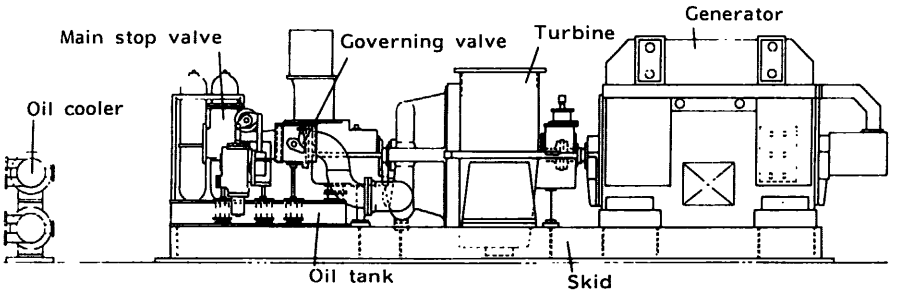


Fig.4 Configuration of Modular-10

LARGE CAPACITY MODULAR TURBINE

To apply the advantages of portable packaged types to large capacity turbines, Mitsubishi developed a standardized modular turbine called Modular-25, and delivered the first unit to Beowawe Double Flash Geothermal Power Plant in Nevada.
The capacity of Beowawe is 17,000 kW, smaller than the standard capacity of 25,000 kW for Modular-25, but Modular-25 with large last stage blading was used because a high condenser vacuum was adopted to take advantage of the plant being located at 1,500 m above the sea level in a cold area of northern Nevada. The plant was put into commercial operation in December, 1985, 14 months after receipt of an order against normal construction period of 18 months.
The reasons why the plant was completed in such a short period though the construction was disturbed by heavy snow are that equipment was designed as package as much as possible and that the whole plant was arranged outdoor with no housing built at all.

The second Modular-25 was delivered to 32,000 kW Coso Geothermal Power Plant in California.
In this power plant, Modular-25 was adopted to generate power as much as possible by accepting more steam flow rate.
Design philosophy to use packaged equipments is similar to Beowawe plant.
This power plant was put into commercial operation in August, 1987 and has been successfully operated.
Photo 3 shows a general view of the power plant.

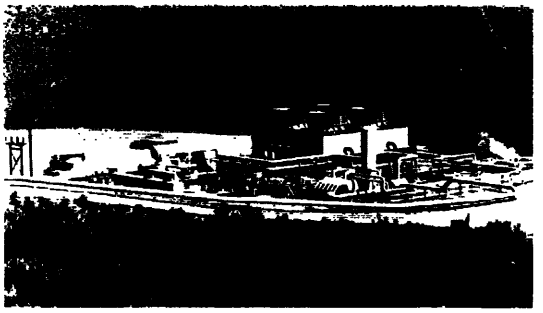


Photo 3 General View of COSO Geothermal Power Plant

Other two Modular-25 are under manufacture for 18,500 kW x 2 East Mesa Geothermal Power Plant.

Specificaiton of the Modular-25 turbine applied to each power plant is shown in Table 2.

Table 2 Specification of Applied Modular-25 Turbine

	Unit Name			Beowawe	Coso	East Mesa
Turbine	Type			Double Pressure Single flow, Impulse-reaction	Double Pressure Single flow, Impulse reaction	Double Pressure Single flow, Impulse reaction
	Rated output		kW	16,660	25,000	18,500
	Max. capability		kW	17,010	32,200	21,700
	Speed		rpm	3,600	3,600	3,600
	Steam condition at MSV	press.	psig	49.1 1.42	65.7/3.98	30.4/2.13
		temp.	°F	294/210 (Sat.)	312/221 (Sat.)	274/219 (Sat.)
		gas content	% (by weight)	0.01	2.0	1.1
	Exhaust pressure	exhaust hood	inHg abs.	1.31	3.07	3.1
		condenser	inHg abs.	1.25	2.84	2.9
	Steam consumption		lbs/hr	177,250/97,220	343,040/154,100	210,100/114,950
	No. of stages		--	5 x 1 flow	5 x 1 flow	4 x 1 flow

A longitudinal section and configuration of Modular-25 are shown in Figs.5 and 6. The turbine is of a single-flow condensing type, and can be used in single flash or double flash plants.

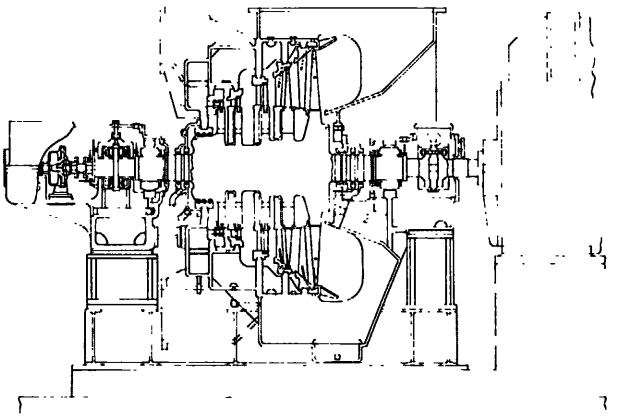


Fig.5 Longitudinal Section of Modular-25

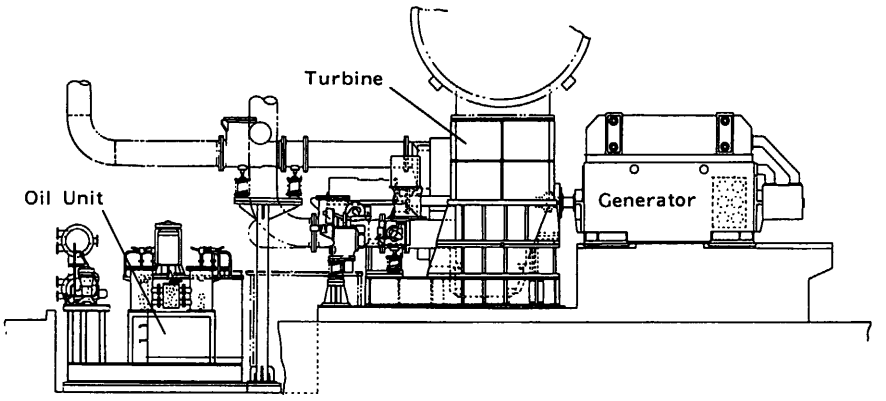


Fig.6 Configuration of Modular-25

The last stage blading is 25 inches long, the longest geothermal turbine blading of Mitsubishi, and can be used for up to 35,000 kW turbines.
The turbine exhausts upward as other portable turbines do and the turbine module is directly installed on the concrete floor, thus eliminating the need for turbine foundation table, etc.

Other portable turbine generators are mounted on a common base plate, and most of them have oil tanks built in, too. However, a large capacity modular turbine generator weighs more than 100 metric tons if assembled in one piece, so a turbine and a generator are modularized separately.
The weight of turbine module is 85 metric tons.

A generator of this class is usually transported in one piece with the rotor assembled in the stator, and so no change to design was necessary.
A generator shipped separately is installed on the concrete floor as it is.

The oil tank is mounted on a common base plate together with the oil cooler and the oil purifier, and this oil unit is delivered after once assembled with the turbine module including interconnecting oil piping in the shop. Thus modularization minimizes installation and piping work at site.
Photos 4 and 5 show a turbine module and an oil unit module being lifted.

Modular-25 was developed as a central power plant rather than a wellhead power plant. However, in view of the strong needs for reduction in erection cost, big modularization of equipment and quick realization of geothermal power generation, this type of modular turbine generator is likely to become popular in the future, too.

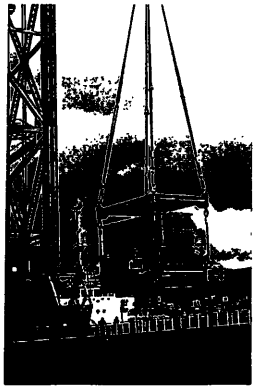


Photo 4 Modular-25 Turbine Module

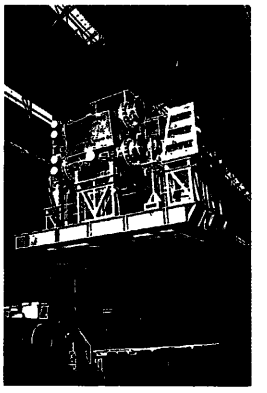


Photo 5 Modular-25 Oil Console

Electric panels and control panels are put in a package house as a control module, which is shipped to the site after being assembled and tested in the shop.
Therefore, the work at the site is limited to plugging in wiring to the control package, and field tests are kept to a minimum, too.

Generally, the unit cost of construction of a geothermal power plant is high comparing with that of fossil power plant, and this was one of the factors which delayed the development of geothermal power generation.
It can be said that one of the ways to reduce the construction cost is to construct an outdoor geothermal power station using a large capacity modular turbine.

The construction cost per kW of 30,000 kW geothermal power plant including equipment cost, erection cost and civil cost is estimated at $1,200~1,300/kW according to the experiences in Beowawe and Coso power plants as shown in Fig.7. The cost of transmission line is not included in the above cost.

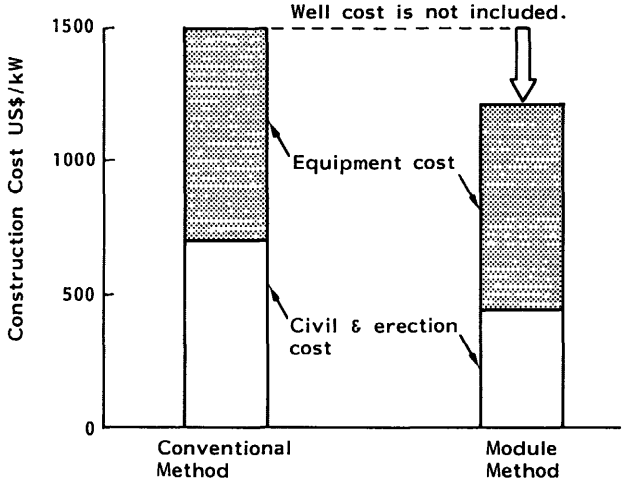


Fig.7 Comparison of Construction Cost in 30,000kW Double Flash Plant

It is obvious that construction of geothermal power plants using outdoor type Modular-25 turbines has much advantage on economy and construction schedule.

Reliability of geothermal power plant using Modular-25 turbine is proved in Beowawe plant of which availability factor is 98.5% and capacity factor is 91.7% up to April,1988.

VERY SMALL GEOTHERMAL PORTABLE TURBINE GENERATORS

While large capacity modular turbines are put to practical use, attention is paid to very small capacity portable power plants, too.

To meet the needs for geothermal power plants less than 200-300 kW to be installed at wellhead much lower in pressure and flow rate of steam than ordinary wells used for geothermal power generation, Mitsubishi developed very small geothermal portable turbine generator called GEO-PACK, and delivered to Ogiri Geothermal Power Plant in Japan.

In GEO-PACK, an induction generator is usually used, complex turbine control equipment is deleted, and ball bearings are used to eliminate the need for lubricating oil system.

The GEO-PACK for Ogiri Plant was designed of a synchronous generator with DEH turbine control system.

This type of portable turbine generator can be used for an in-house power plant using a hot spring well of a hotel, etc., and turbine exhaust steam, directly mixed with cooling water, can fully meet the requirement for a hot water supply system of a hotel and the like.
Fig.8 shows its external view of GEO-PACK.

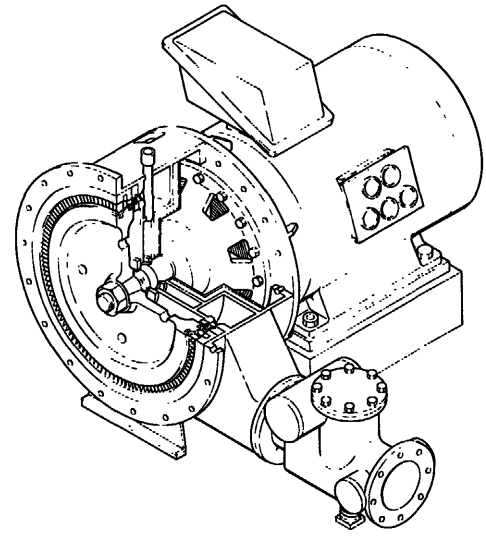


Fig.8 External View of GEO-PACK

CONCLUSION

There is a common perception that a geothermal portable turbine generator is used for a small capacity wellhead power plant, but the emergence of large capacity modular turbines has made it necessary to change this concept.

In the U.S., 30,000 kW class geothermal power plants using large capacity modular turbines have been constructed at a low cost and in a short period, and this trend is likely to become stronger.

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