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FUJI GEOTHERMAL POWER PLANT

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I. FOREWORD

Fuji Electric Co., Ltd. started work in the field of geothermal power generation as early as 1960, long before the first oil crisis. Fuji Electric supplied its first geothermal power generating equipment to Hakone Kowakien of Fujita Kanko Co., Ltd., although it was a small unit. Five years has already passed since Fuji initiated full-scale production in the field of geothermal power generation with the impetus provided by the receipt of an order in 1977 for 40 MW geothermal power generating equipment from Comision Ejectiva Hidroelectrica del Rio Lempa (CEL) of El Salvador in Central America. Fuji has so far received orders for seven plants including eleven units with a total capacity of 337 MW. These units include a plant with a double-flash cycle, portable wellhead power generating equipment etc. With the total production of 337 MW Fuji ranks fourth in the world, but will soon achieve a higher rank. Fuji was able to reach this position in such a short period because of it's great efforts in research and development for geothermal power generating equipment with emphasis on corrosion test of materials. The results of those work and the accumulation of technical expertises in conventional thermal power generation were reflected in the design and manufacture of new geothermal power generating plants.

This report introduces Fuji's records in geothermal power generation and outlines of major plants already delivered.

II. GEOTHERMAL POWER GENERATING PLANTS UNDERTAKEN BY FUJI

1. Plants Undertaken

Table 1 lists the orders for equipment and the map in *Fig. 1* shows destinations of delivered equipment throughout the world.

Since the award of an order in 1977 from CEL of El Salvador in Central America for a fullscale 40 MW geother-mal power generating unit, a series of orders has been awarded. Those include orders for two 55 MW units for NCPA No. 2 Geothrmal Power Generating Plant in the Geisers Area of California, USA, two 1.5 MW units and three 37.5 MW units for the Palimpinon Geothermal Power Generating Plant of the National Power Corporation of the Philippines and one 6 MW unit for Iceland SRH. Now, Fuji's geothermal power generating plants count seven plants including eleven units and their total output reaches 337 MW, thus becoming one of the major fields of Fuji's thermal power plants. These plants include various types such as 40 MW unit for CEL Ahuachapan Geothermal

Table 1 Reference list of geothermal power plants

No.	Customer	Power Plant	Ordered/Commissioned	Capacity (MW)	Type
1	CEL	Ahuachapan	1977/1980	40	Double flash
2	MCPA	NCPA No.2	1979/1981	2 x 55	
3	NPC	Palimpinon	1979/1980	2 x 1.5	Skid mounted, Wellhead
4	SRH	SRH 6MW	1980/1980	6	Skid mounted
5	NPC	Palimpinon	1980/1983	3 x 37.5	
6	DWR	Bottle Rock	1980/1984	55	
7	SCE	Salton Sea	1980/1981	10	

CEL : Comisión Ejecutiva Hidroeléctrica del Río Lempa
NCPA : Northern California Power Agency
NPC : National Power Corporation
SRH : Sudurnes Regional Heating
DWR : Department of Water Resources
SCE : Southern California Edison Company

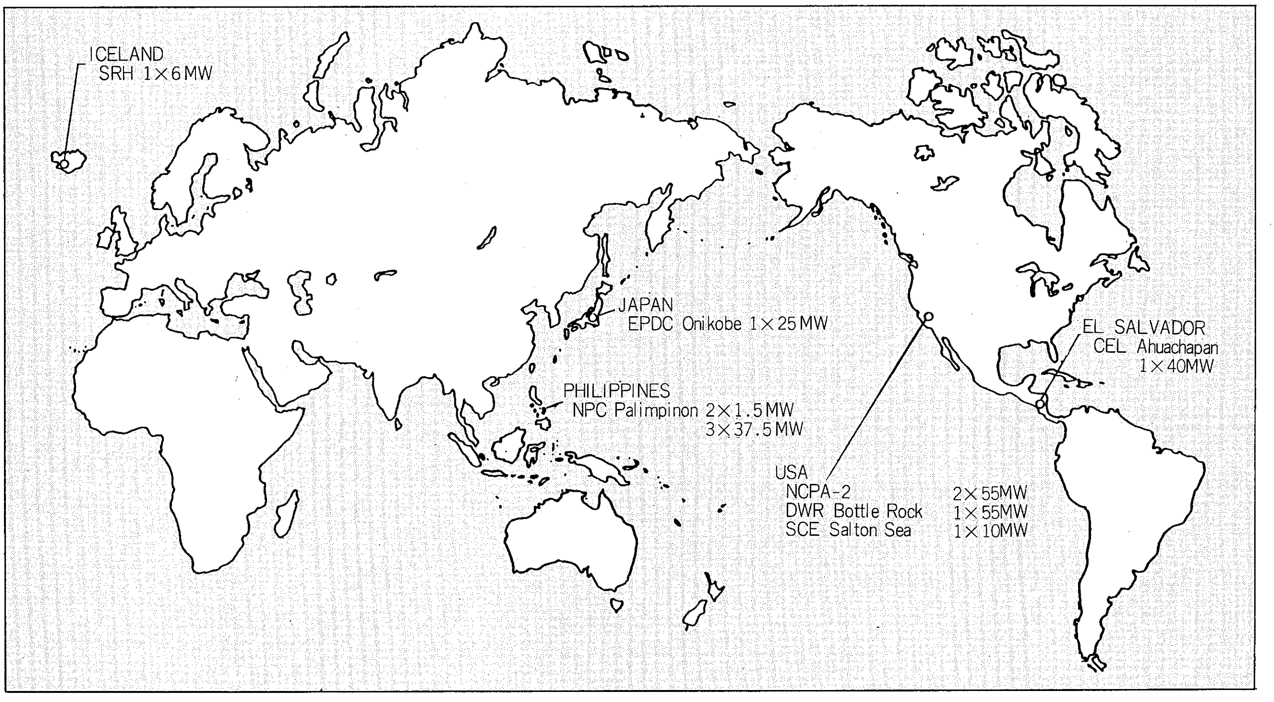


Fig. 1 World map showing Fuji geothermal power plants

Power Generating Plant adopting double slash cycle, two 55 MW units for NCPA No. 2 Geothermal Power Generating Plant of dry steam type, two 1.5 MW portable wellhead power generating units for NPC Palimpinon Geothermal Power Generating Plant, 6 MW unit of Iceland SRH installed in a hot water supply plant and three 37.5 MW units for NPC Palimpinon Geothermal Power Generating Plant ordered on a full turnkey contract basis. This means that in a short period Fuji has gained substantial experience in various types of geothermal power generating systems which are now in actual use.

III. INTRODUCTION OF REPRESENTATIVE PLANTS

The following introduces several representative plants which have already been delivered.

1. Ahuachapan Geothermal Power Generating Plant No. 3 Unit 40 MW Geothermal Power Generating Equipment (El Salvador)

1) Outline of the Plant

This is the first full-scale geothermal power generating plant made by Fuji and was ordered by CEL of El Salvador in Central America in August, 1977. Different from the existing units No. 1 and No. 2 the main feature of this unit is the adoption of double flash cycle which recovers low pressure steam, using flashers, from hot water which was wasted in existing units and uses it for power generation with high pressure steam. The double flash cycle has the following features:

(1) Its equipment and control system becomes more complex and its construction cost is 5-10% higher.

(2) The power output is 20-30% greater than that of single flash system. The gain in output therefore far exceeds the increase in construction cost.

(3) As the wetness of turbine exhaust steam is decreased by about 20%, erosion on low pressure blades is reduced.

(4) The quantity of hot water discharged from the plant is less.

Although many geothermal power generating palnts are in operation throughout the world at present, there are comparatively few plants which employs double flash cycle. These include Hachobaru Geothermal Power Station of Kyushu Electric Power Co., Ltd., in Japan and Ahuachapan Geothermal Power Generating Plant No. 3 Unit abroad.

Fuji's scope of supply to this plant covers almost all the equipment, except for steam production well equipment, such as turbine, generator, condenser, wellhead separator, flasher, cooling tower, various types of pumps etc.

It has been over a year and half since commercial operation of the unit was started at the end of 1980 and it has been operated smoothly without any serious trouble incidental to the first fullscale product. The total operation time until the end of May, 1982 reaches about 11,900 hours with a high availability factor of 99.8%.

Fig. 2 shows the whole view of the plant, *Fig. 3* shows the exterior view of the No. 3 unit, *Fig. 4* shows the main steam flow diagram of the plant and *Fig. 5* shows the general arrangement of the plant.

2) Description of the Main Equipment

Fig. 6 illustrates a cross-section of the 40 MW steam turbine. This is a single cylinder double flow 2 x 7 stage dual pressure turbine. Since this is the first full-scale geothermal power generating plant supplied by Fuji, a double-shell construction similar to the low pressure cylinder of the steam turbine of a conventional thermal power generation plant is employed.

For the condenser, spray and barometric type is employed. In order to resist corrosive geothermal fluids, steel plate clad with 316L stainless steel and solid 316L stainless steel are used for the condenser shell and all of

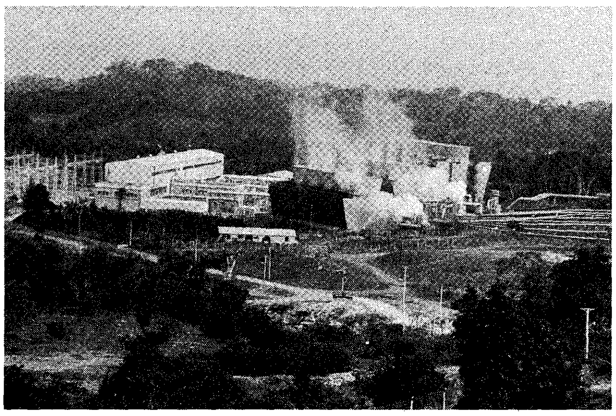


Fig. 2 Whole view of Ahuachapan geothermal power plant

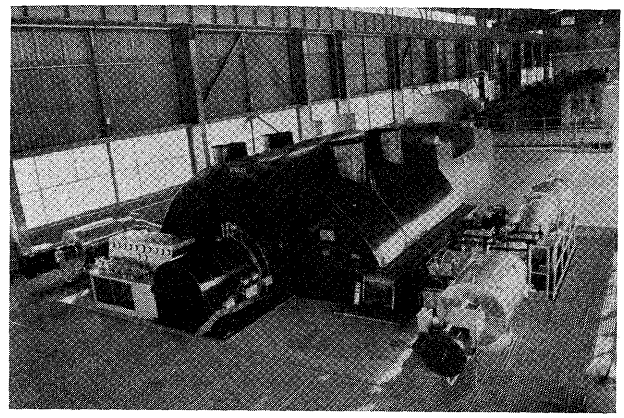


Fig. 3 Exterior view of Ahuachapan No. 3 unit

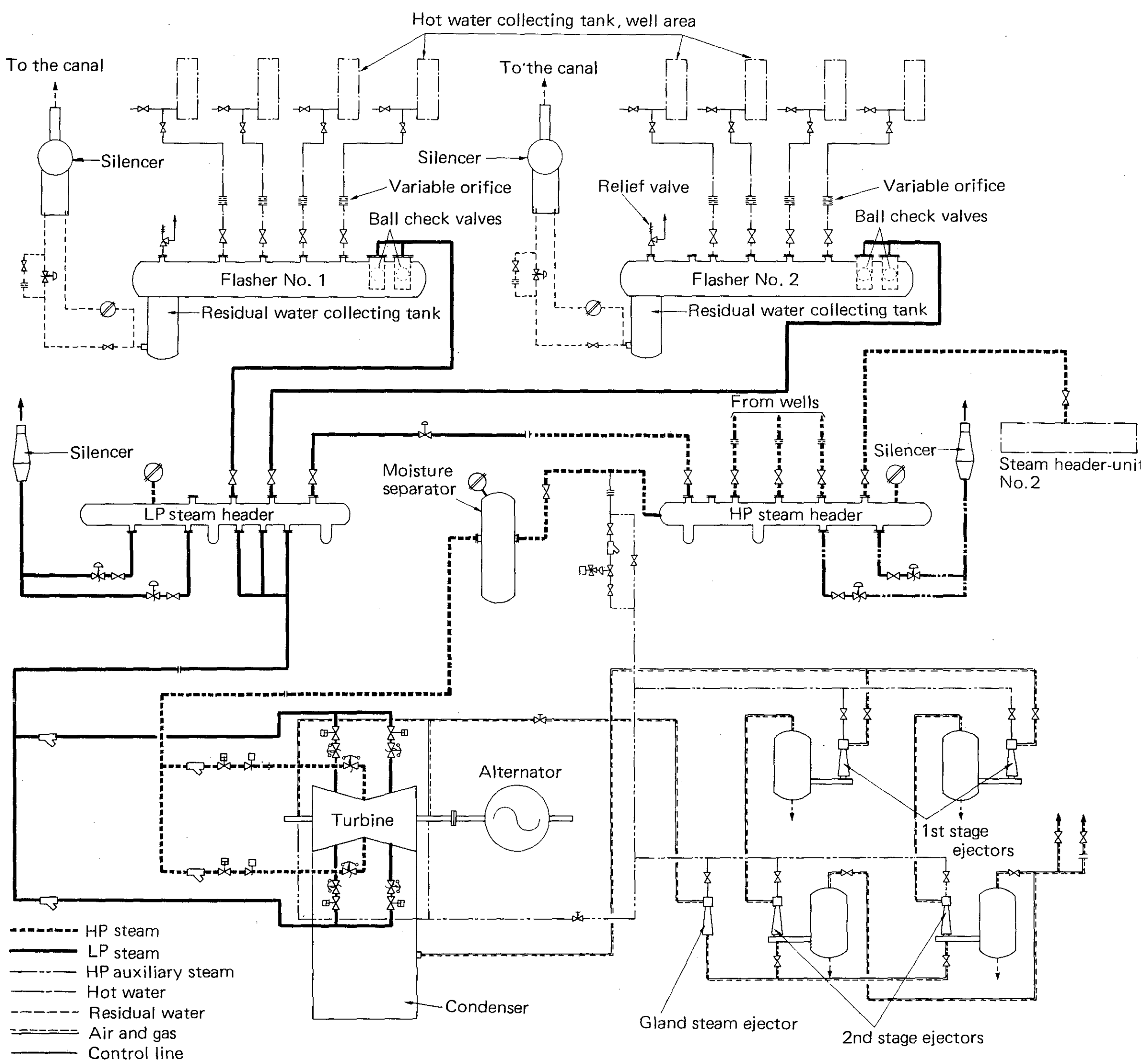


Fig. 4 Main steam flow diagram

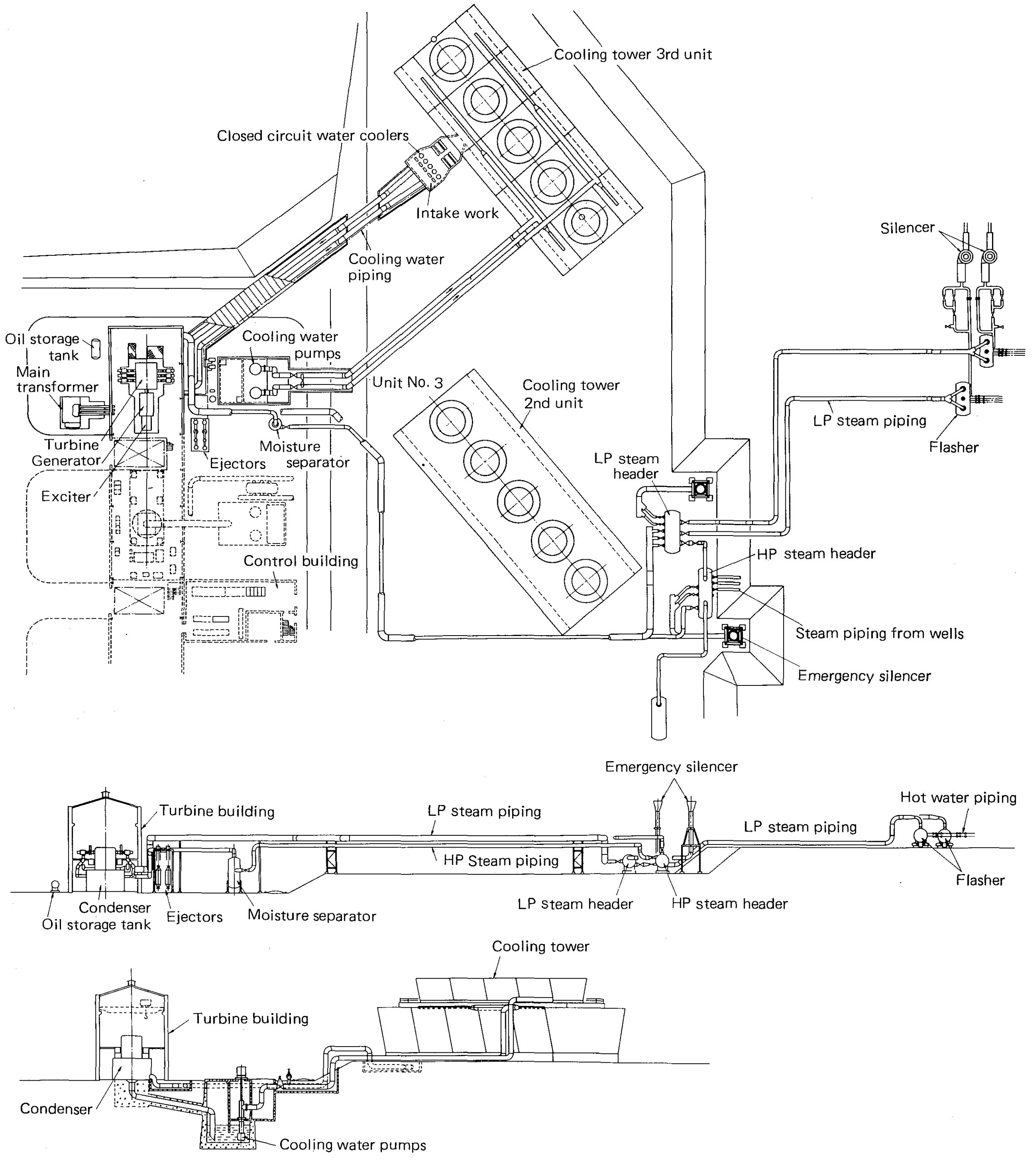


Fig. 5 General arrangement

internal parts respectively.

Fig. 7 shows the condenser under manufacture. It is 4.8 m in width, 9.6 m in length, 4.5 m in height and about 54 t in assembled weight. It was transported to the site in this form as a single unit. As the non-condensable gas content in steam is as low as 0.2% in high pressure steam (0% in low pressure steam), twin two-stage steam jet air ejector is employed for the gas extraction system.

The generator is an enclosed ventilated air-cooled type adopting brushless excitation system to provide easier maintenance.

As is usual with geothermal power generating plants installed in remote and secluded places in the mountains, a circulating system using cooling towers is employed for the main cooling water system. *Fig. 8* shows the cooling water flow diagram. Cooling water flows from the cooling tower cold water basin into the condenser due to the difference in static head and difference in pressure, then flows down to the cooling water pump pit via the condenser tail pipe and is pumped back from the pit to the cooling towers by the cooling water pumps.

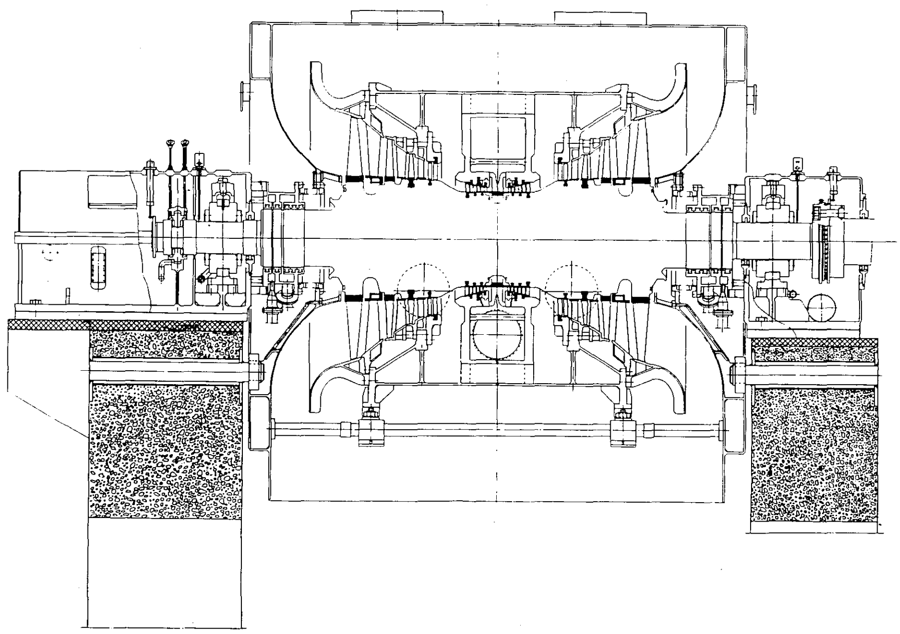


Fig. 6 Section of 40 MW geothermal steam turbine

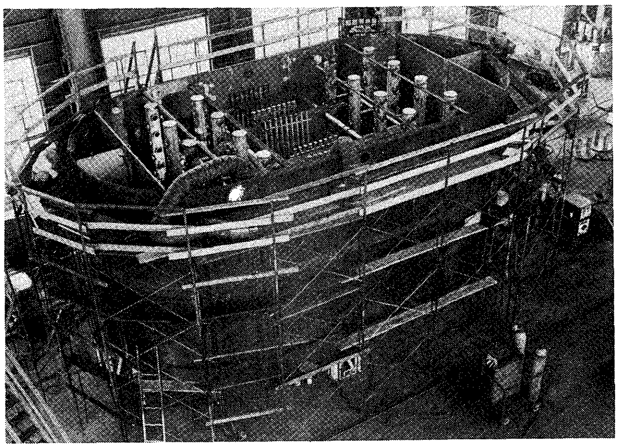


Fig. 7 Spray type condenser under manufacturing

2. NCPA No. 2 55 MW Geothermal Power Generating Equipment (USA)

1) Outline of the Plant

This plant, which was ordered by Northern California Power Agency (NCPA) in California USA in 1979, consists fo two 55 MW units and is installed in the famous Geisers area. Plants in this area have a capacity of about 1800 MW (including those under construction), making it the largest geothermal power complex in the world at present. There are basically two types fo geothermal resources, one is where geothermal energy boils out in the form of hot water (hot water type) and the other is where geothermal energy is provided in the form of steam (staem type). Nearly all geothermal fields are of the hot water type, but in the Geisers area, unusually large-scale steam type geothermal reources exist. Among the seven geothermal power generating plants in Japan, only Matsukawa geothermal power station of Japan Metals Co., Ltd. is of the steam type, while the others are all hot water types.

In the same Geisers area, an order for a similar 55 MW plant for Bottle Rock Geothermal Power Generating Plant from the Department of Water Resources (DWR) of California has also been awarded.

2) Description of the Main Equipment

In accordance with the usual ordering procedure for thermal power generating plants in the USA, the equipment to be supplied are limited to the turbine, generator and their accessories, while the condenser and other equipment are procured under other contracts.

Although the turbine is a single-cylinder double-flow type, similar to the No. 3 unit of Ahuachapan Geothermal Power Generating Plant, an improved single-shell construction is employed to make the turbine more compact and reduce its weight. *Fig 9* shows the cross section of the turbine. As already mentioned, the largest capacity turbine in the world at present is 132.5 MW, but it has two turbine cylinders. This 55 MW geothermal turbine is therefore one of the world's largest in terms of capacity for a single turbine.

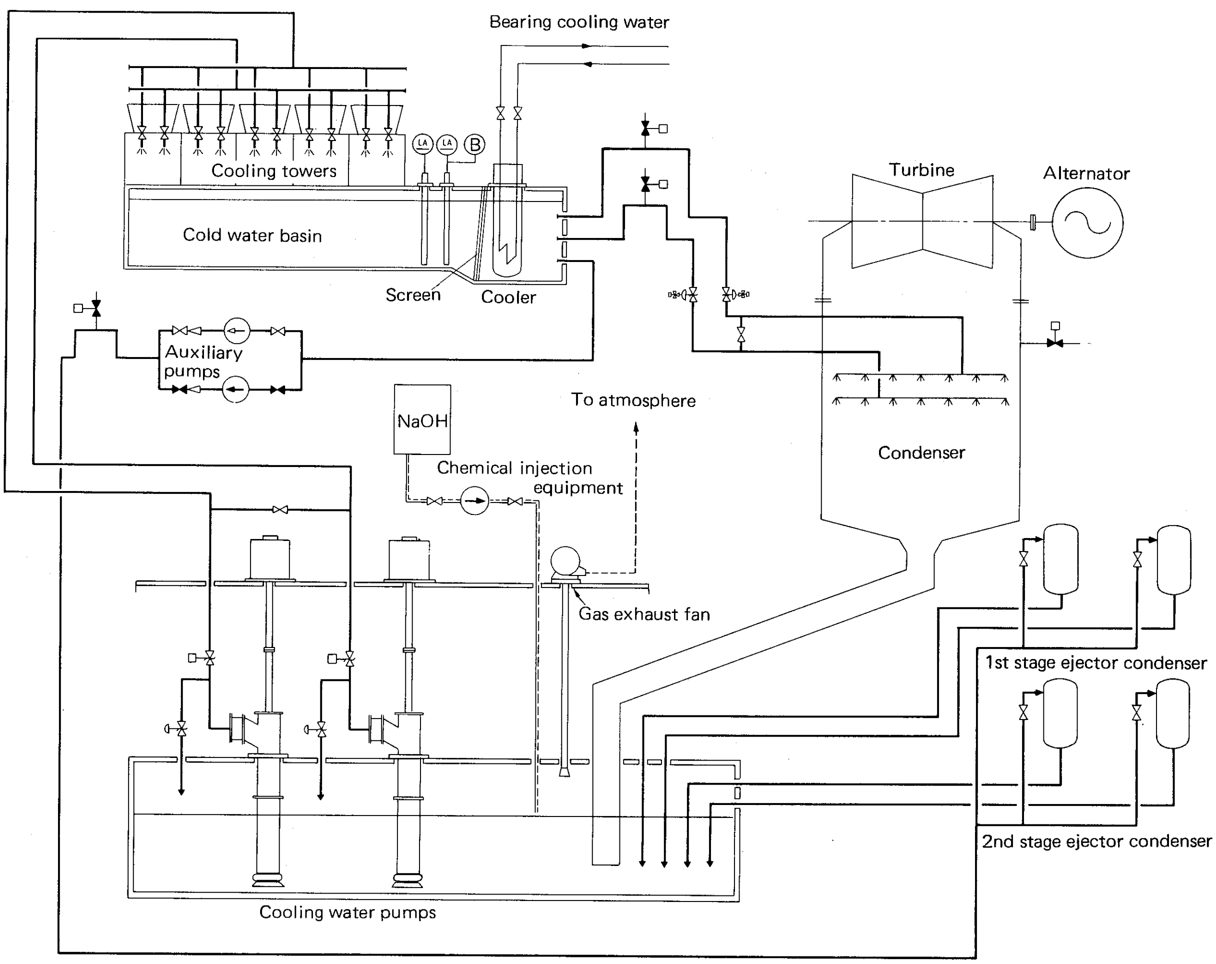
A hydrogen-cooled type generator is employed for this plant.

3. NPC Palimpinon Geothermal Power Generating Plant 1500 kW Wellhead Power Generating Equipment (Philippines)

1) Outline of the Plant

This plant, which was ordered by NPC of the Philippines at the end of 1979 as the wellhead power generating equipment for Palimpinon Geothermal Power Generating Plant to be constructed on Negros Island, consists of two 1500 kW skid mounted turbine-generator units.

Stable supply of geothermal steam over a long period is



: Circulating water piping
: Chemical treatment piping
: Air & gas exhaust piping
: Control line
: Normal opened valve
: Normal closed valve
: Gate valve
: Butterfly valve
: Globe valve
: Check valve
: Motor operated valve
: Regulating valve
LT : Level transmitter
PI, TI : Pressure, temperature indicator
PR, LR, TR : Pres., level, temp. recorder
PA, LA, TA : Pres., level, temp. alarm
B : Trip
○ : Local
⊖ : Remote
: Pneumatic servomotor valve

Fig. 8 Cooling water flow diagram

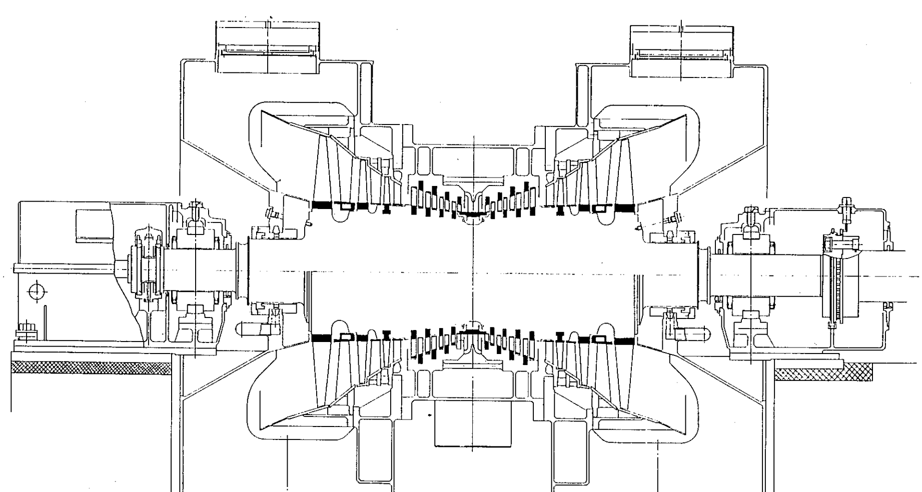


Fig. 9 Cross section of geothermal turbine of NCPA

an indispensable condition for constructing a geothermal power generating plant. It is therefore necessary to excavate geothermal wells and confirm the condition of steam (or hot water) supply prior to the construction of the geothermal power generating plant. In the case of a full-scale geothermal power generating plant, it usually takes four to five years from drilling of the geothermal wells to the completion of the power plant and the utilization of steam from the wells. In order to use the steam blowing out during this construction period wellhead power generating equipment is installed, and the generated power is used for drilling new geothermal wells, for the construction work of the main power generating plant and for feeding power to remote sites. After the main power generating plant is completed, the wellhead equipment will be transferred to a new construction site or left as an emergency power source for the main power generating plant. To serve these purposes, the wellhead power generating equipment has the following features:

(1) Skid-mounted, portable type
(2) Auxiliary equipment driven by a geothermal steam turbine is employed. (To make it possible to start without an external power source.)
(3) Air-cooled auxiliary equipment is employed. (Cooling water is not required.)
(4) Short delivery period
These two units of wellhead power generating equipment started commercial operation in sequence in the autumn of 1980, requiring an extraordinarily short delivery period of less than a year from the award of order to the commercial operation. They are still continuing to operate smoothly. The award of order or this wellhead power generating equipment, its completion in such a short period and its satisfactory operation greatly contributed to the success in acquiring the order for the subsequent three 37.5 MW main power generating units. *Fig. 10* shows the 1500 kW wellhead power generating equipment.

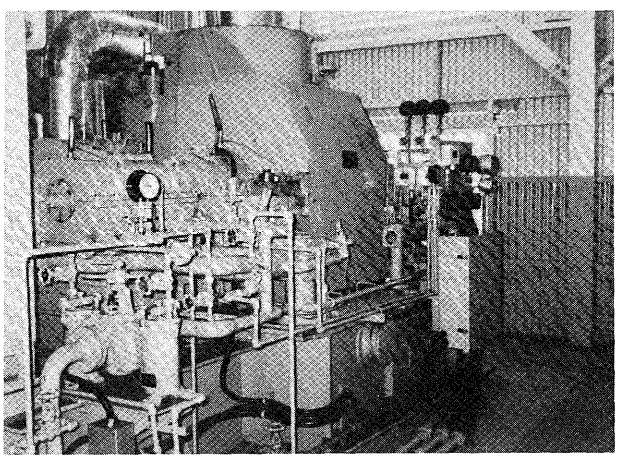


Fig. 10 1500 kW wellhead power generating equipment

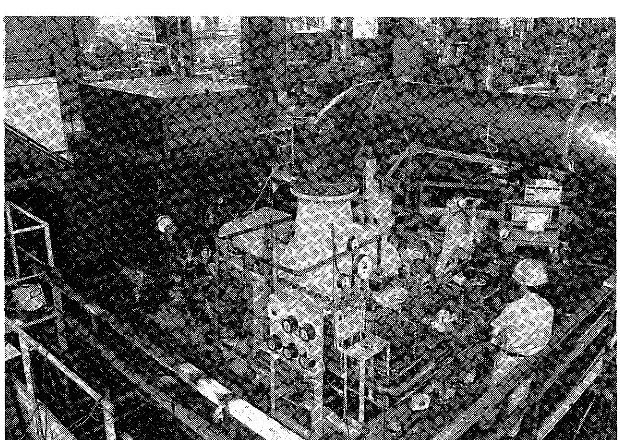


Fig. 11 1500 kW wellhead power generating equipment under workshop test

2) Description of the Main Equipment

The turbine is high speed reaction single-cylinder back-pressure type. Considering that it is a wellhead power generating unit, the following measures are taken for its lubricating oil system.

(1) To make it possible to start the units without an external power source (black start), auxiliary oil pump driven by steam turbine is employed.
(2) To enable the units to operate without cooling water, air-cooled oil cooler is employed.
(3) To make the packages as compact as possible, a main oil tank has been installed in the common bed.
The generator is an open air-cooled type. *Fig. 11* shows the wellhead power generating equipment under workshop testing.

4. SRH Geothermal Power Generating Plant 6 MW Geothermal Power Generating Equipment (Iceland)

1) Outline of the Plant

Iceland is, as is easily supposed from its name, an island country of about 100 thousand km^2 whose northern part lies within the Arctic circle. As the Mid-Atlantic Ridge runs through the country, it has abundant sources of geothermal energy. Its population is, however, only a little over 200,000, and there are few power-consuming industries in the country. Geothermal energy is therefore mainly used as a heat source for room heating, hot water supply, glasshouse cultivation etc., and power generation is more of a by-product of hot water production.

This power generating equipment has been installed in a hot water generating plant of Sudurnes Regional Heating (a kind of public corporation which supplies hot water to the district) in Keflavik city near Keflavik International Airport, the main entry point to Iceland. After driving the turbine and generator to generate power, geothermal steam is introduced into the heat exchanger and used to generate hot water of 80°C.

This power generating equipment also required a very short construction period of less than a year, so the skid-mounted type was employed to reduce the installation period at the site.

Fig. 12 shows the main flow diagram of the plant and *Fig. 13* shows the turbine generator.

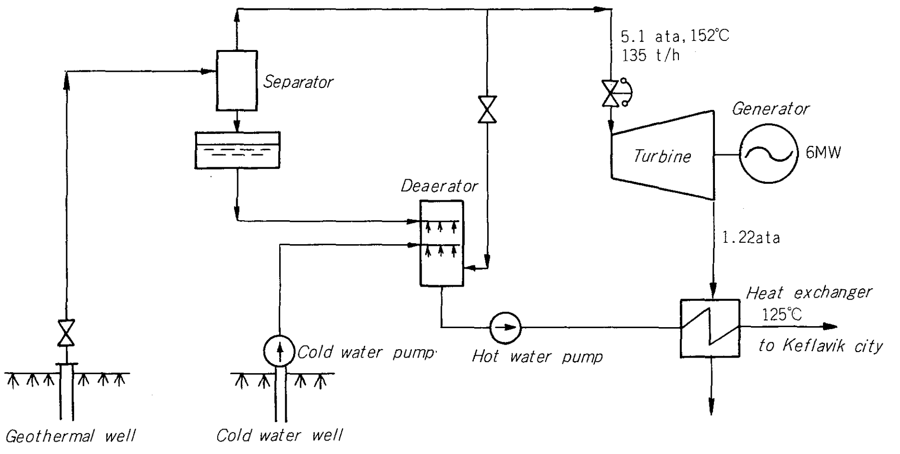


Fig. 12 SRH 6 MW plant main flow diagram

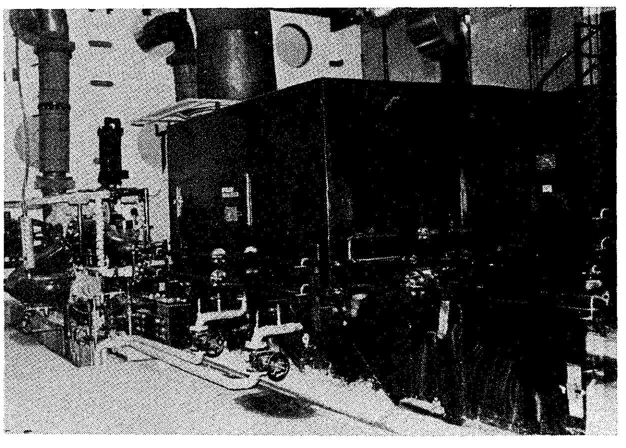


Fig. 13 SRH 6 MW turbine generator

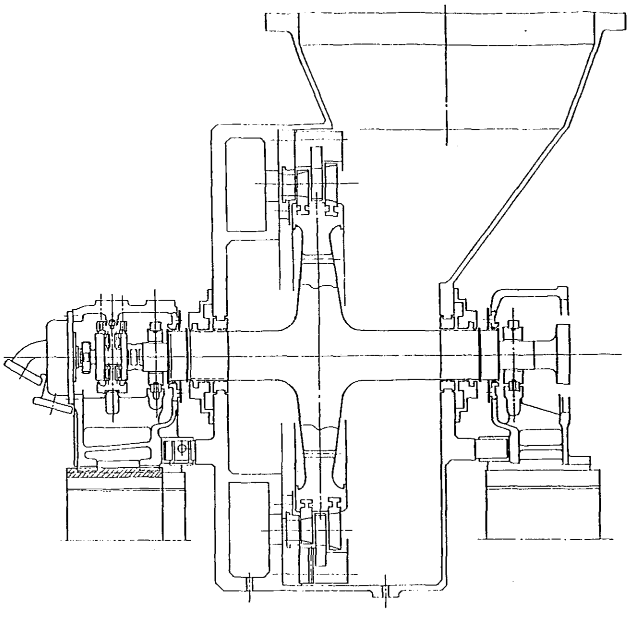


Fig. 14 Section of SRH geothermal steam turbine

2) Description of the Main Equipment

The turbine of this plant has the following features which are different from Fuji's usual geothermal turbines.

(1) A single Curtis stage turbine equipped with three control valves is selected to prevent the lowering of turbine performance under low load in summer.

(2) In order to reduce the capacity of the DC emergency power source, an emergency oil head tank is installed in place of an emergency oil pump. This means that in an emergency case, lubricating oil can flow down from the tank to each bearing by natural head.

(3) To reduce the corrosion of the turbine glands, where geothermal steam mixed with air can cause the most serious corrosion, clean steam from a steam generator which uses geothermal steam for its heat source is supplied to the turbine glands.

Fig. 14 shows a cross-section of the 6000 kW turbine.

IV. AFTERWORD

With the impetus provided by the first oil crisis, solar energy, geothermal energy, wind power, wave power etc., were spotlighted as new energy sources which may provide substitutes for petroleum. Research and development in the technology of using these sources has been promoted in many countries, but lately the pace of this development seems to have slowed down with the background of an oversupply of petroleum and its comparatively stable price. Energy consumption has been increasing with progress of civilization. Japan's rate of dependence on foreign countries for the supply of various energy resources is the highest among the major developed countries and Japan is particularly dependent on foreign sources for petroleum with a dependency ratio of 99.8% on imports. It is therefore very important for Japan to secure stable supplies of energy in future. Although petroleum supply at present is comparatively steady, this basic instability should be a major factor in developing new energy sources.

In view of the importance of geothermal energy among the new energy sources, we intend to continue our effort to develop and supply more economical plants with higher reliability.