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 **TOSHIBA**

M2/TP-6009

GEOTHERMAL TURBINE

No
G/207

TOSHIBA CORPORATION

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1. Present Status of Geothermal Power Generation

The first geothermal power generation in the world was started at Larderello, Italy in 1904. Then, New Zealand succeeded in the geothermal development and became the second geothermal power generating country. These developments were then followed by the United States, Mexico, Japan and the Soviet Union, and at present, about 25 countries are utilizing geothermal power, or investigating geothermal resources.

So far as the geothermal power generation is concerned, the United States of America has surpassed the advanced countries, and is now indicating the highest total output in the world. Japan is also showing a rapid advancement in this line. Further, it is observed that many nations including Mexico are starting the development of geothermal power generation one after another. In the U.S.A. unit having a unit capacity of 132 MW was constructed. Further, 50 MW class unit are being manufactured in each country, and the initially-supposed maximum output limit, 10 to 20 MW, has been far surpassed.

Japan is a prominent volcanic and hot spring country in the world. There are approximately 800 volcanoes in the world, and 80 volcanoes out of which are concentrated in the Japanese Islands. The volcanoes now in activity amount to 10, while hot springs have over 10,000 gushes. Also, it is possible to obtain naturally the underground water which is necessary for geothermal power generation beside the heat (average annual rainfall, 2000 mm), and this constitutes an advantageous factor for the formation of geothermal resources.

The Japanese electric power supply system has widely changed from depending on hydraulic power to mainly depending on thermal power. The requirement of enormous demand has expedited the construction of large capacity thermal power plants which can be erected in the urban district and which can generate electric power at low cost. Along with the change in social situation, however, "environmental pollution" problem caused by air pollution due to sulfurous acid gas and nitrogen oxides produced from the thermal power plant, as well as hot exhaust water and noises has made it difficult to secure the electric power source, and the electric power industry was confronted with a severe situation.

Moreover, due to the fact that the fuel oil is almost entirely imported from abroad and that the power generating cost has been raised by the necessity of procuring fine quality fuel and developing the environmental pollution preventive equipment, the power resources development problem itself has come to be reexamined.

In reflection of such situation, "non-environmental pollution" nature and naturally obtainable fuel of geothermal power generation have come to be spotlighted rapidly.

It is observed from the above that although the development of geothermal power generation is expedited sharply in recent years, steady progress has not been made for 7 to 8 years after the initial start of operation. This is perhaps because a clear answer has not necessarily been given to such problems as whether the geothermal power generation system is paying, and whether an effective geothermal steam is securely obtainable.

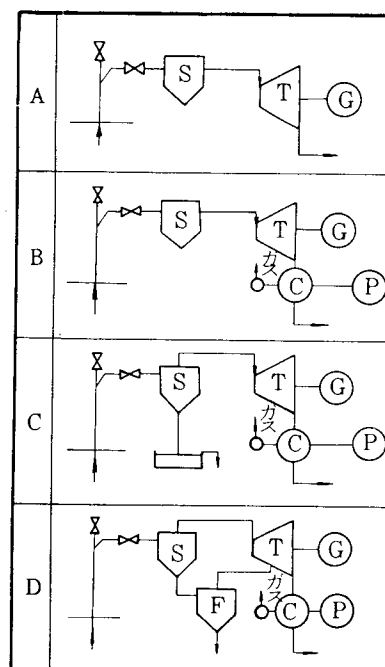
Meanwhile, the Agency of Industrial Science and Technology, Ministry of International Trade and Industry, announced in September, 1973, a clean energy technology development plan, the so-called "Sunshine Plan". Geothermal energy was added as a theme in this plan, and the time is now ripe for a full-scale proving and excavation of geothermal energy and development of the utilization technology.

2. Basic Planning Conditions of Geothermal Turbine Plant

2.1 Selection of Geothermal Power Generation System

Steam and hot water which constitute heat source of geothermal power generation break out from the steam well sometimes individually, and sometimes in mixed state. Further, they contain a large amount of non-condensing gas and corrosive gas. Table 1 shows the example of the generating system adopted up to now. In selecting the power generating system, it is important to give a full consideration to the above-stated conditions and adopt the system best suited to the project.

Table 1. Type of Geothermal Power Generating System



Conception for selection and decision criterion will be as follows: In general, condensing turbine is selected and an effort is made to obtain an output as much as possible from low enthalpy geothermal steam. On the other hand, the backpressure turbine is selected in the following cases.

- (1) Where the exhaust steam heat and useful exhaust substances are utilized.
- (2) Where non-condensing gas is particularly abundant, and condensing system does not prove economical.
- (3) Where the time available for construction work, testing or emergency use is small, and there is frequent transfer of equipment.

Fig. 1 indicates the type of turbine, and the actual records of non-condensing gas and gas content. The back pressure turbine of comparatively small capacity is employed. As the heat drop of steam is small, the steam consumption rate is as large as about 10 kg/kWh, even in the case of condensing turbine. With the back pressure turbine, the drop of output is as large as more than twice that of condensing turbine.

2.2 Unit Capacity and Inlet Pressure

In the geothermal power plant, an important task is to obtain economically as large output as possible from a certain steam well. For this purpose, it is necessary to grasp quantitatively the correlation between pressure, temperature, flow rate, mixing ratio of steam and water, mixing ratio of gas, and scale producing rate.

The optimum design condition varies depending upon the types of hot water well and super heated steam well. In general, the efficiency of steam turbine is improved with an increase in the turbine inlet pressure, and the output increases accordingly. With the steam well, however, the steam quantity sharply decreases at above a certain pressure, and an overall output falls. It is desirable, therefore, to determine the design point by taking into consideration the characteristics of steam turbine and steam well.

Fig. 2 illustrates the steam characteristic curve of Geysers Power Plants, while Fig. 3 shows the steam flow quantity and output characteristic diagram.

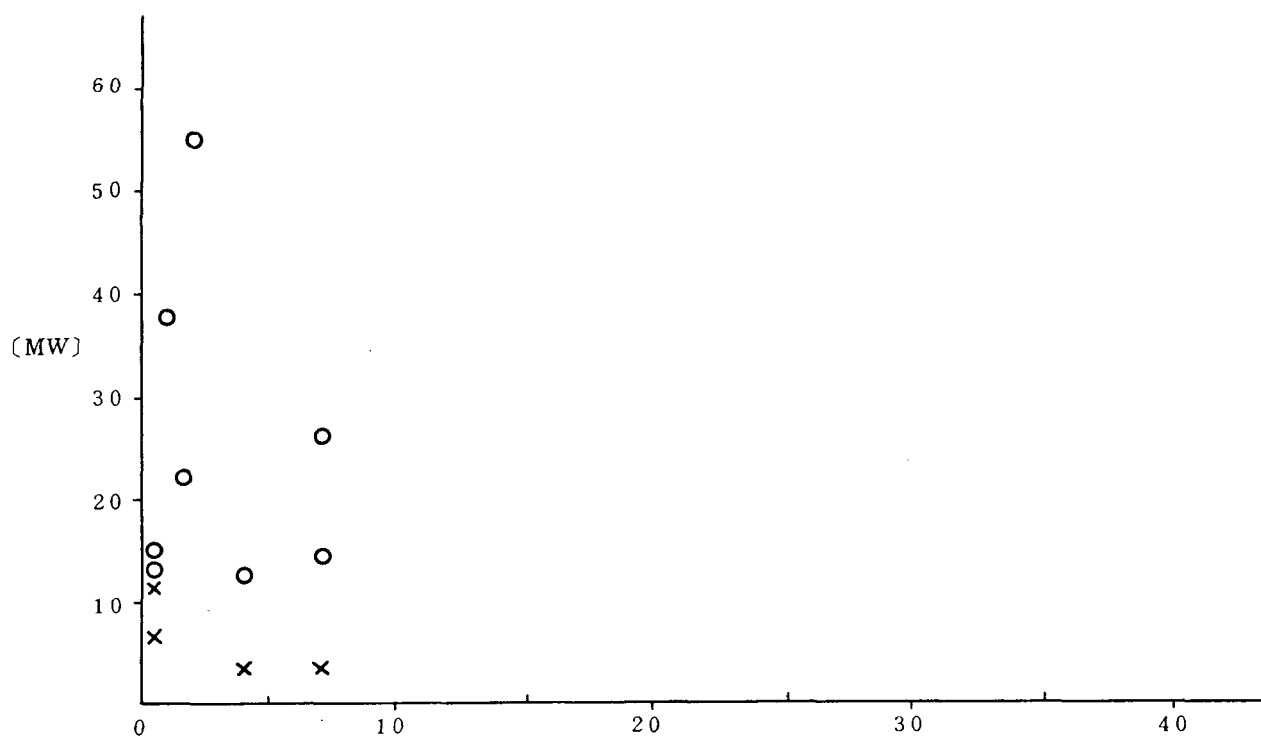


Fig. 1 Type of Turbine, and non-Condensing Gas Content (actual Record)

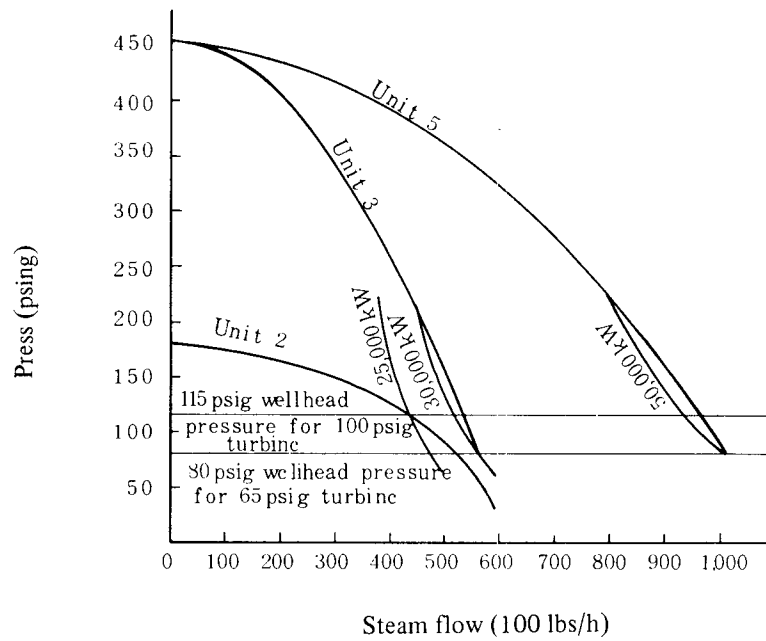


Fig. 2 Steam Characteristic Curves (Geysers Power Plant)

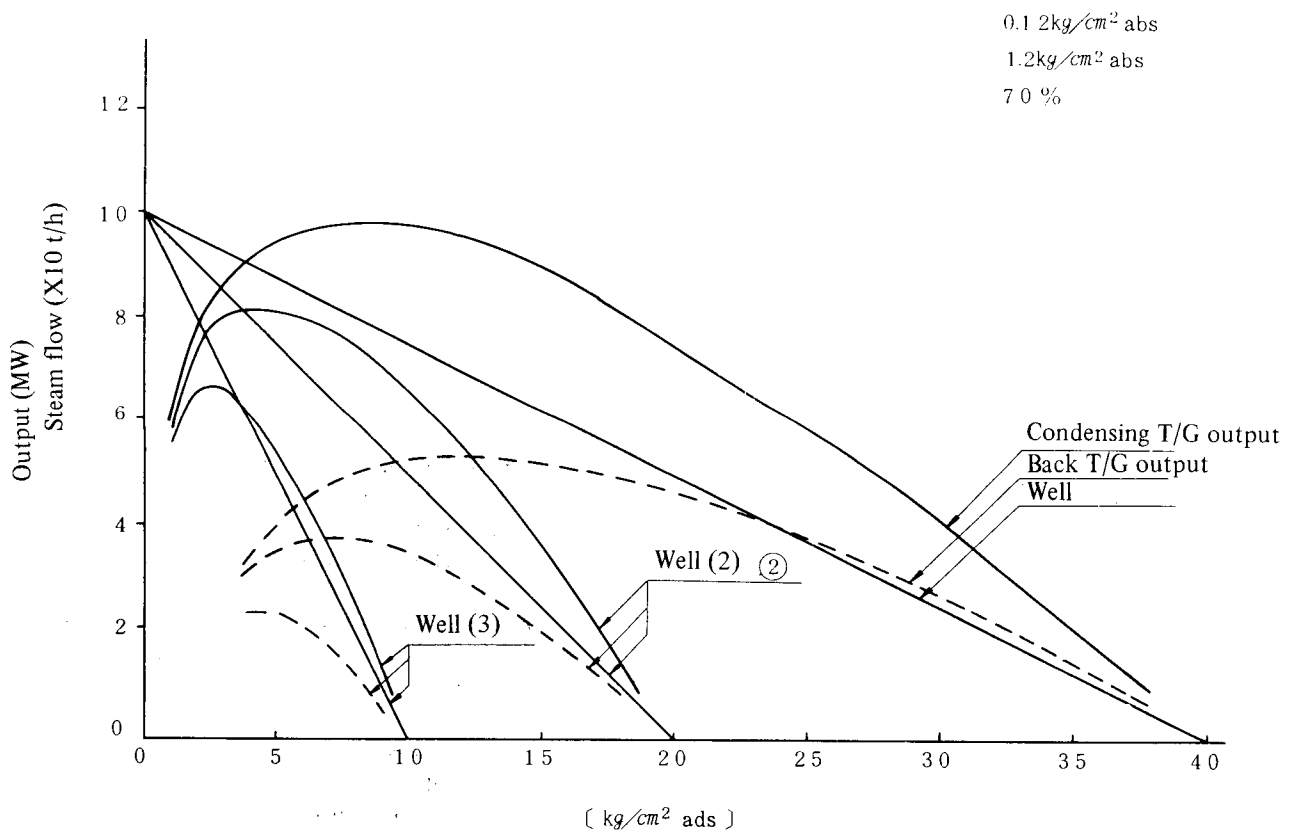


Fig. 3 Steam Flow Rate, Output Characteristic Diagram

Where the geothermal energy is obtained in the form of combination of steam and water, it is considered to have been flushed from hot water and separated into steam water. Hence, it can be regarded as single flush, and the flush pressure capable of obtaining the maximum output can be economically obtained in this case.

Fig. 4 shows the single flush data.

From Fig. 3 and 4 can be seen that the maximum output band exists between approx. 1/4 to 1/5 of the original pressure.

An ideal conclusion can be drawn by examining every steam well characteristic after observing the spouting condition of production well with the progress of the work. However, this is not actually possible from the practical execution of schedule.

Considering from the turbine structure, it is possible to cope with the situation by varying the first stage nozzle area when the change of steam condition is required in future. It is advisable, however, to select the pressure at a slightly low value in consideration of the allowance for auxiliaries such as pipings, valves, condenser, and cooling tower.

Other factors to be considered are as follows:

- (1) Long term life characteristics of wells
- (2) Countermeasure against the fall of output caused by scales
- (3) Prospect of output increase

However, since it is difficult to estimate these factors accurately, a careful judgement must be passed by evading useless allowance and avoiding taking up indefinite conditions.

2.3 Determination of Vacuum

Output of the steam turbine increases with an increase in the condenser vacuum. Since a large quantity of gas is contained in the steam in the case of the geothermal turbine, a big amount of station service power is required for exhausting such gas, and too high degree of vacuum is not economical. Further, higher vacuum is followed by an increase in the final stage wetness and is in turn attended with an increase in the erosion of last stage blade. Generally vacuum is selected between 3" to 4" Hg abs.

Because of a low vacuum, and a condenser of direct-contact type, the ratio of cooling water quantity to the turbine exhaust volume is smaller than in the case of thermal or nuclear power plant, and is 20 to 30 times.

On the other hand, however, its steam consumption is so large as 3 to 4 times that of thermal or nuclear power plant that there is no great difference in the cooling water quantity required for unit output.

2.4 Determination of System Structure and Machine Capacity

After the determination of basic planning conditions through the foregoing studies of various items, the system is first constituted and then the capacity of each machine is determined by the heat balance calculation.

3. Steam Quality and Corrosion Test of Materials

3.1 Steam Quality

The geothermal power generation put to practical use at present can roughly be classified into the following two systems:

- (1) Direct steam utilizing system
- (2) Flush steam utilizing system using hot water

In the (2) system, the hot water is utilized as flush steam, so that the impure solved substances in the injected steam remain in the hot water, and the flush steam is rather purified. This bears a similarity to the nuclear turbine using wet steam, and makes the problems comparatively easy. The machines delivered to Kyushu Electric Power Company and the units for Mexicali in Mexico supplied by Toshiba fall under this type.

The (1) system has the following peculiarities in respect of utilizing the geothermal steam directly.

- (a) Geothermal steam contains gas impurities and has low PH, so that it has a strong corrosive nature.
- (b) The steam contains solid particles produced from the earth's crust.

In planning the direct-steam utilizing turbine, therefore, full consideration must be given to the foregoing points. Especially, it is essential to investigate the nature of steam beforehand, and to select materials suitable to it and to take necessary steps for preventing erosion.

Table 2 shows the comparison of the chemical compositions of steam and its condensed water, between the geothermal power plants ordered to Toshiba and the geothermal power plants abroad already in operation.

The steam at Matsukawa contains gas impurities of 0.2 to 0.6% volume ratio. This volume is a little larger than that of Wairakei in New Zealand, and a bit smaller than that of Geyseys in U.S.A. As for H_2S gas contained in geothermal steam which greatly influences the corrosion of metal, the geothermal steam at Matsukawa district contains H_2S gas in quantity a little larger than that contained in those of other districts.

As for the condensed water, that of Matsukawa contains larger SO_4 , smaller Cl and lower PH than that of Wairakei. This is related with the status that Matsukawa steam contains larger quantity of H_2S , and it is a favourable condition that there is only a small amount of Cl which is apt to cause pitting corrosion or stress corrosion cracking.

The steam of Mexicali district is characterized with higher rate of density of impurities such as Na, K, Cl and S, in comparison with the steam of Matsukawa. For example, Cl contained in the condensed water is as high as 15,000 ppm maximum in the Mexicali plant, then 9.2 ppm in the Matsukawa plant.

The steam of Otake district contains the least gas impurities, and is characterized with the gas structure

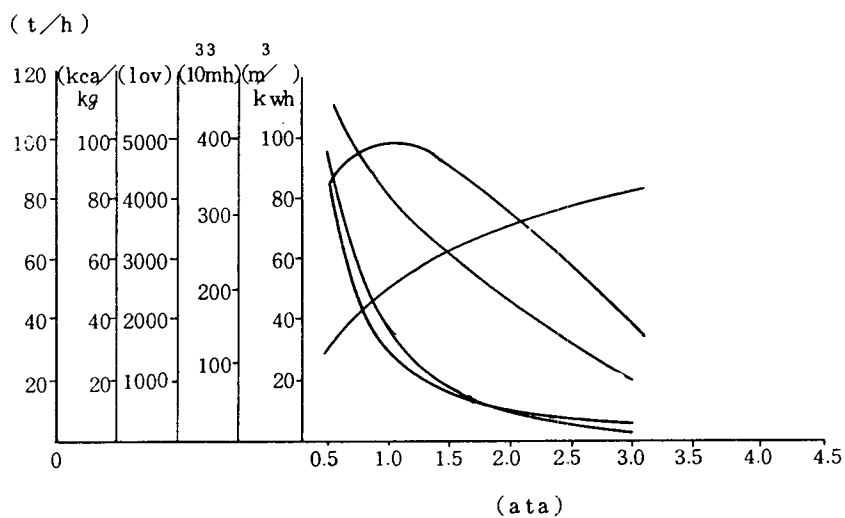


Fig. 4 Single Flush Pressure Checking Data

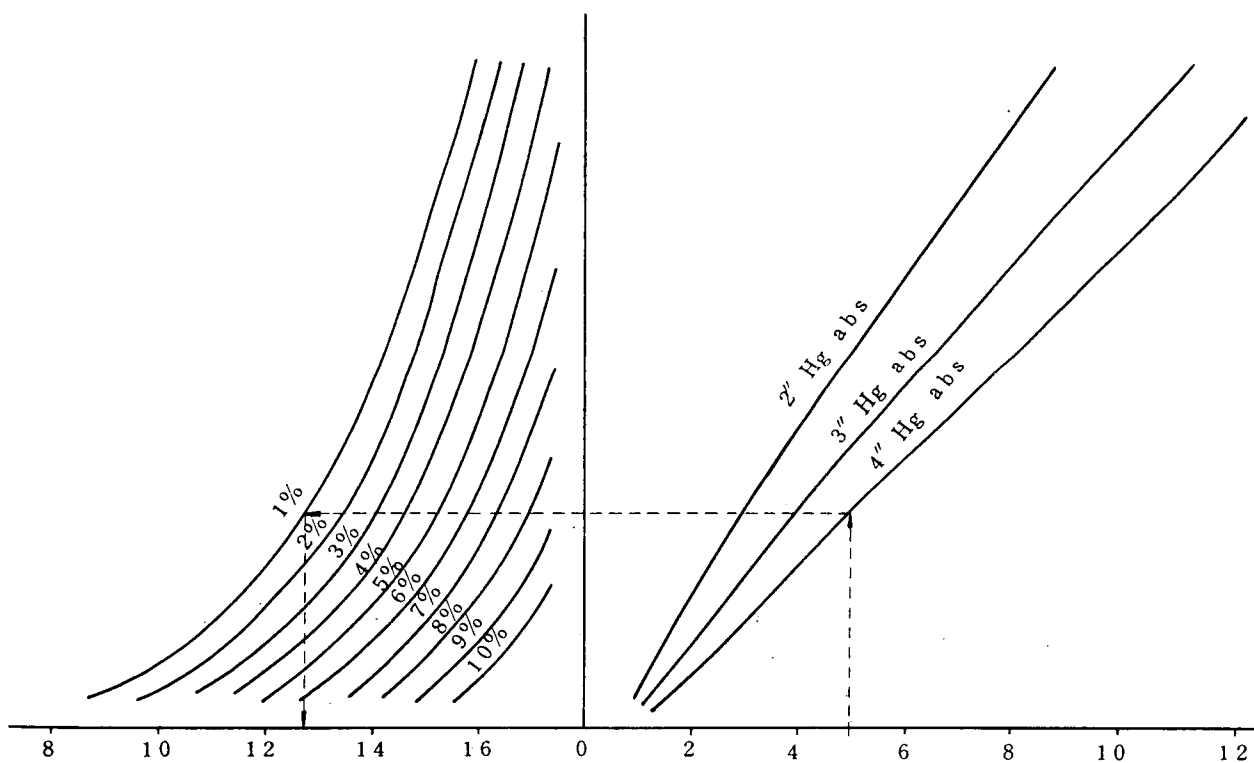


Fig. 5 Relation between Finalstage Wetness and Inlet Steam Pressure

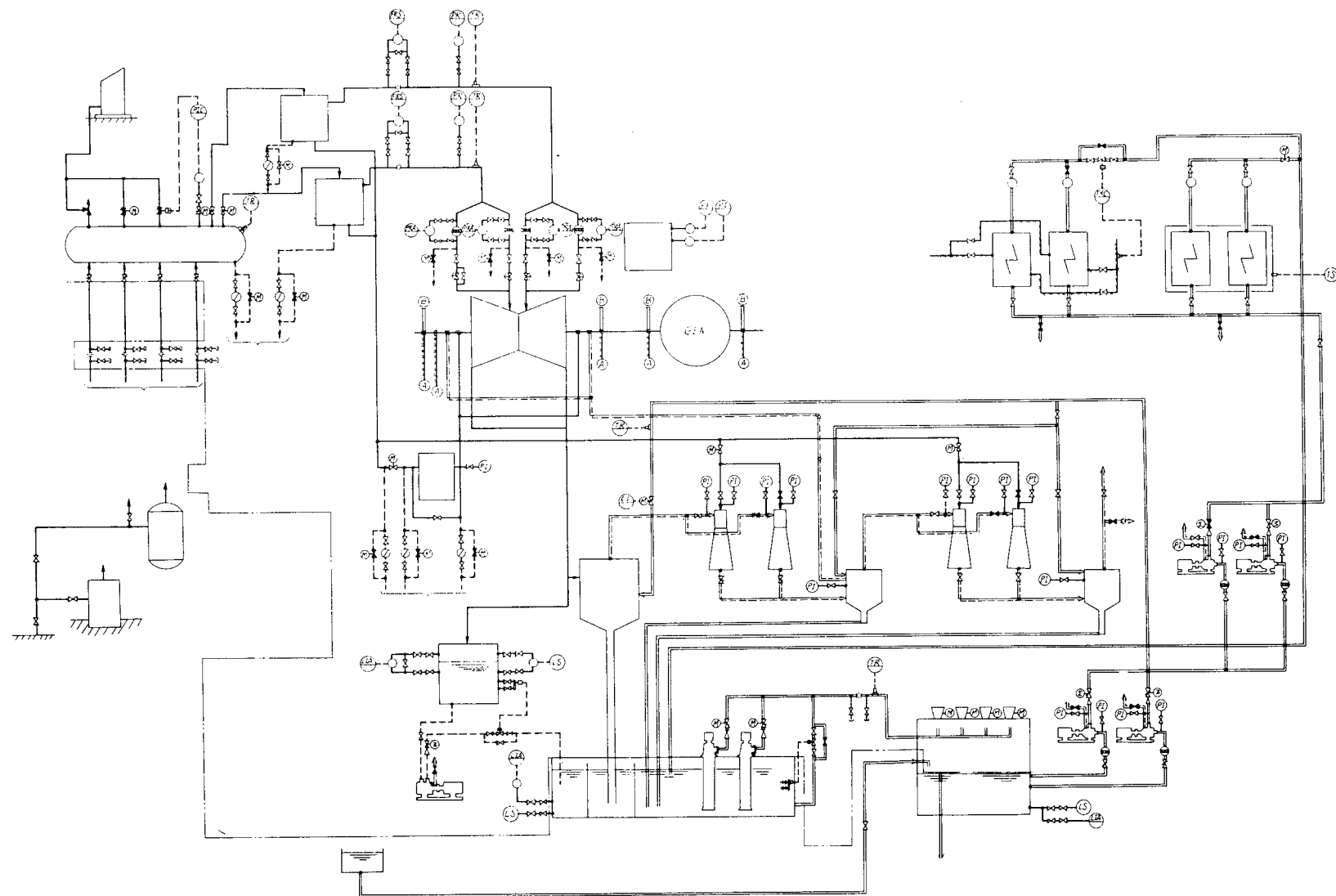


Fig. 6 Piping System Diagram (in the case of barometric condenser)

containing small amount of H_2S and large amount of CO_2 .

3.2 Corrosion Test of Material

In planning the geothermal power generating plant, it is essential to investigate the nature of the steam in that district beforehand, and select the materials to be used, on the basis of the actual records in the experienced plant and the results of the corrosion test at site.

In the case of the Matsukawa 22 MW turbine, all the materials used were selected on the basis of the corrosion test conducted at site partly because it was the first geothermal power plant project in Japan. In the case of the Mexicali 37.5 MW turbine also, the corrosion test was executed for obtaining the fundamental data necessary for determining and checking the propriety of material and the prompt counter-measures against unexpected accidents.

Fig. 7 shows an example of the corrosion test result.

Actual records of corrosion test period are shown below, each test requiring 5 to 12 months.

District	Total test period	Exposed period (days)
Kakkonda	May 25 ~ Nov. 25, 1973	93, 184
Matsukawa	Sept. 1964 ~ July, 1965	69, 127, 168
Mexico	1969 ~ 1970	30, 60, 90, 120, 150
Onikobe (1)	Nov. 2, 1969 ~ April 24, 1970	30, 109, 173
Onikobe (2)	June 29, 1972 ~ June 29, 1973	90, 183, 365

Part of the test results is given below.

- (1) Corrosion test of main materials by the steam at Matsukawa District, Iwate Prefecture.

Test period November, 1964 ~ July, 1965

Test site Matsukawa Geothermal Power Plant

Through the above test, it was possible to grasp corrosiveness of the steam at Matsukawa district and corrosion amount of materials. Also, counter-measures were obtained against the solid matters in the steam, erosion by moisture and corrosion by condensed water.

- (2) No.1 Report on the corrosion test and steam survey for the geothermal steam at Onikobe district.

Test period Jan., 1970 ~ August, 1970

Test site Onikobe, Miyagi Prefecture

Through this survey were obtained the basic data on the corrosion of material and nature of steam, and also the guide line for selecting optimum material suitable for the steam of that district. The test results revealed the difference in constituent between the steams of Onikobe and Matsukawa.

- (3) No.2 Report on the corrosion test by the geothermal steam at Onikobe district.

Test period Jan. to August, 1970

Test site Onikobe, Miyagi Prefecture

Through this test were obtained valuable guiding line on the surface treatment method of materials for Onikobe district steam, condensed water and hot water, corrosion resistance of treated materials, and data on pitting corrosion and stress corrosion cracking.

- (4) H_2S corrosion test at Matsukawa geothermal power plant.

Test period 4 times between June, 1967 and August, 1971

Test site Matsukawa Geothermal P.S.

It was possible by this test to check the corrosion status and secular change of electrical apparatus by the atmosphere of Matsukawa geothermal power plant. Thus, a guiding line was obtained about the optimum material for electrical apparatus at the geothermal power plant.

- (5) Analysis of material corrosion status and steam constituent in the geothermal steam environment at Kakkonda Geothermal Power Plant.

Test period May 25 ~ Nov. 26, 1973

Test site Kakkonda Geothermal Power Plant

This test enabled us to grasp the corrosion status of each material in the steam, condensed water, hot water and river water through the utilization of geothermal steam at Kakkonda Geothermal power station. It also provided the data on the specific corrosion such as stress corrosion cracking. Steam constituent analysis for non-condensed gas, condensed water, hot water were also obtained.

4. Design and Structural Characteristics of Geothermal Turbine Plant Apparatus

4.1 Specification of Turbine Plant Apparatus

Table 3 shows the specifications of the units designed by Toshiba.

The main steam inlet pressure is low as $7 \text{ kg/cm}^2 \text{g}$ at maximum and the steam is saturated steam or include some moisture. The available energy of the steam is small and the volume flow through the turbine is enomouth. The turbine shape is same as that of low pressure section of thermal power plant. The increase of the capacity yield the increase of numbers of exhaust flow. The direct contact water jet condenser are used. Cooling water is cooling tower cooled water.

4.2 The Line Up of Geothermal Steam Turbine

Toshiba has been developing several numbers of geothermal steam turbine, and are making effort to develop better geothermal steam turbines which are suitable for the future plans. The series of geothermal steam turbine are designed as line up through our manufacturing experience.

The design philosophy should better to be refined by the needs in the field, through the cooperation with the actual Engineerings.

Hereafter, we would like to discuss these point, and we would be very much appreciative for the advanced sugestion of the well experienced Engineers.

Table 2 Chemical Composition of Geothermal Steam and Condensed Water

Plant name	Matsukawa	Mexico Mexicali	U · S · A Geysers	New Zealand Wairakei	Italy Larderello	Ohdake
H ₂ O	994~99.8 0.2~0.6	99.6 0.4	98.05~99.51 0.49~1.95	99.76 0.24	95.6~98.9 1.1~4.4	99.8 0.20
H ₂ S	1.29~1.7.7	20.9	1.69~2.99	3.23	2.4~2.5	1.27
CO ₂	79.3~85.2	79.1	63.5~69.3	96.1	92.2~94.2	95.6
H ₂	0.28	-	1.27~1.4.7	-	1.7~1.8	-
CH ₄	1.15 -	- -	1.18~1.5.3 1.3~1.6	- tr~0.69	0.94 -	-
PH	4.35~4.85	5.8~6.6	6.65~7.25	6.0		8.0
K	180	631~2,031	-	60~230		101
Na	280	4,406~7,764	-	900~1,300		874
NH ₃	-	-	134~567	3		
H ₂ SiO ₃	795.5	-	-	360~600		
HCO ₂	-	58~686	483~3,388	SiO ₂ 20~160		SiO ₂ 525
SO ₄ --	1.708.1	4.9~3.8	-	40		113
Cl ⁻	9.2	928~14,934	-	1,500~2,200		1,493
H ₂ S	10.0~5.22	24~165	30~205	0.3		

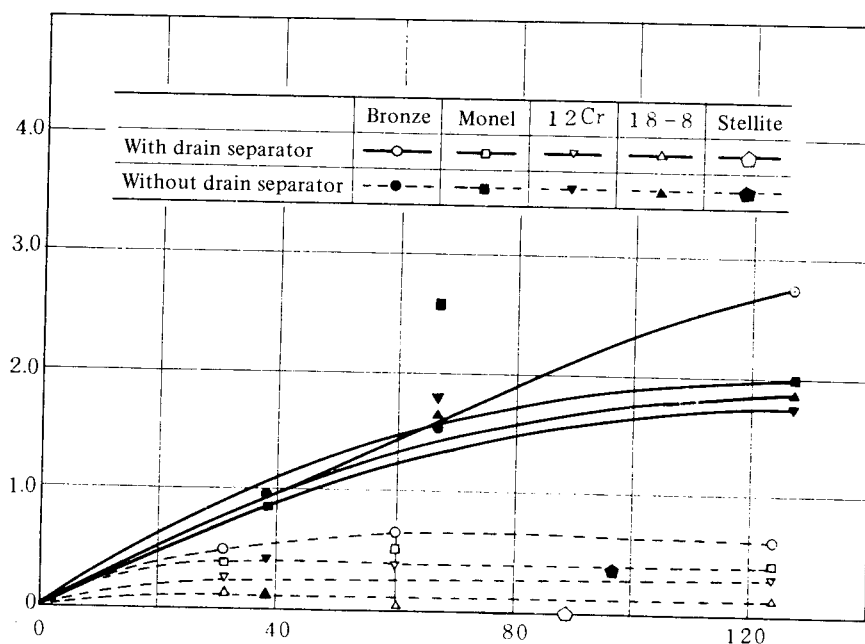
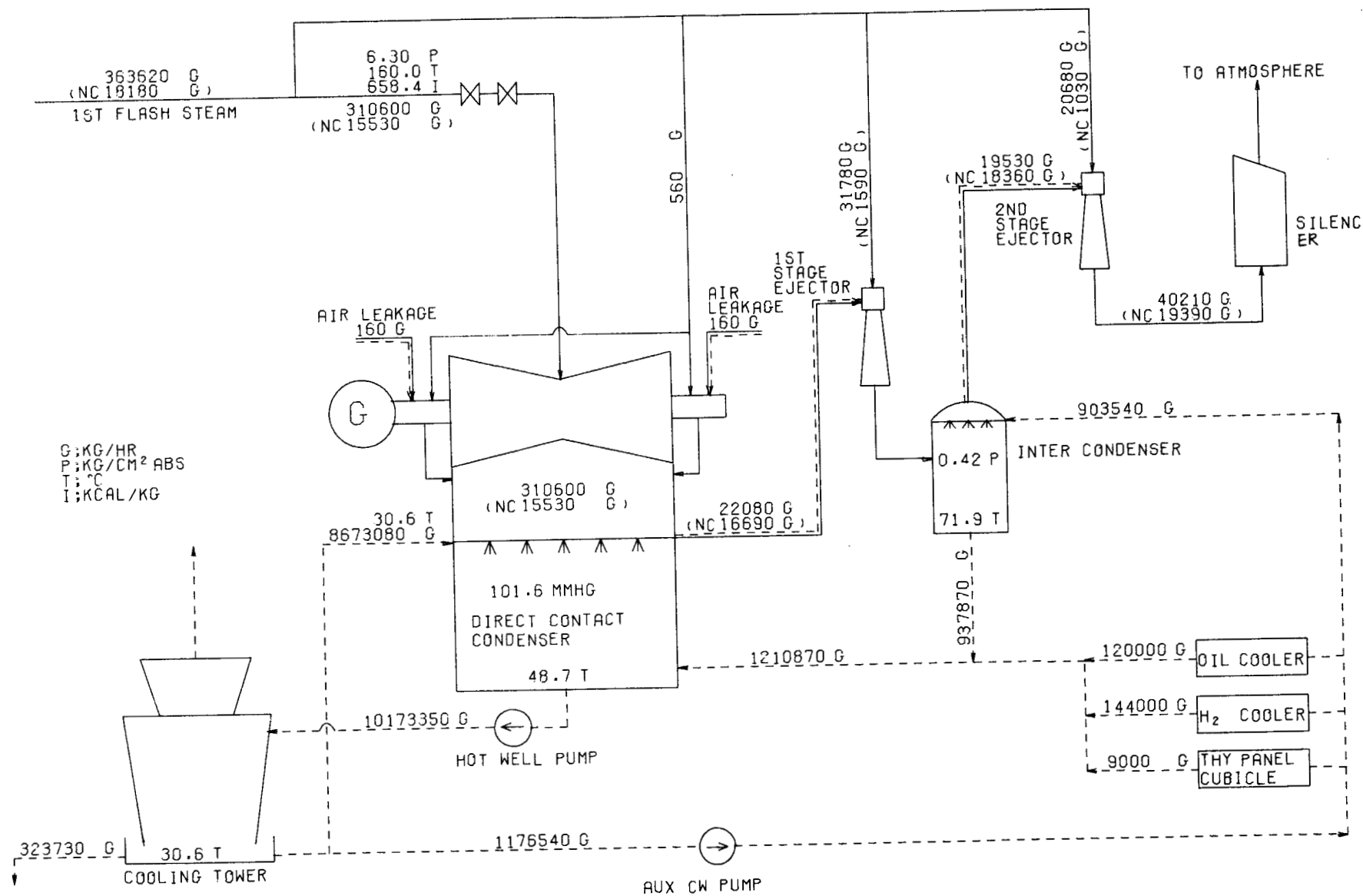


Fig. 7 Results of Corrosion Test on the Model Plant

Table 3

Unit	Matsukawa	Cero Prieto	Geysers	Geysers	Geysers
k W	22,000	37,500	55,000	110,000	114,000
r p m	3,000	3,600	3,600	3,600	3,600
kg/cm ² g	3.5	5.27	7.0	7.0	7.0
°C	147.4 (1%)	160	179	179	179
kg/h	193,000 (20MW)	285,450	411,600	820,110	849,910
mm Hg abs	100 (4")	89 (3.5")	100 (4")	100 (4")	100 (4")
	SCSF 23"	SCDF 20"	SCDF 23"	TC4F 23"	TC4F 23"
	4	6 × 2	6 × 2	6 × 4	6 × 4
	1	2	6	2	1





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