ENGINEERING APPROACH TO THE DEVELOPMENT OF GEOTHERMAL POWER STATIONS

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1. Introduction

As you know Japan is poor in energy resources such as oil, natural gas, coal and uranium. The demand of electrical energy is estimated to be more than 200 million KW by 2000 A. D.

Most of the hydraulic power resources are so fully developed that future electrical energy must be generated by thermal and nuclear power utilizing imported energy resources.

Fortunately, Japan is one of the famous volcanic countries in the world, and is blessed with rich geothermal resources.

The above facts indicate a need to greatly expand the development of geothermal power resources.

After a long period of research the Kyushu Electric Power Company completed No. 1 Unit of the Otake geothermal station with a capacity of 10 MW in August of 1967; next followed No. 2 Unit of the Hachobaru Geothermal station of 50 MW with improved design in May of 1977.

This paper introduces the engineering approach to the development of the geothermal power station throughout our experimental studies.

2. Measurement of Geothermal Well Characteristics

2.1. *Definition of well characteristics*

The so-called "well characteristics" of geothermal wells means the various kinds of physical and chemical properties of well discharge.

The measurements of well characteristics should be performed immediately after the well starts flashing, because they are necessary for constructing a geothermal power plant.

2.2. *Elements of measurement*

For detecting physical well characteristics, the following measurements are undertaken:

1. Mixture rate of the amount, temperature and enthalpy of well discharge with well head pressure, as follows:

(a) Relation between the well head pressure and the steam.

(b) Relation between the well head pressure and the hot water flow rate.

(c) Relation between the well head pressure and the steam temperature.

2. Relation between the maximum closing pressure, rise of pressure after closing, and time.

3. Fluctuation of well characteristics in a short period of time.

4. Mutual interaction of each well.

For detecting chemical well characteristics, the following measurements are undertaken:

1. The amount of chemical composition of non-condensable gas contained in discharged steam.

2. Chemical composition of hot water.

3. Corrosive effect of steam and hot water on the materials used for the plant.

2.3. *Measuring methods of first well discharge*

It is difficult to estimate the well characteristics of the first discharge in a new geothermal field immediately after the well starts flashing because it has been equipped with a well head valve and several simple accessories as shown in Fig. 1.

There are two types of flashing condition in the geothermal well discharge:

(a) Saturated or superheated dry steam.

(b) Mixture of steam and hot water.

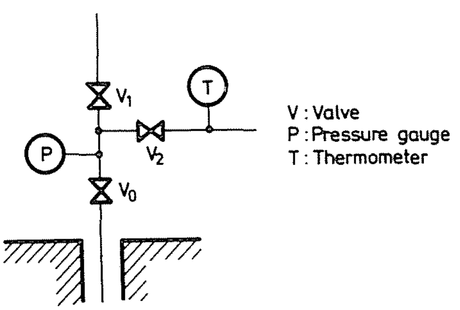


Fig. 1. Well head equipment

As the most important information of this well discharge is the steam condition for designing the steam turbine.

We must get it correctly as fast as possible using the convenient equipment.

2.3.1. *Assessment of the steam quality*

We will be able to judge the quality of the well discharge: whether it consists only of dry steam, or not, by eye-measurement and by checking the relation between the well head pressure and the temperature.

2.3.2. *Assessment of the steam quantity*

The assessment of quantities of well discharge by eye-measurement is so difficult that some suitable measuring instruments must be used.

2.3.2.1. *Dry steam*

When the well discharge consists only of steam, the measurement of the steam flow rate will be rather easy by the conventional orifice method which uses the properly designed measuring pipe line with an orifice and a few auxiliary equipments as shown in Fig. 2.

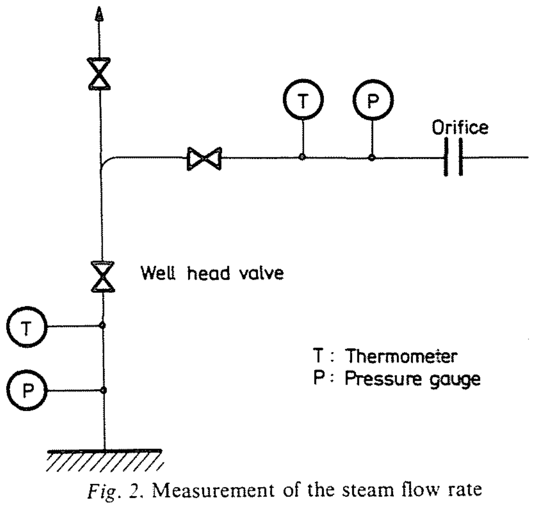


Fig. 2. Measurement of the steam flow rate

2.3.2.2. *Mixture of steam and hot water*

When the well discharge consists of a mixture of steam and hot water, it is difficult to measure the quantities directly with great accuracy.

It the mixture of the well discharge is separated into steam and hot water, each quantity of steam and hot water can be measured with great accuracy.

Therefore the single-phase measurement using the steam—water separator will be the best way in this case. However, the initial measurement contains so many unknown factors that the preliminary test must be checked for the purposes of design and installation with respect from various points of view:

1. Safety
2. strength
3. leakage
4. accuracy

2.4. *Measurement using the steam—water separator*

The measurement using the steam—water separator is shown in Fig. 3, and the processes of measurement are shown as follows:

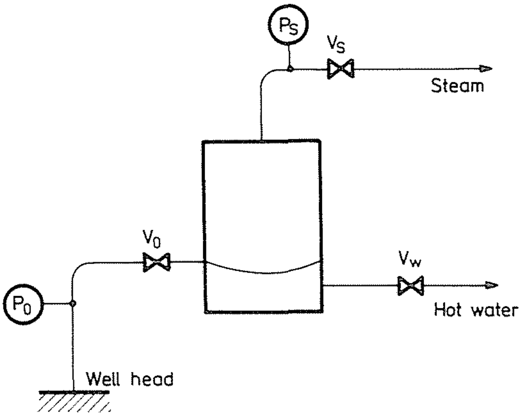


Fig. 3. Measurement using the steam—water separation

1. When V_0 and V_s are fully opened, and V_w is adjusted to keep the inner water of the separator at a high enough level so that the separated steam in the separator is never carried under its bottom, point (a) shows the following situations in Fig. 4 (a) (b):

pressure of the well head	$P_0 = oa'$
pressure of the separator outlet	$P_s = ob'$
steam flow rate	$S = a'Sa$
hot water flow rate	$W = a'Wa$

total quantity of the well discharge is $(a'Sa + a'Wa)$

Actually, point (a) in Fig. 4 (a) shows the situation with maximum quantities of this well discharge.

2. When V_0 is fixed in the fully opened valve position, and V_s is closing along gradually from position (a) to the closing direction, the mutual relation

between P_0 and P_s is shown on curve $a \times b$ in Fig. 4 (a), where (a) is the initial position and (b) is the final position of V_s.

P_0 and P_s increase gradually, and become the maximum pressure at the final closing position of V_s, that is to say the shut-off pressure of this well.

On the contrary, the steam and hot water flow rate S and W decrease gradually, and become zero at this shut-off pressure. Therefore the following relations exist when V_s has been closed completely at the point b in Fig. 4 (a) (b).

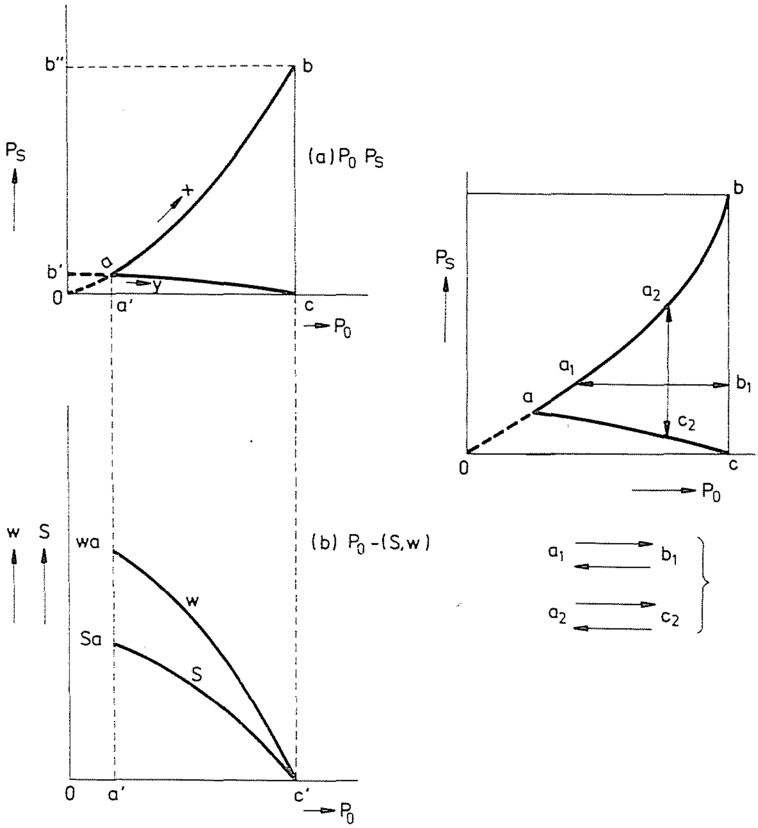


Fig. 4. Relation between well head pressure (P_0) and outlet of separator (P_s), steam flow rate (S), hot water flow rate (W)

$$P_0 = P_s \qquad \therefore oc = ob'' \text{ (Shut-off pressure)}$$
$$S = o$$
$$W = o$$

3. V_s is replaced to the initial valve position again. (V_0 and V_s are in fully opened position again), and V_s is fixed, V_0 is closing from (a) to the closing direction.

The mutual relations between P_0 and P_s are shown on curve ayc in Fig. 4 (a), where (a) is the initial position and (c) is the final position of V_0.

On this curve of ayc, the pressure of P_0 increases and P_s decreases gradually.

At the final position of V_0, P_0 becomes maximum, and P_s becomes zero, that is to say the shut-off pressure of this well.

The flow rate S and W decrease gradually and become zero at this shut-off pressure.

Therefore the following relations are apparent in Fig. 4 (a) (b), when V_0 has been closed completely.

$P_0 = oc$ (Shut-off pressure)
$P_s = o$
$S = o$
$W = o$

4. When a steam—water separator can be used for the measurement of mixed phase geothermal discharge, we come to the following conclusions:

(a) The quantities of geothermal discharge (separated steam and water) can be measured within the limits of abc in Fig. 4 (a).

(b) However, we can try the measurements in every direction (horizontally, vertically, obliquely and so on) adjusting V_0 and V_s suitably within this area of abc as shown in Fig. 4 (c).

2.5. *Calculation of the quantities of steam and hot water*

The systematic diagram of the measurement put to use: the separator is shown in Fig. 5, and the quantities of separated steam and hot water can be calculated with equations described later.

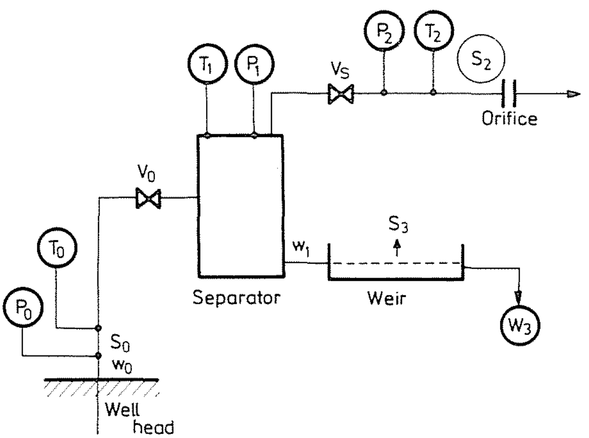


Fig. 5. Systematic diagram of the measurement using the steam—water separator

In Fig. 5, the letters to be used in the calculations are:

P: pressure
S: steam flow rate
W: hot water flow rate
i: enthalpy

The suffixes to be used in the calculations are:

0: in the state of the well head pressure
1: in the state of the separator pressure
2: in the state of the before orifice pressure
3: in the state of the atmosphere
i'_0, i'_1, i'_3: enthalpy of the saturated hot water
$i''_0, i''_1, i''_2, i''_3$: enthalpy of the saturated steam.
S_0, W_0: steam and hot water flow rate in the well head.
S_1, W_1: steam and hot water flow rate in the separator.
S_2: steam flow rate in orifice.
S_3, W_3: flash over steam and hot water flow rate in the weir.

We can get only the following of measurement results:

P_0, T_0: pressure and temperature in the well head measured by pressure gauge and thermometer.
P_1, T_1: pressure and temperature in the separator measured by pressure gauge and thermometer.
S_2: steam flow rate in the measuring pipe line measured by orifice meter.
W_2: hot water flow rate in the weir.

As the steam and the hot water flow rate are measured each under different conditions, these measuring values must be converted into the well head condition. The equations to be used in the calculations are the following:

1. In the orifice and the separator

$$i''_2 s_2 = i''_1 s_1 \tag{1}$$

2. In the weir and the separator

$$i'_1 w_1 = i''_8 s_8 + i'_3 w_3 . \tag{2}$$

$$w_1 = s_3 + w_3 \tag{3}$$

3. In the separator and the well head

$$i''_1 s_1 + i'_1 w_1 = i''_0 s_0 + i'_0 w_0 \tag{4}$$

$$s_1 + w_1 = s_0 + w_0 \tag{5}$$

4. Starting from there equations (1) to (5), the steam and the hot water flow rate are calculated as follow:

(a) weir

$$s_3 = \frac{i'_1 - i'_3}{i''_3 - i'_1} \cdot w_3$$

(b) separator

$$s_1 = \frac{i''_2}{i''_1} \cdot s_2$$

$$w_1 = \frac{i''_3 - i'_3}{i''_3 - i'_1} \cdot w_3$$

(c) well head

$$s_0 = \frac{i''_2}{i''_1} \cdot \frac{(i''_1 - i'_0)}{(i''_0 - i'_0)} \cdot s_2 + \frac{(i'_1 - i'_0)\,(i''_3 - i'_3)}{(i''_0 - i'_0)\,(i''_3 - i'_1)} \cdot w_3$$

$$w_0 = (s_1 + w_1) - s_0$$

2.6. *Expression of the physical well characteristics*

The physical well characteristics obtained in the way described above are shown in Fig. 6.

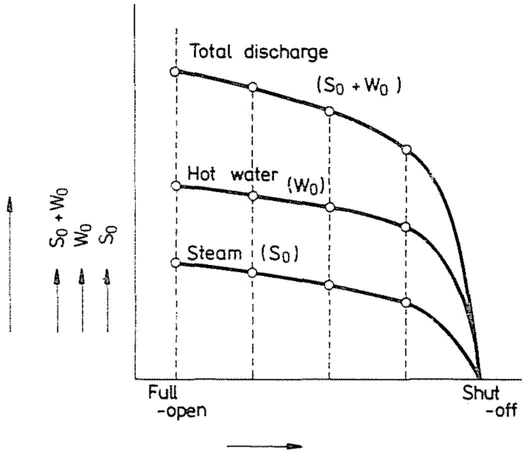


Fig. 6. Physical well characteristics

(1) well head pressure *VS* steam flow rate converted in the well head condition.

(2) well head pressure *VS* hot water flow rate converted in the well head condition.

(3) well head pressure *VS* total well discharge converted in the well head condition.

(4) shut-off pressure.

2.7. *Chemical well characteristics*

2.7.1. *Contents for the chemical well characteristics*

The chemical components to be measured for the well characteristics are shown in Table 1.

2.7.2. *Sampling*

2.7.2.1. *Hot water*

The sampling of hot water may be performed in the weir without any trouble, and the chemical components to be measured are shown in Table 1.

Table 1

Chemical components to be measured for the well characteristics

Item		Hot water	Steam
PH		○	○
conductivity		○	○
total solid	(ppm)	○	○
M (as $CaCo_3$)	(ppm)	○	○
Cl	(ppm)	○	○
CaO	(ppm)	○	○
MgO	(ppm)	○	○
Ionic SiO_2	(ppm)	○	○
Total SiO_2	(ppm)	○	○
Fe	(ppm)	○	○
SO_4	(ppm)	○	○
H_2S	(ppm)	○	○
Na	(ppm)	○	○
K	(ppm)		
non-condensable gas	(Vol. %)		○
H_2S	(Vol. %)		○
CO_2	(Vol. %)		○
O_2	(Vol. %)		○
others	(Vol. %)		○

2.7.2.2. *Steam*

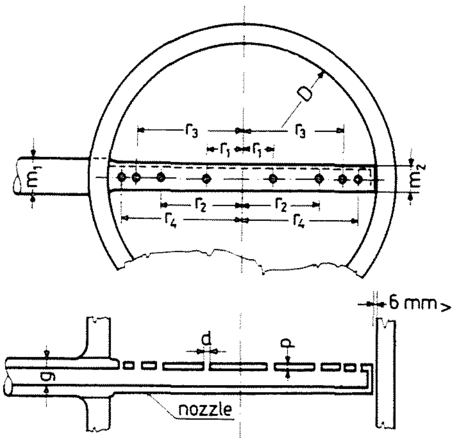
Generally, the sampling of steam involves some trouble.

We must insert a sampling nozzle into the steam pipe line to extract it, and lead it through a water cooler to get the sample for the chemical measurement.

The chemical components to be measured are shown in Table 1, and the measuring methods are the same in case of the hot water except non-condensable gases.

2.7.3. *Sampling nozzle for the steam and the desirable order of sampling nozzle position*

The design of sampling nozzle is shown in Fig. 7, and the steam generally involves so great amounts of hydrogen sulfide gas that stainless steel is the most desirable material.



Item	Steam pipe Diameter D(mm)	Number N	r_1	r_2	r_3	r_4
Design	50~150	4	0.177 D	0.427 D		
	150~300	6	0.144 D	0.337 D	0.454 D	
	above 300	8	0.125 D	0.302 D	0.393 D	0.466 D

Fig. 7. Design of the sampling nozzle

The diameter of the hole on the sampling nozzle can be calculated by the following formula because the steam velocity in the sampling pipe line should be regulated to the same speed as in the original team pipe line.

Therefore,

$$d = D\sqrt{\frac{0.06S}{nE}}$$

d: diameter of hole on the sampling nozzle (mm)
n: no. of holes
D: diameter of the original steam pipe-line (mm)
S: sampling flow rate (Kg/min)
E: steam flow rate in the original steam pipe-line (ton/hr)
The desirable order of sampling nozzle positions is shown in Fig. 8.

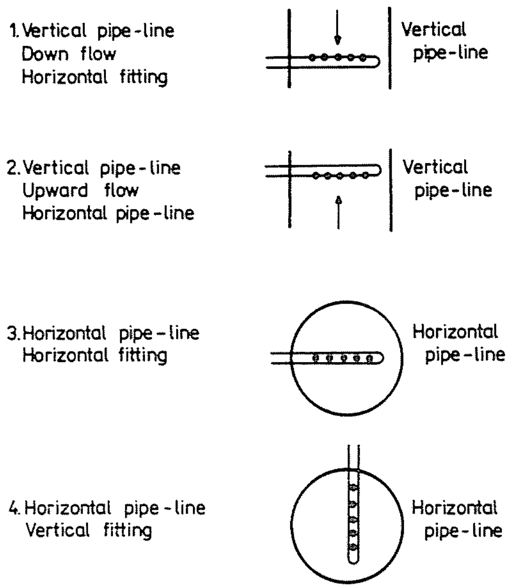


Fig. 8. Desirable order of the sampling nozzle position. 1. Vertical pipe-line. Down flow. Horizontal fitting; 2. Vertical pipe-line. Upward flow. Horizontal pipe-line; 3. Horizontal pipe-line. Horizontal fitting; 4. Horizontal pipe-line. Vertical fitting

2.7.4. *Cooling equipment for the sampling steam*

The cooling equipment for the sampling steam is shown in Fig. 9.
1. Design

$$A = 38.6\,\frac{s}{\theta\alpha}$$

A: surface area of cooling coil (m^2)
S: sampling flow rate (Kg/min)

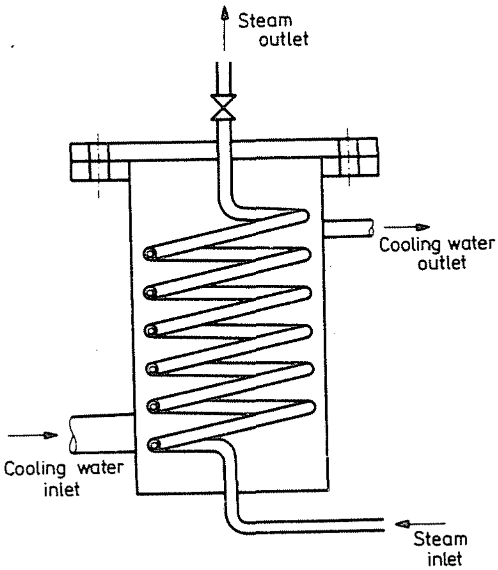


Fig. 9. Cooling equipment of the sampling steam

$$\theta\alpha: \frac{(\theta_1+\theta_2)-(\theta_3+\theta_4)}{2}$$

θ_1: inlet sampling steam temperature (°C)
θ_2: outlet sampling steam temperature (°C)
θ_3: inlet cooling water temperature (°C)
θ_4: outlet cooling water temperature (°C)
38.6: factor ($m^2 \cdot min \cdot °C/kg$)

The steam generally involves so much H_2S that stainless steel is most desirable for the material of the cooling coil.

2.7.5. *Measurement of non-condensable gases*

The apparatus for the measurement of non-condensable gases in the steam is shown in Fig. 10, and the operational technique is as follows:

1. Put the steam in the cooling equipment from the sampling nozzle.

If the steam contains non-condensable gases, they are divided into gas and condensated water in the cooling equipment.

2. Put the sample (gas and condensated water) in the measuring equipment which is filled with water at the beginning of the experiment.

3. The non-condensable gas stays in the gas burette on the top part, and the condensated water stays in the bottle on the lower part, discharging the same amount of water to the outside through the exhaust pipe-line.

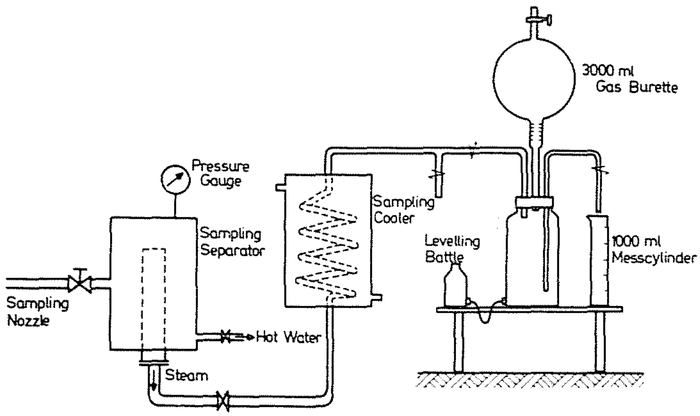


Fig. 10. Apparatus of the measurement of non-condensable gases

4. The equation to be used in the calculation are:

(a) The quantities of measuring gases converted into noımal pressure and temperature condition are:

$$V_0 = (V_1 + V_2) \cdot \frac{P_1}{P_0} \cdot \frac{T_0}{T_1}$$

V_0 : gas quantities converted into normal pressure and temperature condition (CC)
V_1 : measuring gas quantities (CC)
V_2 : dissolved gas quantities in the condensated water (CC)
P_0 : 760 (mmHg)
T_0 : 273 (°K)
T_1 : measuring gas temperature (°K)

(b) The quantities of dissolved gas in the condensated water are:

$$Qc = Qd - V_1$$

$$V_2 = Qc \cdot \lambda$$

Qc : quantities of dissolved gas (CC)
Qd : discharged water from the bottle (CC)
V_2 : quantities of dissolved gas in the condensated water (CC)
λ : Bunsen's factor (dissolved CO_2 gas in the water)

(c) Steam quantities converted into normal pressure and temperature condition:

$$V_{H_2O} = Qc \cdot D \cdot \frac{22.4 \times 10^3}{18}$$

V_{H_2O} : steam quantities converted into normal pressure and temperature (CC)

Qc : condensated water quantities (CC)

D : density of condensated water (g/cm^3)

(d) As a whole (a) (b) and (c), the quantities of non-condensable gases in steam V are:

$$V=\frac{V_0}{V_{H_2O}+V_0}\times 100$$

$$\fallingdotseq\frac{V_0}{V_{H_2O}}\times 100 \quad \text{(Volume \%)}$$

V : non-condensable gas converted into normal pressure and temperature condition.

3. Separator

3.1. *Necessary conditions for the separator*

A separator capacity is required which can separate the mixture into steam and water, and the separated hot water should never get into the steam.

These necessary conditions for the separator from the experimental data are the following:

1. The diameter of the inlet pipe is selected so that steam velocities should not exceed 40 m/s.

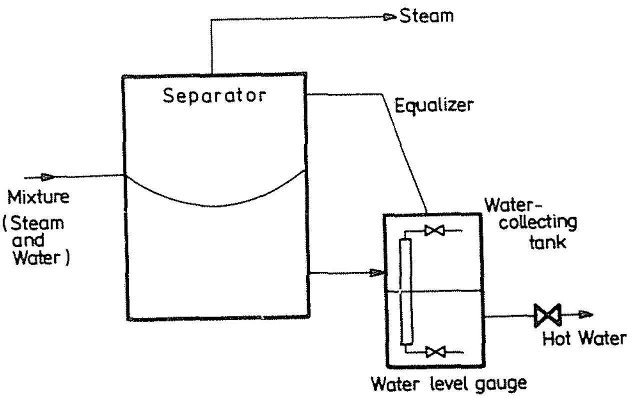


Fig. 11. Steam—water separator equipped with a water collecting tank

2. The upward linear velocities of the steam in the vessel should be less than 4 m/s.

3. The diameter of the outlet of the separator is almost the same as the inlet.

4. The inner water of the separator makes a parabolic surface and its height will change continuously while the well discharge is fluctuating.

If the water is gathered into the water-collecting tank from the bottom of the separator, the separated hot water in the separator can be controlled in this small tank. The water-collecting tank should be equipped with a water-level gauge and an equalizing pipe to equal the inner pressure of the water-collecting tank to the inner pressure of the separator as shown in Fig. 11.

3.2. *Separator types*

There are two types of separator for the geothermal well. One is for test use and the other for plant use.

For the purposes of well characteristics-testing only, an adjusting valve is equipped on the inlet side of the separator.

In order to operate the plant, we have to control the separating steam condition by an adjusting valve which is equipped on the outlet side of the separator.

The former is called "Open type separator" and the latter "Pressure type separator".

3.2.1. *Open type separator*

This type adjusts to the quantities of the well discharge by the opening and closing operation of a valve which is equipped on the inlet of the separator from the shut-off position to the fully open position.

At the fully open position, the quantities of the well discharge and the internal pressure of the separator become maximum. However, the maximum pressure is not so great because the outlet of the separator is open to the atmosphere. It can be made comparatively easily and at low cost. The "Open type separator" is suitable only for the purpose of well characteristics-testing. Fig. 12 and Fig. 13 show the schematic measuring diagram and the structure of the "Open type separator".

3.2.2. *Pressure type separator*

When we use the "Pressure type separator", the separating steam condition is controlled by using an adjusting valve which is equipped with the outlet of the separator.

At the fully open valve position, the well discharge is maximum, and the internal pressure of the separator becomes higher in proportion to the amount of valve closing position, finally it becomes the shut-off pressure of the well.

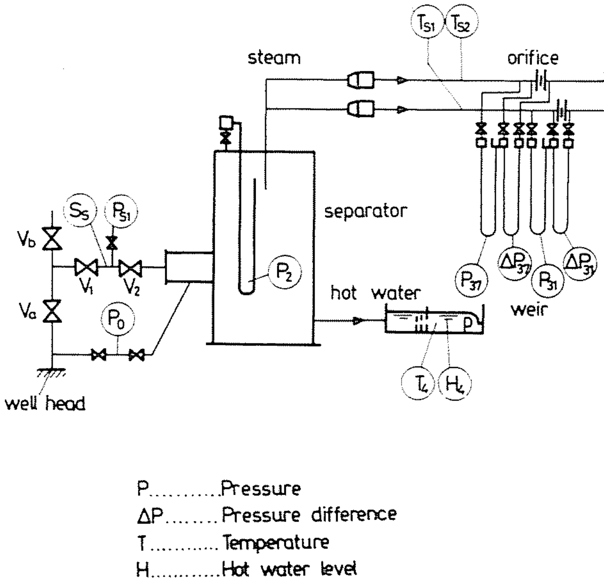


Fig. 12. Systematic diagram of the measurement by open type separator. P ... Pressure; ΔP ... Pressure difference; T ... Temperature; H ... Hot-water level

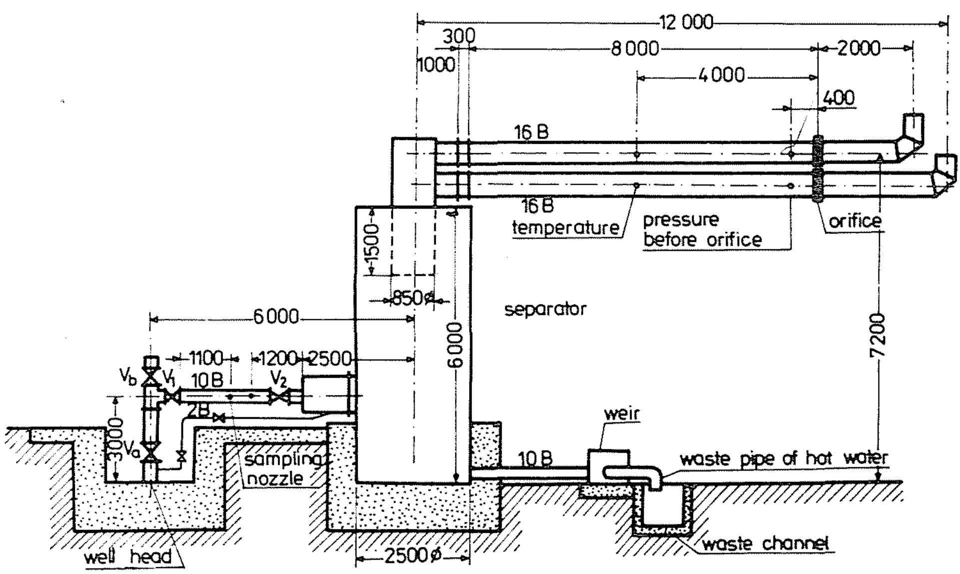


Fig. 13. Open type separator with measuring pipe-line

As the separator should be kept at high pressure and temperature, the production of the separator may be complicated and expensive, but the "Pressure type separator" is indispensable for the geothermal power station. We made three types of separators: A, B and C for testing as shown in Fig. 14, 15 and 16.

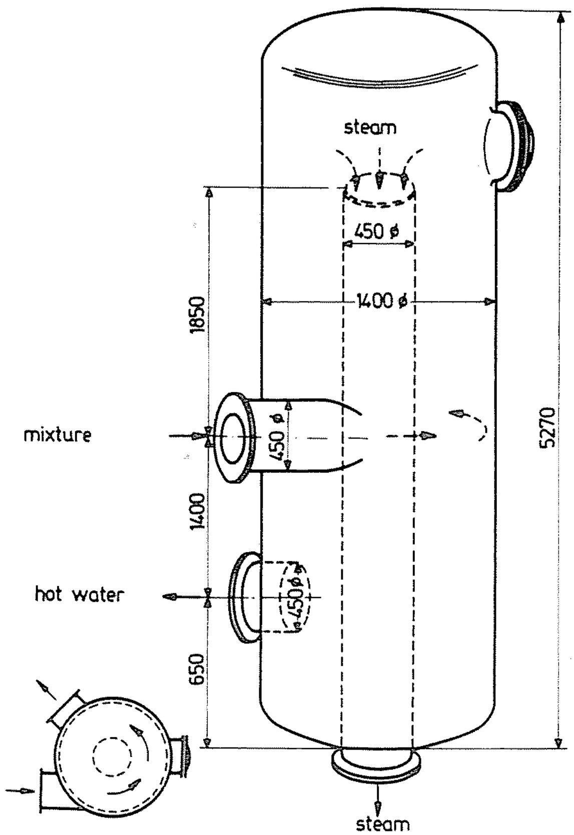


Fig. 14. Pressure type separator (A)

(1) *Type A Separator*

The construction of type A separator is shown in Fig. 14 similar to the Wailakei type in New Zealand.

The structure and the mechanism of the separator are simple.

The well discharge flows into the vessel of the separator through the inlet pipe at the tangential direction of the vessel, and separates into steam and hot water by centrifugal force.

The separated steam rises upward in the vessel going downward in a vertical line through the steam pipe that is fixed on the inside of the vessel and runs from the bottom of the separator, the hot water flows into the hot-water collecting tank as shown in Fig. 11.

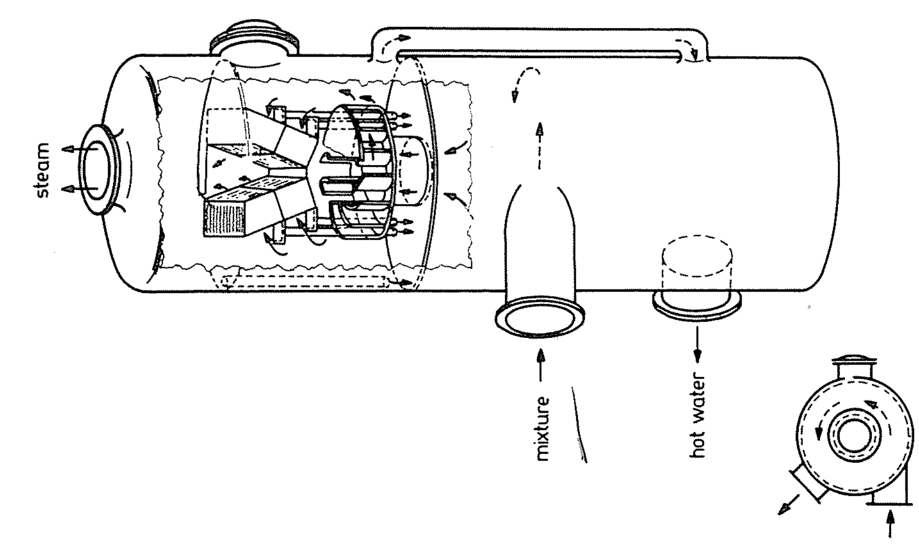


Fig. 15. Pressure type separator (B)

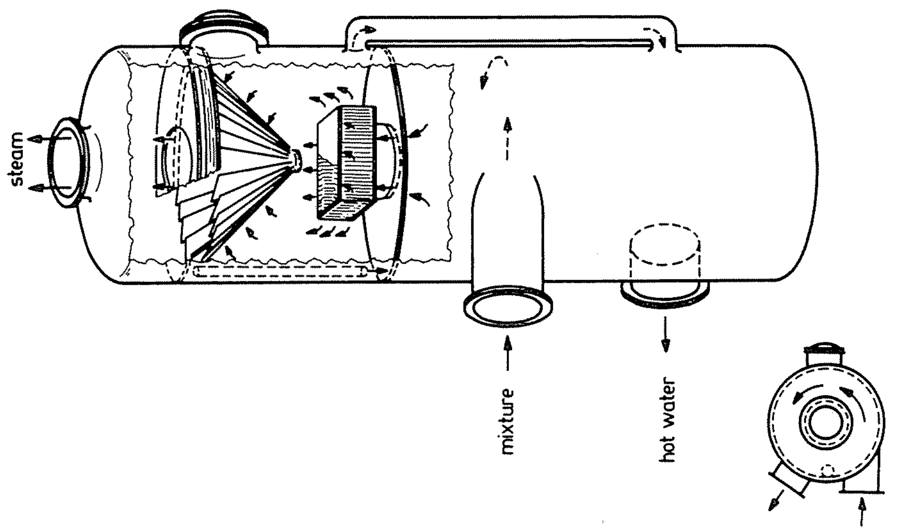


Fig. 16. Pressure type separator (C)

(2) *Type B Separator*

This separator consists of a steam—water separating part and a steam dryer part as shown in Fig. 15.

The well discharge flows into the vessel of the separator through the inlet pipe at the tangent direction of the vessel, and is separated into steam and hot water by centrifugal force in the lower part of the vessel.

The separated steam rises upward and flows into the upper part through the cylinder which is mounted at the middle of the diaphragm plate.

There are two parts of dryer in the upper vessel.

The separated steam goes through the lower dryer first, which is conbined cylindrically with bent blades.

After passing the lower dryer, the steam flows in the corrugate plate type dryer of the upper part, and the steam is purified again.

The steam flows from the top of the separator, and the hot water flows into the hot-water collecting tank from the bottom of the separator.

(3) *Type C separator*

This separator is made like type B except the parts of steam dryer as shown in Fig. 16.

The lower dryer is chevron type, the upper one is the centrifuging type.

3.2.3. *Conclusions about the pressure type separators*

(1) *Efficiency of separation*

All types of A, B and C have excellent properties.

They can produce the steam of more than 99.9% purity within the limited velocities of 40 m/sec in the inlet pipe of the separator.

(2) *Initial pressure loss*

From the types A, B and C, B is the smallest, C is a little bigger than B, and A is between of B and C.

(3) *Production cost*

The construction of A is so simple that the cost is the lowest of the three.

B and C costs almost the same, 30~40% more than A.

(4) *Overall conclusion about pressure type separators*

From the facts described above we may conclude that A is to be recommended in the first place.

4. Environmental Problems

4.1. *Noise due to steam flashing*

When the well discharge begins flashing at the well head without muffler, much noise ensues.

The frequency of the noise produced by steam flashing ranges from low frequency regions to very high frequency regions as shown in Fig. 17.

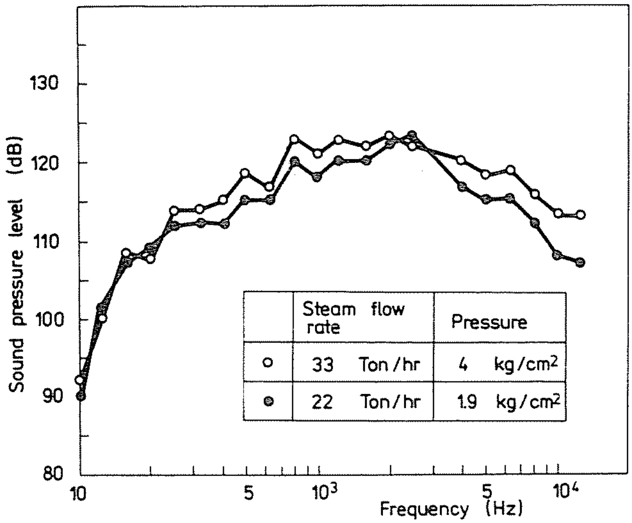


Fig. 17. Frequency spectra of steam flashing noise

An ordinary muffler of expansion chamber type is not effective for abating noise of such high frequencies.

The measurements are performed by using a precision sound level meter and a 1/3 octave band analyser.

The conditions of these measurements are as follows:

1. *Steam flow rate*

(a) 33 ton/hr (pressure at separator outlet 4 kg/cm^2) (gauge pressure)
(b) 22 ton/hr (1.9 kg/cm^2) (gauge pressure)

2. *Measured point*

I meter apart from outlet of the steam flashing pipe (6 inches diameter).

As seen in Fig. 17 the noise contains high energy components in the high frequency region and the noise level increases with increasing flow rates of steam.

We proposed a new special steam muffler; it is designed to satisfy the following three conditions.

1. Good noise reduction, even in high frequency region.
2. Very low resistance against steam flow.
3. Easy to check silica deposits and corrosion due to hydrogen sulfide gas.

The schematic construction of this steam muffler is shown in Fig. 18.

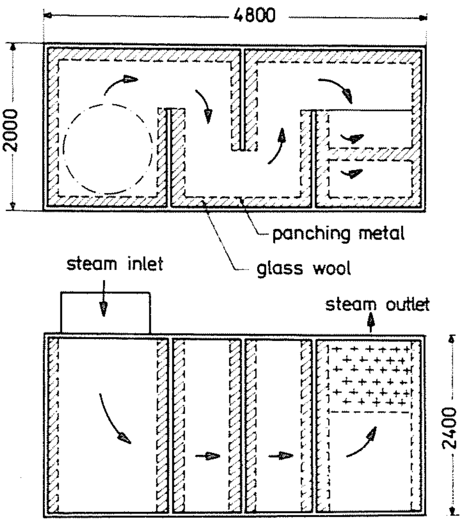


Fig. 18. Construction of steam muffler

Figure 19 shows observed values of sound pressure level, with and without the muffler. Considerable reduction of noise level of high frequency component is obtained and the amount of noise reduction is about 40 dB (A) as shown in Fig. 20.

The attenuation in case of small flow rates is larger than in the case of big flow rates. This means that the big steam flow rate generates secondary noise in the chamber of the muffler.

Improvements were made one after another, and the steam muffler has been combined with the open type separator. Figure 21 shows an improved design of the open type separator for the measurement of the geothermal well characteristics, capable of 35 tons/hr separation of steam.

4.2. *Hot water disposal*

4.2.1. *Silica deposit*

Since geothermal waters are accompanied with chemical and thermal pollution their disposal is important. One of them is silica deposit. In the study

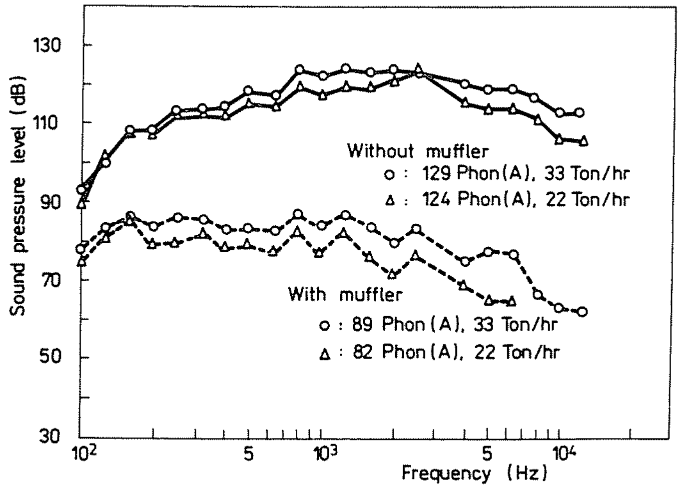


Fig. 19. Sound pressure level with and without muffler

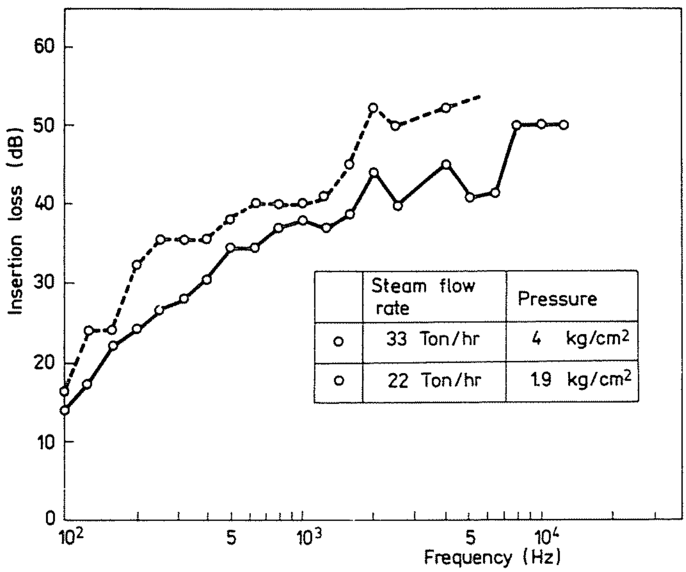


Fig. 20. Noise reduction by steam muffler

it was discovered that the deposit of scale is the fastest immediately after the spout of hot water and slows down as the time passes. The change from ionized silica to colloidal silica takes place in one hour and gathered to the diameter of 0.3 microns in 60 minutes.

A large retaining tank of hot water should be installed to avoid the silica deposit in the hot water disposal line.

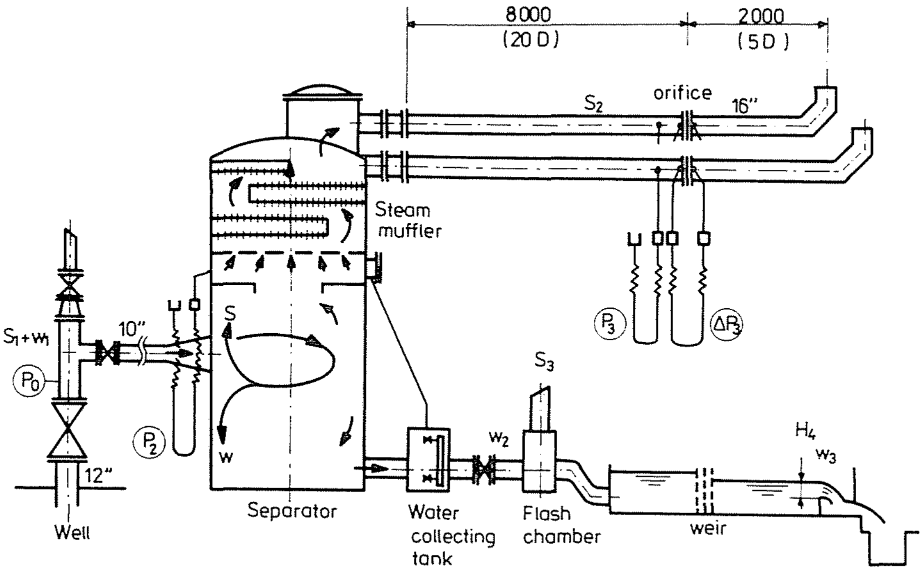


Fig. 21. Improved design of open-type separator combined with steam muffler

4.2.2. *Chemical pollution and others*

The minerals dissolved in the hot water can cause chemical pollution, such as boron, arsenic, salt and so on have an important effect on environment sanitation. The reinjection of geothermal water into the subsurface is desirable not only for environmental protection but also for the maintenance of water balance in the reservoir; a few reinjection wells decrease the amount of suction in a short time.

Thermal influence on reservoirs has been studied, and seismic observation also has been carried out since the reinjections have started but earthquakes caused by reinjection have not been recorded.

5. Improved Design of Geothermal Power Station

5.1. *General*

We initiated a 10 MW geothermal power station in Otake area (Oita Prefecture in Japan) in 1967.

This power station called "single-flash-cycle" is a pilot plant constructed solely for the purpose of conducting various experiments on geothermal power generation.

On the basis of these experiments a 50 MW geothermal power station, the so-called "double-flash-cycle", using not only the primary steam but also the secondary steam flashing from the primary hot water, has been in service without any trouble in Hachobaru area since May 1977. Hachobaru is located a 2 km Southward from Otake.

This 50 MW power station has two unique features:

(1) double-flash-cycle system using a mixed pressure turbine;

(2) Steam—water mixture two-phase flow transmission system.

Figure 22 shows the general idea of double-flash-cycle system. Figure 23 shows system diagrams of the Hachobaru double-flash-cycle power station.

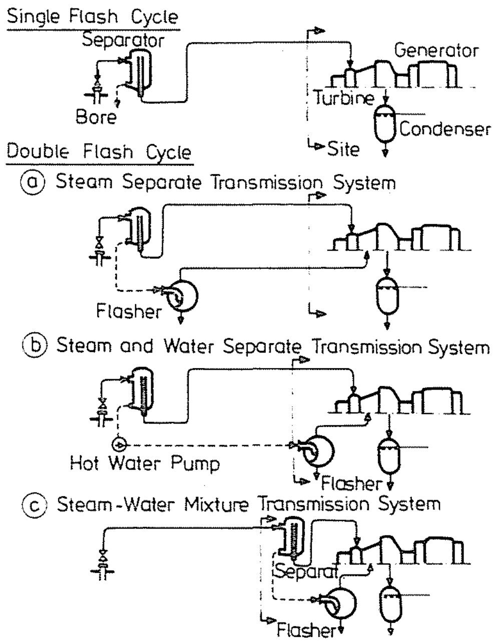


Fig. 22. Hot-water type geothermal power plant cycle and transmission system

The advantages of the double-flash-cycle system are the following:

1. About 15 to 20% more power can be produced with the same geothermal supply than in the single-flash-cycle system.

2. Although the total investment cost of the plant is about 5% more than that of the single-flash-cycle system, the net cost per kilowatt hour is about 10 to 15% lower.

3. Optimum turbine inlet pressure (primary steam pressure) with the same well is about 30% more expensive than that of the single-flash-cycle system, so

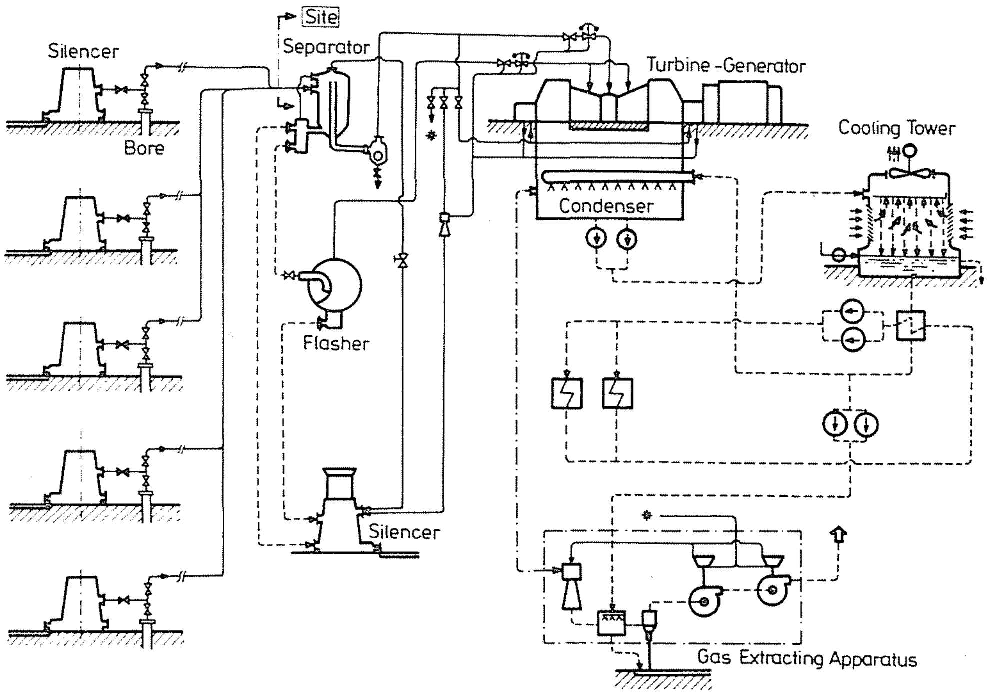


Fig. 23. 50 MW double-flash-cycle plant (Hachobaru Power Station)

that smaller steam pipe and valves can be used, their arrangement becomes easy, and the cost decreases. Higher turbine inlet pressure improves the steam consumption rate, so that smaller condensers, cooling towers, fans, and pumps will suffice. This results in lower plant costs and in lower auxiliary power requirement.

4. As the dry saturated steam from the flasher enters the intermediate stage of the turbine, the wetness of the turbine exhaust steam decreases by 2% and thus blade erosion by drain can be reduced.

5. The waste hot-water temperature falls.

6. The quantity of the waste hot water decreases about 11%.

5.2. *Mixture transmission system*

In the steam—water mixture transmission system the entire steam—water mixture from each well is transmitted as it is in a single pipe to the power station, and the transmission pipe-lines from the wells can be joined together one by one as they proceed towards the power station.

Both the separator and the flasher are located in the power station which ensures easy maintenance, and only one waste hot-water line is required.

We made a few experiments with steam—water mixture direct transmission in Hachobaru area.

1. *Test loop*

A test loop as shown in Fig. 24 was installed.

The well discharge was transmitted in a single pipe-line of 2000 mm diameter and 300 m long.

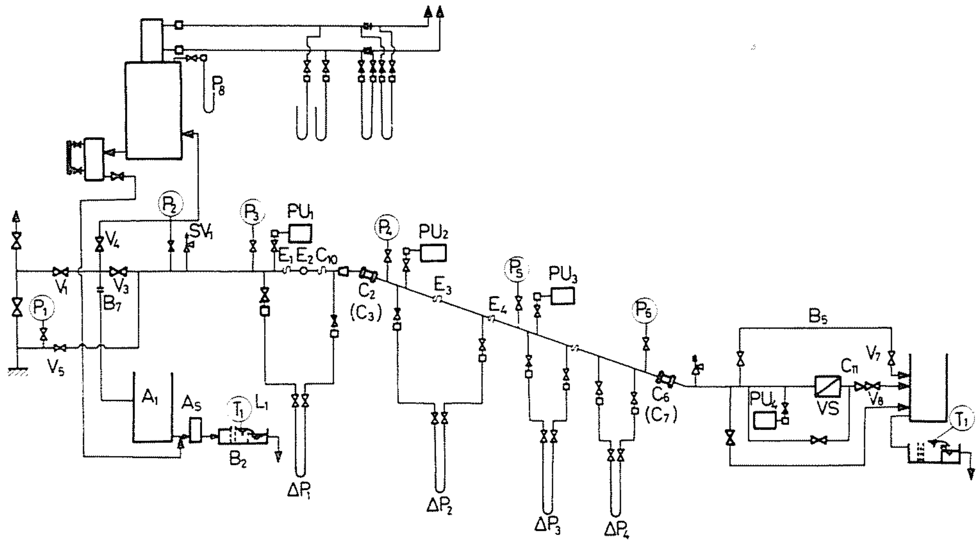


Fig. 24. Systematic diagram of the mixture transmission system on test loop

2. *Test results*

(a) *Stability of flow*

No unusual vibration or noise arised in the steady state, not even in the start-up period.

A stable annular flow was observed through the peek hole.

(b) *Pressure drop*

The pressure drop is 0.25 kg/cm^2 (about 7%) per 100 m length of pipe-line at the velocity of 35 m/sec.

This value is just five times that of the steam pipe-line but this large pressure drop is compensated by other merits of direct transmission.

(c) *Transient test*

The test result of transient response to the sudden shutdown of the flow is shown in Fig. 25 and Fig. 26.

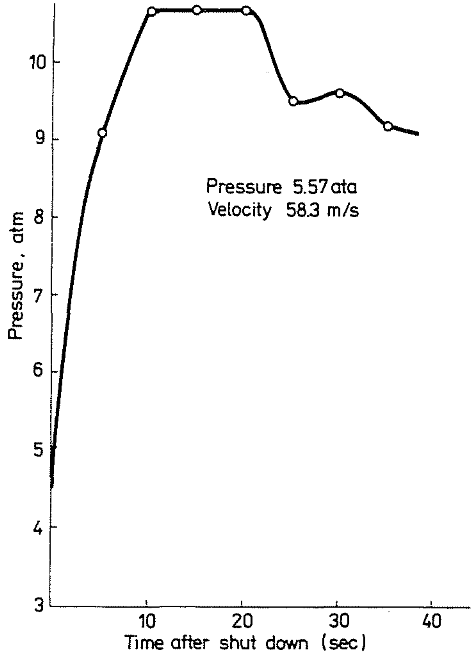


Fig. 25. Pressure fluctuation by sudden shut-down of discharge valve (Max. flow)

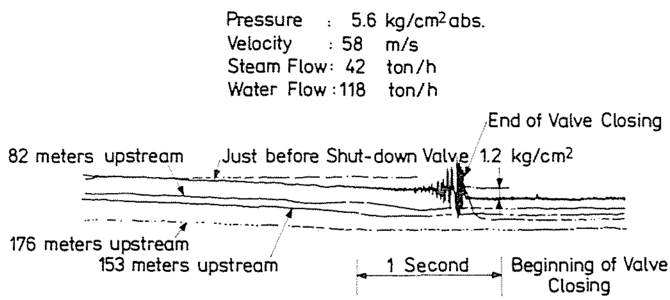


Fig. 26. Oscillograph of pressure change in the transmission pipe-line at sudden shut-down of discharge valve

(d) The thickness of the loop was measured after 73 days of continuous operation. There was almost no corrosion or erosion, and the inner surface of the pipe-line was covered with a thin blackish grayfilm.

6. Conclusions

We explained the progress and background of our basic and extensive studies for the geothermal power plant. At first, we studied the measurements for hot-water type geothermal discharge, and determined the definitions of well characteristics. This studies formed the basis of the engineering approach to the development of geothermal power station which enabled us to complete the first 50 MW geothermal power station of double-flash-cycle system in the world. We hope, particularly in view of the current demand for the efficient use of natural resources, that this paper will serve as a reference for planning hot water type geothermal power stations.

Summary

There are two types of flashing condition in the geothermal well discharge. One is the dry steam type which consists of dry steam only, and the other is the hot-water type which has steam and hot-water in it.

In case of the dry steam type, the measurement of well characteristics is simple, however the hot-water type generally brings difficulties in its train.

As the well discharge of our geothermal field was the hot-water type, we decided to adopt the single-phase measuring system that the well discharge should be separated into the steam and the hot-water put to use in the steam—water separator, and performed the following studies:

1. The measurements for physical and chemical well characteristics.
2. Separators which have excellent performance and durability.
3. Materials used for plants against erosion and corrosion.

On basis of the results of these studies described above, the 10 MW geothermal power station of single-flash-cycle system was completed for test in 1967.

The studies described were carried on over and over again using the 10 MW test plant for several years, and so the 50 MW power station with a double-flash-cycle system was finally completed successfully in 1977.

1. The steam silencer for the reduction of the flashing noise of well discharge.
2. The counterplan for the trouble of silica deposit in the hot-water disposal pipe line.
3. The transmission system of the steam—water mixture.
4. The steam turbine of the double-flash-cycle system.

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