POWER GENERATION WITH A TWO-PHASE ROTARY SEPARATOR TURBINE-PRELIMINARY CONSIDERATION FOR POWER GENERATION USING A DOWNHOLE COAXIAL HEAT EXCHANGER SYSTEM (II)

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1. INTRODUCTION

A downhole coaxial heat exchanger (DCHE) system as shown in Fig.1 was proposed as a new geothermal energy extraction system. A series of studies (Morita and Sugimoto, 1988; Yamada et al., 1988; Fujita et al., 1988) were carried out on power generation using DCHE for the specified well design and temperature distribution in the underground formation. The purpose of these studies is to clarify at what thermal output or effective thermal conductivity of the formation the system becomes economical.

Four effective thermal conductivities of the formation were assumed, and power generation costs were investigated for each effective thermal conductivity. Assumed effective thermal conductivities were 2.7, 10.0, 20.0 and 30.0 kcal/mh°C. A combination of two-phase turbine and steam turbine was selected as the power generation system after comparison with two-phase turbine and multi-flush system.

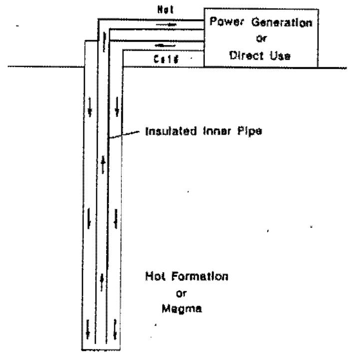

FIG.1 System of the Downhole Coaxial Heat Exchanger

In this study, a set of reinjection temperature and flow rate which gives the maximum net power output was selected for each effective thermal conductivity. Then the optimum design conditions of each power plant were determined for selected four cases, and finally net power output was estimated. The comparison of two-phase turbine with the multi-flush system was also discussed.

2. ENERGY CONVERSION SYSTEM

There are two principal systems of geothermal power generation. One is the multi-flush and steam turbine system as shown in Fig.2, and the other is the two-phase turbine and steam turbine system as shown in Fig.3.

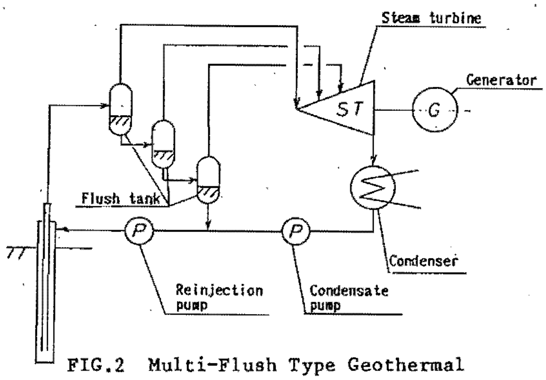

FIG.2 Multi-Flush Type Geothermal Power Plant

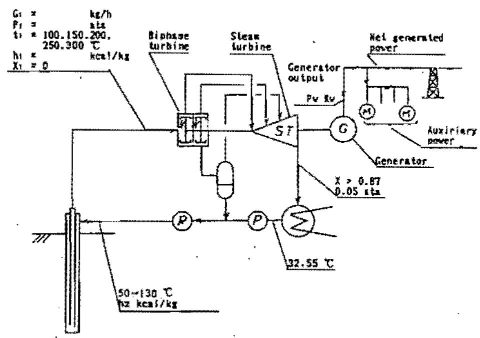

FIG.3 Condition of Biphase turbine system used for the calculation

In the two-phase and steam turbine system, hot water is expanded adiabatically through a two-phase nozzle and high speed two-phase mixture is led to a two-phase turbine. Power is extracted and two-phase mixture is separated into water and steam by two-phase turbine. Then the steam is led to the steam turbine.

In this system, the thermal energy of hot water converted into kinetic energy at the two-phase nozzle is immediately converted into power by the two-phase turbine. Therefore, the irreversibility becomes smaller and converted power becomes larger than that of the conventional flush system (Yamaoka, 1984).

A comparison of the cost performance of the multi-flush and steam turbine system with the two-phase turbine and steam turbine system was carried out. The result showed that two-pahse turbine and steam turbine system gives higher net power output and lower power generation cost at the specified conditions in comparison with the multi-flush and steam turbine system. Consequently, the two-phase turbine and steam turbine power generation system was selected as the power generation system in this paper.

The authors treated Mitsui Biphase Turbine as a two-phase turbine hereinafter in this paper.

3. SELECTION OF THE OPTIMUM CASES

Net power outputs of the power generation plants at 1 year of elapsed time were estimated for every simulated case (Morita and Sugimoto, 1988) assuming that 15 DCHEs provide hot water at saturation pressure to the power plant. Then the optimum case which gives the maximum net power output was selected for each effective thermal conductivity of the formation.

Assumptions for estimation of gross power output are as follows:

1) Condensing temperature was fixed at 32.55 °C considering heat emission in cooling tower in the condition of ambient wet bulb temperature of 20 °C and cooling water in/out temperature of 30/25 °C. Accordingly condensing pressure, that is, exhaust pressure of the steam turbine became 0.05 kg/cm^2 abs.
2) Pressure of intermediate flush stages was selected so that power output became the maximum. However, the wetness fraction of steam turbine exhaust was forced below 13 % by lowering the pressure of the high flushing stages to avoid erosion of the steam turbine blade.
3) Internal efficiencies of the Biphase turbine and the steam turbine adequate for their capacity were used.

According to the above assumption, the thermal efficiency of the power generation cycle defined by the following equation was obtained.

$$\eta = \frac{860 \cdot Pg}{G(h_1 - h_2)} \times 100$$

Where
η : Thermal efficiency (%)
Pg : Gross power generation (kW)
G : Flow rate of hot water (kg/h)
h_1 : Enthalpy of hot water (kcal/kg)
h_2 : Enthalpy of reinjection water (kcal/kg)

The in-house power requirements for reinjection pump, lubricating oil pump, condensate pump, cooling tower fan, cooling water pump and so forth were also estimated for all simulated cases. The power for the transportation of water between the power plant and the DCHEs was not included in the in-house power here, since it depends on the plant and wells' layout.

The net power outputs were obtained subtracting in-house power from the gross power outputs. Then a set of inlet water temperature and flow rate, which gives the maximum net power output at 1 year of elapsed time, was selected for each effective thermal conductivity of the formation.

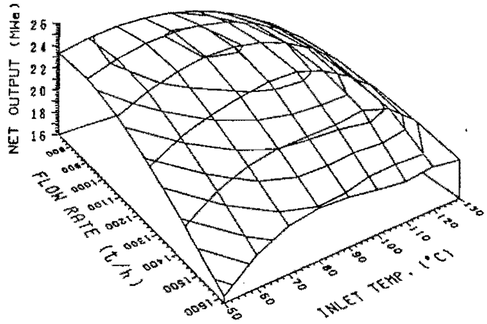

FIG.4 Effect of inlet water temperature and flow rate on net power output

Fig.4 shows an example of the relation among net power output, inlet water temperature of the DCHE and total flow rate from 15 DCHEs for the effective thermal conductivity of 20.0 kcal/mh°C. In this case the maximum net power output is obtained when inlet water temperature of the DCHE and total flow rate are 90°C and 1,080 t/h.

The selected optimum cases for each effective thermal conductivity of the formation are listed in Table 1.

Table 1 The selected optimum cases. Number of DCHEs is 15.

Case	Case 1	Case 2	Case 3	Case 4
Eff. Thermal Cond. (kcal/mh°C)	2.7	10.0	20.0	30.0
Reinjection temperature (°C)	90.0	90.0	90.0	80.0
Flow rate (t/h)	180	540	1,080	1,260
Hot water temperature (°C)	204.6	212.9	209.4	223.7

4. DESIGN POINT AND NET POWER OUTPUT

In this study, we assumed that 3 wells are complete every 4 months for the first 12 wells using 3 drilling rigs, then the last 3 wells are drilled consecutively each taking 4 months. Thus it takes 28 months to drill 15 wells.

The changes of hot water temperature at the inlet of the power plant was calculated based on the change of the outlet water temperature for single DCHE considering the well drilling schedule. The change of total flow rate of the power plant was also calculated.

Fig.5 shows an examples of the change of the hot water temperature and the flow rate.

When hot water temperature changes with time as shown in Fig.5, a determination of the design point is important since it greatly influences the construction cost of the plant and the power output, and consequently the power generation cost.

If the design temperature of the power plant is set at high, i.e. at hot water temperature in an early stage of the plant operation, the construction cost and the running maintenance cost become high. In this case, the plant will be operated at partial load for almost all the plant life, which means poor cost performance.

If the design temperature of the power plant is set at low, i.e. at hot water temperature in a late stage of the plant operation, the construction cost and the running maintenance cost become low. However, a certain fraction of the thermal output of the DCHEs is not used for power generation in the early stage of the plant operation, which means low overall power generation efficiency and also poor cost performance.

The optimum design point which maximizes a total gain throughout the 15 years' payback period (i.e. plant life) was examined for the four cases considering construction cost, running cost and sales of power generation. It was shown that when the design temperature is equal to the hot water temperature after 6 years' plant operation, the total gain becomes the maximum in every case. Therefore, the design temperature is set at the hot water temperature after 6 years' plant operation in this study.

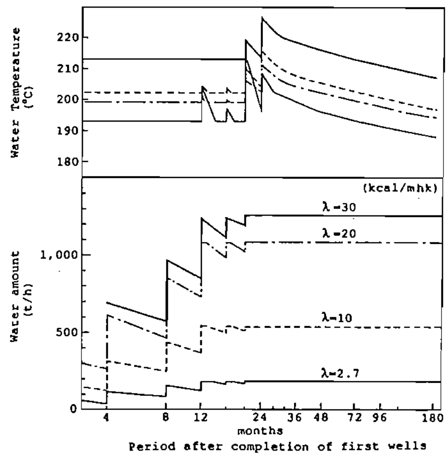

FIG.5 Transition of Hot Water Temperature and Amount during and after Drilling of Wells

The determined design conditions of the power plants are listed in Table 2 for the four cases. The power for the water transportation pump was calculated based on the plant and wells' layout of the four cases (Yamada et al, 1988). Then the change of net power output of the power plants was calculated for the four cases. The result is shown in Fig.6.

Table 2 Design conditions of the power plants. Number of DCHEs is 15.

Case	Case 1	Case 2	Case 3	Case 4
Eff. Thermal Cond. (kcal/mh°C)	2.7	10.0	20.0	30.0
Reinjection temperature (°C)	90.0	90.0	90.0	80.0
Flow rate (t/h)	180	540	1,080	1,260
Hot water temperature (°C)	192.5	201.4	198.6	212.2
Plant Capacity (MW)	3.5	12.8	25.7	37.3

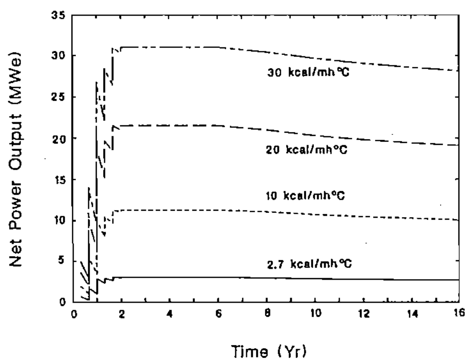

FIG.6 Transition of Net Power Output

5. BIPHASE TURBINE AND MULTI-FLUSH SYSTEM

A Comparison of cost performance of the Biphase turbine and steam turbine system with the multi-flush and steam turbine system was made under the conditions in table 2. The net power output and the construction cost were estimated for both systems as listed in table 3.

Four to six per cent greater net power output is obtained by the Biphase turbine and steam turbine system than by the multi-flush and steam turbine system. Since the cost of Biphase turbine is higher than the flush tanks, the construction cost of the Biphase turbine and steam turbine system is higher by 1 to 3 % than the multi-flush and steam turbine system. As a result, 1 to 5 % lower construction cost per net power output is obtained by the Biphase turbine and steam turbine system than by the multi-flush and steam turbine system. The difference in cost performance increases as effective thermal conductivity or thermal output of the DCHEs become higher.

The above results indicate that the Biphase turbine and steam turbine system is more suitable to power generation using the DCHE.

Table 3 A comparison of cost performance of the Biphase turbine and steam turbine system with the multi-flush and steam turbine system. Number of DCHEs is 15.

Case	Case 1	Case 2	Case 3	Case 4
Eff. Thermal Cond. (kcal/mh°C)	2.7	10.0	20.0	30.0
Biphase Turbine Type				
Net Power Output (kW)	3,014	11,215	21,388	30,669
Construction cost (million Yen)	569	1,539	2,716	3,564
Construction cost/Net Power output (kYen/kW)	189	137	127	116
Multi-flush Type				
Net Power Output (kW)	2,899	10,776	20,324	28,849
Construction cost (million Yen)	554	1,513	2,676	3,519
Construction cost/Net power output (kYen/kW)	191	140	132	122

6. CONCLUSIONS

The net power output of the power plant was estimated. The results obtained in this paper are summarized as follows:

1) There exists a set of flow rate and reinjection temperature which gives the maximum net power output for the specified well conditions.
2) When hot water temperature decreases with time, the design temperature of the power plant influences the cost performance greatly and there exists a design temperature which maximizes total gain over the life of the plant.
3) The Biphase turbine and steam turbine power generation system gives higher net power output and lower power generaion cost at the specified conditions in comparison with the multi-flush and steam turbine system. From an economical point of view, the Biphase turbine and steam turbine system is recommended for power generation using DCHEs.

Power generation using the DCHE has the advantages of being corrosion free, scale free and pollution free. There seem to be no technical problems for power generation system when combined with DCHE.

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