HEAT EXTRACTION USING A DOWNHOLE COAXIAL HEAT EXCHANGER - PRELIMINARY CONSIDERATIONS FOR POWER GENERATION USING A DOWNHOLE COAXIAL HEAT EXCHANGER SYSTEM (I)

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1. INTRODUCTION

A downhole coaxial heat exchanger (DCHE) is applicable to a wide variety of geothermal resources. Especially it is suitable for the development of super hot formations, magma bodies and low productive geothermal reservoirs which produce insufficient amount of hot water or steam for power generation or direct use. These resources were regarded as difficult to develop by ordinary technologies. However, previously proposed DCHEs were not efficient in heat extraction performance, and thought to be not practical method.

The authors investigated the effect of design parameters and operational parameters on the performance of the DCHE using numerical simulator, and clarified that the reverse circulation with highly insulated inner pipe increases thermal output of the DCHE significantly (Morita et al.,1985; Morita and Matsubayashi,1986).

A series of studies (Sugimoto and Morita,1988; Yamada et al.,1988; Fujita et al.,1988) were carried out on power generation using the DCHE for the specified well design and temperature distribution in the formation. The purpose of these studies are to clarify at what thermal output or effective thermal conductivity of the formation the system becomes economical.

In these studies, four effective thermal conductivities of the formation were assumed, and power generation costs were estimated for the four cases.

The computed results such as thermal output and injection pressure were described in this paper. The capacities of the power plants and electric net power outputs were estimated in the separate paper(Sugimoto and Morita,1988) based on these results.

2. ASSUMPTIONS AND CONDITIONS FOR THE SIMULATIONS

Only the case of reverse circulation with insulated inner pipe was investigated. Water is used for a working fluid. It is assumed that heat is transferred only by conduction mechanism in the formation and vertical heat transfer in the formation is negligibly small in comparison with that by water flow in the DCHE.

A combination of two-phase turbine and steam turbine was selected as a power generation system after comparison with two-phase turbine and multi-flush system(Sugimoto and Morita,1988). Thermal output of the DCHE can be converted into electric power more efficiently by a two-phase turbine than by multi-flush system. This leads the power generation cost lower.

In order to fully utilize the performance of two-phase turbine, it was recommended to keep the pressure of water in the DCHE high above the saturation pressure so that flushing occurs only in the two-phase nozzles. Therefore, all simulations were carried out by controlling the injection pressure so that the pressure at the outlet of DCHE becomes equal to the saturation pressure at outlet water temperature. In this case, injection pressure changes with the outlet water temperature or the friction loss in the DCHE.

The configuration of the DCHE used for the simulations is illustrated in Fig. 1. Arrows in the figure indicate the flow direction of water for the reverse circulation. The length of DCHE is assumed to be 3,000 m. The final well completion diameter at the bottom of well is 16.18 cm (6-3/8 in). Since the pumping power required to circulate and pressurize water in the DCHE increases significantly with increase of a flow rate or a rise in temperature, the design of inner pipe influences greatly the power generation cost of the system. In this study, the friction loss in the DCHE was investigated for several designs of the inner pipe. The configuration

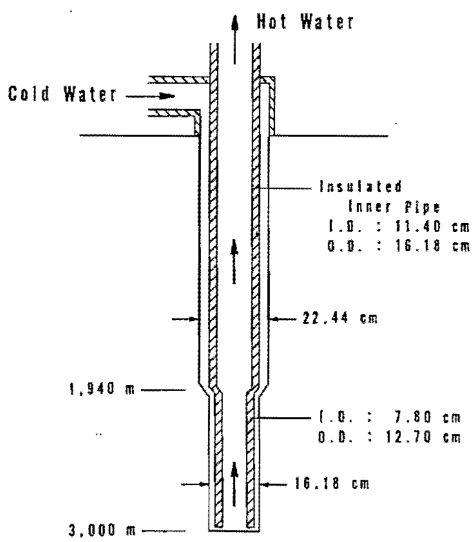

Fig. 1 The Model of DCHE used for the simulations.

in the Fig. 1 was selected to minimize the friction loss in the DCHE. The thermal conductivity of the insulated inner pipe was set to 0.02 kcal/mh°C assuming double tube vacuum insulation pipe for the steam injection operation in oil wells.

The temperature distribution in the formation used for the simulations is shown in Fig. 2. The temperature distribution to 1,500 m in depth is the same as the temperature distribution obtained at N59-TH-2 Well in Toyoha, Hokkaido. This temperature distribution indicates that conductive heat transfer is dominant in shallow part of the well and very strong convection is in the deeper or hotter region. The temperature deeper than 1,500 m was estimated by extrapolating the temperature near 1,500 m. The ground surface temperature and bottom-hole temperature are 15 and 330 °C.

About 2.9 t/h of steam was produced from N59-TH-2 Well during production test. The temperature distribution of N59-TH-4 Well which is 1.5 km distant from the well, is very similar to that of N59-TH-2 Well. This indicates a large extent of hot formation in Toyoha area.

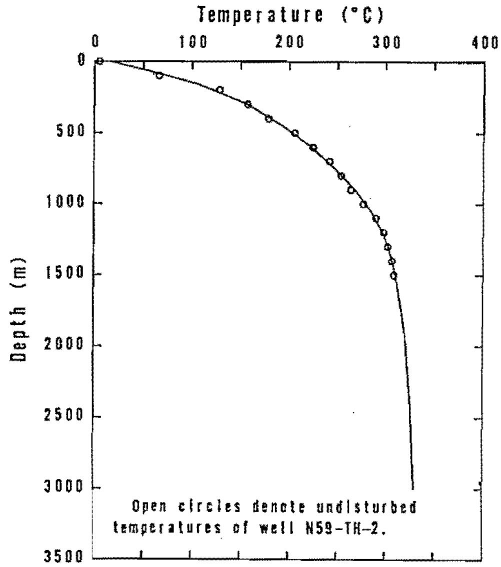

Fig. 2 The temperature distribution used for the simulations.

The specific heat and specific gravity of the formation were assumed to be 0.2 kcal/kg°C and 2,600 kg/m^3. The simulations were carried out for the four effective thermal conductivities of the formation. These are 2.7, 10.0, 20.0 and 30.0 kcal/mh °C. The case where effective thermal conductivity of the formation is 2.7 kcal/mh °C represents purely conductive case.

The range of inlet water temperature (i.e. outlet water temperature of the power plant) investigated in this study is from 50 °C to 130 °C. 50 °C is thought to be practical lower limit of outlet water temperature of the power plant.

Since the ranges of a flow rate were selected for each effective thermal conductivity of the formation considering the efficiency of the power plant, the ranges are different for different effective thermal conductivity. The minimum flow rate is 6 t/h/well for effective thermal conductivity of 2.7 kcal/mh°C, the maximum flow rate is 120 t/h/well for 30.0 kcal/mh°C.

3. RESULTS

3.1 SELECTION OF THE OPTIMUM CASE

The simulations were carried out for a period of 1 year. The computed results at 1 year after onset of the heat extraction were shown in Figs. 3 to 5 for the case of effective thermal conductivity of 20 kcal/mh°C. In this case, the flow rate ranges from 48 to 108 t/h/well.

Fig. 3 shows the dependence of outlet water temperature on inlet water temperature and flow rate. The figure indicates that the outlet water temperature becomes higher as the inlet water temperature increases and/or a flow rate decreases.

Fig. 4 shows the dependence of net thermal output of the DCHE on inlet water temperature and flow rate. It can be seen from the figure that the net thermal output becomes greater as the inlet water temperature decreases and/or a flow rate increases. It is to be noted that some extent of the increase of net. thermal output with the increase of flow rate is due to the increase of friction loss in the DCHE. When the flow rate is sufficiently high, the friction loss in the DCHE is also high, and large pumping power is required to circulate

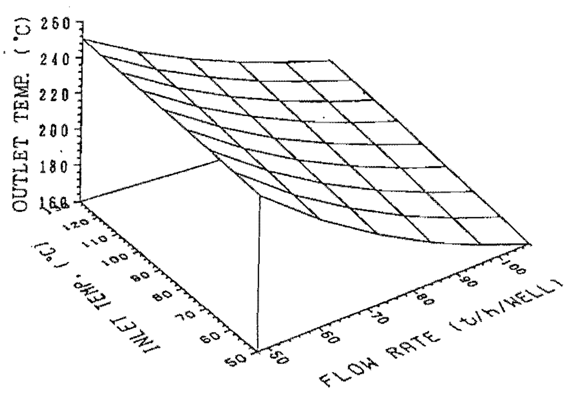

Fig. 3 The effect of inlet water temperature and flow rate on outlet water temperature.

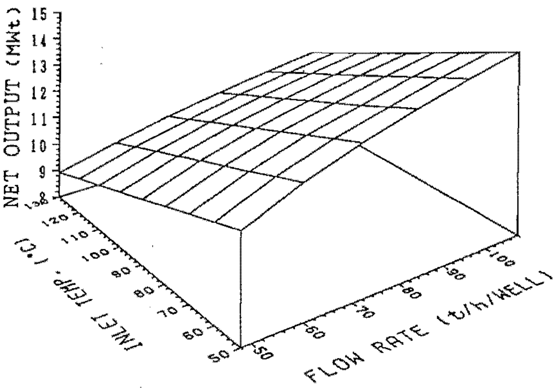

Fig. 4 The effect of inlet water temperature and flow rate on net thermal output.

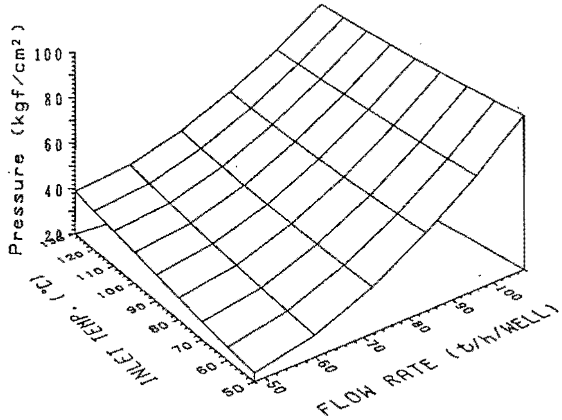

Fig. 5 The effect of inlet water temperature and flow rate on injection pressure.

water in the DCHE. The pumping power for the friction loss changes into the thermal energy in the DCHE.

Fig. 5 illustrates the dependence of injection pressure on inlet water temperature and flow rate. The injection pressure becomes greater as the inlet water temperature and/or a flow rate increase. Since the injection pressure is controlled not to flush in the DCHE, the injection pressure becomes greater for the higher inlet water temperature. Higher inlet water temperature causes higher outlet water temperature, therefore the saturation pressure of water becomes higher at the outlet of the DCHE. The increase of a flow rate causes greater friction loss.

Table 1 Selected four cases.

Case	Case 1	Case 2	Case 3	Case 4
Effective Thermal Conductivity of Formation (kcal/mh℃)	2.7	10.0	20.0	30.0
Inlet Water Temperature (℃)	90	90	90	80
Flow Rate (t/h/Well)	12	36	72	84

In the separate paper (Sugimoto and Morita,1988), net power outputs of the power generation plants were calculated for every simulated cases based on computed results such as in Figs. 3 to 5. Then a set of inlet water temperature and flow rate, which gives the maximum net output, was selected for each effective thermal conductivity of the formation.

The selected four cases are listed in Table 1. The economic analysis was performed for the four cases (Yamada et al.,1988; Fujita et al.,1988).

3.2 CHANGE OF THERMAL OUTPUT AND INJECTION PRESSURE

The long term changes of outlet water temperature and injection pressure of the four cases were estimated. The results were used for the estimation of net power output of the power plant. The change of net thermal output of the DCHE was also estimated.

The estimated long term changes of outlet water temperature and injection pressure over 16 years are shown in Figs. 6 and 7. The changes from 1 year to 16 years after the onset of heat extraction were estimated using the formulae which express the relation between elapsed time and outlet water temperature or injection pressure. These formulae were obtained from computed results over the duration from 100 to 365 elapsed days using least square method.

In the estimation of net power output of the power plants, mixed outlet water temperature of the DCHEs (i.e. inlet water temperature of the Power plant) were calculated based on the changes of the outlet water temperature in Fig. 6 considering well drilling schedule. Pumping powers used in the

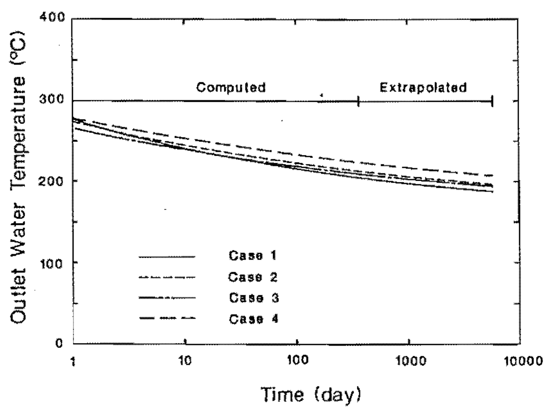

Fig. 6 The change of outlet water temperature with time.

economic analysis were calculated using the injection pressure after 1 year of heat extraction, and kept constant over the plant life.

Fig. 6 shows that the rate of lowering of outlet temperature decreases rapidly with time. The outlet water temperatures after 16 years of heat extraction are 187, 196, 194 and 207 °C for Case 1 to 4, respectively. The rates of lowering of the outlet water temperature at 15 years' elapsed time range from 0.3 to 0.4 °C/year. These rates are very small.

The change of the injection pressures is shown in Fig. 7. The rate of decreasing of the injection pressure also decreases rapidly with time. The decreasing of injection pressure is mainly due to the lowering of outlet water temperature. Lower outlet water temperature results in lower saturation pressure at the outlet of the DCHE. Therefore, the injection pressure to keep water in liquid phase in the DCHE decreases as the outlet water temperature becomes low.

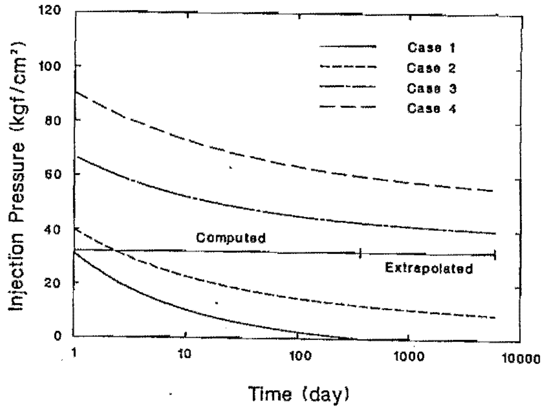

Fig. 7 The change of injection pressure with time.

The injection pressure of Case 1 becomes zero after about 1 year of heat extraction. This indicates that the circulation pressure arisen in the DCHE due to the density difference between water in the annulus and in the inner pipe is sufficiently high for pressurization and circulation of water. In this case,no pumping power is necessary to operate the DCHE.

Also the change of net thermal outputs is shown in Fig. 8. The net thermal outputs after 16 years of operation are 1.5, 5.2, 9.7 and 14.0 MW for Case 1 to 4, respectively.

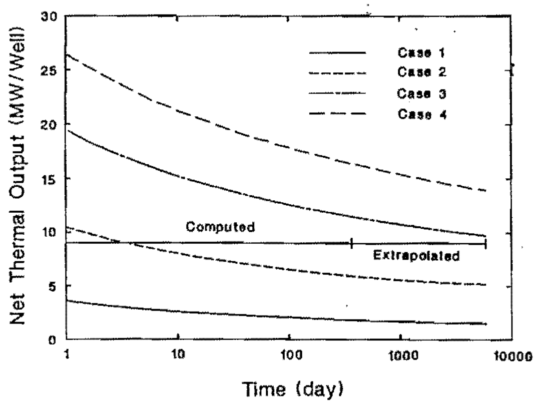

Fig. 8 The change of net thermal output with time.

4. CONCLUSIONS

It was pointed out by recent theoretical and experimental studies that the thermal output of the DCHE increases significantly when convective heat transfer, particularly with phase change, exists in the formation.

In this study, contribution of convective heat transfer in the formation on thermal output was taken into account by changing effective thermal conductivity of the formation. However, available data on effective thermal conductivity are few.

It is necessary to accumulate data on in-situ convection or effective thermal conductivity for more accurate prediction of thermal output. It is important to perform a field heat extraction experiment since the effect of convection in the formation on thermal output of the DCHE is more directly and accurately evaluated by field experiment.

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