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Case Studies on Small-Scale Power Generation with the Downhole Coaxial Heat Exchanger

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ABSTRACT

One of the major features of geothermal resources is its wide variety of existing forms. Hence, it is necessary to develop many types of heat mining methods and to pursue their possibilities. The authors have proposed the Downhole Coaxial Heat Exchanger (DCHE) system for exploitation of undeveloped geothermal resources such as Hot Wet Rock, Super Hot Rock, magma origin fluid systems and magma. The major features of the DCHE include the utilization of a highly insulated inner pipe, reverse circulation (*i.e*., cold water down the annulus and hot water up through the inner pipe) and a completely closed system. Through a heat extraction experiment carried out on the Island of Hawaii in 1991, it was demonstrated that a highly efficient DCHE could be constructed.

The authors have carried out two case studies on small-scale power generation with a 2,000m class DCHE by numerical simulations. In the first case study, the operational behaviors of the DCHE or the power generation system were investigated assuming the temperature profile and the structure of a well in Hijiori, Japan. In this case, two cases where the binary or the Kalina cycles are combined with the DCHE were investigated. In order to estimate the possible order of the net thermal output of the DCHE or the power output of the power generation system, the second case study was carried out for a higher temperature profile than that in Hijiori. In this case, a temperature profile from Toyoha, Japan was assumed.

Through this study, it has been indicated that minimizing pumping power for circulating water in the DCHE is very important for realizing functional power generation. Hence, an appropriate DCHE design is required. A power generation plant which allows a wide range of temperature difference between the hot water and the re-injection water is preferable for combination with the DCHE. Also, It has been shown that 70kW class power generation might be possible at Toyoha, Japan with a DCHE 2,000m deep.

1. INTRODUCTION

The potential of geothermal resources is often said to be great. On the other hand, geothermal resources are different from solar energy and wind power in terms of the wide variety of their existing forms. Thus, in order to utilize potential geothermal resources, it is necessary to develop many types of heat mining methods and to pursue their possibilities.

Closed system downhole heat exchangers seem to be very promising for the exploitation of undeveloped geothermal resources. The authors have been proposing the Downhole Coaxial Heat Exchanger and have been carrying out studies on it (*e.g*., Morita *et al*., 1985; Morita, 1994; Morita and Tago, 1995). The initial purpose of these studies was to exploit high temperature and deep geothermal resources such as Hot Wet Rock, Super Hot Rock adjacent to magma and magma with the DCHE. Figure 1 shows an image of the power generation utilizing DCHEs. In this paper, the results of preliminary studies on small-scale power generation with the DCHE at Hot Wet Rock are introduced.

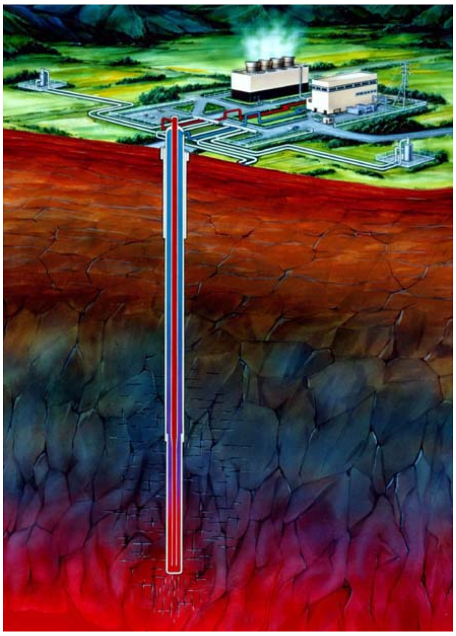

Figure 1: A schematic drawing of power generation with the DCHEs.

2. WHAT IS THE DCHE?

2.1 The Concept

Horne (1980) has analytically investigated the effects of design and operational parameters on the performance of the coaxial type downhole heat exchanger, and has shown that slightly greater thermal outputs can be obtained with reverse circulation (*i.e*., cold water down the annulus and hot water up through the inner pipe).

The present authors along with others have revealed by numerical simulations that very efficient heat extraction can be performed with a highly insulated inner pipe and reverse circulation (Morita *et al*., 1985; Morita and Matsubayashi, 1986), and have named the heat exchanger the "Downhole

Coaxial Heat Exchanger (DCHE)". The concept of the DCHE is shown in Figure 2.

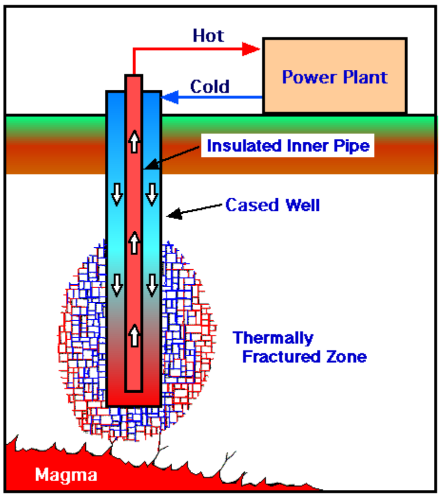

Figure 2: The concept of the DCHE.

Fig. 3 shows an example of temperature profiles in a coaxial type heat exchanger 3,000m deep after 30 days of continuous operation in the case of reverse circulation. In these cases, the initial ground surface and the bottom-hole temperatures are assumed to be 15 ˚C and 350 ˚C, respectively, and the flow rate to be 300 l/min. It can be seen from this figure that the lower the thermal conductivity (*i.e.*, the higher the insulation performance) of the inner pipe, the higher the hot water temperature at the outlet of the heat exchanger. The hot water temperature in the case of a thermal conductivity of 0.01 W/m·K is 98 ˚C higher than that in the case of 46.1 W/m·K which corresponds to the case of a steel pipe.

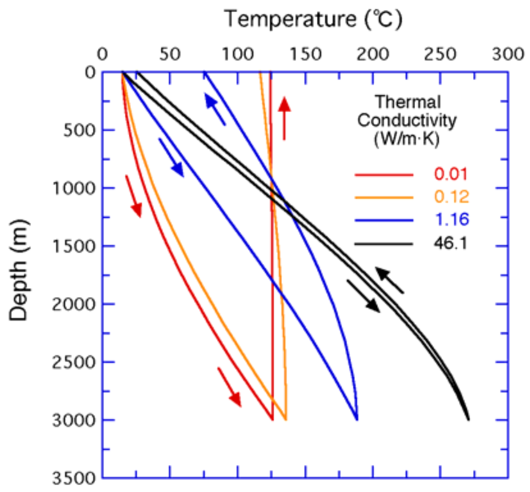

Figure 3: Temperature profiles in the coaxial type heat exchanger in the case of reverse circulation for the different thermal conductivities of the inner pipe.

Fig. 4 shows the relationship between the thermal conductivities of the inner pipe and the net thermal outputs of the heat exchanger corresponding to Fig. 3. The net thermal output in the case of 0.01 W/m·K is more than 10 times greater than that with steel pipe. It is clear that the utilization of highly insulated inner pipe significantly increases the thermal output of the heat exchanger.

In 1991, an experiment to prove the concept of the DCHE was carried out at the HGP-A well on the Island of Hawaii (Morita *et al.*, 1992a; 1992b). High vacuum type double tube insulated pipes were used as the inner pipe of the DCHE. The equivalent thermal conductivity of the insulated pipes in this experiment was determined to be 0.06W/m·K. Through the experiment, it was demonstrated that a highly efficient DCHE could be constructed.

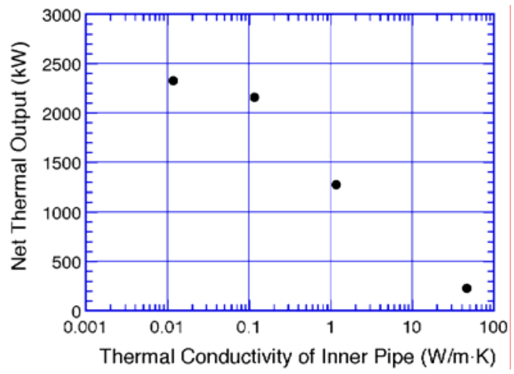

Figure 4: Relationship between the thermal conductivity of the inner pipe and the net thermal output.

2.2 Highly Insulated Pipe for the DCHE

The DCHE can only be realized with a suitable highly insulated pipe. The requirements for the pipe are high insulation performance with thin walls, high temperature resistance and a sufficiently long allowable hanging depth.

Currently commercially available insulated pipes applicable to the deep DCHE are the double tube type pipes produced by the Kawatetsu Tubic Company, Japan, as far as the authors know. In these pipes, the gap between the two tubes is filled with a low conductivity inert gas (Argon). According to the company, the equivalent thermal conductivity of these pipes is 0.07 W/m·K.

3. THE PURPOSE AND OUTLINE OF THIS STUDY

There are areas in which the formation temperature is high and a certain amount (though not sufficient for conventional power generation) of steam or hot water can be found. This kind of geothermal resource can be called Hot Wet Rock. Figure 5 shows examples of high temperature profiles measured in Japan. Most of them show convection type temperature profiles. This indicates that the areas where Hot Wet Rock can be expected are not rare.

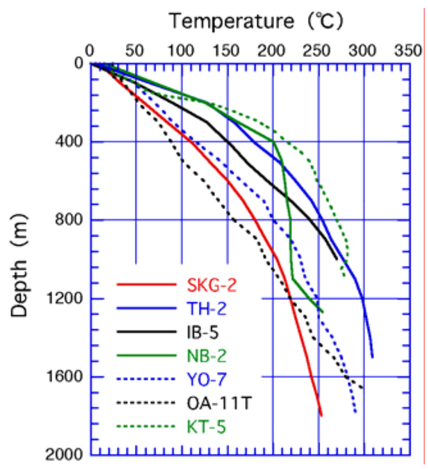

Figure 5: Examples of high temperature profiles in Japan.

Power generation with the DCHE might be one of the applicable methods for the exploitation of Hot Wet Rock. The purpose of this study was to investigate the operational behavior of the DCHE or its power generation system, and to estimate the possible order of the net thermal output of the DCHE or the power output of a small-scale power generation system at Hot Wet Rock.

Two cases were studied, assuming a 2000m class DCHE, by carrying out numerical simulations. The accuracy of the code used in this study has been confirmed to be very high in temperature and pressure computation by comparison with the data from a heat extraction experiment in Hawaii (Morita *et al*., 1992a; 1992b).

In the first case study, supposing the experimental operation of the small-scale power generation in Hijiori, Japan, the temperature profile and the structure of a well in Hijiori were assumed, and the operational behaviors of the DCHE or the power generation system were investigated. In this case, two cases where the binary or the Kalina cycles are combined with the DCHE were investigated.

In order to estimate the possible order of the net thermal output of the DCHE or the power output of the power generation system, the second case study was carried out for a higher temperature profile than that in Hijiori. In this case, the temperature profile measured in Toyoha, Japan was assumed.

3.1 The Power Generation System

3.1.1 System Flow Diagram

Figure 6 shows a flow diagram of the system assumed in this study. In the case of heat extraction with heat exchangers such as the DCHE, higher hot water temperatures, and thus greater thermal outputs, are obtained at the early stage of the heat extraction. And the outlet temperature and thus the thermal output decrease with time. It is desirable to supply hot water to the power plant at constant temperature and flow rate, and hence at constant thermal input.

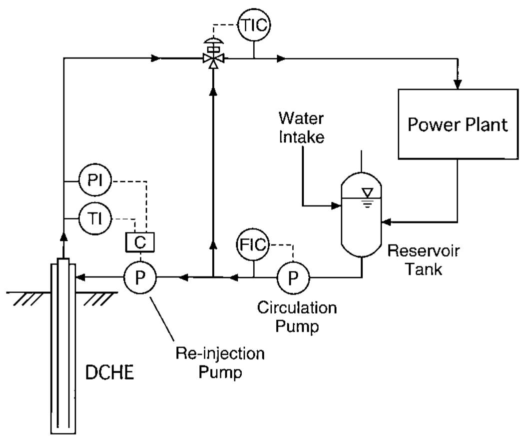

Figure 6: Flow diagram of the power generation system.

In the system shown in Figure 6, the temperature of the hot water to be supplied to the power plant is maintained at a specified value by mixing produced hot water and colder water from the power plant. Also, hot water is supplied at a specified flow rate by the circulation pump. Thus, the temperature of hot water and the thermal input to the power plant are kept constant as long as the capability of the DCHE allows. Because of the characteristics of this system, the flow rate of the circulating water in the DCHE is very small at the early stage of operation, and increases gradually with time with decreasing hot water temperatures.

A re-injection pump is required for keeping circulating water pressurized or to compensate for pressure drops in the DCHE.

3.1.2 Power Generation Plants

The specifications of the binary cycle plant are shown in Table 1. These specifications are determined based on those of the air-cooled 100kW-class plant developed by the Kyushu Electric Company. The hot water temperature, re-injection temperature and the power generation efficiency were assumed to be the same values as those of the 100kW-class plant. However, other values, such as the thermal input to the power plant, *i.e*., the thermal output of the DCHE, and the flow rate, were assumed to be one-half those of the 100kW-class plant. Hence, the expected net power output of the assumed plant was about 50kW. According to the Hisaka Works, the manufacturer of the 100kW plant, the widening of the temperature difference, between the hot water and the re-injection water, is not allowed, due to the characteristics of the cycle of the 100kW-class plant.

Table 1: Specifications of the binary cycle plant assumed in this study (Case Bc).

Case	Bc
Thermal Output of the DCHE (kW)	900
Hot Water Temperature (˚C)	86.0
Re-Injection Temperature (˚C)	76.0
Flow Rate (t/h)	77.3
Gross Power Output (kW)	61.0
Power Generation Efficiency (%)	6.8
In-House Auxiliary Power (kW)	8.2
Net Power Output (kW)	52.8

The specifications for the Kalina Cycle plant are shown in Table 2. The performances shown in this table are the values provided by the Ebara Corporation. According to the company, the requirement for the hot water temperature is not rigid in the case of the Kalina Cycle. Hence, a lower hot water temperature by 2˚C than that assumed in the case of the binary cycle is assumed here, and three cases of wider temperature differences were investigated. The same thermal output of the DCHE as that assumed in the case of the binary cycle was also assumed here. The power outputs, the efficiency and the in-house auxiliary power were determined supposing the utilization of river water for cooling the condenser. The net power outputs range from 55 to 65 kW in the studied cases.

Table 2: Specifications of the Kalina Cycle plant assumed in this study (Cases Kc12 to Kc20).

Case	Kc12	Kc16	Kc20
Thermal Output of the DCHE (kW)	900		
Hot Water Temperature (˚C)	84.0		
Re-Injection Temperature (˚C)	72.0	68.0	64.0
Flow Rate (t/h)	64.5	48.4	38.7
Gross Power Output (kW)	85	80	75
Power Generation Efficiency (%)	9.4	8.9	8.3
In-House Auxiliary Power (kW)	20		
Net Power Output (kW)	65	60	55

It should be noted that the power generation efficiency and the net power output greatly depend on the cooling method. Hence, the differences in the values shown in the above two tables don't directly reflect the difference in their performance or characteristics.

3.2 Other Conditions

Table 3 shows the physical properties of the formation and materials assumed in this study. As the physical properties of the formation, the properties of the granitic rock were assumed as the base case. Cases in which the effective thermal conductivities were 3.6 or 4.1W/m·K were also investigated to examine the effects of the heat transfer performance in the formation on the behavior of the power generation system, though the authors are not confident that such heat transfer performance can be expected at Hot Wet Rock.

Table 3: Physical Properties of the formation and the materials.

Material	Density (kg / m^3)	Specific Heat (J /kg·K)	Thermal Conductivity (W/m·K)
Formation	2,840	880	3.1, 3.6, 4.1
Steel	7,850	470	46.1
Cement	1,830	880	0.93
Inner Pipe	-	-	0.07

As the equivalent thermal conductivity of the insulated inner pipe, 0.07W/m·K was assumed supposing the utilization of the inert gas type double tube insulated pipes. The density and specific heat of the inner pipe were not taken into account in the simulations. The pumping powers were calculated assuming the efficiency of the pump to be 65%.

4. A CASE STUDY FOR EXPERIMENT

Here, all the simulations were carried out for 5 years of continuous operation of the system.

4.1 Structure of the DCHE and Temperature Profile

Figure 7 shows the assumed drilling and casing profiles along with the DCHE. As the drilling and casing profiles, those of the HDR-1 in Hijiori were assumed. The total length of the DCHE is 2,151m. Two different sizes of insulated inner pipe were assumed as shown in this figure, to minimize pressure loss in the DCHE.

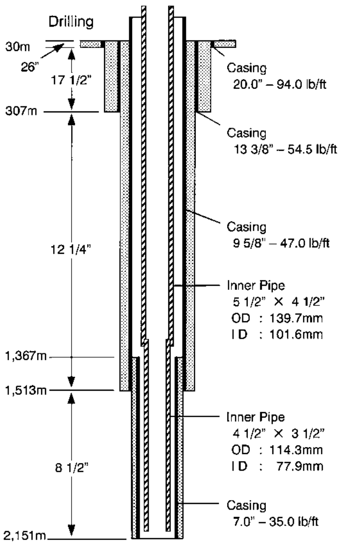

Figure 7: The structure of the DCHE.

Figure 8 shows the assumed temperature profile. The temperatures down to 1,800m in depth are measured temperatures at the SKG-2, and below 2,000m in depth those measured at the HDR-3. The initial temperature at the bottom of the DCHE is 269˚C.

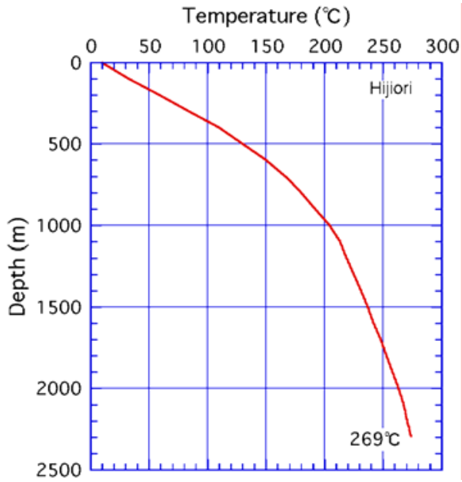

Figure 8: Temperature profile model in Hijiori.

4.2 The Case of the Binary Cycle Plant

4.2.1 General Behavior of the System

Here, the behavior of the system in a case where the effective thermal conductivity of the formation is 4.1W/m·K (hereinafter this case is called Case Bc-4.1W/m·K) is introduced. Since, the typical behavior of the system can be observed in this case.

Figure 9 shows the changes in the hot water temperature at the outlet of the DCHE and in the flow rate of the circulating water in the DCHE. As shown in this figure, at the early stage of operation, a significantly higher outlet temperature than that required by the power plant is obtained, and the flow rate of the circulating water is very small in comparison with the design flow rate, *i.e.*, 77.3t/h. The flow rate increases gradually with a decrease in the hot water temperature. At 5 years in elapsed time, the hot water temperature is still higher than the required temperature by 18˚C. This means that the thermal output of the DCHE is kept constant at the required thermal output, *i.e.*, 900kW, for 5 years in this case.

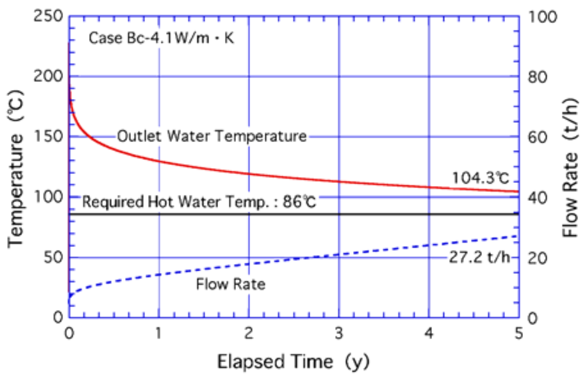

Figure 9: Changes in the hot water temperature and flow rate circulating in the DCHE (Case Bc-4.1W/m·K).

Figure 10 shows the changes in the injection pressure, the pressure at the outlet of the DCHE and the pressure drop in the DCHE corresponding to Figure 9. The injection pressure is constant at 0.098Mpa abs. for 2 years and 8 months except for a very short period just after the onset of operation. This means that the gravity head arisen in the DCHE is greater than the pressure drop in the DCHE and the outlet pressure is higher than the saturation pressure of water at the outlet temperature. Hence, pumping is not necessary during this period for circulation and pressurization of water in the DCHE.

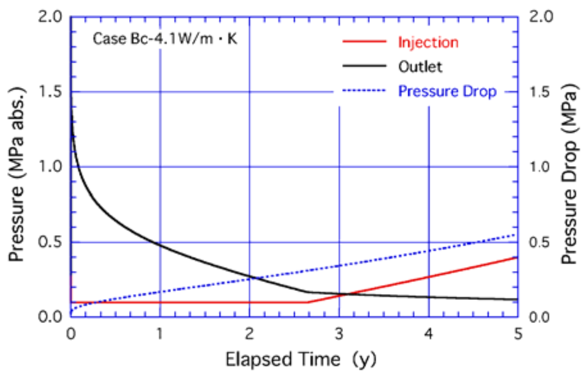

Figure 10: Changes in injection and outlet pressures along with pressure drops in the DCHE (Case Bc-4.1W/m·K).

After this period, pumping is required to circulate and to pressurize water. As shown in this figure, the outlet pressure decreases with decreasing outlet temperature and it approaches 0.098Mpa abs. The outlet pressure becomes 0.098Mpa abs. when the outlet temperature becomes lower than 100˚C.

In the very transient period just after the onset of operation, injection pressure of about 0.89Mpa abs. at maximum is required for about 21 hours to suppress vaporization of hot water in the DCHE. In this period, the outlet pressure reaches up to 2.7Mpa abs. since the outlet temperature reaches 227˚C at maximum.

Figure 11 shows the change in the pumping power. As can be seen from this figure, the pumping power is zero for 2 years and 8 months. Then the power increases gradually and reaches 3.6 kW at 5 years in elapsed time.

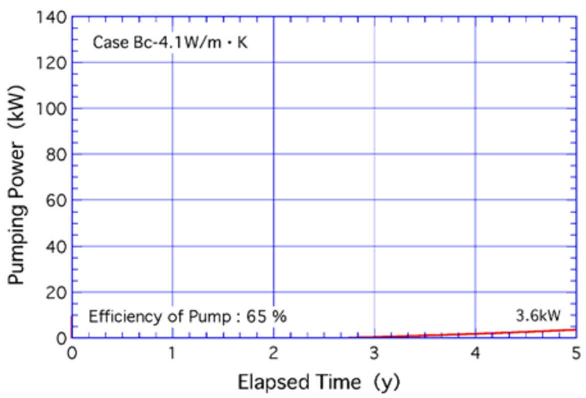

Figure 11: Change in the pumping power for circulating water in the DCHE.

4.2.2 Changes in Net Thermal Output and in Pumping Power for three different effective thermal conductivities

Figure 12 shows the changes in the net thermal output of the DCHE for three different effective thermal conductivities of the formation. It can be seen from this figure that the net thermal output is maintained at the required value, *i.e*., 900kW, for 5 years in the cases where the effective thermal conductivities are 3.6 or 4.1W/m·K. In the case of the Bc-3.1W/m·K, the net thermal output becomes smaller than the required value at about 3 years in elapsed time, and becomes 858kW at 5 years in elapsed time.

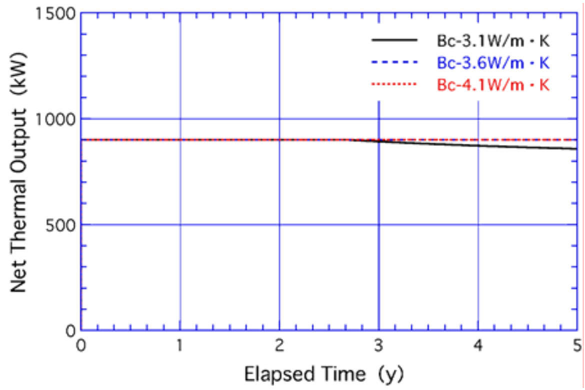

Figure 12: Changes in net thermal output of the DCHE for 3 different effective thermal conductivities of the formation.

Figure 13 shows the changes in the pumping power required for circulation and pressurization of water in the DCHE. The pumping powers at 5 years in elapsed time are 126.6, 57.3 and 3.6kW for the effective thermal conductivities, 3.1, 3.6 and 4.1W/m·K, respectively. It is clear that the power generation system doesn't function as a power generation system because of the large pumping power, except for the Case of Bc-4.1W/m·K.

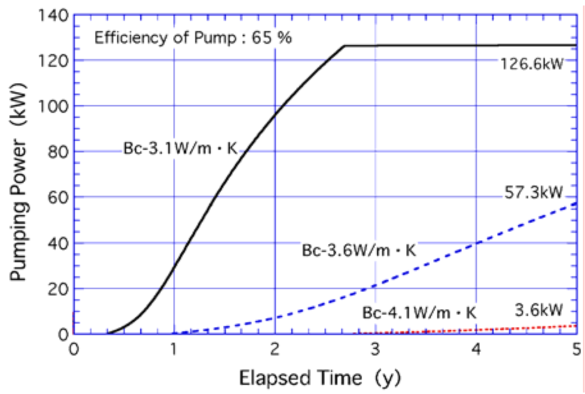

Figure 13: Changes in pumping power for three different effective thermal conductivities of the formation.

The above results indicate that in order to apply the power generation system to a wide variety of geophysical conditions in a functional way, the reduction of the pumping power, and hence pressure drop in the DCHE, is essential. In this connection, the widening of the temperature difference, between the required hot water temperature and the re-injection temperature from the power plant, might be effective. Also, an appropriate design of the well and inner pipe should decrease the pressure drop significantly.

4.3 The Case of the Kalina Cycle Plant

Here, as described before, a lower hot water temperature by 2˚C than that assumed in the case of the binary cycle was assumed and three cases of wider temperature differences than that assumed in the case of the binary cycle were investigated. The assumed temperature differences were 12, 16 and 20˚C, and these cases are denoted by the Cases Kc12, Kc16 and Kc20, respectively,

4.3.1 Case Kc12

Figure 14 shows the changes in the pumping power for the three different effective thermal conductivities of the formation in Case Kc12. These pumping powers are remarkably smaller than those shown in Figure 13, even though the widening of the temperature difference from Case Bc is only 2˚C. The effect of the widening of the temperature difference in the reduction of the pumping power is very clear. However, the power generation system is still not functional except for the case of 4.1W/m·K.

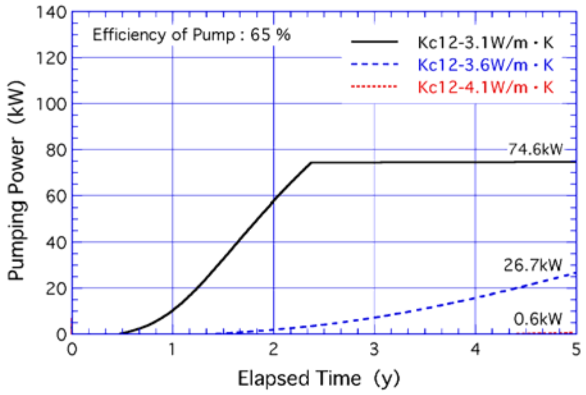

Figure 14: Changes in pumping power (Case Kc12).

Figure 15 shows the changes in the net thermal output of the DCHE. The difference from Figure 12 is observed only in the case where the effective thermal conductivity is 3.1W/m·K.

In Case Kc12-3.1W/m·K, the time at which the net thermal output becomes smaller than the required value comes slightly earlier and the net thermal output at 5 years in elapsed time is somewhat smaller in comparison with Case Bc-3.1W/m·K. This is because of the reduction in the pumping power. The net thermal output is the sum of the extracted heat from the ground and the generated heat in the DCHE by the friction. In this case, the significant reduction in friction loss, and hence the reduction in the generated heat by the friction in the DCHE, brought about the reduction in the net thermal output.

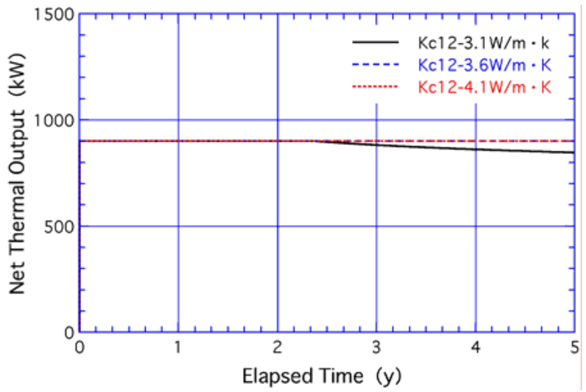

Figure 15: Changes in net thermal output of the DCHE (Case Kc12).

4.3.2 Cases Kc16 and Kc20

The changes in the net thermal output in Cases Kc16 and Kc20 are almost the same as those shown in Figure 15. Figures 16 and 17 show the changes in pumping power for Cases Kc16 and Kc20, respectively. It is clear from these figures that the widening of the temperature difference between the hot water temperature and the re-injection temperature has a remarkable effect in reducing the pumping power.

In Case Kc16, the pumping power at 4.1W/mK of the effective thermal conductivity is zero for 5 years. Also, at 3.6W/m·K, the pumping power at 5 years in elapsed time becomes 9.7kW. Hence, the power generation system might be functional at 3.6W/m·K of the effective thermal conductivity of the formation, too.

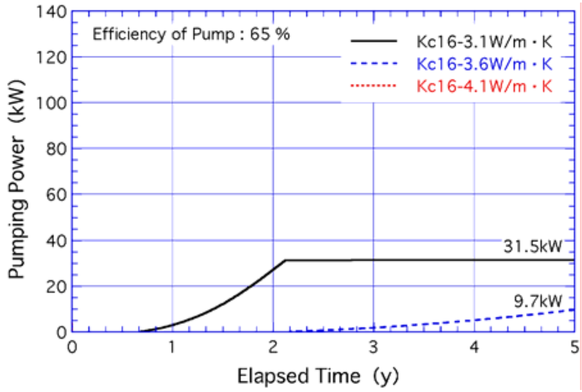

Figure 16: Changes in pumping power (Case Kc16).

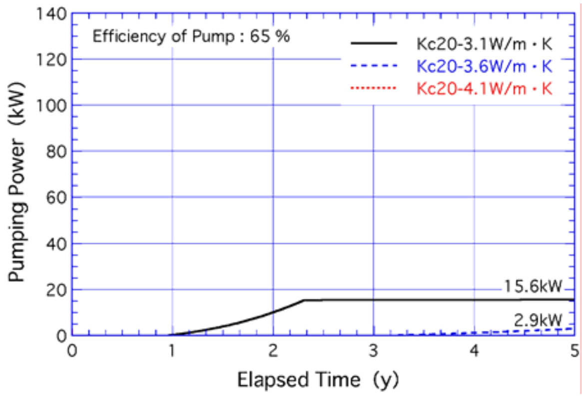

Figure 17: Changes in pumping power (Case Kc20).

In Case Kc20, the pumping power at 3.1W/m·K of the effective thermal conductivity becomes 15.6kW at 5 years in elapsed time. Thus, at all the effective thermal conductivities assumed in this study, the power generation system might be functional in Case Kc20.

The results obtained here indicate that, the wider the temperature difference between the hot water temperature and the re-injection temperature, the wider the functionally applicable geophysical conditions. Hence, for the power plant to combine with the DCHE, a plant that allows a wide range of the temperature difference between the hot water and re-injection water is preferable.

4.4 The Major Results Obtained Here

- In the case of the DCHE, there is a great possibility that the pumping power exceeds the power output of the power generation plant. Hence, minimizing pumping power for circulating water in the DCHE is very important in realizing functional power generation. In this connection, diameters of the well and inner pipe are a critical factor.

- The combination with a power generation system which allows a wide temperature difference, between the hot water and re-injection water, is one of the effective ways in reducing the flow rate in the DCHE, and hence in reducing the pumping power.
- An approximately 40 to 50kW of the net power output might be expected under the conditions assumed here.
- There is a possibility that the DCHE can be operated without pumping for a long duration because of the gravity head which arises in the DCHE.

5. A CASE STUDY ON THE HIGHER FORMATION TEMPERATURE

The purpose of this case study was to estimate the possible order of the net thermal output of the DCHE or the power output of the power generation system. The behavior of the DCHE or the power generation system at the higher formation temperature than that assumed in the former case was investigated supposing the Kalina Cycle as the power plant. All the simulations were carried out for 15 years of continuous operation of the system.

5.1 Conditions of the Simulations

Case Kc20, where the temperature difference is 20˚C, was selected for this case study to minimize the pumping power required for circulation of water in the DCHE. As the effective thermal conductivity of the formation, only 3.1W/m·K was assumed supposing pure conduction in the formation.

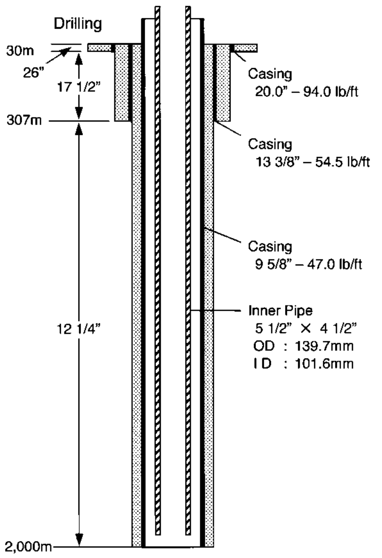

Figure 18: The structure of the DCHE.

The depth of the DCHE was assumed to be 2,000m in this case, and the structure of the DCHE was slightly modified from the one assumed in the former case to reduce the pressure drop in it. Figure 18 shows the structure assumed here. The 9 5/8" casing pipes and 5 1/2" × 4 1/2" insulated pipes were assumed for the entire section of the DCHE.

Figure 19 shows the temperature profile model. This model was determined based on the measured temperatures at the TH-2 in Toyoha, Hokkaido, Japan. The initial temperature at the bottom of the DCHE is 322˚C in this model.

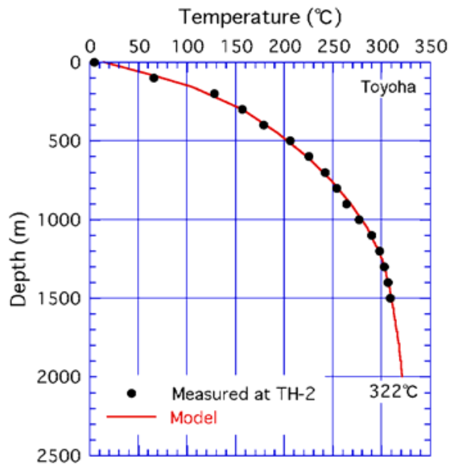

Figure 19: Temperature profile model inToyoha.

5.2 The Major Results

Figure 20 shows the changes in the net thermal output of the DCHE for the cases where the DCHE is operated setting the net thermal output at 900, 1,000, 1,100 or 1,200kW, respectively. As shown in this figure, in the case of 1,200kW, the net thermal output becomes smaller than the set value at about 6 years in elapsed time, and it becomes about 1,100kW at 15 years in elapsed time. Except for this case, the net thermal outputs are kept constant at set values for 15 years.

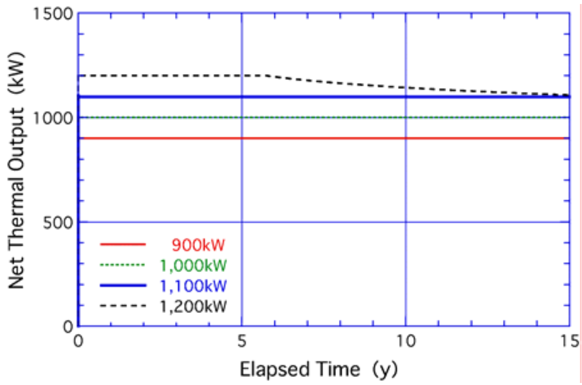

Figure 20: Changes in the net thermal output of the DCHE (Case Kc20).

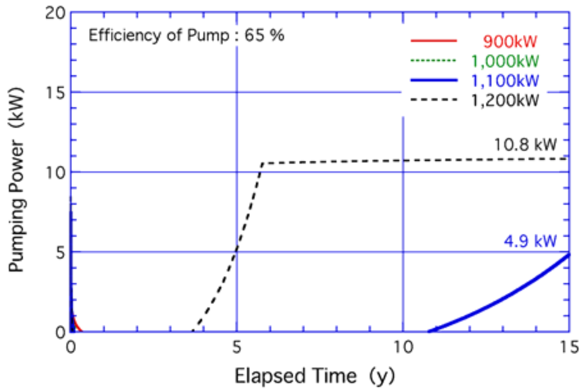

Figure 21: Changes in pumping power (Case Kc20).

Figure 21 shows the changes in the pumping power. In the cases where the net thermal outputs are equal to or smaller than 1,000kW, pumping power is not required for most of the duration except for the period just after the onset of operation. In the cases where the net thermal output was set at 1,100kW or 1,200kW, the pumping power is 4.9kW or 10.8kW, respectively, at 15 years in elapsed time.

The above results indicate that the DCHE might be operated stably at 1,100kW of the net thermal output with less than 5kW of pumping power for 15 years under the conditions assumed here. In this case, the gross power output is calculated to be 91kW assuming the power generation efficiency to be 8.3% from Table 2. Also, assuming the same in-house auxiliary power as in Table 2, *i.e.*, 20kW, the net power output is roughly estimated to be about 70kW.

In this case, in a period just after the onset of the operation, pumping to pressurize the hot water in the DCHE is required for about 35 days. In this period, the outlet temperature and outlet pressure reach up to 284˚C and 6.8Mpa abs. at their peaks, respectively, and the injection pressure of 4.4Mpa abs. at maximum is required.

It should be noted that the estimated net thermal output of the DCHE and the gross or net power outputs are for the case in which the effective thermal conductivity is 3.1W/m·K. The authors assumed this value supposing the case where the heat transfer mechanism is pure conduction. There might be a case in which greater effective thermal conductivity can be expected because of convection in the formation. In such a case, greater output can be obtained. The problem at this moment is that there are only a few measured in-situ effective thermal conductivities at high temperature formations. This makes it difficult to estimate the probable output of the power generation system more accurately. The effective thermal conductivity can be obtained from the data during power generation operation. In this connection, actual power generation or an experiment are desirable.

5. CONCLUSIONS

In this study, small-scale power generation with the DCHE at Hot Wet Rock was investigated. The major results obtained in this study are as follows:

- In the case of the DCHE, the pumping power required for circulating water in the DCHE greatly affects the realization of the functional power generation system. Hence, an appropriate design of the DCHE is preferable.

- For the power generation plant to combine with the DCHE, a power plant which allows a wide range of temperature difference between the hot water and the re-injection water is preferable.

- There is a possibility that the DCHE can be operated without pumping for a long duration because of the gravity head which arises in the DCHE.

- A 40 to 50kW class power generation experiment might be possible at Hijiori, Japan, at least for several years using a DCHE 2,100m deep.

- A 70kW class power generation might be possible at Toyoha, Japan, for about 15 years using a DCHE 2,000m deep.

The estimated power outputs in this study are not great. This suggests that the practical power generation with the DCHE at Hot Wet Rock might be difficult under current economical conditions. However, this system has several major positive points in that the risks or difficulties in prospecting Hot Wet Rock, in constructing the DCHE and in operation of the power generation system are very small. Thus, there might be cases where the system can be applied practically, *e.g.*, the applications at isolated or remote inland areas or islands.

Meanwhile, at Super Hot Rock adjacent to magma or beneath geothermal reservoirs, there is a possibility that super convection (*e.g.*, Dun and Hardee, 1981) or a heat transfer mechanism similar to that of the heat pipe is induced in the surrounding rock mass with heat extraction. In this case, the thermal output of the DCHE, and hence the possibility of practical power generation should be much greater.

Small-scale power generation with the DCHE at Hot Wet Rock can be regarded as a step for power generation at Super Hot Rock. Through experiments or operations at Hot Wet Rock, valuable experiences, data and knowledge required for the next step can be obtained.

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