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DOWNHOLE COAXIAL HEAT EXCHANGER FOR VOLCANIC ENERGY EXTRACTION

by
 K. Morita, National Research Institute for Pollution and Resources, Japan
 O. Matsubayashi, Geological Survey of Japan

Introduction

The amount of heat stored in volcanic terrains is tremendous. However, there would be great difficulty in fully utilizing this energy as long as conventional heat extraction methods are applied. We propose a downhole coaxial heat exchanger system (Figure 1) as a method of extracting geothermal energy. This heat exchanger system is applicable not only to those low-productivity geothermal reservoirs which produce insufficient amounts of steam or hot water for power generation, but also to very high temperature formations, particularly those adjacent to magma bodies or magma itself.

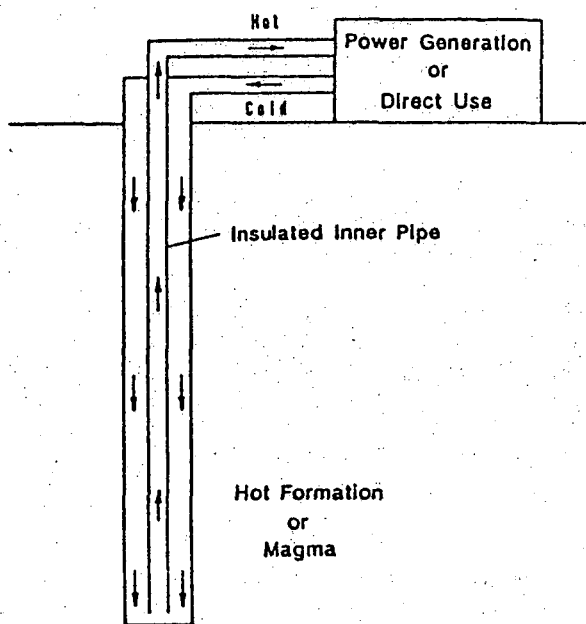


Figure 1. Concept of the downhole coaxial heat exchanger system.

The downhole coaxial heat exchanger system has the following advantages: 1) It is the most efficient heat extraction technique among all the methods using a single well. 2) Its range of applicability is very wide. 3) Because only thermal energy is extracted from the formations, the water circulating in this system is quite clean, and can be directly used for many purposes.

The authors have shown by numerical simulations that the combinations of a highly insulated inner pipe with a reverse circulation as shown in Figure 1 makes the thermal output of the heat exchanger system considerably higher (Morita et al., 1985; Morita and Matsubayashi, 1986). Development of a highly insulated inner pipe for the system as well as laboratory scale model experiments are in progress.

Insulated Inner Pipe and Circulation Mode

Figure 2 shows the temperature profiles in the heat exchanger for reverse circulation at 30 days after onset of heat extraction, with the thermal conductivity of the inner pipe as a parameter. Total depth of the well is kept at 3,000 m, formation thermal conductivity at 2.7 kcal/mh°C, water flow 0.3 m³/min and the geothermal gradient is assumed to be 111.7°C/km. It is obvious from Figure 2 that the outlet water temperature becomes higher with smaller thermal conductivity of the inner pipe. Compared with the case of using an ordinary steel inner pipe with thermal conductivity of the inner

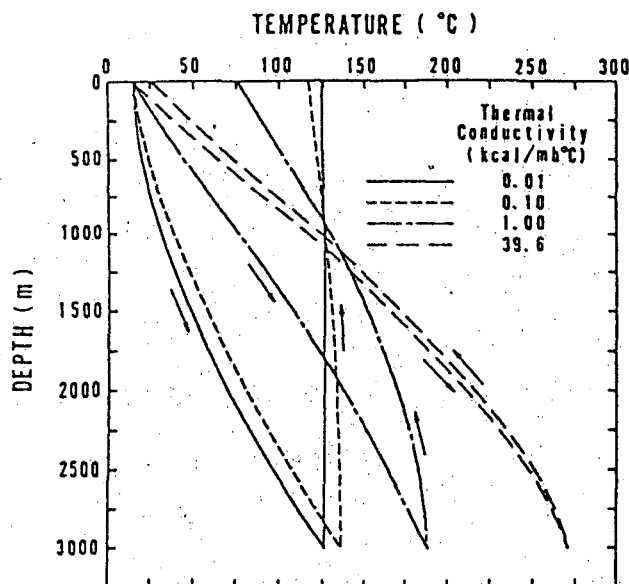


Figure 2. The effect of thermal conductivity of the inner pipe (reverse circulation).

pipe. Compared with the case of using an ordinary steel inner pipe with thermal conductivity of 39.6 kcal/mh°C, highly insulated inner pipe (0.01 kcal/mh°C) enables the outlet water temperature to rise by 98°C, which is equivalent to a net thermal output increase by a factor of 10.3.

The temperature difference between the formation and the water in the annulus even at shallow depths is rather large. This indicates that with reverse circulation heat is extracted not only from deep, high temperature regions of the formation, but also from the shallow, low temperature regions. A self-circulatory system might set in due to the density difference between the down and up-flowing columns in the heat exchanger, thus making

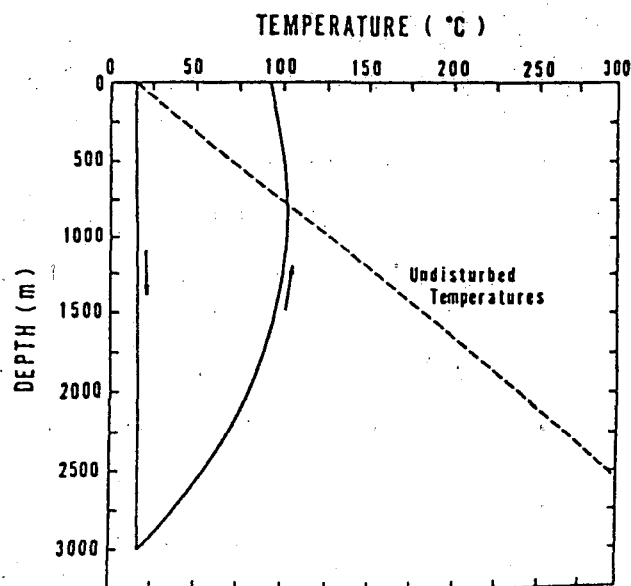


Figure 3. Temperature profile in the heat exchanger (forward circulation).

pumping power unnecessary, except in the case of a steel inner pipe with a thermal conductivity of 39.6 kcal/mh°C.

The effect of utilizing an insulated inner pipe of 0.01 kcal/mh°C for forward circulation is shown in Figure 3. The conditions of simulation are the same as discussed above except for the circulation mode. It is clear that the temperature in the annulus decreases at depths above 800 m, which means that heat loss occurs and heat extraction is effective only at depth intervals below 800 m. Use of insulated inner pipe can increase thermal output also in the case of forward circulation, but the outlet water temperature is 32°C lower and the net thermal output is 30% lower than with reverse circulation.

Thus, an "ideal" heat extraction can be performed by applying highly insulated inner pipe and reverse circulation.

Heat Extractivity Index

In a previous study, we have investigated the relation between the equilibrium temperature distribution in the formation and the net thermal output of this system and proposed the following index as a measure to estimate the net thermal output of this system and proposed the following index as a measure to estimate the net thermal output (Morita and Matsubayashi, 1988):

$$\text{Heat extractivity index } (^\circ\text{C km}) = \int_0^b (t(z) - t_{in}) dz$$

where b is the well depth, t_{in} is inlet water temperature, and $t(z)$ is the equilibrium temperature as a function of depth in the formation.

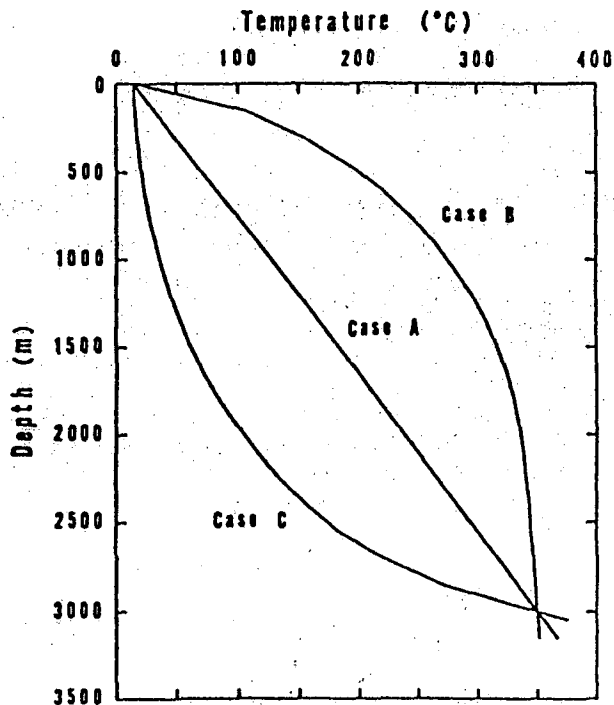


Figure 4. Equilibrium temperature distributions used for the simulations in Fig. 5.

Figure 4 shows the three typical equilibrium temperature distributions in the formation, assuming the well depth and bottomhole temperature to be 3,000 m and 350°C.

The relation between the heat extractivity index and the net thermal output at one year after the onset of heat extraction is shown in Figure 5, the flow rate and inlet water temperature are assumed to be 0.3 m³/min and 15°C, respectively.

Symbols in Figure 5 without case specification are those with a linear formation temperature distribution similar to Case A. From this figure it can be seen that thermal output is essentially in proportion with the heat extractivity index, no matter what the temperature profile may look like and no matter how deep the well may be.

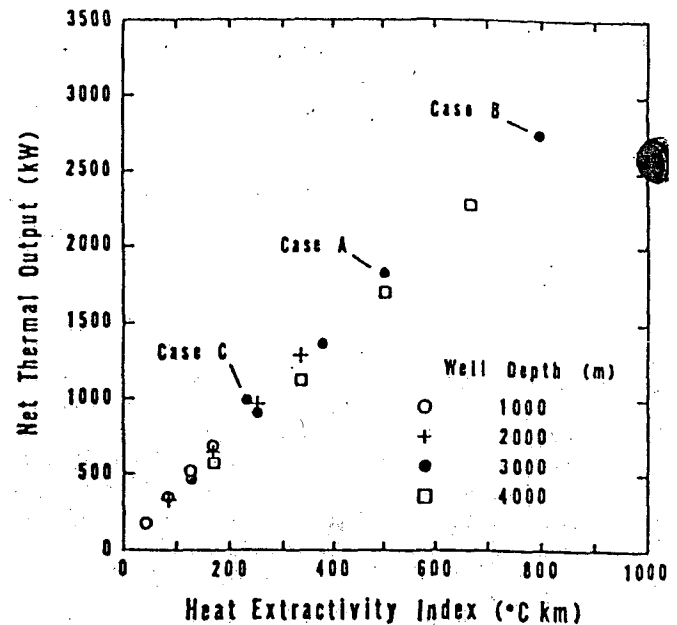


Figure 5. The relation between the heat extractivity index and the net thermal output.

This indicates that, for a given equilibrium bottomhole temperature, a temperature profile convex such as Case B in Figure 4 has a high heat extractivity index, allowing a greater thermal output than that in Case A or C. A temperature distribution such as that of Case B indicates the existence of strong convection particularly at levels below a certain depth. Earlier experimental studies (e.g. Dunn and Hardee, 1981; Colp, 1982) and theoretical studies (e.g. Kimura et al., 1987) have shown the possibility of enhancement of thermal output by convection in the formation by a factor of four or even larger, compared with the purely conductive case.

In this respect, we can say the proposed system performs best with a temperature profile such as Case B.

Development of Highly Insulated Inner Pipe

In order to carry out a small-scale field experiment, a small bore, highly insulated inner pipe has been developed and its insulation performance has been evaluated in the laboratory.

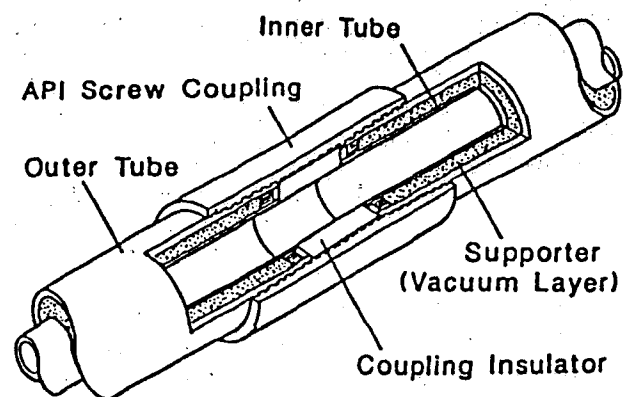


Figure 6. Structure of the insulated inner pipe.

Figure 6 shows the configuration of the coupling portion of the inner pipe, which is basically composed of inner and outer tubes with a vacuum layer in between. The vacuum layer is filled with a certain kind of powder which works as a supporter and allows better insulation with a relatively low vacuum pressure. The length of the pipe is 6 m, with outer and inner diameters of 48 and 24 mm, respectively and an API standard screw coupling is attached at both ends.

The evaluated equivalent thermal conductivity, which includes poor insulation at the coupling portion, is about 0.015 kcal/mh °C for experimental temperatures of 300 °C and 16 °C at the inner and outer surfaces of the pipe. This is an excellent value for a small-diameter pipe and is very promising for use in the downhole coaxial heat exchanger system.

Conclusion

The maximum thermal output obtained in this work was 2.7 MW. We would like to emphasize that this rate was obtained considering only conductive heat transfer as a heat transfer mechanism in the formation. A greater heat extraction rate is expected if the formation permeability is high enough to allow convective heat transfer.

However, there have been very few field works to estimate the effect of convective heat transfer on the heat extraction rate of a single-well system. So, it would be necessary to obtain field data aiming at estimating the effect of enhanced heat transfer by convection in the formation which is pertinent to the downhole coaxial heat exchanger system.

References

- Colp, J.L. (1982, Sandia National Laboratories, SAND82-2377.
- Dunn, J.C. and Hardee, H.C. (1981), *J. Volcanol., and Geotherm. Res.*, Vol. 11, 189-201.
- Kimura, S. et al. (1987), *J. Geotherm. Res. Soc. of Japan*, Vol. 9, No. 1, 19-30.
- Morita, K. et al. (1985), *GRC, Trans. Vol. 9, Part 1*, 45-50.
- Morita, K. and Matsubayashi, O. (1986), *J. Geotherm. Res. Soc. of Japan*, Vol. 8, No. 3, 301-322.
- Morita, K. and Matsubayashi, O. (1988), *J. Geotherm. Res. Soc. of Japan*, Vol. 10, No. 2, 109-129.

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