In Situ REKA Probe Measurements at Fran Ridge and in the ESF

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INTRODUCTION

A thermal probe method, called REKA (Rapid Evaluation of K and Alpha) has been used for determining thermal conductivity (K) and diffusivity (Alpha) at both the Large Heated Block Tests and in the ESF. The REKA method involves a single borehole probe with a heater and temperature measurement section. An elliptical temperature field is generated by the heater, and the temperature distribution along the length of the probe is recorded at several locations and at given time intervals for a period of 6 to 24 hours. A trial-and-error evaluation procedure is used to determine the unknown thermophysical properties by minimizing the RMS error between the measured and calculated temperature fields. If a conduction-only thermal model is used in the evaluation, the thermophysical properties will include the rockmass and the moisture effects, and the values will represent effective properties. If a hydrothermal model is also used, the difference between the effective and the rock matrix thermophysical properties can be related to hydrothermal characteristics¹. A reusable REKA probe can be applied to measure in situ rock properties in a short, open hole, e.g., in a rockbolt

borehole, at low cost. A permanent REKA probe has to be grouted in the insertion hole, if an open hole is not acceptable due to the disturbance it may cause to other site characterization activities.

DESCRIPTION OF THE ACTUAL WORK

ESF Alcove 5 Measurements

Effective thermal conductivity and diffusivity measurements were taken at five different locations in the Drift Scale Test bed at Yucca Mountain. The measurement system employed includes a reusable REKA thermal probe, an HP3421A data acquisition unit, and an HP71B controller. The REKA probe consists of a linear array of 6 thermocouples, centered 0.025 m apart, and an integral heater which is powered by 7 W using an HP3611A DC power supply. The thermocouples are mounted on a flexible, expandable Kapton foil. Thin, flexible copper rings are formed under each thermocouple sensor, for providing an average temperature reading along the circumference of the borehole at each thermocouple location. The probe heater is positioned near the rock wall surface and is centered 0.1 m from the closest thermocouple of the array. The heater is mechanically expandable, for providing sufficient thermal contact between the heating element and the rock surface.

Fran Ridge Measurements

Three permanent REKA probes are grouted into the large rock block at Fran Ridge. The measurement system consists of an HP75000 data acquisition unit, and a PC controller with a phone modem for remote communication. The REKA probe consists of a linear array of 9 thermocouples, centered 0.0125 m apart, and a thin-foil heater which is powered by 2 W using an HP3611A DC power supply. The thermocouples are mounted on a flexible, perforated Kapton foil for sufficient grout bonding.

RESULTS AND DISCUSSION

ESF Alcove 5 Measurements

The measured temperature fields were evaluated using two different evaluation model assumptions. Since both assumptions have merits, and it is difficult to make a fair selection at this time, both sets are included.

Table 1 shows the ESF Alcove 5 evaluation results, assuming that the rock mass temperature is only affected by the REKA probe's heater during the 12-hour measurement period; therefore, no rockmass background temperature correction is needed.

Table 1. ESF Alcove 5 Evaluation Results with No Background Temperature Correction.

Location	Error of Fit (°C)	Conductivity, K (W/m°C)	Diffusivity , Alpha (m² /s)
1	0.033	1.69	0.76 x 10⁻⁶
2	0.037	1.95	0.77 x 10⁻⁶
3	0.024	1.86	0.91 x 10⁻⁶
4	0.039	1.88	0.82 x 10⁻⁶
5	0.025	1.70	0.85 x 10⁻⁶

Table 2 shows the ESF Alcove 5 evaluation results, assuming that the rock mass temperature changes with time during the 12-hour measurement period due to both the REKA probe's heater and some other heating or cooling effect, such as a change in the ambient temperature. A rockmass background temperature correction is applied based on the assumptions that (1) the rockmass temperature changes uniformly along the length of the REKA probe, and (2) the change in the background temperature as a function of time equals the difference between the simulated and measured temperatures with time taken at the thermocouple of the probe farthest away from the heater's center; while the simulated temperature is obtained using the best estimate for K and Alpha.

Table 2. ESF Alcove 5 Evaluation Results with Background Temperature Correction.

Location	Error of Fit (°C)	Conductivity, K (W/m°C)	Diffusivity , Alpha (m² /s)
1	0.015	1.72	0.93 x 10 ⁻⁶
2	0.010	1.92	0.90 x 10 ⁻⁶
3	0.018	1.89	1.04 x 10 ⁻⁶
4	0.015	1.93	1.09 x 10 ⁻⁶
5	0.025	1.76	0.97 x 10 ⁻⁶

It is difficult to choose between the results of Table 1 and Table 2 because both underlying assumptions have merits, as well as weaknesses. The evaluation results in Table 2 have fit significantly better between the measured and simulated temperature fields than have those in Table 1. However, this is due to the identified rockmass background temperature correction, which cannot be verified by direct measurement, and which may result in a distortion upon the thermophysical properties, especially Alpha.

Fran Ridge Measurements

The measured temperature fields were evaluated using again two different evaluation model assumptions; however, only one set of results for only one probe is included in this publication for the sake of brevity. The effective conductivity and diffusivity results with time are shown in Figure 1. As shown, both values are quite consistent with time, varying only slightly around an average of 1.95 W/m/K for heat conductivity, and $0.65 \times 10^{-6} \text{ m}^2/\text{s}$ for thermal diffusivity. There is an apparent correlation between the variations conductivity and diffusivity, which indicates that the specific heat and the density are approximately constant with time. Therefore, the variation can only be explained by the convective effects caused by moisture and/or vapor migration.

CONCLUSIONS

- * Results of the in-situ REKA probe measurements agree very well with the expected values at both Fran Ridge and in the ESF.
- * The REKA method is sensitive enough to detect convective effects.
- * More analytical and experimental studies are needed regarding the effects of the rockmass background temperature correction in the evaluation procedure.

REFERENCES

1. Danko, G. and Buscheck, T.A., (1993). "Single-hole In Situ Heater Tests for Hydrothermal Characterization at Yucca Mountain," Proceedings, Fourth International High Level Nuclear Waste Conference, April, Las Vegas, Nevada, pp. 975-985.

Figure. 1. Heat Conductivity and Thermal Diffusivity results for probe 3 at Fran Ridge