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HANFORD NUCLEAR RESERVATION

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ABSTRACT

The purpose of this work was to evaluate the thermal conductivities and diffusivities of a group of basalt cores from the Gable Mountain area. Thermal conductivities were measured, using a steady-state comparator apparatus, at a fixed stress and at two temperature levels. Specific heats were calculated as a function of temperature from oxide analyses. Bulk densities were measured at room conditions; densities at elevated temperatures were estimated from available thermal expansion data. From the above data, thermal diffusivities were calculated.

INTRODUCTION

There are several alternatives to solve the problem of nuclear waste disposal. One of the possible solutions is that of deep underground burial in rock formations with low permeability. Studies are being carried out with basalts of the Columbia River Basin to determine the feasibility of this formation as a storage medium. One important question is whether the thermal loadings on the rock, imposed by the heat generated from radioactive decay, would compromise the suitability of the rock formation as an isolation barrier. Another consideration is that the thermomechanical and related responses of the rock must be understood so that a repository design can be generated which will ensure that the stored waste canisters are accessible and retrievable during the initial period of high heat flux. A set of heater experiments is being planned to study the thermomechanical behavior of the basalt flow (the Pomona flow) in the Gable mountain area of the Hanford Nuclear Reservation in Eastern Washington State. The present work evaluates the thermal properties of basalt from various flows. These properties are required as inputs to thermal models of the heater experiments as well as for modeling of a hypothetical repository.

SPECIMEN PREPARATION

Specimens used in the experimental work were obtained from six cores provided by Rockwell-Hanford Operations, Richland Washington. The samples are identified by the name of the specific basalt flow (Umtanum, Pomona, or Gable Mountain) from which they came and by the identification of the borehole (DH-5 or DB-5) from which the core was recovered. A brief visual description of the specimens as they were used in the experiments is given in Appendix A.

The four cores from boreholes DB-5 were about 6 cm in diameter by 11 to 17 cm long. The cores from borehole DH-5 were 4.7 cm in diameter by 14 cm long. DB-5 cores were diamond drilled longitudinal to the axis to obtain test specimens of 5.08 cm in diameter. These were then cut and faced to a height of 3.20 cm keeping parallelism between faces within +0.015 cm. DH-5 cores were cut to the same required height, but these two samples were left at their original diameter since it was smaller than the diameter of the specimen holder in our thermal conductivity apparatus (5.08 cm). The results for the small diameter samples were corrected, as explained below, for this diameter change.

PROPERTIES EVALUATION PROCEDURES

Specimens were first subjected to a vacuum of 0.025-0.050 mm of Hg overnight. Next, to saturate them, they were submerged in distilled water while still under vacuum. The increase in the weight of the specimens was found to be less than 0.5 g. This minor increase was probably the result of surface wetness. It was therefore concluded that few interconnected pores were present in these samples and that permeability would be very low and out of the range of the available measuring apparatus.

Bulk densities were measured at room temperature and then corrected to specific temperatures using a volumetric expansion coefficient of 16.2×10^{-6} $^oC^{-1}$ (p. 37, Ref. 1). This correction was less than 1/2% at 200^{o}C.

Specific heats were calculated using the method described by Somerton.[2] This method involves the summation of the heat contents of the individual constituents of the rock samples based on oxide analysis. Data for the oxide analyses (see Table 1) were taken from "Preliminary Feasibility Study on Storage of Radioactive Wastes in Columbia River Basalts."[7] We used the data given for Pomona A1266 to calculate the specific heat for our samples of Pomona DB-5 (3[illegible] ft and 420 ft); we used the data given for Gable Mountain K1005 for our samples of Gable Mountain DB-5 (521 ft and 524 ft); and we used the oxide analysis provided to us with the samples of DH-5 Umtanum.

Thermal conductivities were measured in a standard steady-state comparator thermal conductivity apparatus.[3,4] Measurements were made at a constant stress of 500 psi and at constant average temperatures of 55 and 123^{o}C for

Table 1: Summary of oxide analysis results used.*

		SiO_2 (%)	Al_2O_3 (%)	FeO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	MnO (%)	SrO (%)	M/Bal. (%)
Umtanum (from DH-5 log)	2749 ft	54	12.7	12.7	3.7	7.0	3.1	1.6	2.1	–	–	98.3
	2808 ft	55	12.6	12.5	3.9	7.3	3.1	1.9	2.1	–	–	100.9
Pomona (1)	A1266	52.6	14.4	11.0	7.6	9.7	2.4	0.7	1.6	0.19	0.016	100.3
Gable Mountain (2) (Esquatzel)	K1005	52.7	13.2	14.1	4.2	7.0	2.9	1.5	2.8	–	–	98.4

*Data from Ref. 7, Vol. 1, Table III.

(1) Values assumed for Pomona DB-5 samples.

(2) Values assumed for Gable Mountain DB-5 samples.

the water-saturated (wet) samples. In the case of the undersized samples (DH-5), the space left between sample and test cell was filled with distilled water, and the observed thermal conductivity values were corrected assuming one-dimensional heat conduction through the parallel water-rock system.

Good agreement with the expected trend of variation of thermal conductivity with temperature, based on correlation given in Ref. 3, was obtained as shown in Fig. 1(b). Based on this observation all thermal conductivity curves were extrapolated to 200°C. Extrapolation was necessary since the 200°C temperature was too high for measurements in the standard apparatus. Extrapolation was made following the trend dictated by the two experimental points obtained for each sample except in two cases (DB-5, 390 ft and DB-5, 542 ft) in which values obtained show slightly different trends. In these two cases, the trends of their companion samples (DB-5, 420 ft and DB-5, 521 ft, respectively) were utilized in the extrapolation. Accuracy of the results from the standpoint of the measuring equipment should be well within ±5% as Anand[4] has shown by error analysis.

Thermal diffusivities were calculated using the relation:

$$\alpha = k/\rho C_p$$

where

α = thermal diffusivity,

k = thermal conductivity,

ρ = density,

C_p = specific heat.

RESULTS

Calculated specific heat results, as shown in Table 2 and Fig. 1(a), were found to follow the expected trend of variation with temperature and

Table 2: Specific heats based on oxide analysis in Cal/g°K.

Temp. °C	Umtanum (DH-5)		Pomona A1266*	Gable Mountain K1005**
	2749 ft.	2808 ft.		
50	0.217	0.221	0.234	0.219
100	0.235	0.239	0.253	0.237
150	0.247	0.251	0.267	0.250
200	0.257	0.262	0.278	0.260
250	0.266	0.271	0.287	J.269
300	0.275	0.279	0.296	0.277

*Values assumed for Pomona DB-5 samples.

**Values assumed for Gable Mountain DB-5 samples.

had the same order of magnitude as previous results obtained for similar materials.[5]

Table 3 lists the experimentally determined thermal conductivities at temperatures of approximately 55°C and 123°C, together with interpolated specific heats, bulk densities, and derived thermal diffusivities for the same temperatures while Table 4 shows estimated values of the same thermal properties at 200°C. Figures 1(b) and 1(c) illustrate the temperature variations of thermal conductivity and thermal diffusivity for the different rock samples. These values are in good agreement with values obtained for Mohole basalts[5] and also with results of other investigators[6] for

Table 3: Thermal properties of Gable Mountain cores.

Core - Rock Unit	Temp °C	Th. Cond. Watts/m°K	Sp. Heat Cal/g°K	Th. Diff. cm²/sec	Temp °C	Th. Cond. Watts/m°K	Sp. Heat Cal/g°K	Th. Diff. cm²/sec	Density g/cm³ @ 20°C
DH-5 Umtanum									
2749 ft	55	1.57	0.219	6.16×10^{-3}	123	1.51	0.240	5.4×10^{-3}	2.78
2808 ft	56	1.49	0.223	5.70	125	1.45	0.245	5.05	2.80
DB-5 Pomona									
390 ft	54	1.75	0.236	6.18	123	1.68	0.260	5.38	2.87
420 ft	56	1.73	0.237	6.06	124	1.68	0.260	5.36	2.88
DB-5 Gable Mtn. (Esquatzel)									
521 ft	56	1.62	0.221	6.30	123	1.57	0.249	5.42	2.78
542 ft	55	1.54	0.221	5.91	123	1.47	0.243	5.13	2.82

Table 4: Estimated thermal properties values at 200°C.

Core - Rock Unit	Temp °C	Th. Cond. Watts/m°K	Sp. Heat Cal/g°K	Th. Diff. cm²/sec	Density g/cm³ @ 200°C
DH-5 Umtanum					
2749 Ft	200	1.44	0.257	4.83×10^{-3}	2.77
2808 ft	200	1.41	0.262	4.61	2.79
DB-5 Pomona					
390 ft	200	1.63	0.278	4.90	2.86
420 ft	200	1.61	0.278	4.82	2.87
DB-5 Gable Mtn.					
521 ft	200	1.52	0.260	5.04	2.77
542 ft	200	1.42	0.260	4.65	2.81

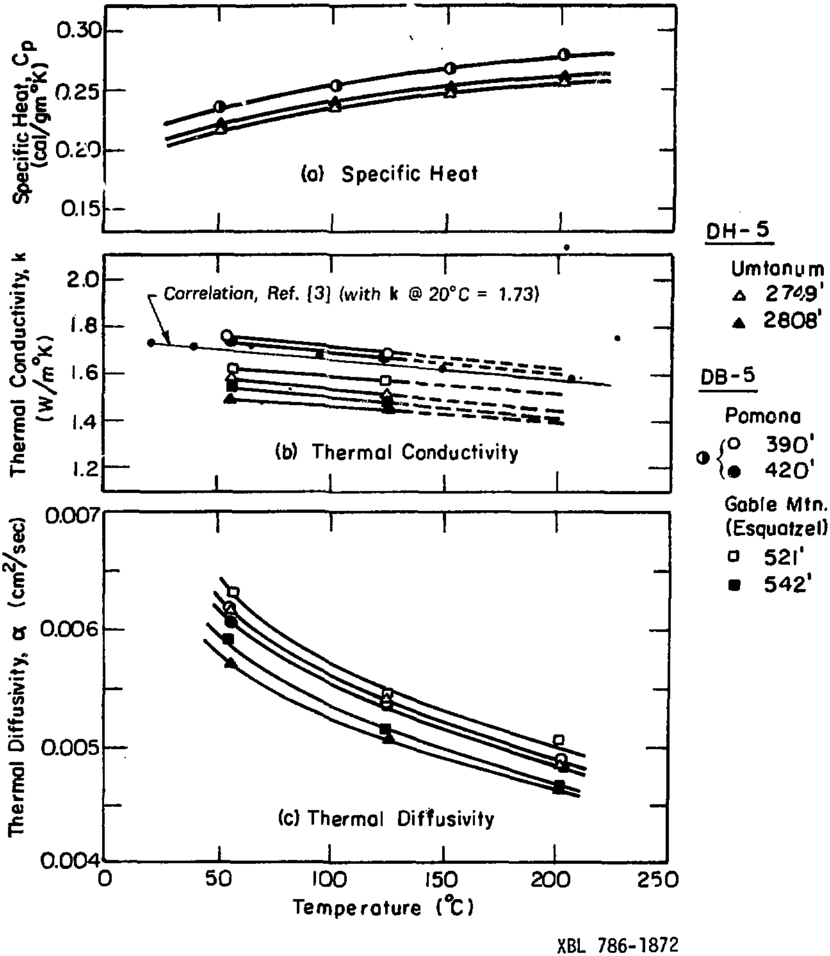

Fig. 1. (a) Specific heat, (b) thermal conductivity, and (c) thermal diffusivity for the basalt samples studied, as functions of temperature. [Symbols on curves of Fig. 1(a) and 1(c) are present only to distinguish different curves and do not represent data points.]

vesicular basalts from Hawaii, as shown in Table 5. The latter results show a tendency to be higher than our results, but the agreement is good considering the higher density of the Hawaiian samples and the probable differences in composition. The porosity of the Hawaiian samples chosen for comparison ranges between 4.4 and 7%.

Table 5: Comparison of results at 35°C with those of Ref. (6) having similar density.

This study Sample	Th. Cond. at 35°C* Watts/cm°K	Density g/cm³	Hawaiian Sample No. Ref. 6	Th. Cond. at 35°C Watts/cm°K	Density g/cm³
DH-5 Umtanum					
2749 ft	1.58	2.77	614	1.66	2.807
2808 ft	1.50	2.79	615	1.72	2.817
DB-5 Pomona					
390 ft	1.77	2.86	625	1.73	2.919
420 ft	1.75	2.87	616	1.79	2.882
DB-5 Gable Mtn.					
521 ft	1.64	2.77	614	1.66	2.807
542 ft	1.55	2.81	615	1.72	2.817

*extrapolated from Fig. 1 (b)

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APPENDIX A, Visual description of specimens as they were used in the experimental work.

DH-5 Umtanum

2749 ft: Dark gray in color with a lighter gray vertical band crossing the center about 2 mm thick. Several small missing chips (about 1 mm long) around edges and one larger chip (about 12 x 3 x 3 mm) held in place during experiments.

2808 ft: Light gray in color, very small chips missing around edges.

DB-5 Pomona

390 ft: Light gray with very small black nodules (about 0.3 mm in diameter) distributed in the specimen.

420 ft: Light gray with the same kind but fewer black nodules than the preceding specimen.

DB-5 Gable Mountain (Esquatzel)

521 ft: Vertically fractured specimen in two pieces with good contact between them, light gray color (much darker gray on the fractured faces). Shows some small uncommunicated pores on the surfaces and one larger pore (about 4 mm in diameter by 5 mm in depth).

524 ft: Dark gray (almost black) in color, shows pores of about the same size but fewer than the preceding specimen.

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Editors Note: In the absence of the authors, this report has been edited by Tin Chan and Andrew DuBois--both of Earth Science Division of the Lawrence Berkeley Laboratory.