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Statistical Analysis on the Thermal Conductivity of Rocks in the Republic of Korea

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ABSTRACT

A thermal property database has been constructed using web GIS for the republic of Korea. Thermal diffusivity, thermal conductivity, volumetric heat capacity, density and porosity were measured on a collection of 1,560 rock samples in the laboratory. The sample spacing was generally 2 to 10 km with irregular distance. Basic statistics were calculated and classified into igneous, metamorphic and sedimentary rock types. The number of samples and the minimum, maximum, mean, median and standard deviation of the thermal conductivity of the rocks were determined. The effects of thermal diffusivity, porosity and dry density on thermal conductivity were compared. The statistical analysis of thermal conductivity and other thermal properties is very useful in the practical utilization design of geothermal systems.

1. INTRODUCTION

Thermal conductivity of rocks is a critical parameter used in geothermal utilization design. Generally, the thermal conductivity ranges given in the compilations of rock properties (Clauser and Heunges, 1995) are too broad to be useful in the application of a specific site because thermal properties are highly dependent on site specific characteristics. The distribution and spatial variability of the thermal conductivity are needed as input parameters in the design process. Knowledge of the thermal conductivity of rocks is essential for solving many geothermal utilization design problems (Schilling, 1999). Many measurements have been taken to develop a geothermal data base in Korea, and the thermal conductivity of rocks was studied as a critical parameter. The thermal conductivity, thermal diffusivity, porosity and density were used for statistical analysis. Statistic and scatter plots were used to define the characteristics and relationships of the data.

2. METHOD

1,560 rock samples were used to measure physical properties in the republic of Korea (Figure 1). The sample collection was conducted without bias on location and geologic distribution. Thermal conductivity was measured using a LFA 447 Nanoflash instrument (Natzsch, 2002). The instrument determines thermal diffusivity, specific heat and thermal conductivity by means of the flash diffusivity method (Parker, et al., 1961). The specific heat capacity can be obtained with thermal diffusivity by using a multi-sample configuration system and testing a reference sample adjacent to the unknown. Thus, a single test yields thermal diffusivity, and thermal conductivity can be determined with prior knowledge of density (Gaal, et al., 2004). Pyroceram 9606 was used as a standard reference sample, having an error less than 5%. This method is fast and produces results with high accuracy and very good repeatability. Intact rock samples without cracks or weathering were shaped for a proper sample size for the measuring equipment. The applied sample size is 25mm diameter and 3 mm thickness, which is suitable for most rock samples except for highly heterogeneous rocks.

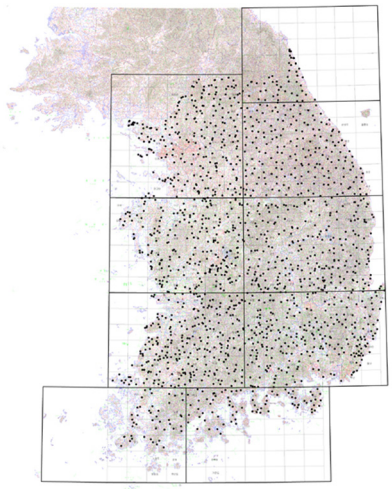

Figure 1: Distribution of sample locations in Korea (indicated by black dots).

3. THERMAL CONDUCTIVITY OF ROCKS

The thermal conductivity of rocks depends on mineral composition, porosity, density, rock microstructure, anisotropy, pressure and temperature (Clauser and Huenges, 1995). Porosity and density were compared with thermal conductivity as dependent variables. The measured saturated thermal conductivity, porosity and dry density of total rock samples are shown in Table 1. The saturated thermal conductivities of the samples range from 1.6 to 8.76$Wm^{-1}K^{-1}$, porosities range from 0.001 to 0.303, and densities range from 1.580 to 3.170 kg m^{-3}. Dry density has a normal distribution, and saturated thermal conductivity has a log-normal distribution (see Figure 2).

Table 1: Saturated thermal conductivity, porosity and dry density of 1,560 rock samples.

Statistics	*Saturated Thermal conductivity (W/m-K)*	*Porosity*	*Dry density (kg/m^3)*
Minimum	1.6	0.001	1580
Maximum	8.76	0.303	3170
Mean	3.542	0.018	2656
SD	0.996	0.022	0.107
Variance	0.9923	0.0005	0.0114
Skewness	1.53	4.60	-0.37
Kurtosis	3.82	34.58	9.241

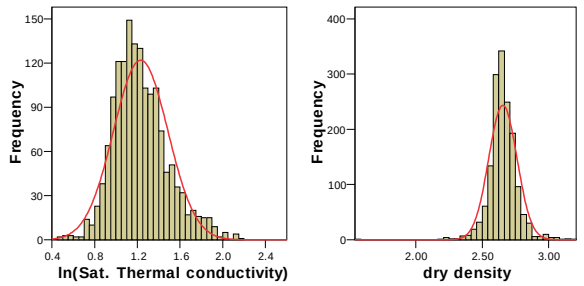

Figure 2: Histograms of saturated thermal conductivity and dry density measured by laboratory test on the 1,560 rock samples. Saturated thermal conductivity data are shown for log-normal distribution and dry density data are shown for normal distribution.

Table 2: The number of samples and the minimum, maximum, mean, median and standard deviation of the saturated thermal conductivity ($Wm^{-1}K^{-1}$) of rocks in Korea.

	rock	No.	Min.	Max.	Mean	Med.	Std. D.
igneous	granite	512	1.82	7.71	3.33	3.24	0.67
	andesite	76	2.04	5.81	2.80	2.75	0.54
	diorite	42	1.60	4.86	2.87	2.72	0.73
	feldspar porphyry	38	2.44	4.19	3.23	3.17	0.43
	tuff	36	1.77	4.56	2.95	2.92	0.50
	quartz porphyry	13	2.80	4.45	3.44	3.49	0.48
	felsite	10	2.84	5.12	3.41	3.19	0.69
	granite porphyry	10	2.51	5.46	3.37	3.08	0.89
	rhyolite	10	2.62	5.02	3.51	3.20	0.78
	acidic dike	6	2.04	4.91	3.93	4.24	1.00
metamorphic	gneiss	359	1.64	8.20	3.72	3.57	0.93
	schist	41	2.58	8.39	4.40	4.33	1.16
	phyllite	27	2.64	6.53	4.08	3.94	0.90
	quartzite	25	2.17	8.45	5.69	6.10	1.70
	hornfels	19	2.61	6.71	3.46	3.17	1.00
	quartz schist	8	3.74	8.76	6.08	6.40	1.65
	amphibolite	6	2.34	5.09	3.68	3.42	1.16
	andesitic porphyry	6	1.67	3.39	2.87	3.07	0.64
sedimentary	sandstone	175	2.05	7.59	3.81	3.40	1.19
	limestone	57	2.25	6.84	3.83	3.59	1.12
	breccia	17	2.48	4.18	3.13	3.20	0.41
	mudstone	15	2.71	5.63	3.69	3.22	0.97
	siltstone	10	2.59	5.59	3.49	3.16	0.86
	conglomerate	8	2.59	5.21	3.43	3.19	0.84
	shale	7	2.55	5.80	3.82	3.21	1.32

The samples were classified into 3 types and 25 kinds of rocks. The number of samples and the minimum, maximum, mean, median and standard deviation of saturated thermal conductivity of rocks were identified, as shown in Table 2. Granite, gneiss and sandstone account for the largest number of samples in the igneous, metamorphic and sedimentary rock types, respectively. As quartz rich rocks, quartz schist and quartzite have high mean thermal conductivities of 6.08 and 5.69 $Wm^{-1}K^{-1}$. In terms of average thermal conductivities, igneous rocks range from 2.80 to 4.24 $Wm^{-1}K^{-1}$, metamorphic rocks range from 2.87 to 6.08 $Wm^{-1}K^{-1}$, and sedimentary rocks range from 3.13 to 3.83 $Wm^{-1}K^{-1}$. The correlations between saturated thermal conductivity, dry density, porosity and thermal diffusivity are shown in Figure 4. The scatter plot of saturated thermal conductivity versus thermal diffusivity shows linear correlation, and the scatter plot between dry density and porosity shows an inverse linear relationship. There was weak correlation between saturated thermal conductivity and both porosity and dry density because rock-forming mineral contents are more a dominant factor in determining the thermal conductivity of the samples (Figure 4).

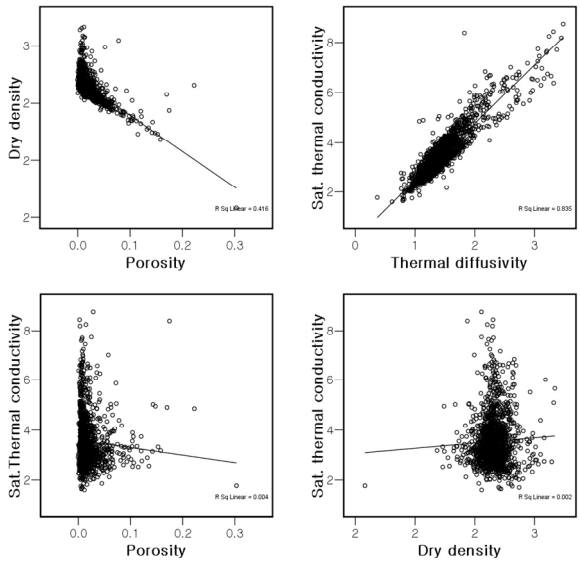

Figure 4: Scatter plots showing the relationships between dry density (kgm^{-3}), porosity, saturated thermal conductivity ($Wm^{-1}K^{-1}$) and thermal diffusivity ($10^{-2}cm^2s^{-1}$).

4. CONCLUSIONS

Several thermal properties of a total number of 1,560 rock samples were measured in the laboratory, and the resulting table of thermal conductivity versus rock type is given. In terms of average saturated thermal conductivity, igneous rocks range from 2.80 to 4.24 $Wm^{-1}K^{-1}$, metamorphic rocks range from 2.87 to 6.08 $Wm^{-1}K^{-1}$ and sedimentary rocks range from 3.13 to 3.83 $Wm^{-1}K^{-1}$. Linear correlation between saturated thermal conductivity and thermal diffusivity was shown and inverse linear correlation between dry density and porosity represented were observed. There was weak correlation between saturated thermal conductivity and both porosity and dry density, because rock-forming mineral contents are a dominant factor in the determination of thermal conductivity in the samples. Future studies are needed to define the characteristics of the rock property database.

REFERENCES

Clauser, C. and Huenges, E.: Thermal conductivity of rocks and minerals, Rock physics and phase relations, Ed. T. Ahrens, AGU, (1995), 105-126.

Gaal, P.S., Thermitus M.-A., and Daniela E. S.: Thermal conductivity measurement using the fresh method, Journal of thermal analysis and calorimetry, 78, (2004), 185-189.

Natzsch Instruments Inc.: Instruction manual LFA 447, (2002)

Schilling, F.R.: A transient technique to measure thermal diffusivity at elevated temperatures, 11, (1999), 1115-1124.