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Geothermal Resource Assessment for EGS in Korea

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ABSTRACT

An assessment of the geothermal resource in Korea was performed using the volume method. In Korea, subsurface temperatures range from 23.9 – 47.9°C at a depth of 1 km, 34.2 – 79.7°C at a depth of 2 km, 44.2 – 110.9°C at a depth of 3 km, 53.8 – 141.5°C at a depth of 4 km, and 63.1 – 171.6°C at a depth of 5 km. The total available subsurface geothermal energy in Korea is 4.25×1021 J from the surface to a depth of 1 km, 1.67×1022 J to a depth of 2 km, 3.72×1022 J to a depth of 3 km, 6.52×1022 J to a depth of 4 km, and 1.01×1023 J to a depth of 5 km. In particular, the southeastern part of Korea exhibits high temperatures and high amounts of stored energy at depth. If only 2% of geothermal resource from surface to a depth of 5 km is exploited in Korea, it would be equivalent to about 200 times the annual consumption of primary energy (~2.33×108 TOE) in Korea in 2006.

1. INTRODUCTION

In Korea, geothermal energy has been used for hot spring and balneology for thousands of years and was recently developed for space cooling/heating. Additionally, future geothermal development will put greater emphasis on enhanced geothermal systems (EGS) in Korea.

To meet the recent and future requirements for sophisticated analyses of available geothermal resources, a geothermal resource assessment was performed in Korea to investigate the geothermal potential of the entire country for various geothermal applications, including EGS. This study is the first systematic effort to estimate the geothermal resources of Korea.

2. GEOLOGY

The geology of Korea is composed of relatively old rocks, including Precambrian metamorphic basement rocks (e.g., gneiss and schist), Paleozoic and Mesozoic sedimentary rocks, the Jurassic and Cretaceous granites that occupy about 50% of Korea, and some young volcanic rocks. More detailed geological information regarding Korea is given by Lee (1988) and Chough et al. (2000).

3. THEORY

The volume method, which estimates the amount of energy contained within a certain volume of rock, was used in this assessment. The volume method is the most commonly used method for the assessment of geothermal resources (Nathenson, 1975; White and Williams, 1975; Muffler and Cataldi, 1978; Muffler, 1979) and has been recently applied for geothermal resource assessments in the U.S. (Blackwell et al., 2006; Tester et al., 2006).

Heat content (Q) at depth can be estimated by the volume method as:

$$Q=\rho C_p V \Delta T \quad (1)$$

Where ρ is density, C_p is specific heat, V is rock volume, and ΔT is the temperature difference between the top and bottom of the rock volume.

The temperature at depth for a crystalline rock terrain can be expressed as:

$$T(z)=\frac{A_o b^2}{K}(1-e^{-z/b})+(\frac{q_o-A_o b}{K})z+T_o \quad (2)$$

Where T(z) is temperature at depth z, A_o is surface heat production, b is attenuation depth, K is thermal conductivity, q_o is surface heat flow, and T_o is surface temperature.

Table 1: Summary of geothermal data to estimate available geothermal energy and construct temperature at depth maps for Korea

	A_0 ($\mu W/m^3$)	C_p (J/kgK)	K (W/mK)	q_0 (mW/m^2)	T_0 (˚C)	ρ (kg/m^3)
Mean	2.04	857	3.54	65.2	14.4	2,674
Range Value	0.18 - 5.70	523 – 1,181	1.60 – 8.76	35.2 - 102.3	8.6 - 16.7	1,883 – 3,182
Number of data	180	1,560	1,560	353	54	1,560

4. DATA

To estimate available geothermal energy and to construct temperature at depth maps in Korea, various geothermal data have been used. These include 1560 thermal property data (e.g., thermal conductivity, specific heat, and density), 353 heat flow data, 54 surface temperature data, and 180 heat production data. A summary of geothermal data used to estimate available geothermal energy and construct temperature at depth maps for Korea are shown in Table 1.

4.1 Heat Flow

In this study, 353 heat flow data compiled by Kim and Lee (2007) were used for the geothermal resource assessment. In Korea, the mean geothermal gradient is 25.1°C/km, and the mean heat flow is 60 mW/m^2. The southeastern, central western, and the northeastern parts of Korea exhibit high heat flow values.

4.2 Thermal Properties

A total of 1560 of fresh outcrop samples was collected from throughout Korea. For temperature estimation at depths, thermal conductivity was assumed to be vertically homogeneous. Thermal conductivity and specific heat of 1560 rock samples were measured using a LFA-447 Xenon flash lamp machine from Netzsch. The densities of 1560 samples were measured using an AccuPyc 1330 Pycnometer gas displacement technique instrument from the Micromeritics Instrument Corporation. The mean, the range and the number of thermal property data are shown in Table 1.

4.3 Heat Production

A total of 180 heat production values in basement rocks (granite and gneiss) were estimated using chemical analysis and gamma-ray logs. Among 180 heat production data, a total of 125 heat production data were estimated by chemical analysis, while a total of 55 heat production data were estimated from gamma-ray logs. The mean heat production was found to be 2.040 μW/m^3 for granite samples and 2.041 μW/m^3 for gneiss samples. The mean heat production of the entire data set is 2.040 μW/m^3.

4.4 Surface Temperature

Koo et al. (2006) collected ground surface temperatures (GSTs) that have been measured and digitally recorded at 58 Korean Meteorological Administration (KMA) stations from 1981 to 2002. Then, they estimated the mean GST for each station after data adjustment that included removing erroneous data.

In the KMA data set, the lowest GST of 8.58°C was measured at Daegwallyeong (842 m above sea level) located in the Taebaek Mountains in northeastern Korea, while the highest GST of 18.31 °C was observed at Seogwipo (51.0 m above sea level) on Jeju island in southern Korea. The mean measured GST was 13.9 °C.

5. RESULTS

5.1 Temperature at Depths

Temperatures were estimated using Equation 2 from depths of 1 – 5 km at 1 km intervals. A contour map of the temperature distribution at 5 km is given in Figure 1. The accuracy of temperature estimations at depth cannot be checked directly because there are no deep boreholes in Korea. However, Blackwell et al. (2006) found that agreement between measured and estimated temperatures in the 3 – 6 km depth range in the Unite States is within ±20° C.

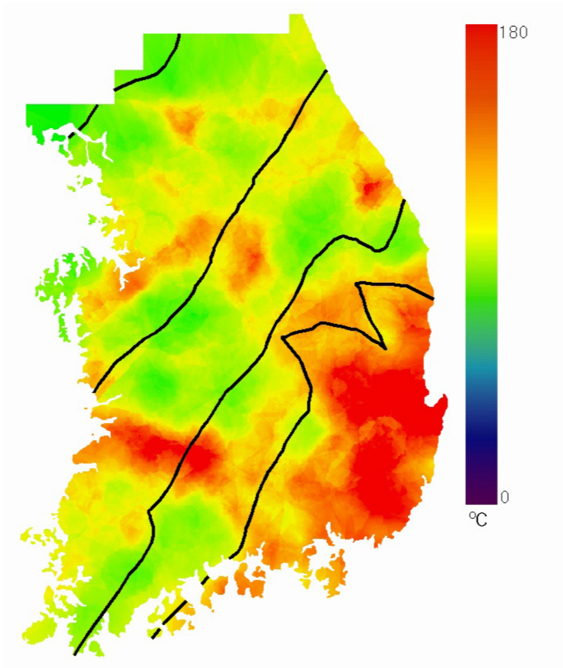

Figure 1: Temperature distribution at 5 km in Korea. The southeastern part of Korea exhibits the highest temperatures.

5.2 Heat Content

The total available subsurface geothermal energy in Korea was estimated using Equation 1, and the results are shown in Table 2. Southeastern Korea in particular exhibited high temperatures and energy content at depth.

Table 2: Heat content in Joule, GTOE, and 2% of total heat content in GTOE for different depth intervals in Korea

Depth Interval	*Heat Content in J*	*Heat Content in GToe*	*Heat Content in GToe (2%)*
0 ~ 1 km	4.25×10^{21}	101.1	2.0
0 ~ 2 km	1.67×10^{22}	398.7	8.0
0 ~ 3 km	3.72×10^{22}	884.9	17.7
0 ~ 4 km	6.52×10^{22}	1,552.8	31.1
0 ~ 5 km	1.01×10^{23}	2,396.0	47.9

6. CONCLUSION

Southeastern Korea exhibited high temperatures and energy contents at depth. If only 2% of the geothermal resource from the surface to a depth of 5 km is developed in Korea, it would be equivalent to about 200 times annual consumption of primary energy (~2.33×10^8 TOE) in Korea in 2006.

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