P-05-208

Oskarshamn site investigation

Drill hole KLX07A

Thermal conductivity and thermal diffusivity determined using the TPS method

Bijan Adl-Zarrabi
SP Swedish National Testing and Research Institute

October 2006

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-05-208

Oskarshamn site investigation

Drill hole KLX07A

Thermal conductivity and thermal diffusivity determined using the TPS method

Bijan Adl-Zarrabi
SP Swedish National Testing and Research Institute

October 2006

Keywords: Thermal properties, Thermal conductivity, Thermal diffusivity, Heat capacity, Transient Plane Source method, AP PS 400-05-061.

Abstract

Thermal properties on five specimens of drill hole KLX07A, Oskarshamn, were measured at ambient temperature (20°C). The specimens were collected on five levels in the drill hole at depth of approximately 350 m, 370 m, 390 m, 410 m and 430 m. The rock type of the samples is mapped as Ävrö granite (501044). The determination of the thermal properties is based on a direct measurement method, the so called "Transient Plane Source Method (TPS), Gustafsson, 1991 /2/.

Thermal conductivity and thermal diffusivity at 20°C were in the range of 2.23–3.25 W/(m, K) and 1.10–1.56 mm^2/s respectively. The heat capacity, which was calculated from the thermal conductivity and diffusivity, ranged between 1.73 and 2.29 $MJ/(m^3, K)$.

Sammanfattning

Termiska egenskaper hos fem provkroppar från borrhål KLX07A, Oskarshamn, bestämdes vid rumstemperatur (20 °C) med den s k TPS-metoden, ”Transient Plane Source”, användes för bestämning av de termiska egenskaperna, Gustafsson 1991 /2/. Proverna hade tagits från fem nivåer i borrhålet vid ca 350 m, 370 m, 390 m, 410 m och 430 m. Den karterade bergarten är Ävrö granit (501044).

Den termiska konduktiviteten och den termiska diffusiviteten hos provkropparna vid 20 °C var 2.23–3.25 W/(m, K) respektive 1.10–1.56 mm^2/s. Från värdena på dessa parametrar kunde värmekapaciteten beräknas och befanns ligga i intervallet 1.73–2.29 $MJ/(m^3, K)$.

Contents

1 Introduction

SKB is planning to build a final repository for nuclear waste in bedrock. A final repository for nuclear waste demands knowledge about thermal properties of the rock. Oskarshamn, Sweden, is one of the areas selected for site investigations. The activity presented in this report is part of the site investigation program at Oskarshamn /1/.

This report presents investigations of thermal properties of rock samples from borehole KLX07A at Oskarshamn, see Figure 1-1. The thermal properties thermal conductivity and thermal diffusivity have been determined by using the Transient Plane Source Method (TPS), Gustafsson, 1991 /2/. The method determines thermal conductivity and diffusivity of a material. The volumetric heat capacity can be calculated if the density is known. The dry and wet densities, as well as porosity of the samples, were determined within the scope of a parallel activity.

***Figure 1-1**. Location of the drill hole KLX07A, October 2005, within and close to the Oskarshamn candidate area.*

Rock samples were selected at Oskarshamn based on the preliminary core logging with the strategy to investigate the properties of the dominant rock types. The specimens to be tested were cut from the rock samples in the shape of circular discs. The rock samples arrived at SP in October 2005. The thermal properties were determined on water-saturated specimens. Testing was performed during November–December 2005.

The controlling documents for the activity are listed in Table 1-1. Activity Plan and Method Descriptions are SKB's (The Swedish Nuclear Fuel and waste Management Company) internal controlling documents as well as SP's (Swedish National Testing and Research Institute) Quality Plan (SP-QD 13.1).

Table 1-1. Controlling documents for performance of the activity.

Activity Plan	**Number**	**Version**
KLX07A. Bergmekaniska och termiska laboratoriebestämningar	AP PS 400-05-061	1.0
Method Description	**Number**	**Version**
Determining thermal conductivity and thermal capacity by the TPS method	SKB MD 191.001	2.0
Quality Plan		
SP-QD 13.1		

2 Objective and scope

The purpose of this activity is to determine the thermal properties of rock specimens. The obtained thermal properties will be used as input data for mechanical and thermal analysis in a site descriptive model that will be established for the candidate area selected for site investigation at Oskarshamn.

3 Equipment

Technical devices for determination of thermal properties in question were:

- Kapton sensor 5501, radius of the sensor was 6.403 mm, and output of power was 0.7 W. The sensor 5501 fulfils the recommended relation between the radius of sensor and geometry of the samples in /3/.
- TPS-apparatus, Source meter Keithley 2400, Multimeter Keithley 2000 and bridge, see Figure 3-1.
- PC + Microsoft Office and Hot Disk version 5.4.
- Stainless Sample holder.

Function control of TPS instrumentation was performed according to BRk-QB-M26-02 (SP quality document), see Appendix A.

The experimental set-up is shown in Figure 3-2.

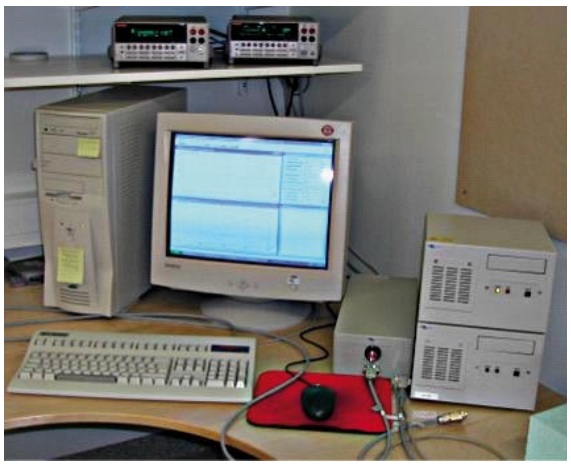

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

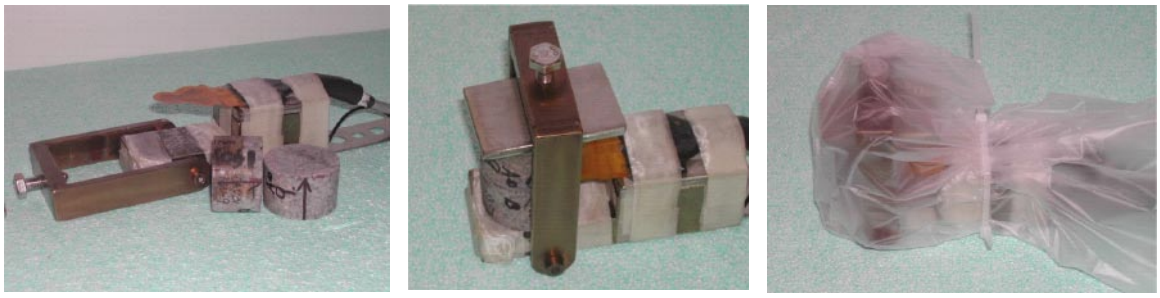

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

Determination of thermal properties conductivity and diffusivity was made in compliance with SKB's method description SKB MD 191.001 (SKB internal controlling document) and Hot Disc Instruction Manual /3/ at SP Fire Technology.

The density determinations, which were performed in a parallel activity at SP, were carried out in accordance with SKB MD 160.002 (SKB internal controlling document) and ISRM /4/.

4.1 Description of the samples

Five pairs of cores (designated A and B) were sampled from drill hole KLX07A, Oskarshamn, Sweden. The cores were collected at the depth between 350 m–430 m. The ten specimens with a thickness of 25 mm each were sampled from the samples at SP; see Figure 3-2. The diameter of the specimens was about 50 mm. The rock type, identification marks and depth of the specimens are presented in Table 4-1. Detailed geological description of the rock is given in SKB's BOREMAP of KLX07A and in the SICADA database at SKB.

4.2 Test Procedure

The present activity was performed parallel to another activity, conducted by the department of Building Technology and Mechanics at SP, and by which the wet and dry density as well as the porosity of the specimens were determined.

The following logistic sequence was applied for the two activities:

1. Specimens were cut and polished by SP Building Technology and Mechanics.
2. Specimens were photographed by SP Building Technology and Mechanics.
3. Specimens were water saturated and wet density was determined by SP Building Technology and Mechanics /3/.
4. Specimens were sent from SP Building Technology and Mechanics to SP Fire Technology.
5. Thermal properties were determined by SP Fire Technology.
6. Specimens were sent from SP Fire Technology to SP Building Technology and Mechanics.
7. Dry density of the specimens was determined at SP Building Technology and Mechanics.

Table 4-1. Rock type and identification marks, rock types and sampling level (borehole length) of the specimens from KLX07A (rock-type classification according to the Boremap).

Identification	Rock type	Sampling level (Adj seclow)
KLX07A-90V-01	Ävrö granite (501044)	347.96
KLX07A-90V-02	Ävrö granite (501044)	368.96
KLX07A-90V-03	Ävrö granite (501044)	388.67
KLX07A-90V-04	Ävrö granite (501044)	408.20
KLX07A-90V-05	Ävrö granite (501044)	428.12

The principle of the TPS-method is to install a sensor consisting of a thin metal double spiral, embedded in an insulation material, between two rock samples. During the measurement the sensor works both as a heat emitter and a heat receptor. The input data and results of the direct measurement are registered and analysed by the same software and electronics that govern the measurement. The method gives information on the thermal conductivity and diffusivity of a material, and from the parameters the volumetric heat capacity can be determined, provided the density is known.

The specimens were water saturated and stored under this condition for 7 days. This yielded complete water saturation, whereupon the density and the thermal properties were determined. The specimens were photographed before testing.

The thermal properties of the water-saturated specimens were measured in ambient air (20°C). In order to remain water saturation and obtain desired temperature, the specimens and the sensor were kept in a plastic bag during the measurements, see Figure 3-2.

Each pair of specimens (A and B) was measured five times. The time lag between two repeated measurements was at least 20 minutes. The result of each measurement was evaluated separately. The average value of these five measurements was calculated.

Measured raw data were saved as text files and analysed data as Excel files. These files were stored on the hard disc of the measurement computer and sent to the SKB catalogue at the SP network. Further calculations of mean values and standard deviations were performed in the same catalogue.

Determinations of the thermal properties as well as density and porosity measurements were performed during November and December 2005.

The dry weight was measured after the specimens had been dried to constant mass according to ISMR /4/ at 105°C. The drying procedure took seven days.

4.3 Nonconformities

There were no deviations to the plan.

5 Results

5.1 Thermal properties

Mean values of measured data, five repeated measurements, are reported in 5.1.1 and 5.1.2 and in the SICADA database at SKB. Values of each separate measurement as described in 4.2 are reported in Appendix B. Furthermore, the total measuring time, the ratio between total measuring time and characteristic time, and the number of analysed points is presented in Appendix C. In a correct measurement the ratio between the total measuring time and the characteristic time should be between 0.4 and 1.

5.1.1 Test results, sample by sample

Sample KLX07A-90V-01

Figure 5-1. *Specimens KLX07A-90V-01.*

Table 5-1. Porosity, wet and dry density of specimens KLX07A-90V-01, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX07A-90V-01	2,750	2,750	0.4
Sec low: 347.958			

Table 5-2. Thermal properties of sample KLX07A-90V-01 at ambient temperature.

KLX07A-90V-01 Sec low: 347.958	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³. K)]
20°C			
Mean value	2.23	1.29	1.73
Standard deviation	0.003	0.004	0.007

Sample KLX07A-90V-02

Figure 5-2. *Specimens KLX07A-90V-02.*

Table 5-3. Porosity, wet and dry density of specimens KLX07A-90V-02, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX07A-90V-02	2,680	2,680	0.4
Sec low: 368.963			

Table 5-4. Thermal properties of sample KLX07A-90V-02 at ambient temperature.

KLX07A-90V-02 Sec low: 368.963	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.11	1.56	1.99
Standard deviation	0.001	0.004	0.006

Sample KLX07A-90V-03

Figure 5-3. *Specimens KLX07A-90V-03.*

Table 5-5. Porosity, wet and dry density of specimens KLX07A-90V-03, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX07A-90V-03	2,670	2,660	0.7
Sec low: 388.667			

Table 5-6. Thermal properties of sample KLX07A-90V-03 at ambient temperature.

KLX07A-90V-03 Sec low: 388.667	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.25	1.52	2.14
Standard deviation	0.007	0.006	0.009

Sample KLX07A-90V-04

Figure 5-4. *Specimens KLX07A-90V-04.*

Table 5-7. Porosity, wet and dry density of specimens KLX07A-90V-04, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX07A-90V-04 Sec low: 408.200	2,740	2,730	0.6

Table 5-8. Thermal properties of sample KLX07A-90V-04 at ambient temperature.

KLX07A-90V-04 Sec low: 408.200	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	2.52	1.10	2.29
Standard deviation	0.001	0.004	0.007

Sample KLX07A-90V-05

Figure 5-5. *Specimens KLX07A-90V-05.*

Table 5-9. Porosity, wet and dry density of specimens KLX07A-90V-05, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX07A-90V-05 Sec low: 428.120	2,690	2,680	0.4

Table 5-10. Thermal properties of sample KLX07A-90V-05 at ambient temperature.

KLX07A-90V-05 Sec low: 428.120	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	2.93	1.53	1.91
Standard deviation	0.017	0.024	0.042

5.2 Results for the entire test series

Table 5-11 displays the mean value of five repeated measurements of the thermal properties. Standard deviation is shown in Table 5-12.

The thermal conductivity and thermal diffusivity of specimens representing different depths at 20°C were in the range 2.23–3.25 W/(m, K) and 1.10–1.56 mm^2/s respectively. From these results the heat capacity was calculated and appeared to range between 1.73 and 2.29 $MJ/(m^3, K)$. A graphical representation of the heat conductivity and heat capacity versus borehole length is given in Figure 5-6.

The rock type of all specimens is Ävrö granite. However, the measured thermal properties of specimens KLX07A-90V-01 and KLX07A-90V-04 deviated from the other specimens. There is a large grain in specimen KLX07A-90V-01, see Figure 5-1. The grain cover a large part of the sensor area and this could be a reason for lower thermal conductivity in comparison with the other specimens. To find out the reason of deviation in specimen KLX07A-90V-04 further investigations is needed.

Standard deviations of the specimen KLX07-90V-05 is substantially higher than the other specimens. However, this deviation is in the acceptance range of repeatability of the measurements.

Table 5-11. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
KLX07A-90V-01	2.23	1.29	1.73
KLX07A-90V-02	3.11	1.56	1.99
KLX07A-90V-03	3.25	1.52	2.14
KLX07A-90V-04	2.52	1.10	2.29
KLX07A-90V-05	2.93	1.53	1.91

Table 5-12. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
KLX07A-90V-01	0.003	0.004	0.007
KLX07A-90V-02	0.001	0.004	0.006
KLX07A-90V-03	0.007	0.006	0.009
KLX07A-90V-04	0.001	0.004	0.007
KLX07A-90V-05	0.017	0.024	0.042

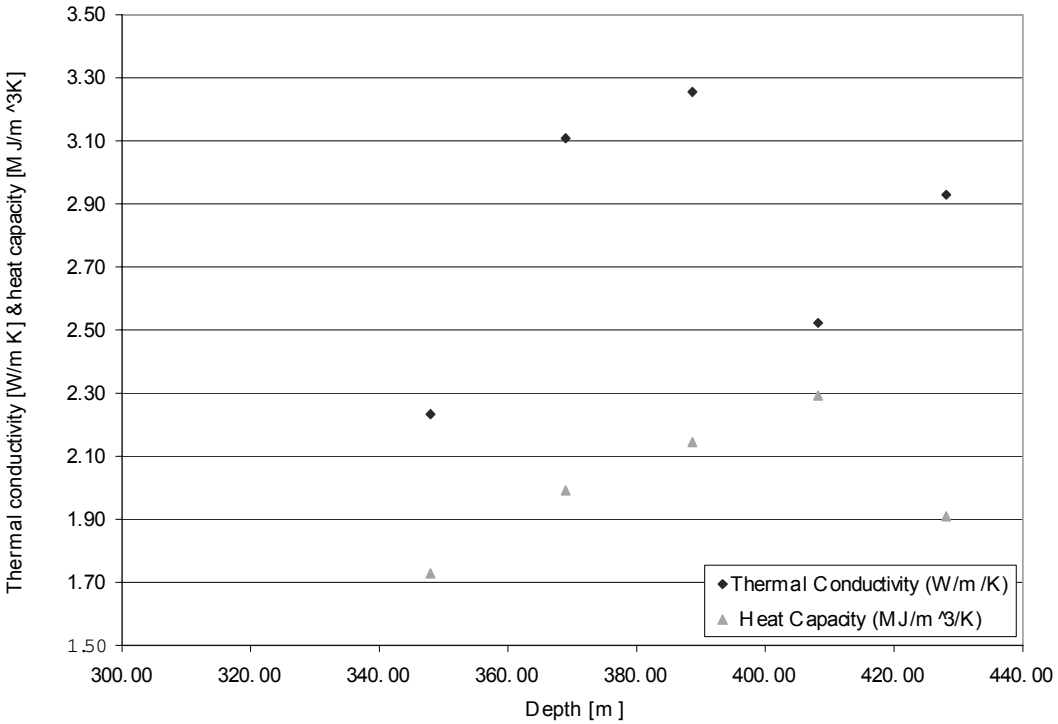

Figure 5-6. *Thermal conductivity and heat capacity at different depth at 20°C.*

6 References

/1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

/2/ **Gustafsson S E, 1991**. "Transient plane source techniques for thermal conductivity and thermal diffusivity measurements of solid materials". Rev. Sci. Instrum. 62 (3), March 1991, American Institute of Physics.

/3/ Instruction Manual Hot Disc Thermal Constants Analyser Windows 95 Version 5.0, 2001.

/4/ **ISRM, 1979.** ISRM Commission on Testing Methods.

Appendix A

Calibration protocol for Hot Disk Bridge System

Electronics:	Keithley 2400	Serial No. 0925167
	Keithley 2000	Serial No. 0921454
Hot Disk Bridge:		Serial No. 2003-0004
Computation Device:		Serial No. 2003-0003. ver 1.5
Computer:	Hot Disk computer	Serial No. 2003-0003
Test sample:	SIS2343. mild steel	Serial No. 3.52
Sensor for testing:	C5501	

Test measurement: 10 repeated measurements on the test sample at room temperature.
Conditions: Power 1 W. Measurement time 10 s.

Results.

Thermal Conductivity:	13.48 W/(m. K)	±0.04 %
Thermal Diffusivity:	3.516 mm^2/s	±0.12 %
Heat Capacity:	3.842 $MJ/(m^3. K)$	±0.15 %

This instrument has proved to behave according to specifications described in BRk-QB-M26-02.

Borås 29/09 2005

Patrik Nilsson

Appendix B

Table B-1 Thermal properties of samples at 20°C.

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
KLX07A-90V-01			
1	2.23	1.30	1.72
2	2.23	1.30	1.72
3	2.23	1.29	1.73
4	2.24	1.29	1.73
5	2.24	1.29	1.74
KLX07A 90V-02			
1	3.11	1.57	1.98
2	3.11	1.56	1.99
3	3.11	1.56	1.99
4	3.11	1.56	1.99
5	3.11	1.55	2.00
KLX07A 90V-03			
1	3.25	1.52	2.14
2	3.25	1.51	2.15
3	3.25	1.52	2.15
4	3.26	1.53	2.13
5	3.26	1.51	2.15
KLX07A 90V-04			
1	2.52	1.11	2.28
2	2.52	1.10	2.30
3	2.52	1.10	2.29
4	2.52	1.10	2.30
5	2.52	1.10	2.29
KLX07A 90V-05			
1	2.96	1.49	1.98
2	2.94	1.53	1.92
3	2.92	1.55	1.89
4	2.91	1.55	1.88
5	2.91	1.55	1.88

Appendix C

Table C-1. Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time(s)	Total/Char. Time	Points
KLX07A-90V-01			
1	20	0.59	52–187
2	20	0.59	54–187
3	20	0.59	58–187
4	20	0.58	56–187
5	20	0.58	57–187
KLX07A 90V-02			
1	20	0.76	58–200
2	20	0.76	58–200
3	20	0.76	58–200
4	20	0.76	58–200
5	20	0.75	58–200
KLX07A 90V-03			
1	20	0.74	70–200
2	20	0.73	70–200
3	20	0.74	70–200
4	20	0.74	70–200
5	20	0.73	70–200
KLX07A 90V-04			
1	20	0.54	58–200
2	20	0.53	58–200
3	20	0.53	58–200
4	20	0.53	58–200
5	20	0.53	58–200
KLX07A 90V-05			
1	20	0.68	42–187
2	20	0.69	42–186
3	20	0.70	67–187
4	20	0.70	69–186
5	20	0.70	69–187