P-05-129

Oskarshamn site investigation

Drill hole KLX06A

Thermal properties: heat conductivity and heat capacity determined using the TPS method

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May 2005

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Keywords: Thermal properties, Rock mechanics, Thermal conductivity, Thermal diffusivity, Heat capacity, Transient plane source method.

Abstract

Thermal properties on seven specimens of drill hole KLX06A, Laxemar, were measured at ambient temperature (20°C). The specimens were sampled on five levels in the drill hole ranging between 200 m and 285 m. The rock types of samples are mapped as Ävrö granite and Diorite-gabbro. The determination of the thermal properties are based on a direct measurement method, the so called "Transient Plane Source Method" (TPS), Gustafsson, 1991 /1/.

Thermal conductivity and thermal diffusivity of specimens at depth 200 m–285 m (approximately 20 m intervals) and specifically at 225 m at 20°C were in the range of 2.25–3.52 W/(m, K) and 0.93–1.71 mm^2/s respectively.

Sammanfattning

Termiska egenskaper hos sju provkroppar från borrhål KLX06A, Laxemar, bestämdes vid rumstemperatur (20°C). Proverna har tagits från fem nivåer i borrhålet mellan 200 och 285 m. De karterade bergarterna är av typen Ävrögranit och diorit-gabbro. TPS metoden, ”Transient Plane Source”, användes för bestämning av de termiska egenskaperna, Gustafsson, 1991 /1/.

Den termiska konduktiviteten och den termiska diffusiviteten hos provkropparna vid 20°C och vid djupen 200 m–285 m, samt specifikt vid 225 m, var 2,25–3,52 W/(m, K) respektive 0,93–1,71 mm^2/s.

Contents

1 Introduction

The objective of this investigation was to measure thermal properties of borehole KLX06A at Laxemar, see Figure 1-1, at ambient temperature (20°C) by using the TPS-method /1/. The thermal properties were determined for water-saturated specimens. The specimens, in form of circular discs, were cut from rock cores. The samples were selected based on the preliminary core logging and with the strategy to primarily investigate the properties of the dominant rock properties. The principle of the TPS method is to place a sensor between two rock samples. The sensor consists of a thin metal double spiral, embedded in an insulation material. 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 heat conductivity and diffusivity of a material and from this the volumetric heat capacity can be determined, if the density is known.

The test programme follows the activity plan AP PS 400–05-012 (SKB internal controlling document) and is controlled by SP-QD 13.1 (SP quality document).

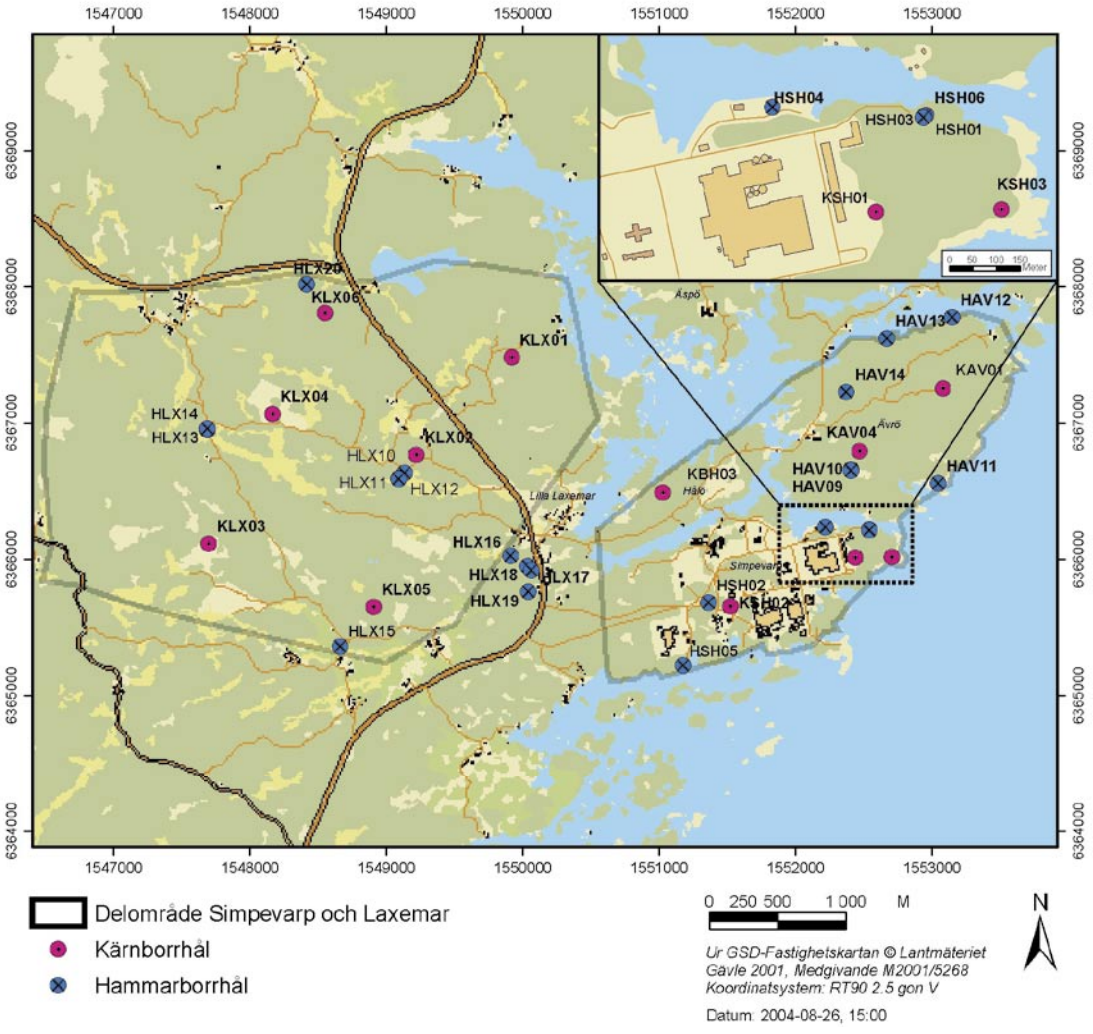

Figure 1-1. *Location of the drill hole KLX06A at the Oskarshamn site investigation area.*

The samples were water saturated and stored in this condition for seven days. This yields complete water saturation whereupon the density and the thermal properties were determined. The specimens were photographed before testing.

The rock cores arrived to SP in February 2005. The testing was performed during April 2005.

Determination of thermal properties was made in accordance to SKB's method description SKB MD 191.001, (SKB internal controlling document) at SP Fire Technology. Density was determined in accordance to SKB MD 160.002, (SKB internal controlling document) at SP Building Technology and Mechanics.

2 Objective and scope

The purpose of the testing is to determine the thermal properties of rock specimens. The results shall be used for the site descriptive modelling of thermal properties, which will be established for the candidate area selected for site investigations at Oskarshamn.

The samples are taken from the borehole KLX06A in Laxemar. The specimens were sampled on five levels in the drill hole, randomly distributed at approximately 20 m intervals between 200 m and 285 m. The investigated rock types are mapped as Ävrö granite and Diorite-gabbro.

3 Equipment

Technical devices for determination of thermal properties used 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 /2/.
- TPS-apparatus, Source meter Keithley 2400, Multi-meter Keithley 2000 and bridge, see Figure 3-1.
- PC + Microsoft Office and Hot Disk version 5.4.
- Stainless Sample holder.

Specimen mounting is shown in Figure 3-2.

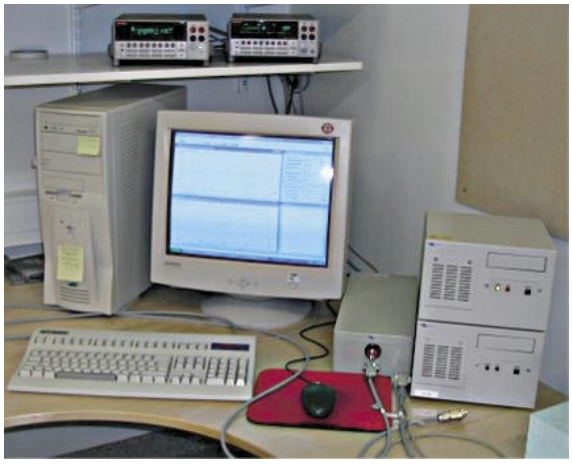

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

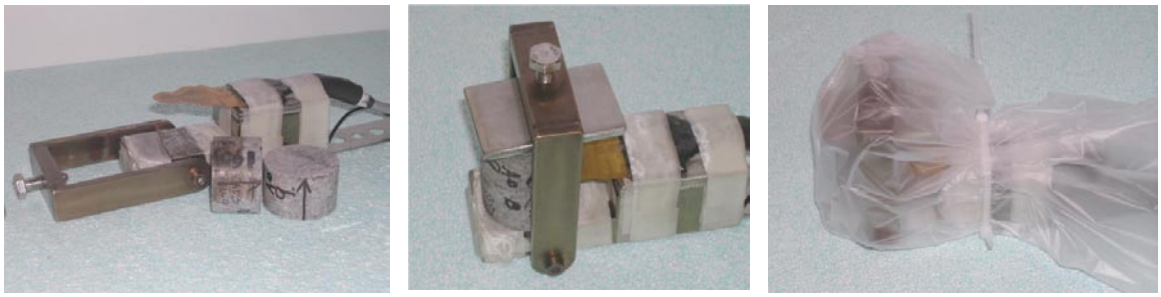

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

Determination of thermal properties was made in accordance to SKB's method description SKB MD 191.001, (SKB internal controlling document) and Hot Disc Instruction Manual /2/ at SP Fire Technology.

Density was determined in accordance to SKB MD 160.002 (SKB internal controlling document) and ISRM /3/.

4.1 Description of the samples

Seven pairs of cores were collected from drill hole KLX06A, Laxemar, Sweden. Rock cores one to five were randomly sampled with approximately 20 m interval at depth between 200 m and 285 m. Rock cores six and seven were sampled at 225 m. The fourteen 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 KLX06A and in the SICADA database at SKB.

Table 4-1. Rock type and identification marks (Rock-type classification according to the overview mapping).

Identification	Rock type	Sampling depth (Adj sec low)
KLX06A-90V-01	Ävrö granite	199.31
KLX06A-90V-02	Ävrö granite	221.37
KLX06A-90V-03	Ävrö granite	243.24
KLX06A-90V-04	Ävrö granite	263.60
KLX06A-90V-05	Ävrö granite	285.61
KLX06A-90V-06	Diorite-gabbro	224.78
KLX06A-90V-07	Diorite-gabbro	224.84

4.2 Test procedure

4.2.1 Thermal properties

The following steps were performed:

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

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

Each core pair 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.

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

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

Thermal properties, density and porosity measurements were performed during April 2005.

Dry weight was measured after the specimens had been dried to constant mass according to ISMR /3/ at 105°C. The drying procedure took seven days.

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 KLX06A-90V-01

Figure 5-1. *Specimens KLX06A-90V-01.*

Table 5-1. Porosity, wet and dry density of specimens KLX06A-90V-01, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-01 Adj sec low: 199.31	2,670	2,660	0.3

Table 5-2. Thermal properties of sample KLX06A-90V-01 at ambient temperature.

KLX06A-90V-01 **Adj sec low: 199.31**	**Conductivity** **[W/(m, K)]**	**Diffusivity** [mm²/s]	**Heat capacity** [MJ/(m³, K)]
20°C			
Mean value	3.25	1.48	2.20
Standard deviation	0.013	0.008	0.021

Sample KLX06A-90V-02

Figure 5-2. *Specimens KLX06A-90V-02.*

Table 5-3. Porosity, wet and dry density of specimens KLX06A-90V-02, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-02	2,650	2,650	0.6
Adj sec low: 221.37			

Table 5-4. Thermal properties of sample KLX06A-90V-02 at ambient temperature.

KLX06A-90V-02 Adj sec low: 221.37	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.47	1.57	2.21
Standard deviation	0.011	0.008	0.013

Sample KLX06A-90V-03

Figure 5-3. *Specimens KLX06A-90V-03.*

Table 5-5. Porosity, wet and dry density of specimens KLX06A-90V-03, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-03	2,650	2,650	0.5
Adj sec low: 243.24			

Table 5-6. Thermal properties of sample KLX06A-90V-03 at ambient temperature.

KLX06A-90V-03 Adj sec low: 243.24	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.24	1.40	2.31
Standard deviation	0.004	0.003	0.006

Sample KLX06A-90V-04

Figure 5-4. *Specimens KLX06A-90V-04.*

Table 5-7. Porosity, wet and dry density of specimens KLX06A-90V-04, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-04	2,670	2,660	0.5
Adj sec low: 263.60			

Table 5-8. Thermal properties of sample KLX06A-90V-04 at ambient temperature.

KLX06A-90V-04 Adj sec low: 263.60	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.10	1.71	1.81
Standard deviation	0.004	0.004	0.006

Sample KLX06A-90V-05

Figure 5-5. *Specimens KLX06A-90V-05.*

Table 5-9. Porosity, wet and dry density of specimens KLX06A-90V-05, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-05	2,660	2,650	0.4
Adj sec low: 285.61			

Table 5-10. Thermal properties of sample KLX06A-90V-05 at ambient temperature.

KLX06A-90V-05 Adj sec low: 285.61	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.52	1.42	2.49
Standard deviation	0.005	0.003	0.009

Sample KLX06A-90V-06

Figure 5-6. *Specimens KLX06A-90V-06.*

Table 5-11. Porosity, wet and dry density of specimens KLX06A-90V-06, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-06	2,880	2,870	1.0
Adj sec low: 224.78			

Table 5-12. Thermal properties of sample KLX06A-90V-06 at ambient temperature.

KLX06A-90V-06 Adj sec low: 224.78	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	2.25	0.93	2.42
Standard deviation	0.005	0.007	0.023

Sample KLX06A-90V-07

Figure 5-7. *Specimens KLX06A-90V-07.*

Table 5-13. Porosity, wet and dry density of specimens KLX06A-90V-07, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX06A-90V-07	2,880	2,870	1.0
Adj sec low: 224.84			

Table 5-14. Thermal properties of sample KLX06A-90V-07 at ambient temperature.

KLX06A-90V-07 Adj sec low: 224.84	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	2.31	0.98	2.36
Standard deviation	0.007	0.007	0.021

5.1.2 Results for the entire test series

Table 5-15 shows the mean value of five repeated measurements of the thermal properties. Standard deviation is shown in Table 5-16.

Thermal conductivity and thermal diffusivity of specimens at different depth at 20°C were in the range of 2.25–3.52 W/(m, K) and 0.93–1.71 mm^2/s respectively.

Table 5-15. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
KLX06A-90V-01	3.25	1.48	2.20
KLX06A-90V-02	3.47	1.57	2.21
KLX06A-90V-03	3.24	1.40	2.31
KLX06A-90V-04	3.10	1.71	1.81
KLX06A-90V-05	3.52	1.42	2.49
Mean value, levels 200–285	3.32	1.52	2.20
KLX06A-90V-06	2.25	0.93	2.42
KLX06A-90V-07	2.31	0.98	2.36
Mean value, level 225	2.28	0.96	2.39

Table 5-16. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m. K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3. K)$]
KLX06A-90V-01	0.013	0.008	0.021
KLX06A-90V-02	0.011	0.008	0.013
KLX06A-90V-03	0.004	0.003	0.006
KLX06A-90V-04	0.004	0.004	0.006
KLX06A-90V-05	0.005	0.003	0.009
KLX06A-90V-06	0.005	0.007	0.023
KLX06A-90V-07	0.007	0.007	0.021

Graphical presentation of results

Variation of the thermal conductivity and heat capacity in relation to depth of the sampling at different temperatures are shown in Figure 5-8.

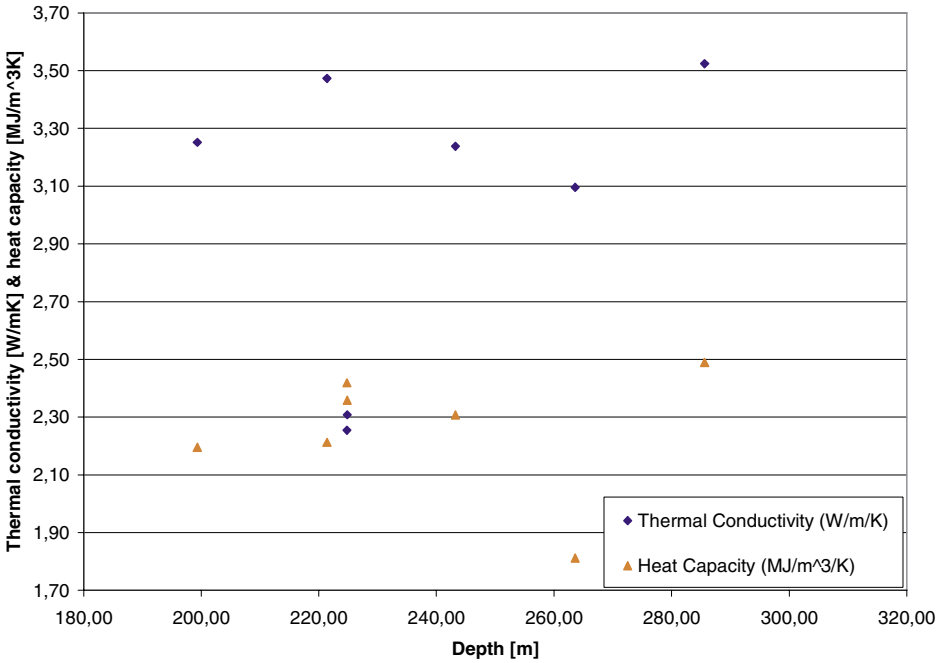

Figure 5-8. *Thermal conductivity and heat capacity at different depth at 20°C.*

5.2 Discussion

There were no deviations to the plans.

6 References

/1/ **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.

/2/ **Instruction Manual Hot Disc Thermal Constants Analyser Windows 95 Version 5.0, 2001.**

/3/ **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:	13.47 W/(m. K)	±0.05 %
Thermal Diffusivity:	3.511 mm^2/s	±0.22 %
Heat Capacity:	3.837 $MJ/(m^3. K)$	±0.22 %

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

Borås 24/01, 2005

Patrik Nilsson

Appendix B

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

Measurement number	Conductivity [W/(m. K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3. K)]
KLX06A-90V-01			
1	3.27	1.47	2.22
2	3.26	1.48	2.21
3	3.25	1.48	2.20
4	3.25	1.48	2.20
5	3.23	1.50	2.16
KLX06A-90V-02			
1	3.47	1.57	2.20
2	3.49	1.56	2.23
3	3.48	1.57	2.21
4	3.48	1.58	2.20
5	3.46	1.56	2.21
KLX06A-90V-03			
1	3.24	1.40	2.31
2	3.23	1.40	2.31
3	3.24	1.41	2.30
4	3.23	1.41	2.30
5	3.24	1.40	2.31
KLX06A-90V-04			
1	3.10	1.71	1.81
2	3.10	1.71	1.81
3	3.09	1.71	1.80
4	3.09	1.71	1.81
5	3.09	1.70	1.82
KLX06A-90V-05			
1	3.53	1.41	2.49
2	3.53	1.41	2.50
3	3.52	1.42	2.49
4	3.52	1.42	2.48
5	3.52	1.42	2.48
KLX06A-90V-06			
1	2.25	0.94	2.40
2	2.26	0.92	2.44
3	2.26	0.93	2.44
4	2.25	0.93	2.42
5	2.25	0.94	2.40
KLX06A-90V-07			
1	2.30	0.99	2.33
2	2.31	0.97	2.38
3	2.31	0.98	2.37
4	2.31	0.98	2.37
5	2.31	0.98	2.35

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
KLX06A-90V-01			
1	20	0.72	31–200
2	20	0.72	46–200
3	20	0.72	39–200
4	20	0.72	48–200
5	20	0.73	38–200
KLX06A-90V-02			
1	20	0.73	47–191
2	20	0.62	22–164
3	20	0.76	59–200
4	20	0.77	45–200
5	20	0.75	62–199
KLX06A-90V-03			
1	20	0.66	57–193
2	20	0.67	75–196
3	20	0.59	47–172
4	20	0.65	50–191
5	20	0.68	45–200
KLX06A-90V-04			
1	20	0.83	53–200
2	20	0.83	43–200
3	20	0.83	42–199
4	20	0.83	38–200
5	20	0.83	34–200
KLX06A-90V-05			
1	20	0.60	43–175
2	20	0.68	60–200
3	20	0.65	47–190
4	20	0.69	51–200
5	20	0.69	57–200
KLX06A-90V-06			
1	20	0.45	45–199
2	20	0.45	53–200
3	20	0.45	49–200
4	20	0.45	32–200
5	20	0.46	35–200
KLX06A-90V-07			
1	20	0.48	70–200
2	20	0.47	68–200
3	20	0.41	43–174
4	20	0.46	41–196
5	20	0.48	33–200