P-04-186

Forsmark site investigation

Drill hole KFM01A

Thermal properties: thermal conductivity and specific heat capacity determined using the Hot Disk thermal constants analyser (the TPS technique) – Compared test

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August 2004

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Abstract

The thermal conductivity (TC) and the specific heat capacity (Cp) of 10 drill core samples from drill hole KFM01A, Forsmark, Sweden, have been measured with the Hot Disk® Thermal Constants Analyser (the TPS method). The rock type of the samples is Medium-grained metagranodiorite-granite.

The specimens were sampled on one level in the drill hole: 500 m. The thermal conductivities at 20°C were in the range 3.64–3.98 W/mK, at 50°C in the range 3.54–3.81 W/mK and at 80°C in the range 3.37–3.57 W/mK. The specific heat capacity at 20°C were in the range 1.97–2.34 MJ/m^{3}K, at 50°C in the range 2.16–2.49 MJ/m^{3}K and at 80°C in the range 2.29–2.59 MJ/m^{3}K.

Generally the thermal conductivity of the samples decreased with temperature with an average of 7.9% from 20°C to 80°C, whereas the specific thermal capacity increased with c 17% within the same temperature interval.

Contents

1 Introduction and objective

This document reports the data collected by laboratory investigations regarding thermal properties of drill core samples from borehole KFM01A at Forsmark, Sweden, see Figure 1-1, which is one of the activities performed as part of the on-going site investigation. The work was carried out in accordance with activity plan AP PF 400-04-06 (SKB internal controlling document) and method description MD 191.001, version 1.9 (SKB internal controlling document).

The objective of this investigation was to measure thermal properties of samples from borehole KFM01A at different temperature levels (20, 50 and 80°C) by using the TPS method. The measurements were carried out on water saturated cylindrical specimens cut from the 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 types.

Specimens from borehole KFM01A were taken from the Forsmark site on February 24, 2003, by SKB and the Swedish National Testing and Research Institute (SP). The cores were marked and cut and the thermal properties measured at the SP laboratory during December 2003. The rock cores arrived at Hot Disk AB, Uppsala, on February 16, 2004, and the measurements were carried out in February and March 2004. Prior to the measurements the samples were water saturated for at least 7 days and the density was determined in accordance with SKB MD 160.002, version 1.9 (SKB internal controlling document).

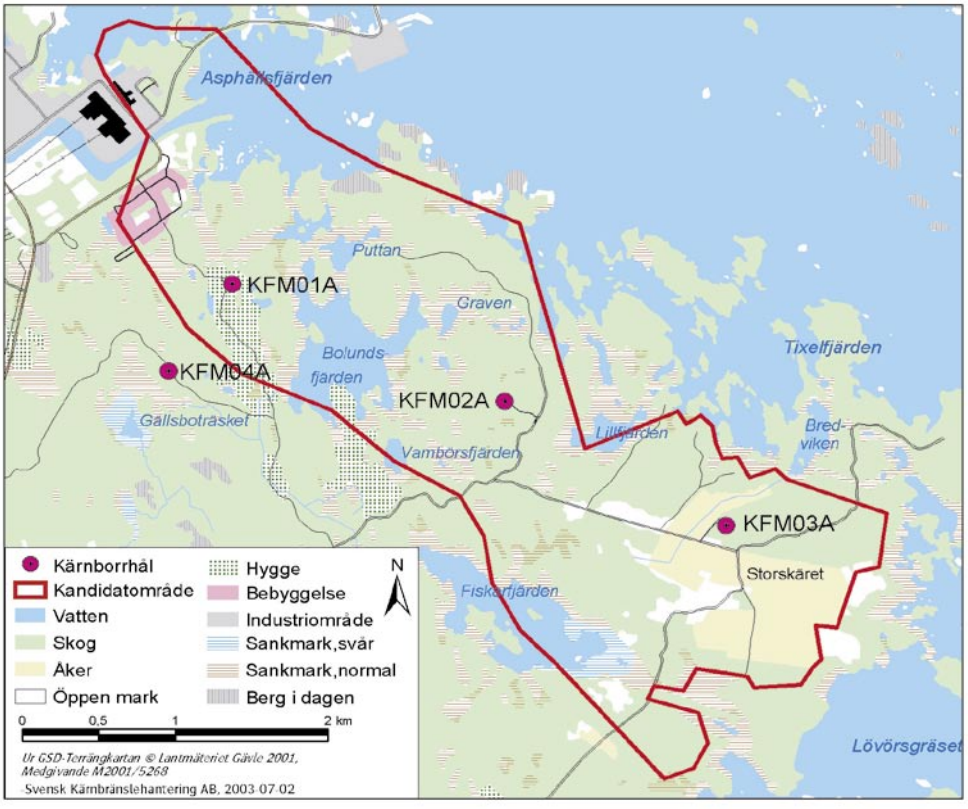


Figure 1-1. *The candidate area with the first four deep core drilled boreholes at Forsmark.*

The principle of the TPS instrument is to place a circular temperature probe and heater between two pieces of the sample. This probe consists of a Ni-spiral covered by an insulating material (MICA or KAPTON). During the measurement, a constant power is emitted by the sensor and the heating of the specimen is recorded simultaneously. The data is then treated in the Hot Disk software and the thermal conductivity (TC), thermal diffusivity (TD) and specific heat capacity (C_p) is determined.

2 Scope

The results from the tests performed by Hot Disk AB are to be compared to measurements carried out at SP, Borås. The specimens from borehole KFM01A in Forsmark were sampled from c 500 m borehole length.

The results will also be used in the rock thermal model, which will be established for the candidate area selected for site investigations at Forsmark.

3 Equipment

The equipment used for the measurements was a Hot Disk thermal constants analyser.

The following components are included in the Hot Disk instrument (Figure 3-1):

1. Hot Disk bridge unit,
2. Keithley 2400 source/metre,
3. Keithley 2000 volt metre,
4. PC,
5. Computation Device,
6. Hot Disk SW, version 5.7.

The sensor used for the measurements (Figure 3-2) had a radius of 6.401 mm (S/N C5501) and the temperature of the sample was regulated with a ThermoHaake C50P oilbaath. Sample set-up is shown in Section 4.2.

Additional equipment was rubber bands, plastic bags, table cloth and plastic straps, see Section 4.2.

Figure 3-1. *Hot Disk instrument.*

Figure 3-2. *Hot Disk sensor.*

4 Execution

4.1 Samples

The samples were received on February 16, 2004, and all the samples were carefully taken out of the box and catalogued in a table "SKB-sample register" (Table 4-1). This sample register was used as a log of the measurements. A cross was put into the table at each completed measurement. The samples are labeled FOIA-90V-X, where X denotes a number.

A total of 26 (52 samples, 25 mm high, 50 mm diameter) cores were sampled from one level of borehole KFM01A, Forsmark. The samples tested by Hot Disk came from the depths (borehole length) around 490 metres according to Table 4-2. Detailed geological description of the rock is given in SKB's BOREMAP of KFM01A in the SICADA database at SKB.

Table 4-1. SKB sample register. The two columns denoted "Weight" contains the individual weights of the two sample bodies.

Sample ID	Soaking date	Measurement date	Weight (g) (wet)	Weight (g) (wet)	22°C	50°C	80°C	Comment on measurement
FOIA-90V-16	27 feb	11/3	138.52	138.85	X	X	X	Ok
14	27 feb	12/3	138.83	138.45	X	X	X	Ok
13	27 feb	12/3	135.27	138.72	X	X	X	Ok
12	27 feb	10/3	138.76	138.14	X	X	X	Ok
15	2 mar	15/3	138.84	139.00	X	X	X	Ok
20	2 mar	15/3	138.64	138.63	X	X	X	Ok
18	2 mar	17/3	138.80	137.27	X	X	X	Ok
19	4 mar	17/3	138.06	136.36	X	X	X	Ok
17	4 mar	18/3	138.69	138.91	X	X	X	Ok
11	4 mar	16/3	137.84	137.22	X	X	X	Re-measurement Sensor break-down
Re-measurements								
FOIA-90V-11	>7 days	29/3	137.84	137.225	X	X	X	Ok

Table 4-2. Rock type and identification marks. All rock types are medium grained.

Sample ID	Rock Type	Sampling depth (Sec Low)
F01A-90V-11	Metagranodiorite granite	492.51
F01A-90V-12	Metagranodiorite granite	493.85
F01A-90V-13	Metagranodiorite granite	493.97
F01A-90V-14	Metagranodiorite granite	494.09
F01A-90V-15	Metagranodiorite granite	494.20
F01A-90V-16	Metagranodiorite granite	494.32
F01A-90V-17	Metagranodiorite granite	494.43
F01A-90V-18	Metagranodiorite granite	494.62
F01A-90V-19	Metagranodiorite granite	494.74
F01A-90V-20	Metagranodiorite granite	494.94

4.2 Measurements

All measurements were carried out with the Hot Disk Bridge system and an oil-bath (ThermoHaake C50P) for temperature regulations.

Prior to the measurement all samples were soaked in water for a period of at least 7 days. With a rough frequency of one sample per day, the samples were taken out from the water and dried with a wet cloth and after that immediately weighed and measured.

The samples were then prepared for the measurement in the following way:

1. The sensor was sandwiched between the samples and the sample pieces were thoroughly forced together with a plastic strap, see Figure 4-1.

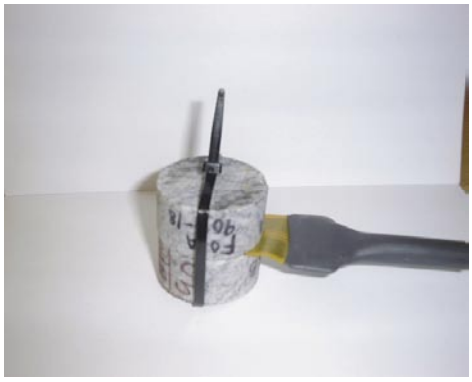


Figure 4-1.

2. The sensor, sample and plastic strap were then enclosed in a plastic bag (air was manually sucked out of the plastic bag and the bag was thereafter sealed off with a rubber band), see Figure 4-2.

Figure 4-2.

3. The next layer was a wet cloth wrapped around the sample (fixation: a rubber band). This was done so that the plastic bags were not punctured, see Figure 4-3.

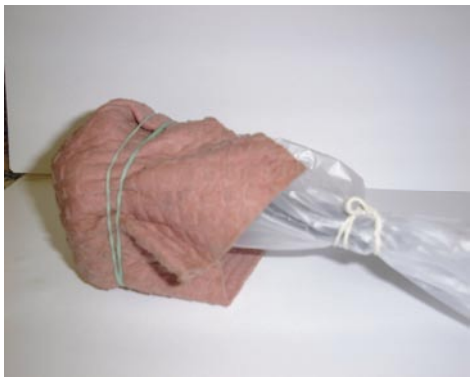


Figure 4-3.

4. Finally, a last plastic bag enclosed the whole "sample package" (air was manually sucked out of the plastic bag and the bag was thereafter sealed off with a rubber band), see Figure 4-4.

Figure 4-4.

As a cooling and heating facility an oil bath was used with a special sample compartment immersed into the bath. The oil bath keeps the temperature stable whithin at least +/–1°C. In order to allow fast heat transfer from the oil to the sample, the sample compartment was filled with water. The plastic bags + sample were suspended in so that the sample was hanging freely in the water, see Figure 4-5.

Figure 4-5.

Five measurements were carried out at each temperature (20°C, 50°C and 80°C) for each sample. The sensor chosen for the measurements was a C5501 (radius 6.401 mm) and power and measurement time were 0.7 W and 20 s respectively. These measurement parameters proved to give a rough temperature increase of 0.5–1.5 K in the interval of calculation, a total to characteristic time well whithin the interval 0.3 and 1.0 and an experimental probing depth less than the maximum allowed probing depth.

Before increasing the temperature to the next temperature level, the measured files were monitored to assure that the measurement series was complete. In those cases where one measurement could be doubted (for any reason) an extra measurement was carried out. The measurement files (raw data files) were stored on the measurement computer and also on the server and one personal computer for safety. The files were named as:

FOIA-90V-Samplenumber_temperature. Sequence number.hot.

Example: FOIA-90V-1_80.3.hot.

After the measurements the samples were stored in room temperature (RT) without any cover.

Calculations of the measurement files were carried out according to the Hot Disk manual, entailing that the selected points of calculation were chosen so that the points fitted the thermal conductivity equation as well as possible. The data were then transferred into Microsoft® Excel for further treatment.

Since the Hot Disk Constants Analyser is an absolute method, there is no need for calibration in between measurements. The quality of the sensors was checked regularly by measuring a SIS 2343 mildsteel sample. If no deviation to the normal value 13.88 +/–0.7 W/mK (5%), the sensor was judged as fully functioning.

4.3 Nonconformities

Sample FOIA-90V-11 was re-measured since the sensor used was suspected to have been broken during the measurement. The sample was then again soaked in water for 7 days and then measured in the same manner as the other samples. The results from these measurements were compared to the original ones, see Section 5.3.

5 Results

Mean values of measured data, five repeated measurements, are reported in Section 5.1 and in the SICADA database (field note no Forsmark 96) at SKB. Values of each separate measurement are reported in Appendix.

5.1 Measurement results per sample

The results of the measurements are given in the tables and figures below (Tables and Figures 5-1 to 5-10). All values are means from 5 individual measurements. Graphs from the measurements are presented in Appendix. TC = thermal conductivity, Cp = specific heat capacity and Std = standard deviation.

FOIA-90V-11

Table 5-1 and Figure 5-1. Results and picture for sample FOIA-90V-11.

FOIA-90V-11 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m³K]	Std [MJ/m³K]
20	3.868	0.006	2.336	0.003
50	3.72	0.01	2.490	0.006
80	3.427	0.005	2.52	0.05

FOIA-90V-12

Table 5-2 and Figure 5-2. Results and picture for sample FOIA-90V-12.

FOIA-90V-12 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.84	0.02	2.33	0.02
50	3.65	0.02	2.446	0.003
80	3.42	0.02	2.502	0.007

FOIA-90V-13

Table 5-3 and Figure 5-3. Results and picture for sample FOIA-90V-13.

FOIA-90V-13 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.71	0.01	2.18	0.01
50	3.58	0.03	2.41	0.03
80	3.37	0.02	2.59	0.02

FOIA-90V-14

Table 5-4 and Figure 5-4. Results and picture for sample FOIA-90V-14.

FOIA-90V-14 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.832	0.003	2.27	0.00
50	3.67	0.02	2.42	0.00
80	3.422	0.007	2.48	0.04

FOIA-90V-15

Table 5-5 and Figure 5-5. Results and picture for sample FOIA-90V-15.

FOIA-90V-15 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.8193	0.0008	2.30	0.00
50	3.69	0.01	2.46	0.02
80	3.51	0.01	2.58	0.01

FOIA-90V-16

Table 5-6 and Figure 5-6. Results and picture for sample FOIA-90V-16.

FOIA-90V-16 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.78	0.02	1.99	0.05
50	3.68	0.03	2.25	0.05
80	3.45	0.02	2.35	0.05

FOIA-90V-17

Table 5-7 and Figure 5-7. Results and picture for sample FOIA-90V-17.

FOIA-90V-17 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.76	0.02	2.12	0.04
50	3.64	0.01	2.39	0.01
80	3.37	0.02	2.47	0.03

FOIA-90V-18

Table 5-8 and Figure 5-8. Results and picture for sample FOIA-90V-18.

FOIA-90V-18 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.64	0.01	1.97	0.00
50	3.54	0.01	2.16	0.01
80	3.37	0.02	2.29	0.07

FOIA-90V-19

Table 5-9 and Figure 5-9. Results and picture for sample FOIA-90V-19.

FOIA-90V-19 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.72	0.004	2.14	0.01
50	3.58	0.01	2.33	0.01
80	3.39	0.01	2.46	0.00

FOIA-90V-20

Table 5-10 and Figure 5-10. Results and picture for sample FOIA-90V-20.

FOIA-90V-20 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.98	0.01	2.25	0.01
50	3.81	0.01	2.39	0.01
80	3.57	0.01	2.44	0.01

5.2 Summary of results

Below, Table 5-11, the results of the thermal conductivity (TC) and the specific heat capacity (Cp) are presented for each temperature and the different specimens.

Table 5-11. Thermal conductivity and Specific heat capacity, with corresponding standard deviations for the samples FOIA-20V-11 to FOIA-20V-20. The re-measured series are included in the average values.

Sample (20°C)	TC [W/mK]	Std [W/mK]	Cp [MJ/m³K]	Std [MJ/m³K]
FOIA-90V-11	3.87	0.006	2.34	0.003
FOIA-90V-12	3.84	0.02	2.33	0.02
FOIA-90V-13	3.71	0.01	2.18	0.01
FOIA-90V-14	3.83	0.003	2.27	0.005
FOIA-90V-15	3.82	0.001	2.30	0.002
FOIA-90V-16	3.78	0.02	1.99	0.05
FOIA-90V-17	3.76	0.02	2.12	0.04
FOIA-90V-18	3.64	0.008	1.97	0.004
FOIA-90V-19	3.72	0.004	2.14	0.01
FOIA-90V-20	3.98	0.007	2.25	0.01
FOIA-90V-11 Remeas	3.85	0.02	2.32	0.05
Mean level 490 m	**3.80**	**0.010**	**2.20**	**0.019**
Sample (50°C)	**TC [W/mK]**	**Std [W/mK]**	**Cp [MJ/m³K]**	**Std [MJ/m³K]**
FOIA-90V-11	3.72	0.01	2.49	0.006
FOIA-90V-12	3.65	0.02	2.45	0.003
FOIA-90V-13	3.58	0.03	2.41	0.03
FOIA-90V-14	3.67	0.02	2.42	0.00
FOIA-90V-15	3.69	0.01	2.46	0.02
FOIA-90V-16	3.68	0.03	2.25	0.05
FOIA-90V-17	3.64	0.01	2.39	0.01
FOIA-90V-18	3.54	0.01	2.16	0.01
FOIA-90V-19	3.58	0.01	2.33	0.01
FOIA-90V-20	3.81	0.01	2.39	0.01
FOIA-90V-11 Remeas	3.70	0.010	2.45	0.005
Mean level 490 m	**3.66**	**0.017**	**2.38**	**0.015**
Sample (80°C)	**TC [W/mK]**	**Std [W/mK]**	**Cp [MJ/m³K]**	**Std [MJ/m³K]**
FOIA-90V-11	3.43	0.005	2.52	0.05
FOIA-90V-12	3.42	0.02	2.50	0.007
FOIA-90V-13	3.37	0.02	2.59	0.02
FOIA-90V-14	3.42	0.007	2.48	0.04
FOIA-90V-15	3.51	0.01	2.58	0.01
FOIA-90V-16	3.45	0.02	2.35	0.05
FOIA-90V-17	3.37	0.02	2.47	0.03
FOIA-90V-18	3.37	0.02	2.29	0.07
FOIA-90V-19	3.39	0.01	2.46	0.00
FOIA-90V-20	3.57	0.01	2.44	0.01
FOIA-90V-11 Remeas	3.50	0.01	2.57	0.007
Mean level 490	**3.44**	**0.014**	**2.48**	**0.027**

The results from Table 5-11 are plotted vs depth below in Figure 5-11 a, b and c. The depths have been taken from Table 4-2. The thermal conductivities at 20°C were in the range 3.64–3.98 W/mK, at 50°C in the range 3.54–3.81 W/mK and at 80°C in the range 3.37–3.57 W/mK.

The specific heat capacities at 20°C were in the range 1.97–2.34 MJ/m^{3}K, at 50°C in the range 2.16–2.49 MJ/m^{3}K and at 80°C in the range 2.29–2.59 MJ/m^{3}K.

Generally the thermal conductivity of the samples decreased with temperature with an average of 7.9% from 20°C to 80°C (values taken from Table 5-11, average values for each temperature).

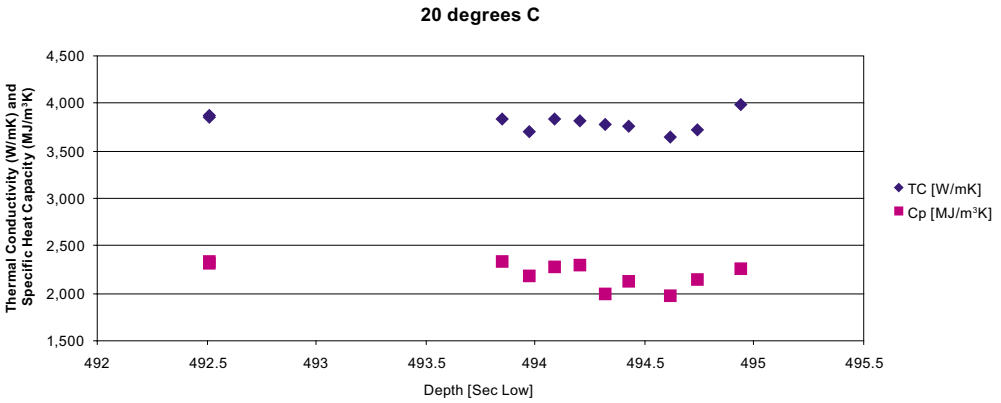


Figure 5-11a. *The results plotted vs depth. Cp and TC at 20 degrees C.*

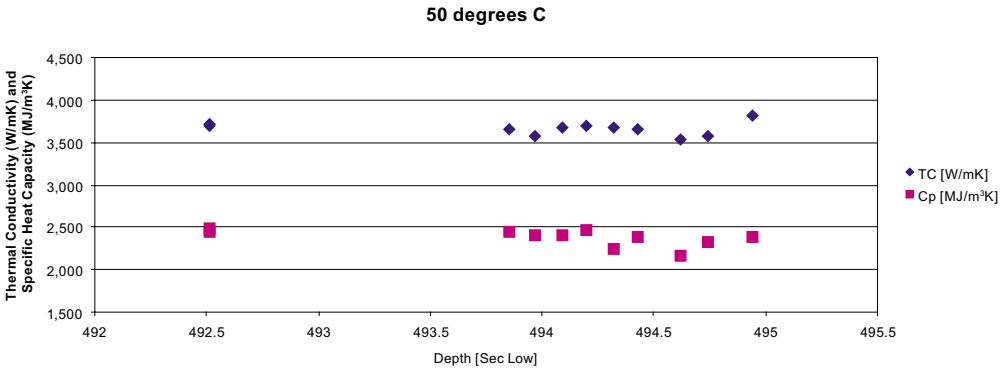


Figure 5-11b. *The results plotted vs depth. Cp and TC at 50 degrees C.*

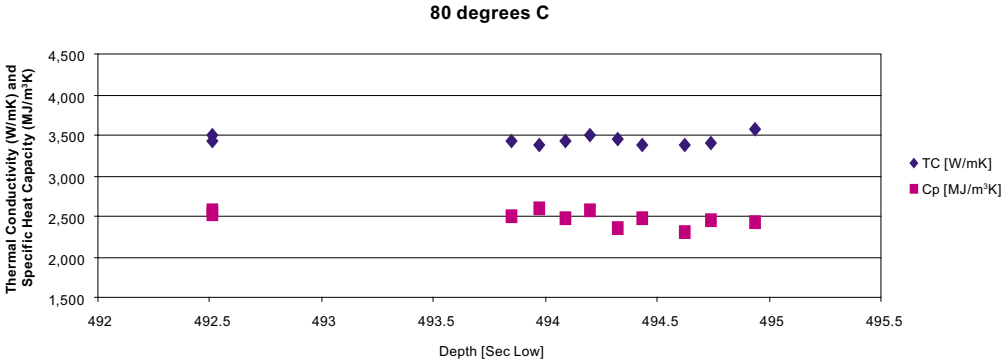


Figure 5-11c. *The results plotted vs depth. Cp and TC at 80 (c) degrees C.*

5.3 Deviations from measurement plan

In those cases where it was found necessary, additional measurements were carried out to ensure high quality of the data.

- Sample FOIA-90V-11 was remeasured due to suspected sensor malfunction (for procedure, see Execution section). The results are given below (Table 5-12). The sensor vs sample orientation was not considered during these measurements. Thus the results can derive from different volumes of the sample.

Table 5-12 (a and b). The results of the original measurement respectively the re-measurement of sample FOIA-90V-11 (a) is the same table as Table 5-1 and the average values in (b) are included in the average values in Table 5-11.

a)

FOIA-90V-11 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.868	0.006	2.336	0.003
50	3.72	0.01	2.490	0.006
80	3.427	0.005	2.52	0.05

b)

FOIA-90V-11 remeasurement Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m^{3}K]	Std [MJ/m^{3}K]
20	3.85	0.02	2.32	0.05
50	3.70	0.01	2.446	0.005
80	3.50	0.01	2.571	0.007

- The following measurements were replaced with extra measurements.

  –FOIA-90V-18_20.1a.hot, due to deviating disk resistance.

5.4 Discussion

Thermal conductivity and Specific heat capacity of rock samples from borehole KFM01A, Forsmark, have been measured with the Hot Disk instrument at Hot Disk AB, Uppsala. The thermal conductivity of the measured samples is strongly temperature dependent. Common for the samples is that the thermal conductivity is decreasing with increasing temperature, whereas the specific heat capacity is increasing with increasing temperature. In average the thermal conductivity is decreasing with 7.9% over the temperature interval 20–80°C for the specimens. The remeasured values (new sensor and resoaked for at least 7 days) show little deviation from the original measurements. Thus, it is concluded that the original measurements are of the same quality as the other measurements. The specific heat capacity values tend to increase with temperature some 17% over the temperature interval 20–80°C (from Table 5-11).

It is possible that the inhomogenities in the samples may affect the results, entailing that the mounting of the sensor is crucial for the measurement result.

Appendix

Measurement results and thermal conductivity and heat capacity plots

On the following pages the results per sample is given (Table A1 and figures following the table).

Table A1. The Measurement results for all individual measurements.

File	Points for calculation	T[C]	TC [W/mK]	TD [mm²/s]	Cp [MJ/m³K]
FOIA-90V-11_20. 1.hot	(50–200,tc)	20°C	3.860	1.651	2.338
FOIA-90V-11_20. 2.hot	(50–200,tc)	20°C	3.865	1.654	2.336
FOIA-90V-11_20. 3.hot	(50–200,tc)	20°C	3.867	1.659	2.330
FOIA-90V-11_20. 4.hot	(50–200,tc)	20°C	3.872	1.658	2.336
FOIA-90V-11_20. 5.hot	(50–200,tc)	20°C	3.875	1.657	2.338
AVERAGE			**3.868**	**1.656**	**2.336**
STDEV			**0.006**	**0.003**	**0.003**
STDEV %			**0.156**	**0.207**	**0.139**
FOIA-90V-11_50. 1.hot	(50–200,tc)	50°C	3.739	1.504	2.487
FOIA-90V-11_50. 2.hot	(50–200,tc)	50°C	3.727	1.497	2.490
FOIA-90V-11_50. 3.hot	(50–200,tc)	50°C	3.721	1.489	2.499
FOIA-90V-11_50. 4.hot	(51–200,tc)	50°C	3.712	1.495	2.482
FOIA-90V-11_50. 5.hot	(50–200,tc)	50°C	3.710	1.489	2.492
AVERAGE			**3.722**	**1.495**	**2.490**
STDEV			**0.012**	**0.006**	**0.006**
STDEV %			**0.324**	**0.410**	**0.252**
FOIA-90V-11_80. 1.hot	(50–200,tc)	80°C	3.420	1.404	2.437
FOIA-90V-11_80. 2.hot	(51–200,tc)	80°C	3.424	1.346	2.543
FOIA-90V-11_80. 3.hot	(50–200,tc)	80°C	3.431	1.342	2.556
FOIA-90V-11_80. 4.hot	(50–200,tc)	80°C	3.430	1.353	2.534
FOIA-90V-11_80. 5.hot	(50–200,tc)	80°C	3.431	1.348	2.545
AVERAGE			**3.427**	**1.359**	**2.523**
STDEV			**0.005**	**0.025**	**0.049**
STDEV %			**0.144**	**1.865**	**1.938**
FOIA-90V-12_20. 1.hot	(82–200,tc)	20°C	3.870	1.633	2.370
FOIA-90V-12_20. 2.hot	(80–200,tc)	20°C	3.850	1.656	2.325
FOIA-90V-12_20. 3.hot	(80–200,tc)	20°C	3.839	1.655	2.320
FOIA-90V-12_20. 4.hot	(80–200,tc)	20°C	3.837	1.648	2.328
FOIA-90V-12_20. 5.hot	(80–200,tc)	20°C	3.823	1.652	2.314
AVERAGE			**3.844**	**1.649**	**2.332**
STDEV			**0.018**	**0.009**	**0.022**
STDEV %			**0.458**	**0.563**	**0.955**
FOIA-90V-12_50. 1.hot	(66–200,tc)	50°C	3.673	1.501	2.447
FOIA-90V-12_50. 2.hot	(66–200,tc)	50°C	3.660	1.496	2.447
FOIA-90V-12_50. 3.hot	(63–200,tc)	50°C	3.650	1.490	2.450
FOIA-90V-12_50. 4.hot	(63–200,tc)	50°C	3.643	1.491	2.443

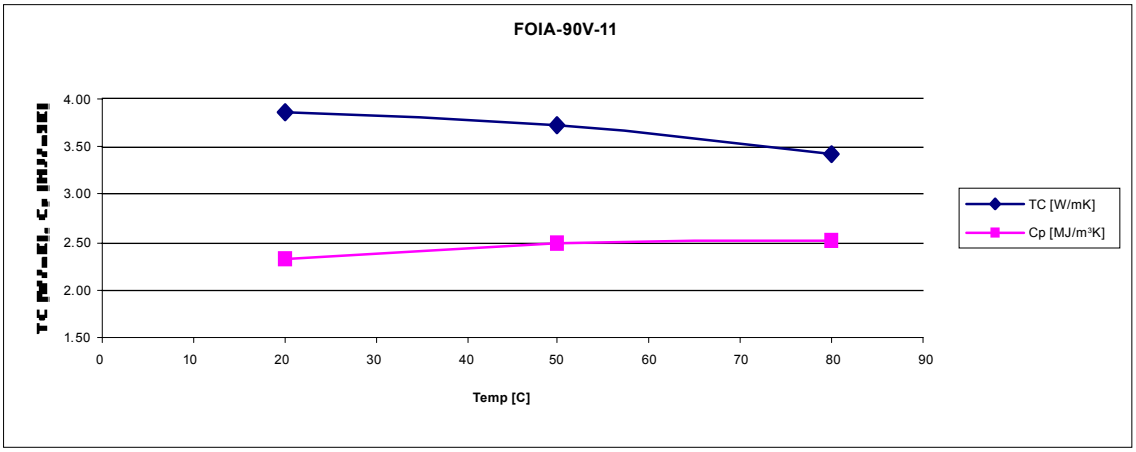
File	Points for calculation	T[C]	TC [W/mK]	TD [mm²/s]	Cp [MJ/m³K]
FOIA-90V-12_50. 5.hot	(65–200,tc)	50°C	3.634	1.489	2.441
AVERAGE			**3.652**	**1.493**	**2.446**
STDEV			**0.015**	**0.005**	**0.003**
STDEV %			**0.413**	**0.333**	**0.140**
FOIA-90V-12_80. 1.hot	(63–200,tc)	80°C	3.440	1.376	2.501
FOIA-90V-12_80. 2.hot	(63–200,tc)	80°C	3.422	1.369	2.500
FOIA-90V-12_80. 3.hot	(61–200,tc)	80°C	3.412	1.367	2.497
FOIA-90V-12_80. 4.hot	(64–200,tc)	80°C	3.406	1.354	2.516
FOIA-90V-12_80. 5.hot	(64–200,tc)	80°C	3.399	1.360	2.499
AVERAGE			**3.416**	**1.365**	**2.502**
STDEV			**0.016**	**0.008**	**0.007**
STDEV %			**0.474**	**0.612**	**0.300**
FOIA-90V-13_20. 1.hot	(49–200,tc)	20°C	3.693	1.708	2.162
FOIA-90V-13_20. 2.hot	(49–200,tc)	20°C	3.714	1.699	2.187
FOIA-90V-13_20. 3.hot	(50–200,tc)	20°C	3.719	1.697	2.192
FOIA-90V-13_20. 4.hot	(50–200,tc)	20°C	3.713	1.705	2.178
FOIA-90V-13_20. 5.hot	(50–200,tc)	20°C	3.712	1.706	2.176
AVERAGE			**3.710**	**1.703**	**2.179**
STDEV			**0.010**	**0.005**	**0.012**
STDEV %			**0.274**	**0.290**	**0.530**
FOIA-90V-13_50. 1.hot	(58–200,tc)	50°C	3.607	1.490	2.420
FOIA-90V-13_50. 2.hot	(46–200,tc)	50°C	3.615	1.466	2.466
FOIA-90V-13_50. 3.hot	(47–200,tc)	50°C	3.572	1.486	2.403
FOIA-90V-13_50. 4.hot	(46–200,tc)	50°C	3.559	1.491	2.386
FOIA-90V-13_50. 5.hot	(47–200,tc)	50°C	3.554	1.482	2.399
AVERAGE			**3.581**	**1.483**	**2.415**
STDEV			**0.028**	**0.010**	**0.031**
STDEV %			**0.778**	**0.699**	**1.291**
FOIA-90V-13_80. 1.hot	(23–200,tc)	80°C	3.400	1.300	2.616
FOIA-90V-13_80. 2.hot	(24–200,tc)	80°C	3.381	1.295	2.611
FOIA-90V-13_80. 3.hot	(27–200,tc)	80°C	3.370	1.304	2.584
FOIA-90V-13_80. 4.hot	(26–200,tc)	80°C	3.362	1.312	2.563
FOIA-90V-13_80. 5.hot	(26–200,tc)	80°C	3.344	1.300	2.572
AVERAGE			**3.371**	**1.302**	**2.589**
STDEV			**0.021**	**0.006**	**0.023**
STDEV %			**0.620**	**0.480**	**0.901**
FOIA-90V-14_20. 1.hot	(49–200,tc)	20°C	3.836	1.686	2.275
FOIA-90V-14_20. 2.hot	(50–200,tc)	20°C	3.830	1.689	2.267
FOIA-90V-14_20. 3.hot	(50–200,tc)	20°C	3.830	1.688	2.269
FOIA-90V-14_20. 4.hot	(50–200,tc)	20°C	3.831	1.689	2.269
FOIA-90V-14_20. 5.hot	(50–200,tc)	20°C	3.832	1.682	2.279
AVERAGE			**3.832**	**1.687**	**2.272**
STDEV			**0.003**	**0.003**	**0.005**
STDEV %			**0.068**	**0.181**	**0.215**
FOIA-90V-14_50. 1.hot	(23–200,tc)	50°C	3.696	1.531	2.415
FOIA-90V-14_50. 2.hot	(26–200,tc)	50°C	3.678	1.522	2.416

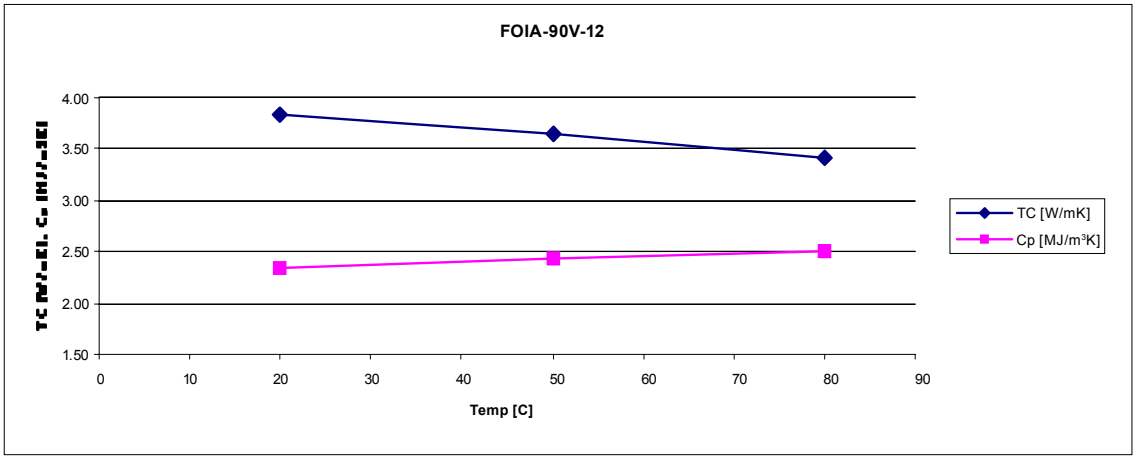
File	Points for calculation	T[C]	TC [W/mK]	TD [mm²/s]	Cp [MJ/m³K]
FOIA-90V-14_50. 3.hot	(28–200,tc)	50°C	3.666	1.518	2.416
FOIA-90V-14_50. 4.hot	(24–200,tc)	50°C	3.660	1.516	2.414
FOIA-90V-14_50. 5.hot	(25–200,tc)	50°C	3.646	1.508	2.419
AVERAGE			**3.669**	**1.519**	**2.416**
STDEV			**0.019**	**0.008**	**0.002**
STDEV %			**0.515**	**0.558**	**0.069**
FOIA-90V-14_80. 1.hot	(26–200,tc)	80°C	3.433	1.375	2.497
FOIA-90V-14_80. 2.hot	(26–200,tc)	80°C	3.417	1.375	2.486
FOIA-90V-14_80. 3.hot	(26–200,tc)	80°C	3.420	1.381	2.476
FOIA-90V-14_80. 4.hot	(26–200,tc)	80°C	3.414	1.357	2.516
FOIA-90V-14_80. 5.hot	(26–200,tc)	80°C	3.425	1.421	2.410
AVERAGE			**3.422**	**1.382**	**2.477**
STDEV			**0.007**	**0.024**	**0.040**
STDEV %			**0.212**	**1.713**	**1.624**
FOIA-90V-15_20. 1.hot	(45–200,tc)	20°C	3.820	1.666	2.293
FOIA-90V-15_20. 2.hot	(44–200,tc)	20°C	3.820	1.660	2.301
FOIA-90V-15_20. 3.hot	(42–200,tc)	20°C	3.819	1.660	2.300
FOIA-90V-15_20. 4.hot	(41–200,tc)	20°C	3.819	1.661	2.300
FOIA-90V-15_20. 5.hot	(42–200,tc)	20°C	3.819	1.662	2.298
AVERAGE			**3.819**	**1.661**	**2.300**
STDEV			**0.001**	**0.001**	**0.002**
STDEV %			**0.020**	**0.048**	**0.066**
FOIA-90V-15_50. 1.hot	(55–200,tc)	50°C	3.699	1.486	2.489
FOIA-90V-15_50. 2.hot	(49–200,tc)	50°C	3.691	1.498	2.464
FOIA-90V-15_50. 3.hot	(31–200,tc)	50°C	3.691	1.505	2.453
FOIA-90V-15_50. 4.hot	(50–200,tc)	50°C	3.685	1.488	2.477
FOIA-90V-15_50. 5.hot	(50–200,tc)	50°C	3.662	1.504	2.434
AVERAGE			**3.686**	**1.496**	**2.463**
STDEV			**0.014**	**0.009**	**0.021**
STDEV %			**0.383**	**0.582**	**0.854**
FOIA-90V-15_80. 1.hot	(49–200,tc)	80°C	3.526	1.365	2.583
FOIA-90V-15_80. 2.hot	(50–200,tc)	80°C	3.511	1.365	2.572
FOIA-90V-15_80. 3.hot	(50–200,tc)	80°C	3.511	1.360	2.581
FOIA-90V-15_80. 4.hot	(50–200,tc)	80°C	3.504	1.360	2.576
FOIA-90V-15_80. 5.hot	(50–200,tc)	80°C	3.502	1.365	2.566
AVERAGE			**3.511**	**1.363**	**2.576**
STDEV			**0.010**	**0.003**	**0.007**
STDEV %			**0.271**	**0.187**	**0.255**
FOIA-90V-16_20. 1.hot	(36–183,tc)	20°C	3.762	1.931	1.949
FOIA-90V-16_20. 2.hot	(35–200,tc)	20°C	3.779	1.910	1.978
FOIA-90V-16_20. 3.hot	(53–200,tc)	20°C	3.801	1.845	2.060
FOIA-90V-16_20. 4.hot	(41–200,tc)	20°C	3.799	1.888	2.012
FOIA-90V-16_20. 5.hot	(45–200,tc)	20°C	3.759	1.930	1.948
AVERAGE			**3.780**	**1.901**	**1.989**
STDEV			**0.020**	**0.036**	**0.047**
STDEV %			**0.523**	**1.868**	**2.381**

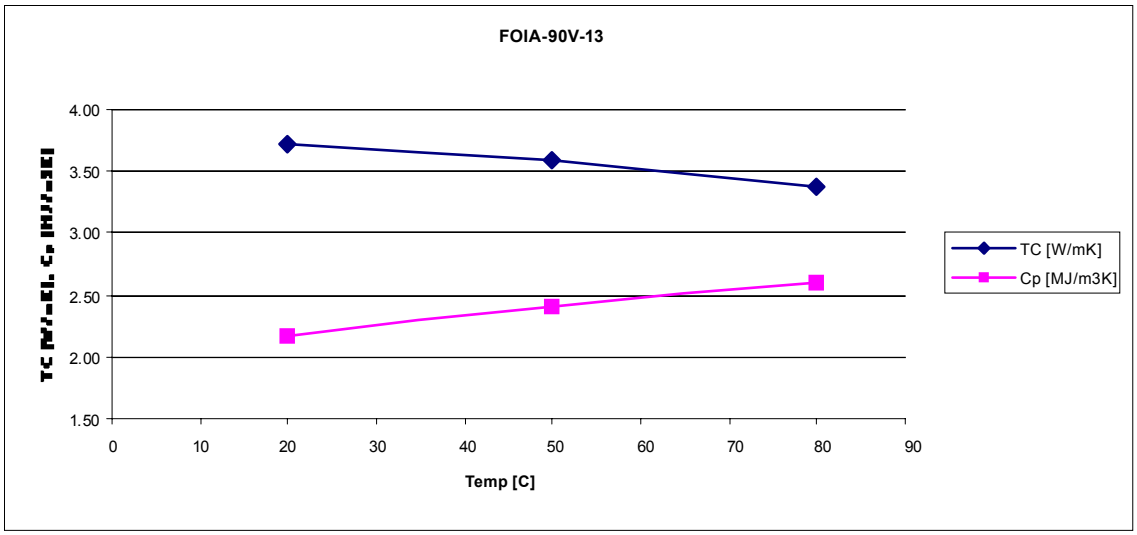
File	Points for calculation	T[C]	TC [W/mK]	TD [mm²/s]	Cp [MJ/m³K]
FOIA-90V-16_50. 1.hot	(27–200,tc)	50°C	3.710	1.664	2.229
FOIA-90V-16_50. 2.hot	(67–200,tc)	50°C	3.668	1.625	2.257
FOIA-90V-16_50. 3.hot	(46–200,tc)	50°C	3.707	1.601	2.315
FOIA-90V-16_50. 4.hot	(49–200,tc)	50°C	3.699	1.615	2.290
FOIA-90V-16_50. 5.hot	(50–200,tc)	50°C	3.638	1.672	2.176
AVERAGE			**3.684**	**1.636**	**2.254**
STDEV			**0.031**	**0.031**	**0.054**
STDEV %			**0.836**	**1.898**	**2.404**
FOIA-90V-16_80. 1.hot	(44–200,tc)	80°C	3.445	1.490	2.312
FOIA-90V-16_80. 2.hot	(44–200,tc)	80°C	3.450	1.453	2.375
FOIA-90V-16_80. 3.hot	(43–200,tc)	80°C	3.439	1.471	2.338
FOIA-90V-16_80. 4.hot	(40–200,tc)	80°C	3.485	1.441	2.418
FOIA-90V-16_80. 5.hot	(41–200,tc)	80°C	3.444	1.490	2.311
AVERAGE			**3.453**	**1.469**	**2.351**
STDEV			**0.019**	**0.022**	**0.045**
STDEV %			**0.541**	**1.479**	**1.935**
FOIA-90V-17_20. 1.hot	(75–200,tc)	20°C	3.756	1.794	2.093
FOIA-90V-17_20. 2.hot	(76–200,tc)	20°C	3.797	1.732	2.193
FOIA-90V-17_20. 3.hot	(75–200,tc)	20°C	3.746	1.783	2.101
FOIA-90V-17_20. 4.hot	(76–200,tc)	20°C	3.753	1.784	2.104
FOIA-90V-17_20. 5.hot	(75–200,tc)	20°C	3.750	1.779	2.108
AVERAGE			**3.760**	**1.775**	**2.120**
STDEV			**0.021**	**0.025**	**0.041**
STDEV %			**0.555**	**1.388**	**1.951**
FOIA-90V-17_50. 1.hot	(76–200,tc)	50°C	3.661	1.542	2.374
FOIA-90V-17_50. 2.hot	(76–200,tc)	50°C	3.650	1.522	2.398
FOIA-90V-17_50. 3.hot	(75–200,tc)	50°C	3.644	1.525	2.389
FOIA-90V-17_50. 4.hot	(75–200,tc)	50°C	3.639	1.531	2.376
FOIA-90V-17_50. 5.hot	(76–200,tc)	50°C	3.630	1.520	2.388
AVERAGE			**3.645**	**1.528**	**2.385**
STDEV			**0.012**	**0.009**	**0.010**
STDEV %			**0.322**	**0.579**	**0.411**
FOIA-90V-17_80. 1.hot	(75–200,tc)	80°C	3.368	1.368	2.463
FOIA-90V-17_80. 2.hot	(76–200,tc)	80°C	3.391	1.365	2.485
FOIA-90V-17_80. 3.hot	(75–200,tc)	80°C	3.371	1.334	2.526
FOIA-90V-17_80. 4.hot	(75–200,tc)	80°C	3.380	1.380	2.448
FOIA-90V-17_80. 5.hot	(77–200,tc)	80°C	3.341	1.369	2.441
AVERAGE			**3.370**	**1.363**	**2.473**
STDEV			**0.019**	**0.017**	**0.034**
STDEV %			**0.549**	**1.263**	**1.390**
FOIA-90V-18_20. 1.hot	(62–200,tc)	20°C	3.631	1.845	1.969
FOIA-90V-18_20. 2.hot	(61–200,tc)	20°C	3.637	1.840	1.976
FOIA-90V-18_20. 3.hot	(62–200,tc)	20°C	3.635	1.845	1.970
FOIA-90V-18_20. 4.hot	(61–200,tc)	20°C	3.638	1.846	1.971
FOIA-90V-18_20. 5.hot	(61–200,tc)	20°C	3.653	1.848	1.977
AVERAGE			**3.641**	**1.845**	**1.973**

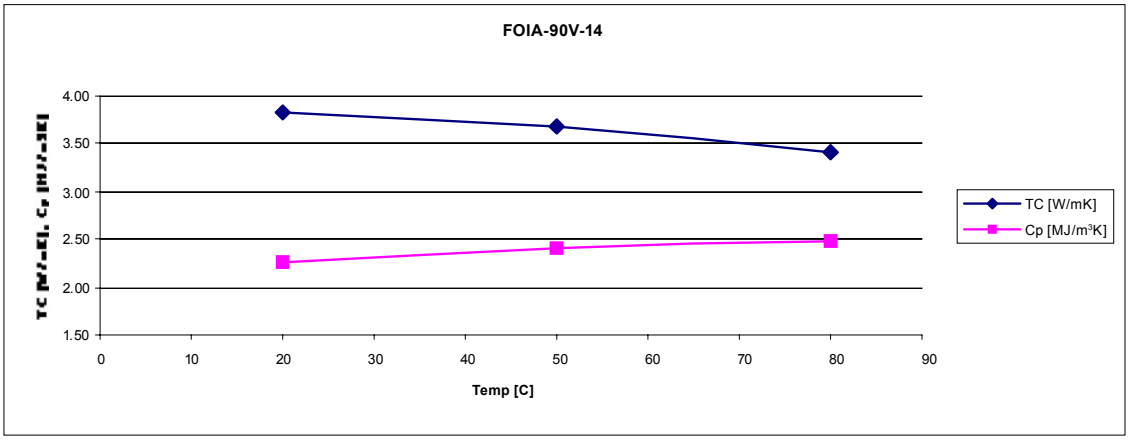
File	Points for calculation	T[C]	TC [W/mK]	TD [mm²/s]	Cp [MJ/m³K]
STDEV			**0.008**	**0.003**	**0.004**
STDEV %			**0.222**	**0.178**	**0.188**
FOIA-90V-18_50. 1.hot	(61–200,tc)	50°C	3.562	1.645	2.165
FOIA-90V-18_50. 2.hot	(62–200,tc)	50°C	3.547	1.639	2.165
FOIA-90V-18_50. 3.hot	(61–200,tc)	50°C	3.534	1.637	2.159
FOIA-90V-18_50. 4.hot	(62–200,tc)	50°C	3.536	1.629	2.170
FOIA-90V-18_50. 5.hot	(62–200,tc)	50°C	3.527	1.642	2.148
AVERAGE			**3.541**	**1.638**	**2.161**
STDEV			**0.014**	**0.006**	**0.008**
STDEV %			**0.393**	**0.360**	**0.391**
FOIA-90V-18_80. 1.hot	(95–200,tc)	80°C	3.368	1.535	2.194
FOIA-90V-18_80. 2.hot	(58–200,tc)	80°C	3.370	1.461	2.306
FOIA-90V-18_80. 3.hot	(58–200,tc)	80°C	3.404	1.425	2.390
FOIA-90V-18_80. 4.hot	(63–200,tc)	80°C	3.351	1.458	2.298
FOIA-90V-18_80. 5.hot	(58–200,tc)	80°C	3.339	1.460	2.288
AVERAGE			**3.367**	**1.468**	**2.295**
STDEV			**0.025**	**0.041**	**0.070**
STDEV %			**0.734**	**2.771**	**3.032**
FOIA-90V-19_20. 1.hot	(66–200,tc)	20°C	3.719	1.738	2.140
FOIA-90V-19_20. 2.hot	(59–200,tc)	20°C	3.721	1.730	2.151
FOIA-90V-19_20. 3.hot	(58–200,tc)	20°C	3.716	1.734	2.142
FOIA-90V-19_20. 4.hot	(57–200,tc)	20°C	3.723	1.732	2.149
FOIA-90V-19_20. 5.hot	(58–200,tc)	20°C	3.714	1.741	2.133
AVERAGE			**3.719**	**1.735**	**2.144**
STDEV			**0.004**	**0.005**	**0.008**
STDEV %			**0.117**	**0.277**	**0.383**
FOIA-90V-19_50. 1.hot	(65–200,tc)	50°C	3.599	1.539	2.339
FOIA-90V-19_50. 2.hot	(60–200,tc)	50°C	3.586	1.533	2.338
FOIA-90V-19_50. 3.hot	(60–200,tc)	50°C	3.580	1.533	2.335
FOIA-90V-19_50. 4.hot	(61–200,tc)	50°C	3.571	1.532	2.330
FOIA-90V-19_50. 5.hot	(58–200,tc)	50°C	3.565	1.537	2.320
AVERAGE			**3.580**	**1.535**	**2.333**
STDEV			**0.013**	**0.003**	**0.008**
STDEV %			**0.366**	**0.181**	**0.341**
FOIA-90V-19_80. 1.hot	(60–200,tc)	80°C	3.410	1.385	2.462
FOIA-90V-19_80. 2.hot	(60–200,tc)	80°C	3.404	1.385	2.458
FOIA-90V-19_80. 3.hot	(60–200,tc)	80°C	3.393	1.381	2.456
FOIA-90V-19_80. 4.hot	(60–200,tc)	80°C	3.385	1.378	2.457
FOIA-90V-19_80. 5.hot	(58–200,tc)	80°C	3.377	1.371	2.464
AVERAGE			**3.394**	**1.380**	**2.459**
STDEV			**0.013**	**0.006**	**0.003**
STDEV %			**0.393**	**0.436**	**0.141**
FOIA-90V-20_20. 1.hot	(71–200,tc)	20°C	3.986	1.757	2.268
FOIA-90V-20_20. 2.hot	(69–200,tc)	20°C	3.976	1.767	2.251
FOIA-90V-20_20. 3.hot	(70–200,tc)	20°C	3.981	1.763	2.259
FOIA-90V-20_20. 4.hot	(69–200,tc)	20°C	3.967	1.780	2.229

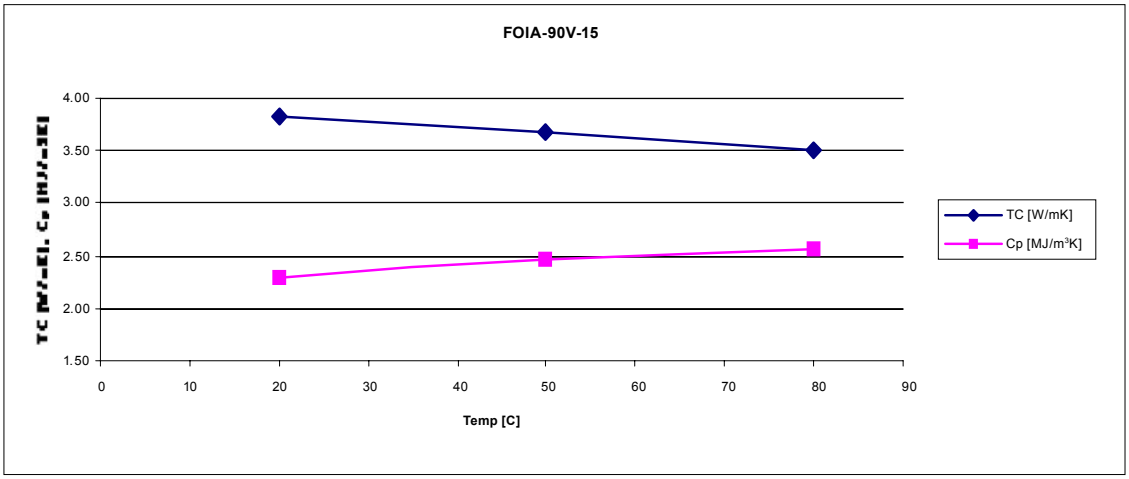
File	Points for calculation	T[C]	TC [W/mK]	TD [mm²/s]	Cp [MJ/m³K]
FOIA-90V-20_20. 5.hot	(69–200,tc)	20°C	3.980	1.766	2.254
AVERAGE			**3.978**	**1.767**	**2.252**
STDEV			**0.007**	**0.008**	**0.015**
STDEV %			**0.184**	**0.469**	**0.650**
FOIA-90V-20_50. 1.hot	(62–200,tc)	50°C	3.829	1.588	2.411
FOIA-90V-20_50. 2.hot	(63–200,tc)	50°C	3.811	1.594	2.390
FOIA-90V-20_50. 3.hot	(60–200,tc)	50°C	3.811	1.595	2.389
FOIA-90V-20_50. 4.hot	(61–200,tc)	50°C	3.796	1.593	2.384
FOIA-90V-20_50. 5.hot	(63–200,tc)	50°C	3.793	1.598	2.374
AVERAGE			**3.808**	**1.594**	**2.390**
STDEV			**0.014**	**0.004**	**0.014**
STDEV %			**0.377**	**0.228**	**0.571**
FOIA-90V-20_80. 1.hot	(56–200,tc)	80°C	3.571	1.478	2.416
FOIA-90V-20_80. 2.hot	(55–200,tc)	80°C	3.580	1.464	2.446
FOIA-90V-20_80. 3.hot	(54–200,tc)	80°C	3.570	1.464	2.439
FOIA-90V-20_80. 4.hot	(55–200,tc)	80°C	3.561	1.457	2.444
FOIA-90V-20_80. 5.hot	(57–200,tc)	80°C	3.555	1.453	2.447
AVERAGE			**3.567**	**1.463**	**2.438**
STDEV			**0.010**	**0.010**	**0.013**
STDEV %			**0.278**	**0.663**	**0.530**
FOIA-90V-11_20_Ommät. 1.hot	(37–200,tc)	20°C	3.882	1.704	2.278
FOIA-90V-11_20_Ommät. 2.hot	(61–200,tc)	20°C	3.846	1.611	2.388
FOIA-90V-11_20_Ommät. 3.hot	(60–200,tc)	20°C	3.851	1.652	2.331
FOIA-90V-11_20_Ommät. 4.hot	(42–200,tc)	20°C	3.845	1.680	2.288
FOIA-90V-11_20_Ommät. 5.hot	(40–200,tc)	20°C	3.847	1.678	2.293
AVERAGE			**3.854**	**1.665**	**2.315**
STDEV			**0.016**	**0.036**	**0.045**
STDEV %			**0.413**	**2.137**	**1.946**
FOIA-90V-11_50_Ommät. 1.hot	(36–200,tc)	50°C	3.716	1.515	2.452
FOIA-90V-11_50_Ommät. 2.hot	(35–200,tc)	50°C	3.701	1.512	2.447
FOIA-90V-11_50_Ommät. 3.hot	(36–200,tc)	50°C	3.697	1.514	2.442
FOIA-90V-11_50_Ommät. 4.hot	(36–200,tc)	50°C	3.690	1.512	2.440
FOIA-90V-11_50_Ommät. 5.hot	(36–200,tc)	50°C	3.696	1.510	2.447
AVERAGE			3.700	1.513	2.446
STDEV			0.010	0.002	0.005
STDEV %			**0.267**	**0.134**	**0.196**
FOIA-90V-11_80_Ommät. 1.hot	(36–200,tc)	80°C	3.524	1.371	2.570
FOIA-90V-11_80_Ommät. 2.hot	(35–200,tc)	80°C	3.511	1.365	2.573
FOIA-90V-11_80_Ommät. 3.hot	(36–200,tc)	80°C	3.505	1.366	2.566
FOIA-90V-11_80_Ommät. 4.hot	(36–200,tc)	80°C	3.489	1.351	2.582
FOIA-90V-11_80_Ommät. 5.hot	(36–200,tc)	80°C	3.490	1.360	2.566
AVERAGE			**3.504**	**1.363**	**2.571**
STDEV			**0.015**	**0.007**	**0.007**
STDEV %			**0.418**	**0.542**	**0.256**

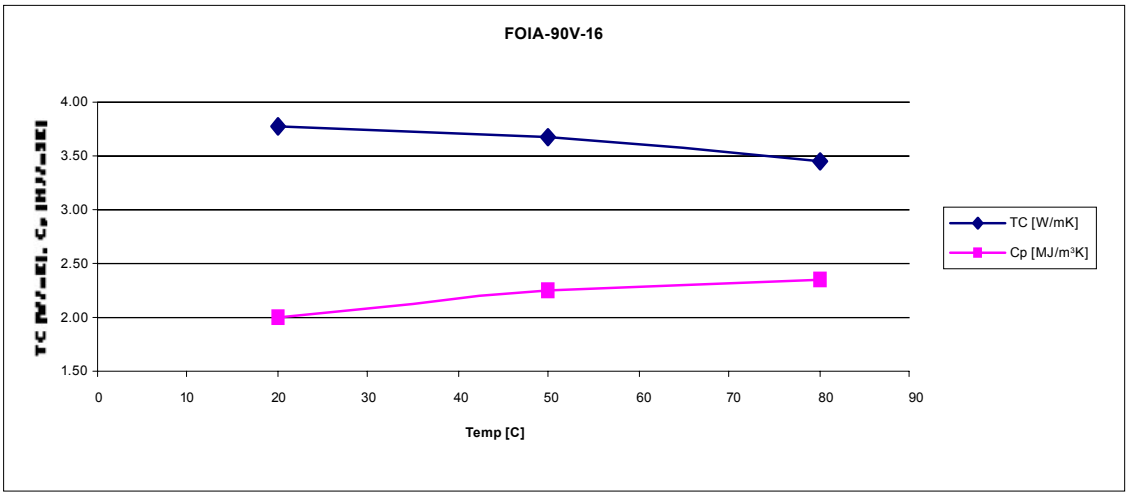

FOIA-90V-11
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]

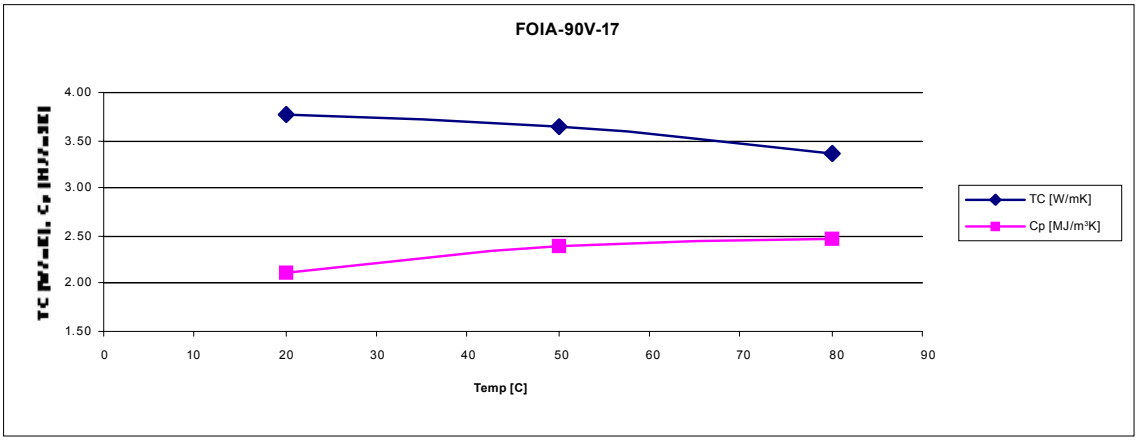

FOIA-90V-12
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]

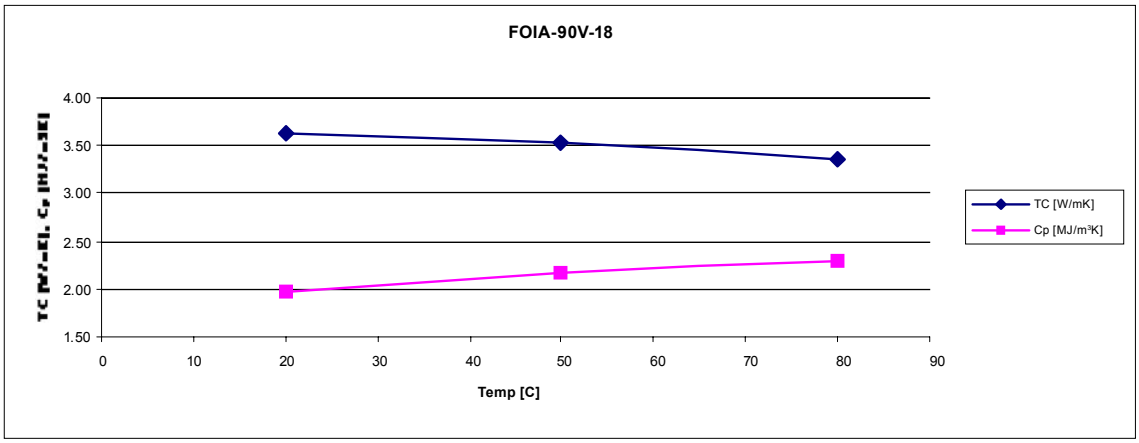

FOIA-90V-13
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]

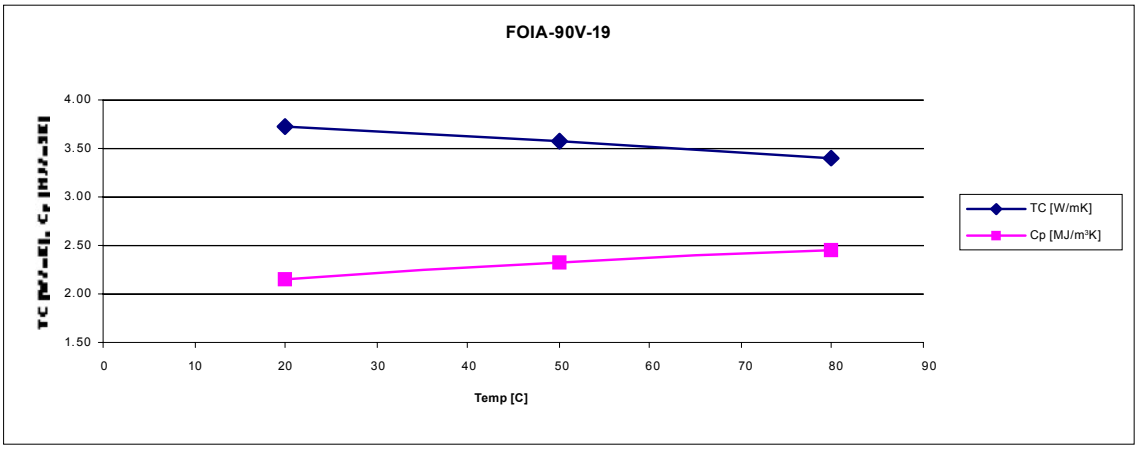

FOIA-90V-14
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]

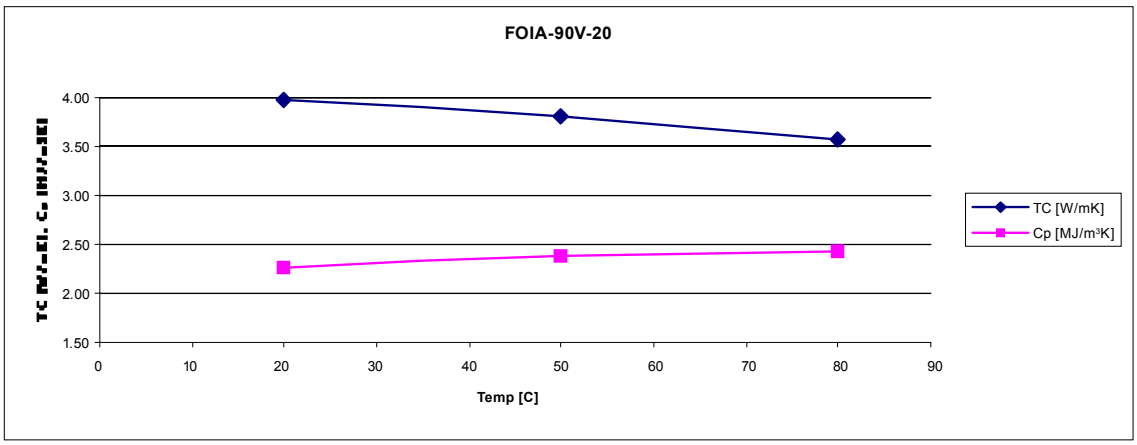

FOIA-90V-15
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]


FOIA-90V-16
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]


FOIA-90V-17
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]


FOIA-90V-18
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]


FOIA-90V-19
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]


FOIA-90V-20
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m³K]