Thermal Response Test - Experiences in Germany

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Abstract

To design borehole heat exchangers (BHE) for Underground Thermal Energy Storage (UTES) or Ground Source Heat Pumps (GSHP), the knowledge of underground thermal properties is paramount. In small plants (residential houses), these parameters usually are estimated. However, for larger plants (commercial GSHP or UTES) the thermal conductivity should be measured on site.

A useful tool to do so is a thermal response test, carried out on a borehole heat exchanger in a pilot borehole (later to be part of the borehole field). For a thermal response test, basically a defined heat load is put into the hole and the resulting temperature changes of the circulating fluid are measured. Since mid 1999, this technology now also is in use in Germany for the design of larger plants with BHEs, allowing sizing of the boreholes based upon reliable underground data.

Introduction

With the theoretical fundamentals established in the 80s, the first practical tests with a mobile equipment were done in 1995 in Sweden (EKLÖF & GEHLIN, 1996). A similar equipment was built and tested from 1996 on in USA (AUSTIN, 1998). A somewhat different approach was used in the Netherlands, with cooling of the ground by means of a heat pump (VAN GELDER et al., 1999).

At least two mobile test rigs for thermal response tests are currently existing in Germany (SANNER et al., 1999). First tests have been done in summer 1999. Figure 1 shows a typical test setup, and table 1 lists the tests known to the authors by spring 2000.

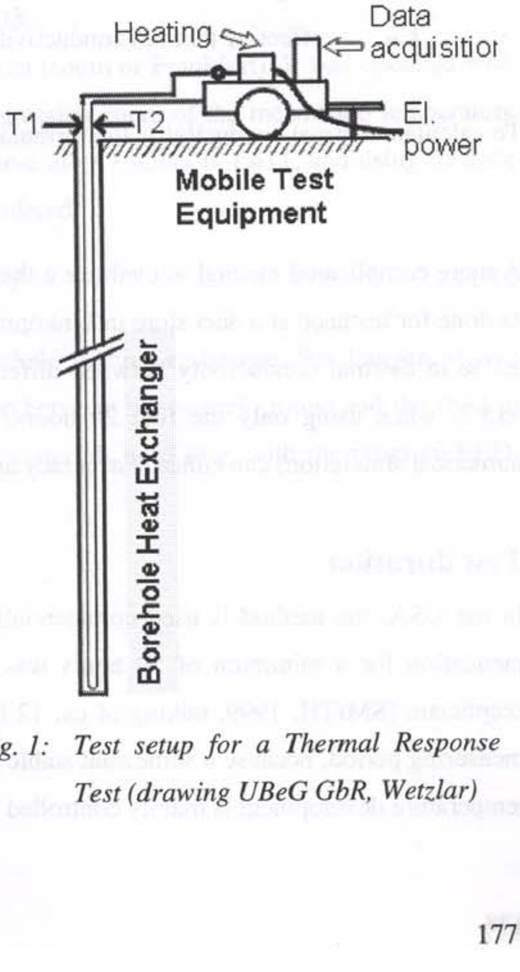

Fig. 1: Test setup for a Thermal Response Test (drawing UBeG GbR, Wetzlar)

Table 1: Thermal response tests carried out in Germany in 1999 and early 2000

Project	Type of BHE	Geology	Thermal conductivity λ_{eff}	Borehole thermal resistance
Attenkirchen	Single-U-tube, PB	Quarternary and tertiary silt and clay	1.62 W/m/K	0.50 K/(W/m)
Emden	Double-U-tube	Quarternary and tertiary silt, sand and gravel	Test carried out with Dutch equipment, no further information	
Erfurt	Double-U-tube, PE 32 mm	Mesozoic sediments	2.78 W/m/K	0.18 K/(W/m)
Herford	Double-U-tube, PE,	Mesozoic marls, limestones and shales	Groundwater flow too high, no response testing possible (s. text)	
Langen	Double-U-tube, PE 32 mm	Quarternary and tertiary sand and clay	2.79 W/m/K	0.11 K/(W/m)
Minden	Double-U-tube, PE 32 mm	marly clay	2.51 W/m/K	0.12 K/(W/m)
Werne	Double-U-tube, PE 32 mm	Cretaceous marl, clayey („Emschermergel“)	1.45 W/m/K	0.11 K/(W/m)

Test evaluation

The easiest way to evaluate thermal response test data makes use of the line source theory. The following formula is given in EKLÖF & GEHLIN (1996):

$$k = \frac{Q}{4\pi H \lambda_{eff}} \qquad [1]$$

with k Inclination of the curve of temperature versus logarithmic time
Q heat injection/extraction
H length of borehole heat exchanger
λ_{eff} effective thermal conductivity (incl. influence of groundwater flow, borehole grouting, etc.)

To calculate thermal conductivity, the formula has to be transformed:

$$\lambda_{eff} = \frac{Q}{4\pi H k} \qquad [2]$$

A more complicated method to evaluate a thermal response test is parameter estimation using numerical modeling, as done for instance at a duct store in Linköping (HELLSTRÖM, 1997). SPITLER et al. (1999) found a deviation of ±5 % in thermal conductivity between different methods of evaluation of the measured data with 50 hours, but ±15 % when using only the first 20 hours. More advanced evaluation methods (parameter estimation through numerical simulation) can enhance accuracy and give additional information, but can reduce test time only slightly.

Test duration

In the USA, the method is used commercially. This gave way to the wish for a shorter test duration. A recommendation for a minimum of 50 hours was given (SKOUBY, 1998; SPITLER et al., 1999), but there is also scepticism (SMITH, 1999, talking of ca. 12 hours). In general, there are physical limits for the shortening of the measuring period, because a somewhat stable heat flow has to be achieved in the ground. In the first few hours, the temperature development is mainly controlled by the borehole filling and not by the surrounding soil or rock. A time of 48 h is considered by the authors as the minimum test period. Table 2 shows the test duration and other data of 5 tests carried out in Germany before spring 2000.

In the evaluations made of the German tests, the minimum duration criterium as established by EKLÖF & GEHLIN (1996) proved helpful:

$$t_b = \frac{5r^2}{\alpha} \qquad [3]$$

with t_b lower time limit of data to be uesed

r borehole radius

α thermal diffusivity ($\alpha = \lambda / \rho c_p$), with estimated values

However, an optical crosschecking is recommended, because the measured data may deviate from the theoretical assumptions. It is also worthwhile to calculate the minimum duration criterium again with the thermal conductivity resulting from the first evaluation, to start a kind of iteration.

Table 2: Test duration and other data of selected thermal response tests in Germany

Project	Test duration	ground temp.	injected heat	borehole depth	borehole diameter
Attenkirchen	250 h	15,6 °C	2.65 kW	35 m	150 mm
Erfurt	244 h	ca. 13 °C	4.36 kW	99,7 m	160 mm
Langen	50.2 h	12.2 °C	4.90 kW	99 m	150 mm
Minden	90.5 h	11.2 °C	4.36 kW	92 m	150 mm
Werne	66.3 h	12.4 °C	3.35 kW	75 m	194 mm

Experiences from Thermal Response Testing in Germany

The first test in Germany was made for a large office building in Langen (south of Frankfurt). It was operated with the equipment of UBeG GbR in summer 1999. Figure 2 shows the regression curve of the mean fluid temperature from 6.9 to 50 hours, on a logarithmic scale. The inclination of the curve after 7 hours is 1.411, and using formula [2] and the values given in table 2, the thermal conductivity can be calculated:

$$\lambda_{eff} = \frac{4900}{4\pi\ 99 \cdot 1.411} = 2.79 \qquad [4]$$

A second value that can be determined by a response test is the borehole thermal resistance. For Langen, it was calculated as $r_b = 0.11$ K/(W/m). This value gives the temperature drop between the natural ground and the fluid in the pipes. It is also possible to calculate r_b from the dimensions and materials used (e.g. with the program EED, HELLSTRÖM et al., 1997); the result is $r_b = 0.115$ K/(W/m)

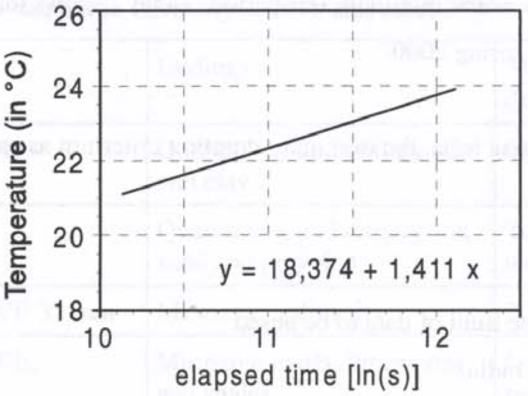

Fig. 2: Regression curve of mean fluid temperature in Thermal Response Test in Langen (original data s. fig. 3)

For good results, it is crucial to set up the system correctly and to minimize external influences. This is done easier with heating the ground (electric resistance heaters) than with cooling (heat pumps). However, even with resistance heating, the fluctuations of voltage in the grid result in fluctuations of the thermal power injected into the ground. With a heat pump, ambient air temperature (condensor cooling) and the dynamic system behaviour of a themodynamical cycle also have to be taken into account, making control of a steady heat extraction/injection more difficult. With simple resistance heaters, a longer test duration allows for automatical statistical correction of the power fluctuations, and results in trustworthy evaluation. Temperature curves from some tests are shown in figure 3.

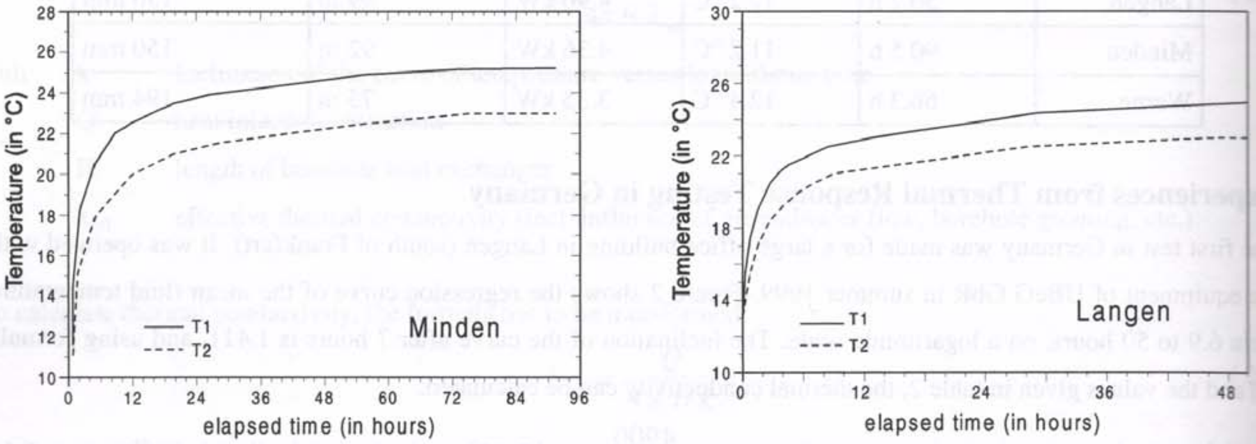

Fig. 3: Temperature curves for inlet (T1) and outlet (T2) temperatures of borehole heat exchanger in two thermal response tests

One of the tests delivered rather strange results, which could be explained by the specific geologic situation. In a borehole heat exchanger in the region of Herford (s. table 1), the temperature increased in the first hour, and then kept steady over several days. Also after an increase of the original heat injection rate of 3.34 kW to a value of 5.32 kW, the temperature showed the same behaviour with short increase followed by a steady level (figure 4). An evaluation with the line source method is impossible in this case, because the temperature curve shows no inclination. Using EED to make a simple parameter estimation delivered values of $\lambda > 60$ W/m/K. An explanation could be, that a very strong groundwater flow in the borehole carried most of the heat away. In the borehole tested, no grouting was done, but the hole was filled with sand. A high groundwater inflow also was detected during drilling. Because a thermal response test does not distinct between conductive and convective heat transport, an abnormally high convective heat transport makes the evaluation impossible.

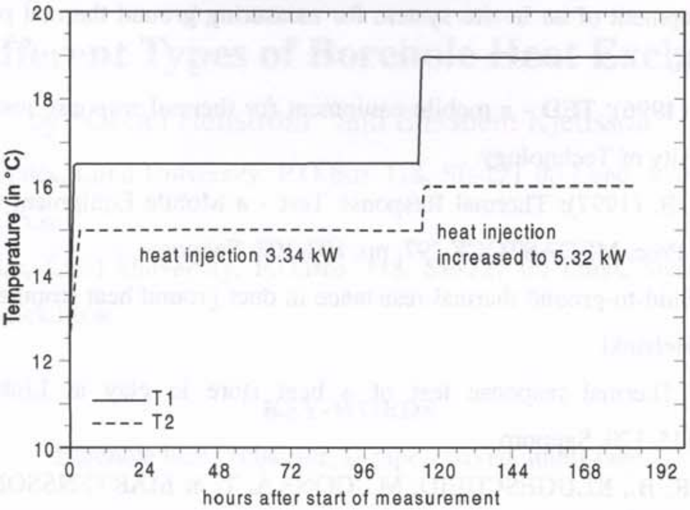

Fig. 4: Temperature curve for thermal response test with very high groundwater flow

Conclusions

With the thermal response test, accurate data for design of borehole heat exchangers can be obtained on site. The equipment can easily be made mobile, as it was done with the first Swedish tool in a light trailer (EKLÖF & GEHLIN, 1996). The equipment of Landtechnik Weihenstephan consists of two portable containers (figure 5), that of UBeG of a frame with the heating equipment and a control cupboard, both mounted on a light trailer.

Within the German participation in Annex 12 and Annex 13 of the IEA Energy Storage Implementing Agreement, further development will be done, and test with higher temperature (for high temperature BTES) are planned. Thermal response testing surely will develop into a standard tool in the design process of larger borehole heat exchanger fields.

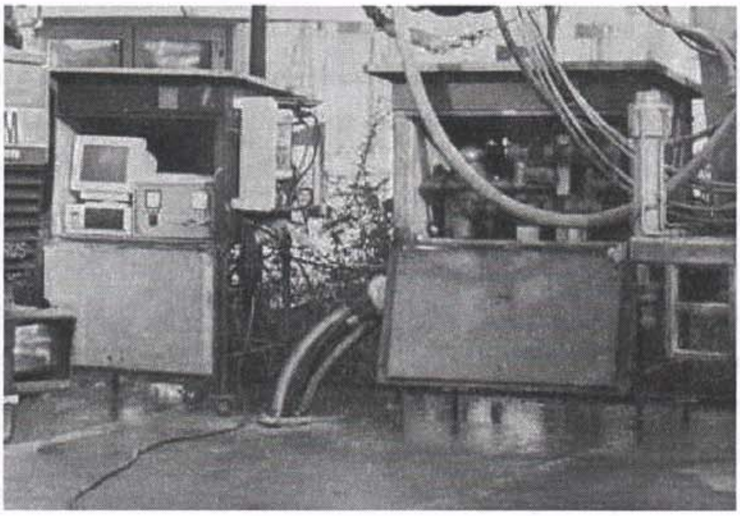

Fig. 5: Equipment for thermal response test of Landtechnik Weihenstephan, housed in 2 portable containers

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