NEW MEASUREMENT TECHNIQUES FOR GEOTHERMAL HEAT PUMP - BOREHOLE HEAT EXCHANGER QUALITY CONTROL

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Abstract: Two new measurement tools have been developed in order to improve the sizing reliability and the installation quality of geothermal heat pumps with large borehole heat exchanger (BHE) arrays.

The ground thermal conductivity λ is a decisive property for dimensioning borehole heat exchangers, and, especially, of systems with BHE arrays. Although λ can be determined on rock samples from the borehole in the laboratory or in situ by a customary thermal response test (a BHE circulation experiment), both methods need special equipment and are time-consuming. Therefore a small, light and wireless probe with p and T sensors and a programmable microprocessor has been developed (NIMO-T). The wireless probe is lowered into one tube of the BHE where it sinks under its adjustable weight and records pressure and temperature while going down, at preselected time intervals. After the probe has reached the U-tube bottom it stops there and is flushed back to the surface by a small pump for recovery and data retrieval. A measurement run in a 300 m deep BHE takes less than 60 minutes. The depth-temperature-profile allows determination of rock thermal conductivity, identification of groundwater flow, quality control of the backfilling and advanced analysis of thermal response tests.

The second tool is a device to check the leak tightness of borehole heat exchanger tubes, a prerequisite of safe operation and thus of permitting. The new probe measures automatically the pressure answer at the BHE outlet tube over time with respect to a defined pressure signal at the BHE inlet. The temporal variation of the inlet-pressure is adjusted with respect to the engineering norm SN 805. If the pressure answer at the outlet is not within the limits given by the SN 805-norm, the BHE fails the leak tightness test. If the pressure answer is correct, a test certificate is generated automatically.

Key Words: ***borehole heat exchangers, wireless temperature logging, thermal conductivity profile, pipe tightness test***

1 INTRODUCTION

Borehole heat exchangers (BHE), coupled with heat pumps are nowadays increasingly applied for space heating and cooling. The heat exchange between the BHE and the surrounding ground depends directly on the ground thermal conductivity λ at the site in question. λ is thus a key parameter in designing borehole heat exchanger (BHE)-coupled geothermal heat pump systems: the specific heat extraction rate (Watt per meter BHE length) is directly proportional to λ and the temperature difference between the circulated fluid and the undisturbed ground temperature. This must be considered especially in the design of BHE groups: optimization of the BHE group by determining the BHE number and depth must be implemented immediately after receiving the λ information.

2 WIRELESS TEMPERATURE LOGGING

2.1 NIMO-T

Thermal conductivity λ can be determined on rock, which is in fact time consuming and expensive. For rapid λ determinations, a new, wireless temperature logging tool (NIMO-T; Figure 1) has been developed. NIMO-T consists of pressure and temperature sensors and a mini-datalogger/programmed microprocessor in a closed metal tube. The key components of the built-in probe electronics are the analog/digital converter, the microprocessor and the EEPROMs (=electric erasable/programmable read-only memory) for data storage. All components have been selected after careful evaluation. For example, an A/D converter with 16bit resolution has been chosen.

Figure 1: NIMO-T: Wireless tool for continuous temperature measurements in borehole heat exchangers. See Table 1 for technical details.

For temperature measurements in borehole heat exchangers, NIMO-T is lowered into one tube of the U-shaped BHE where it sinks under its adjustable weight and records pressure (=depth) and temperature while going down (Figure 2a). The specific weight of the probe can be adjusted by changing the (red) heat part. NIMO-T is switched on using a permanent magnet.

NIMO-T sinks with a velocity of approx. 0.1 m/s down the U-tube. It measures temperature and water pressure every 2 to 8 seconds. The time interval between each measurement can be set via the delivered software.

After the probe has reached the U-tube bottom it stops there and then it is flushed back to the surface by a small pump for recovery and data retrieval (Figure 2b). From the measured temperature-depth profile and the local heat flow value the λ profile around the BHE in question can be calculated.

Table 1: NIMO-T specifications

Diameter	23	mm
Length	179, 219, 247	mm
Specific weight	1.16, 1.02, 0.95	mm
Weight	120	g
Measurement range for temperature	-5 bis +50	°C
Measurement range for pressure	0 - 40	bar
Maximum depth	400	m
Design pressure	110	bar
Measurement accuracy of temperature	± 0.0015	°C relative
	± 0.1	°C absolute
Measurement accuracy of pressure	± 0.02	bar relative
	± 0.1	bar absolute
Measurement intervals	2, 4, 6, 8	s
Memory size	16384	values
Measurement time/battery	3	hours

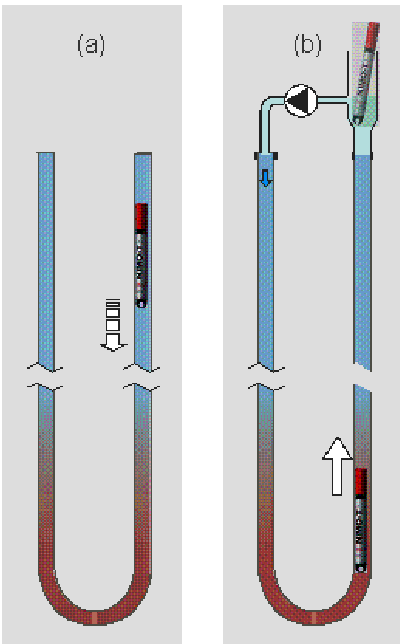

Figure 2: Wireless temperature logging in borehole heat exchanger using NIMO-T.

2.2 Example of application

Before measurement, NIMO-T is configured to start data acquisition. If necessary, the weight of the probe is adjusted by exchanging the head part of the probe. The time interval for data acquisition and storage is also set. After the probe has reached the bottom of the BHE it is retrieved and attached to a personal computer for data readout. Figure 3 (left) shows a typical measured temperature-depth profile, along with the geologic profile of the BHE drillhole. A 300 m deep BHE can be measured in less than 60 minutes.

For validation of the thermal conductivity profile calculated (details see below), laboratory measurements on cutting samples from the same boreholes have been performed. The equipment as well as the measurement method is described in detail in Schärli and Rybach (2001).

The thermal conductivity calculation is based on pure conduction. Therefore, disturbing effects like the influence of ground temperature changes (due to paleoclimatic variations), groundwater flow effects must be eliminated from the measured values beforehand. From the measured temperature profile the local geothermal gradient is then calculated layerwise (1st derivative; ∇T_i: temperature gradient of depth section i)

$$\nabla T_i = \frac{T_u - T_1}{z_u - z_1} \qquad (1)$$

where T_u is the temperature measured at the top ($z = z_u$) and T_1 at the bottom ($z = z_1$) of interval i.

Finally, with the local terrestrial heat flow value q_{loc} (obtainable from regional heat flow maps; e.g. Medici and Rybach 1995), the thermal conductivity of each individual depth section can be calculated:

$$\lambda_i = \frac{q_{loc}}{\nabla T_i} \qquad (2)$$

2.3 Results and discussion

The kind of results obtainable by the wireless probe is presented in Figure 3. On the left side, the temperature profile is displayed (black line) along with the profile of the temperature gradient. The latter is given by a blue line (original data with a constant Δz of 1.1 m and by a brown line (smoothed; gliding average over Δz = 13 m). The right side of Figure 3 displays the thermal conductivity profile as calculated by eq. (2). For comparison, the results of laboratory measurements of thermal conductivity are also given (black vertical bars). The agreement is remarkably good; thus the method of calculating the thermal conductivity profile from the temperature profile measured by the wireless probe yields highly reliable, in-situ thermal conductivities.

Often the "Thermal Response Test (TRT)" method (fluid circulation in a BHE with subsequent outflow and inflow temperature measurements) is used for in-situ thermal conductivity determinations (see e.g. Sanner et al., 2005). The common method provides a mean value of thermal conductivity, averaged over the entire borehole length. In combination with temperature logging during the test, NIMO-T can provide information about the vertical variation of ground thermal properties, if information about the local heat flow or measurements of rock samples are not available. This new TRT method is described in detail by Wagner and Rohner (2008).

Besides thermal conductivity determinations there are numerous other applications for the wireless probe: 1) Lithological subdivision of the borehole profile, 2) data base for paleoclimatic studies, 3) identification of groundwater flow.

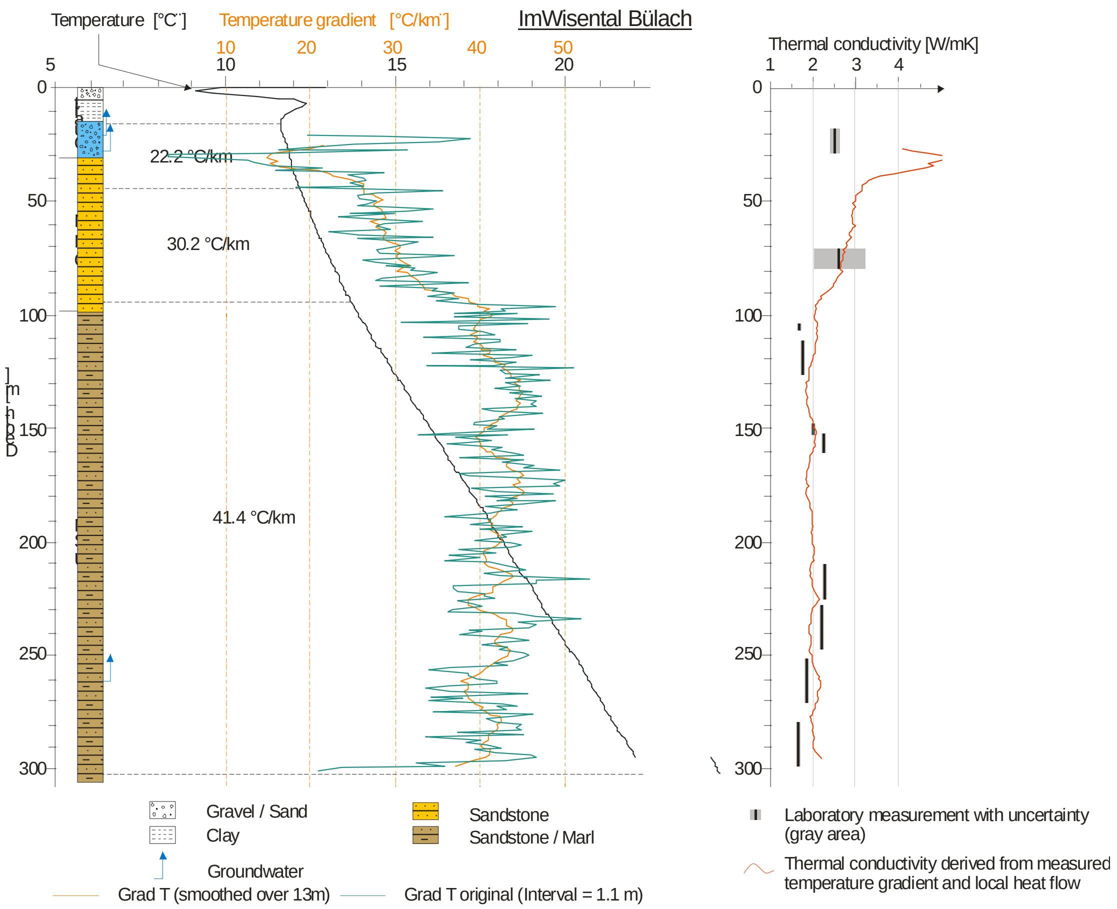

Figure 3: BHE borehole *Im Wiesental, Bülach* near Zurich. Left: geologic column, measured temperatures (with gradient sections; black line), gradient calculated with the original measurement spacing of Δz=1.1 m (blue line) and smoothed over Δz=13 m). Right: calculated thermal conductivity profile (brown line) with laboratory results (black bars).

3 PRESSURE TEST CONTROL UNIT

The main issue in BHE-coupled geothermal heat pump systems is safe operation, especially in view of groundwater protection requirements. Liciensing authorities rigorously request the experimental proof of the tightness of the BHE heat exchanger tubes; leakage is just not tolerated. The authorities usually require the compliance of new BHE installations with an accepted engineering norm.

The industry norm SN EN 805 demands, that tubing in the ground, in particular BHE tubes, must be checked with respect to leak tightness. This norm defines that each BHE tube must undergo a specific contraction procedure after installation into the borehole. The details of this norm are not discussed here in detail. Figure 4 shows the contraction procedure of the test, which has to be applied to each BHE tube. The test procedure is described in the new Swiss norm SIA 384/6, which is going to be published in 2008.

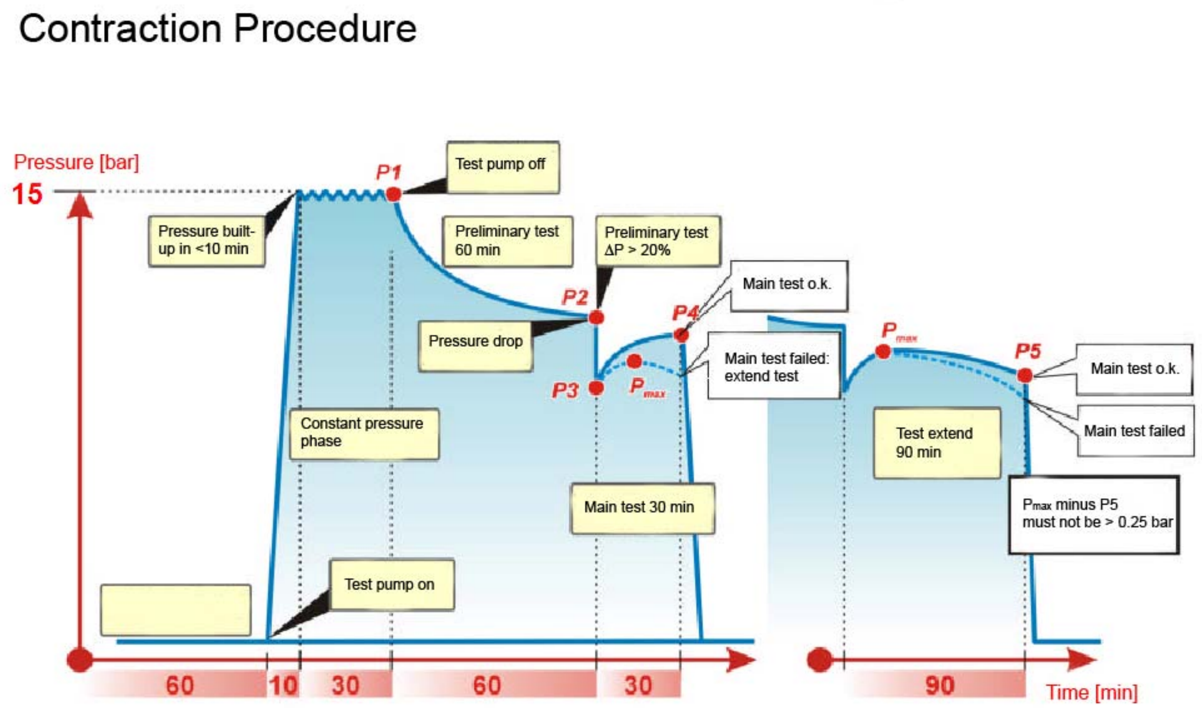

Figure 4: Borehole heat exchanger contraction procedure.

To date, such tests were performed manually. Now a new device, which performs the test automatically and guarantees a reliable test result, has been developed. The device is equipped with pressure, temperature and flow meters in order to record all relevant parameters of the test. The data is stored in the memory of the device during measurement. The test is evaluated after the end of the test. The preliminary design of the device is shown in Figure 5. After test execution, the data is transferred to a PC, where a fraud resistance test certificate can be created.

The device is currently at stage of development. Several tests on BHE have been carried out with a fully operational proto-type. The device will be ready for routine operations in 2008.

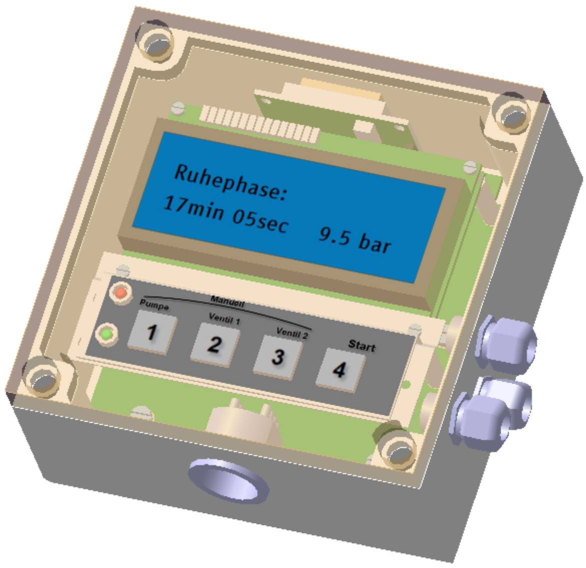

Figure 5: Device to perform automatically the borehole heat exchanger contraction procedure for tube tightness testing.

4 CONCLUSIONS

Two instruments have been devised and tested in order to improve the dimensioning and the safe operation of borehole heat exchanger-coupled geothermal heat pump (GHP) systems: 1) the wireless borehole temperature logging device NIMO-T, and 2) the PRESSURE TEST CONTROL UNIT.

The ground thermal conductivity and its spatial distribution in the volume of interest is a key parameter in dimensioning large GHP systems, with multiple BHEs, especially in view of the thermal performance. With the device NIMO-T the temperature profile of a BHE borehole is determined in relatively short time. The data enable to derive, along with a Thermal Response Test (see Wagner and Rohner 2008), the vertical profile of thermal conductivity. This information is especially needed in proper dimensioning of large GHP systems.

The BHE tube tightness is a prerequisite of safe operation; licencing authorities require tightness tests performed on-site. The device PRESSURE TEST CONTROL UNIT also enables rapid measurements; the results are compared with norm values and in case of compliance a test certificate is produced.

Both devices have been repeatedly and successfully tested under field conditions; their deployment in routine operation is now underway.

ACKNOWLEDGEMENTS

The authors would like to thank Markus Geissmann from the Federal Office of Energy of Switzerland for supporting the NIMO-T development.

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