Thermally enhanced grout and the reduction of borehole thermal resistance

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KEY WORDS

Ground Source Heat Pumps, BTES, Borehole Heat Exchangers, Grouting

ABSTRACT

Thermally enhanced grouting material is available in USA since ca. 10 years. Meanwhile, also in Europe such material can be purchased. The advantage of its use is a significant reduction in the borehole thermal resistance, which governs the temperature losses between the undisturbed ground and the fluid inside the BHE pipes. Another option to reduce the borehole thermal resistance is the use of spacers in order to keep the individual pipes apart and bring them closer to the borehole wall.

INTRODUCTION

The borehole thermal resistance consists of the following components (see fig. 1):

Transition resistances	ground – filling material	a_{gv}
	filling material – pipe	a_{vr}
	pipe – fluid	a_{rf}
Material resistances	filling material	r_v
	pipe material	r_r

The total borehole thermal resistance can be written as:

$$r_b = a_{gv} + r_v + a_{vr} + r_r + a_{rf}$$

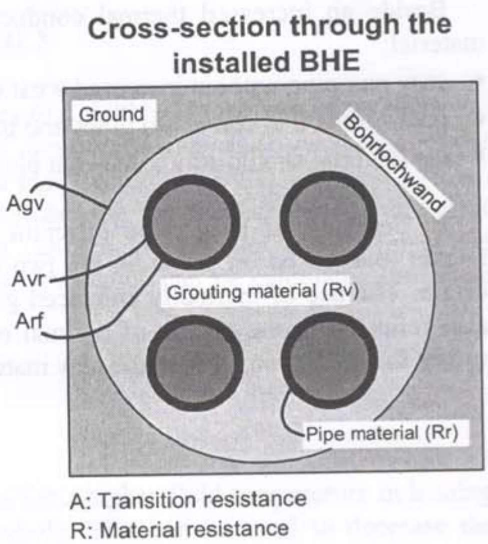


Fig. 1. Schematic of the concept of borehole thermal resistance r_b

THERMALLY ENHANCED GROUT

From fig. 1 it is obvious that the thermal conductivity of the filling material has a much higher influence than that of the pipe material, because the pipe thickness is small compared to the filling thickness. The transition resistances a_{gv} and a_{vr} are governed by the quality of the grouting; with pumping the material from the borehole bottom by use of a tremie pipe, a complete fill can be achieved, and the two resistances become virtually zero. The transition resistance a_{rf} is governed by the fluid flow, i.e. if the flow is turbulent (good heat transfer) or laminar (poor heat transfer).

Table 1 gives some values for typical BHE, calculated with the r_b-function of EED; the effect could meanwhile also be demonstrated in situ, using the Thermal Response Test on BHE with different grouting materials.

Table 1. Data for r_b for different grouting materials (calculated, with borehole diameter 150 mm, U-tube shank spacing 70 mm, pipe diameter 32 mm)

Type of BHE	λ grout	r_b
single-U, PE	0.8 W/m/K	0.196 K/(W/m)
	1.6 W/m/K	0.112 K/(W/m)
double-U, PE	0.8 W/m/K	0.134 K/(W/m)
	1.6 W/m/K	0.075 K/(W/m)

In Scandinavian countries grouting is rarely done. In most cases the holes in rock are stable, and the borehole heat exchangers (BHE) are sitting in the hole surrounded by groundwater. This allows for conductive and convective heat transport. However, in the rest of Europe, BHE are usually grouted. The water authorities typically require grouting in order to prevent pollutants entering the groundwater, but also from the point of view of heat transfer grouting is desirable in many cases. The German guideline VDI 4640 as well as the Swiss guideline AWP T1 require grouting, in VDI 4640 only with a few exceptions in shallow holes.

Grouting material usually is a suspension of bentonite and cement in water. There are several ways to increase the thermal conductivity of grouting material:

- addition of quartz (disadvantage: possible wear on pumps)
- addition of graphite (disadvantage: high price)

Beside an increased thermal conductivity, there are other required properties of the grouting material:

- easy pumping without increased wear on pumps
- good filling and contact to pipes and borehole wall, good plugging of the hole
- the material should stay somewhat plastic, to follow thermal dilatation of the pipes

In Germany, at least three different brands of thermally enhanced grout are available on the market, one based on graphite, the two others on fine-grained quartz of different particle size and origin. The use of thermally enhanced grout meanwhile has become a standard option. This fact is also reflected in the results of thermal response tests made over the past years, showing lower r_b-values for BHE grouted with the new material (table 2).

Table 2. Results of Thermal Response Tests on BHE with normal and thermally enhanced grout (grey); tests with double-U-tube made of HDPE, in most cases DN32 PN10. All tests performed by UBEG GbR, Wetzlar. The author acknowledges gratefully the permission to use this data.

No.	Borehole depth	Borehole diameter	Borehole thermal resistance r_b
1	99 m	150 mm	0,11 K/(W/m)
2	75 m	194 mm	0,11 K/(W/m)
3	92 m	150 mm	0,12 K/(W/m)
4	117 m	200 mm	0,12 K/(W/m)
5	91 m	146 mm	0,10 K/(W/m)
6	70 m	160 mm	* 0,08 K/(W/m)
7	100 m	180 mm	* 0,08 K/(W/m)
8	26 m	160 mm	0,10 K/(W/m)
9	59.5 m	200 mm	* 0,08 K/(W/m)
10	70 m	150 mm	* 0,07 K/(W/m)
11	99.3 m	324/180 mm	* 0,06 K/(W/m)
12	99 m	150 mm (?)	0,10 K/(W/m)
13	42.5 m	180 mm	* 0,08 K/(W/m)
14	100 m	200 mm	0,11 K/(W/m)
15	120 m	180 mm	* 0,08 K/(W/m)
16	70 m	180 mm	0,16 K/(W/m)
17	118 m	160 mm	* 0,06 K/(W/m)
18	99 m	160 mm	* 0,09 K/(W/m)
19	91 m	130 mm	* 0,07 K/(W/m)
20	100 m	180 mm	* 0,08 K/(W/m)

* grouted with thermally enhanced grout „Stüwatherm" or „Thermocontact"

THE USE OF SPACERS FOR DOUBLE-U-TUBES

Spacers have been developed to keep the individual pipes of a double-U-tube at a given distance. Usually these spacers are set every 2-3 meters. Some drillers communicate an easier installation of the BHE, while others complain about the more rigid and thicker pipe bundle.

In a standard BHE the shank spacing between the pipes carrying the fluid down and up varies arbitrarily between minimum (the pipes touch each other) and maximum (the pipes contact the borehole wall). The resulting difference in borehole thermal resistance can be calculated (borehole diameter 150 mm):

shank spacing	borehole thermal resistance
40 mm	0.2227 K/(W/m)
80 mm	0.1298 K/(W/m)

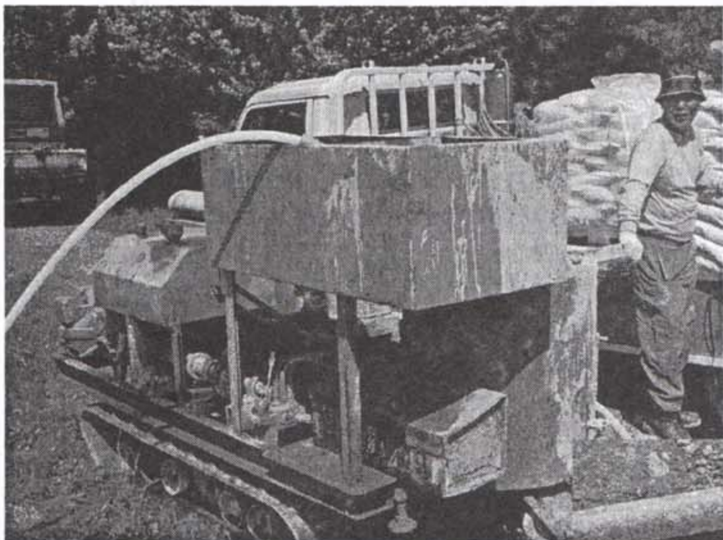
In practical use a low borehole thermal resistance allows for a higher fluid temperature in heating mode, with the same ground temperature around the borehole. This can be used to decrease the necessary borehole length for a given heat load. With the spacer the values of possible BHE length reduction given in table 3 can be calculated.

Table 3. Possible BHE length reduction with the use of spacers

ground thermal conductivity λ	Theoretical case, fixed shank spacing increased from 40 mm to 80 mm	Possible practical BHE length reduction
2,0 W/m/K	12,5 %	ca. 6 %
3,5 W/m/K	16,3 %	ca. 8 %

CONCLUSIONS

Thermally enhanced grouting material is an efficient way to improve the heat transfer of BHE. With the material currently on the market, the disadvantages of earlier attempts e.g. in Switzerland can be avoided. The effect of a reduced borehole thermal resistance could be proven in the field through a number of thermal response tests. Thermally enhanced grout now is a standard option, and a German brand meanwhile has been used for BHE installation as far away as South Korea (fig. 2). Spacers are another option, the use of which depends on the drillers experience. The use of both spacers and thermally enhanced grout for the same BHE does not result in a much better performance, because spacers bring the pipes close to the borehole wall and render the thermally enhanced grout almost useless, and the grout on the other hand lowers the borehole thermal resistance more than the spacers can do. Thus the driller should choose one of the options to improve BHE performance.



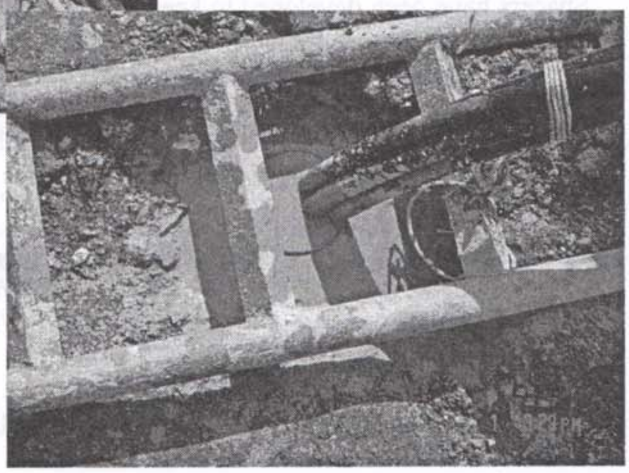


Fig. 2. Grouting device in South Korea at the test site of HP System Tech, Daejon, and BHE grouted successfully with EWS Thermocontact (photos: courtesy HP System Tech)