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In-situ investigation on the effects of groundwater flows around borehole heat exchangers

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Although vertical Borehole Heat Exchangers (BHE) is a booming technology for both cooling and heating buildings, several improvements could still be proposed in the dimensioning of such systems. Nowadays, most of the dimensioning methods consider only radial conductive heat flux around BHE using a homogeneous ground thermal conductivity determined from thermal response tests (TRT) or tables. Impacts of groundwater flows on the heat refurbishment around BHE are generally not explicitely considered.

Many numerical or analytical studies have investigated and quantified the positive impact of groundwater flows on the performance of BHE [4]. However, those results are rarely compared and validated with in-situ temperature measurements around BHE. Such measurements require the installation of temperature sensors in the ground around BHE.

In this work, an experimental platform composed of 4 vertical BHE drilled at depths of 85 m has been exploited. The 4 vertical BHE cross a succession of horizontal geological layers (Fig. 1). The study focuses on the heat transfers in a 30-m thick sand unconfined aquifer layer, whose 17 m are saturated. Each BHE is equipped with PT100 (installed at the extremities of the unconfined aquifer and just below the groundwater table level). Based on the expected direction of groundwater fluxes, the upstream BHE is thermally activated with a pre-determined heat injection and duration. The temperature evolution is recorded by means of PT100 sensors in the activated BHE and in the three non-activated BHEs. Groudwater velocity in the upper part of the aquifer is characterized through a non-convential tracer test [1] performed in a piezometer drilled at the center of the 4 BHE ($v= 7\ 10^{-7}$ m/s).

A clear impact on the groundwater flows on the temperature field in the aquifer around the activated BHE is observed. To quantify the heat transfers in the ground around the activated BHE, a methodology was developed to infer the hydro-geothermal parameters of the ground, namely the intrinsic thermal conductivity, the volumetric heat capacity and groundwater velocity and direction. From an analytical solution considering conductive, advective and dispersive heat transfers [2], the hydro-geothermal parameters of the ground are obtained by fitting the measured to the predicted temperatures evolution (Fig. 2 – Table 1). The obtained hydro-geothermal parameters demonstrate (i) a groundwater velocity in the upper part consistent with the value measured in-situ, (ii) the important role of the saturated aquifer that significantly enhances the apparent thermal conductivity of the ground and, in case of groundwater flows, induces an anisotropic propagation of the temperature plume [3](Fig.3), as well as (iii) the non-uniform groundwater flows along the saturated part of the aquifer (Table 1).

Contributor statement

Valériane Gigot : conceptualization, methodology, formal analysis, investigation, validation, visualization, writing – original draft
Bertrand François : funding acquisition, methodology, writing – review & editing, supervision
Pierre Gerard : funding acquisition, methodology, project administration, supervision, writing – review & editing

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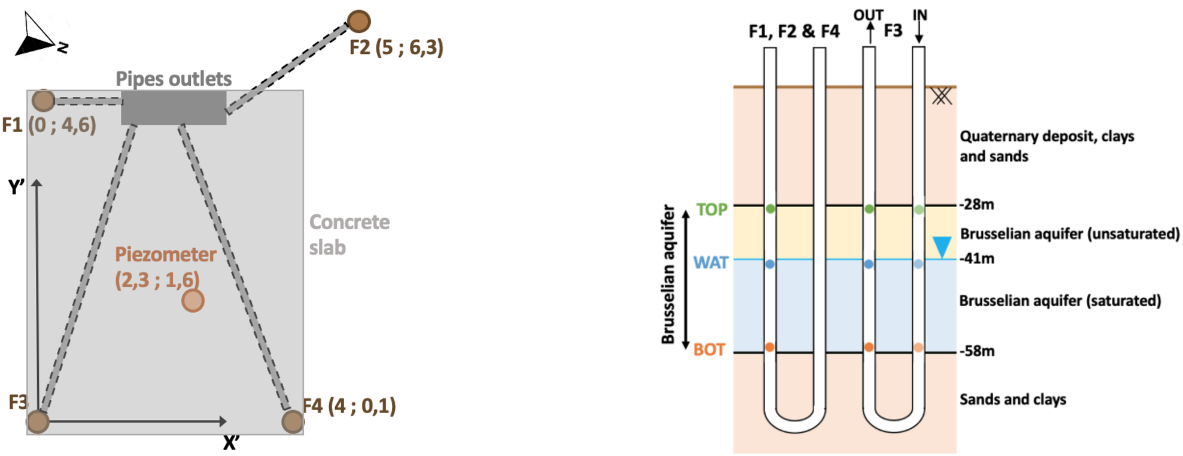

(a) (b)

Figure 1: (a) Location of the 4 boreholes heat exchangers (F3 is thermally-activated and F1, F2 & F4 are non-activated) and the piezometer (coordinates in meters); (b) Geological profile and location of the PT100 sensors.

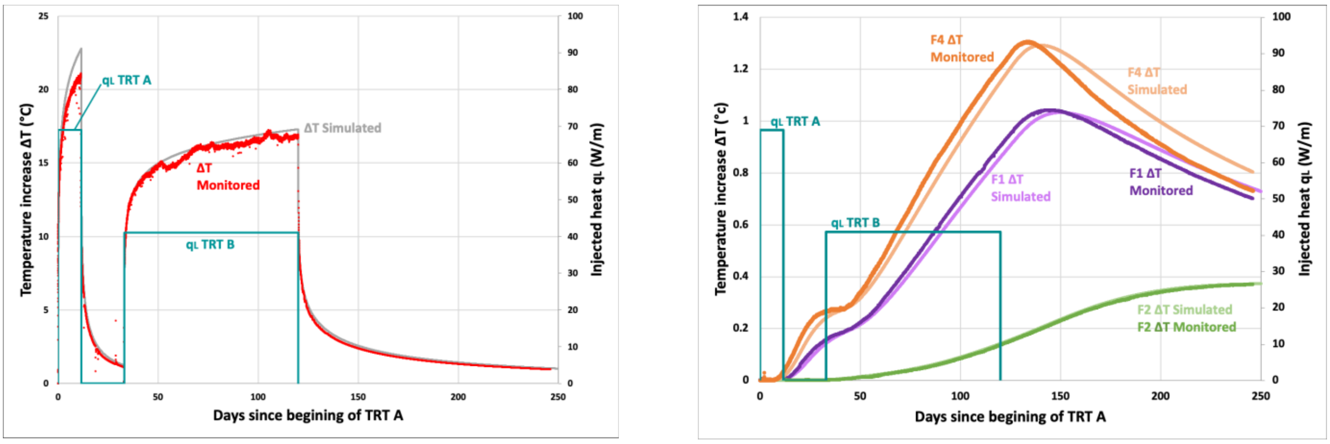

Figure 2: Example of comparison between monitored and simulated temperature evolution during the discontinuous thermal activation of F3 at TOP level (a) in the activated BHE; (b) in the 3 non-activated BHE

	TOP level	WAT level	BOT level
BHE thermal resistance (mK/W)	0,09		
Ground intrinsic thermal conductivity (W/mK)	1,8	2,2	2,2
Ground volumetric heat capacity (MJ/m³K)	1,9	2,4	2,4
Groundwater velocity (m/s)	-	$3\ 10^{-7}$	0
Dierction of groundwater flows (° ; from x')	-	14	-

Table 1 : Ground hydro-geothermal parameters inferred at different levels of the sand unconfined aquifer layer

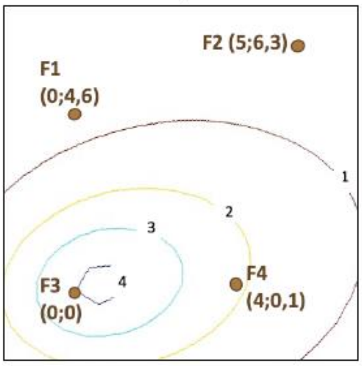

Figure 3 : Prediction of anisotropic increase in temperature (°C) around activated BHE (F3) at WAT level

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