III - A232

Localisation of chemical active zones at the subsurface by using Fibre Optic Distributed Temperature Sensing.

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Abstract: This work shows a method for determination of chemical active zones at the subsurface. It presents a method of determining the location and the intensity of such zones. The method was proven by application of Fibre Optic Distributed Temperature Sensing (FODTS).

I. Introduction

Geophysical measuring methods are in daily use of geoenvironmental engineers. New methods are constantly coming up and improve the accuracy and variety of measurable parameters. But the variety and quality of gauges for determination of geo-chemically reactions by using geophysical measure methods in the subsurface are still not satisfying. Many of the chemical reactions taking place at the subsurface are exothermic or endothermic reactions. An example for such reactions is for instance the reaction of pyrite oxidation in the subsurface of a dump. Those reactions cause particularly dramatic decreases of the pH-value of the groundwater. If this groundwater is infiltrating into the surface water, it might become hazardous to peoples live. If it would be possible to determine the location of such oxidation zones, precautions could be undertaken and their effects optimised.

For maintaining the problem the following solution strategy was developed. Variations in temperature distribution in the subsurface are caused through 2):

A temperature variations at the surface through vertical heat penetration,
B internal heat production sources and
C heat transport through groundwater flow.

The vertical penetration of heat from the surface into an unsaturated subsurface (A) can be described by a vertical one-dimensional heat transfer model 2). If it would be possible to determine the vertical distribution of temperature in the subsurface with a high spatial resolution and high accuracy and without any impact on the underground through the monitoring process, the comparison of the data obtained and the data of such a model would enable the possibility to determine the location and the summarily quantity of (B) and (C).

Such an investigation was conducted by the Centre of Environmental Research Halle/Leipzig and other participants. Fibre Optic Distributed Temperature Sensing (FODTS) attached on a Soil Groundwater Monitoring System (SGM - system) was therefore utilised. Due to the high spatial resolution (≥ 0.25m) of the FODTS and its high accuracy (0.1K) the gauge seamed to be very suitable.

The system was installed on the dump of the remaining pit Cospuden/Germany at a 50m deep borehole. The temperature was measured monthly with a spatial resolution of 0.5m and a accuracy of ± 0.05K. The method and the results of this investigation are presented in detail in 2) and will be described as a survey within this presentation.

II. Sensing Method

The applied fibre optic temperature sensing mechanism utilises the Raman scattering effect.

Raman scattering is used in applications for distributed fibre optic temperature sensing. From its mechanical attitude the Raman effect is an non-elastic scattering effect 1).

A coherent laser light beam is launched into an optical fibre. In case of normal temperature impact on the fibre, only low loss of backscattered laser light occurs at the end of the fibre. In case of a temperature impact, the microscopic properties of the fibre change and also the loss of the backscattered laser light intensity at the end of the fibre changes. The loss of laser light intensity can be related to the size of the temperature impact on the fibre. By pulsing the laser light beam and knowing the speed of the laser light pulse in the fibre, the location and size of the temperature impact along the fibre can be determined.

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III. Mathematical Model

The general equation for the heat penetration through a porous medium is given by:

$$\frac{\partial T}{\partial t} = -\Theta\frac{\rho_w \rho_s}{\rho c} v \cdot \nabla T + \nabla\lambda \cdot \nabla T + \kappa \nabla^2 T + \frac{\dot{Q}}{\rho c} \qquad (1)$$

where $\rho c = -\Theta \rho_w \rho_s + (1-\phi)\rho_s c_s$, is the total heat capacity per volume, and $\kappa = \lambda / \rho c$ the thermal diffusivity. Due to the assumption of an vertical one-dimensional process equation (1) simply reads

$$\frac{\partial T}{\partial t} = \frac{\kappa}{\lambda}\frac{\partial \lambda}{\partial z}\frac{\partial T}{\partial z} + \kappa\frac{\partial^2 T}{\partial z^2} + \frac{\dot{Q}}{\rho c} \qquad (2)$$

The interpretation of the measured temperature profile versus depth can be achieved by comparison to pure heat conduction, without internal heat sources.

$$\frac{\partial T}{\partial t} = \frac{\kappa}{\lambda}\frac{\partial \lambda}{\partial z}\frac{\partial T}{\partial z} + \kappa\frac{\partial^2 T}{\partial z^2} \qquad (3)$$

The computation results by using equation (3) have then been subtracted from the measured data. The difference ΔT obtained was than related to the term Q which represents internal heat production sources and heat transport through groundwater flow.

$$\dot{Q} = -\lambda\frac{\partial^2 \Delta T}{\partial^2 z^2} - \frac{\partial \lambda}{\partial z}\frac{\partial \Delta T}{\partial z} + \rho c\frac{\partial \Delta T}{\partial t} \qquad (4)$$

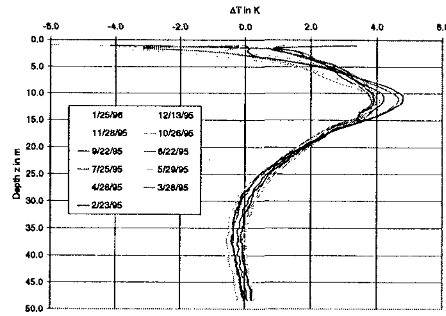

Figure 1: Difference between measured data and computed data versus the depth

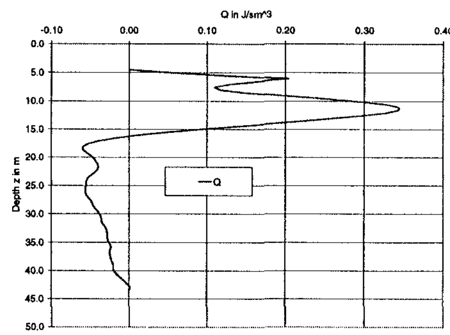

Figure 2: Heat production rate versus depth in J/sm^3

IV. Results

The comparison of measured data and computed data shows a heating effect of about 4K (see also Figure 1). By using equation (4) the heat source term $\dot{Q}$ was computed and the result is shown in Figure 2. This results match with results from geophysical pre-investigation and measurement of the water level in the borehole. The following results have been found:

A Impact on temperature balance within a depth of 5- 30m.
B Location of chemical active zones within a depth of 6 - 11m.
C Location of the interface of unsaturated saturated porous media at a depth of about 11m.
D Due to a high accuracy of the gauge a temperature effect within a depth of 15 - 50m has been found, which can not be explained yet.

V. References

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