Injection Wells with Fiber Optics from the Surface to the Reservoir

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Operational Monitoring of Thermal Dynamics in Deep Geothermal Production and Injection Wells with Fiber Optics from the Surface to the Reservoir

Introduction

To ensure a sustainable use of the deep geothermal resources, a reliable production must be ensured regarding well integrity, microseismicity, and thermal/hydraulic changes in the reservoir. Monitoring of a geothermal well during all life cycles is therefore crucial. However, conventional methods for measuring inside boreholes are usually temporally and spatially limited. Distributed fiber optic sensing allows for permanent monitoring of various physical parameters in high resolution during all times. This work focusses on the use of Distributed Temperature Sensing (DTS) in a deep hydrogeothermal reservoir.

The Upper Jurassic ‘Malm’ aquifer in the Bavarian Molasse Basin is Germany’s most actively used geothermal reservoir. At a geothermal heat plant in Munich that consists of three doublets, a permanent fiber optic monitoring system was installed in 2019 in two wells. A third well is being equipped in 2024. Among others, the temperature data collected is being used for thermal and hydraulic characterization and monitoring of the reservoir and borehole.

Introduction

Distributed Fiber Optic Sensing

Distributed fiber optic sensing (DFOS) is an optical measuring method that allows to continuously measure physical parameters such as temperature (DTS) and strain/acoustics (DAS) along fibers with high accuracy (DTS: 1 meter, 10 minutes, ± 0.6°C in this case). Distributed Temperature Sensing analyses specific parts of the backscattered light from laser pulses that are sent along the fiber to measure the temperature at each point in the fiber. The depth of each measuring point is calculated by the two-way travel time. Installation of fiber optic monitoring systems in geothermal wells is not yet standard and the installation can be technically challenging. Additionally, fiber optic pressure/temperature gauges are installed at this geothermal site to calibrate temperature readings and monitor the pressure in the reservoir.

DTS Data Interpretation Results

The temperature data collected in the producer TH4 is used as a permanent monitoring system and to address topics in the borehole and reservoir that can not be quantified using conventional data:

- Geothermal gradient assessment
- Flow zone interpretation & observation
- Reservoir pressure
- Interference between wells
- Production temperature tracing and prognosis
- Lithology assessment
- Fluid level detection
- Heat loss quantification (heat conductivity)
- Pump monitoring

Conclusion & Outlook

The Malm aquifer is a heterogeneous carbonate aquifer with a complex interplay between fractures, karstification and dolomitization that control permeability. The hydraulically active zones derived from conventional production logging (PLT spinner) could be confirmed and quantified more precisely by DTS data through injection profiling [2] and especially inverse modelling of production profiles [3] in 2021 and repeatedly during the following production phase.

References


Figure A: Location and setup of the fiber optic monitoring system. A detailed view shows the paths of the six wells and the installed (yellow/dashed) and planned (yellow/dashed/dotted) fiber optic cables in schematic views of the borehole. The high deviation of the walls up to 87° is not shown in this figure.

Figure B: Interaction between Wells

Function principle of Distributed Temperature Sensing: An interrogator sends laser pulses along a fiber. In each location, parts of the light are backscattered. The backscattered light consists of different elements that are altered in temperature. The DTS Interrogator looks at the ratio of Raman-Anti-Stokes and Stokes to calculate the distributed temperature. Modified after [1].

Figure C: Distributed Fiber Optic Sensing

Figure D: DTS profiles of production well TH4 during different times of maximum production (115 l/s).

Figure E: Pump monitoring

- Heat loss quantification (heat conductivity)
- Pump monitoring

Figure F: Heat plot of DTS data from well TH4 during long-term pumping and injection test with 16 month after cold-water injection and subsequent first commissining in 2021. On the 02.07.2021 the producer TH4 and the injector TH5 went into production influencing the temperature in the borehole of well TH4. A hydraulic connection is also visible in the pressure data (> 0.6 bar in TH4). The well into production on the 16.01.2023.

Figure G: The inversely modeled hydraulically active zones from DTS profiles for 2 different times in the reservoir of TH4. The 2 uppermost flow zones can be linked to strongly karstified areas. Within 2 years, production temperatures increased by 1°C, which can be explained by shifts in the flow zones.

Figure H: Flow zone interpretation & observation

Figure I: Lithology assessment

Figure J: Fluid level detection

Figure K: Heat plot of DTS data from well TH4 during long-term pumping and injection test with 16 month after cold-water injection and subsequent first commissining in 2021. On the 02.07.2021 the producer TH4 and the injector TH5 went into production influencing the temperature in the borehole of well TH4. A hydraulic connection is also visible in the pressure data (> 0.6 bar in TH4). The well into production on the 16.01.2023.

Figure L: Heat loss quantification (heat conductivity)

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