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심 병완[1], 이 영민[2], 김 형찬[3], 송 윤호[4]

Fiber optic distribution temperature sensing in a borehole heat exchanger system

Byoung Ohan Shim, Youngmin Lee, Hyoung Chan Kim, Yoonho Song

Key words: fiber optic sensing, distribution temperature sensing, borehole heat exchanger, thermal line sensor, geothermal heat pump

Abstract: Fiber optic distributed temperature sensing and thermal line sensor are applied in an observation borehole and a 200m deep borehole heat exchanger. For the case of permanently installed system fiber optic DTS is very useful. By comparing with TLS, fiber optic DTS shows good accuracy and reliability. Ground water flow can give influences at heat exchange rate of the heat pump system. According to the hydraulic characteristics and temperature-depth profile, we consider that temperature-depth profile do not seem to be dependent on ground water flow. A permanent installation of fiber optic cable is expected as a reliable temperature measurement technique in a borehole heat exchanger system.

1. Preface

Temperature measurements in a borehole are important for determining thermal gradient and temperature variation of subsurface. The thermal gradient gives clues as to what is happening underground. Ground water movements are noticeable and identifiable if there is an understanding of how temperature reacts to different mediums and situations. Temperature sensing technology has been rapidly developed and the method is various according to the purpose. We selected two sensing methods to construct temperature-depth profiles. Also two different data sets are compared and tested how much temperature differences exist between the methods in the study area (Fig. 1).

Fig. 1 represents the layout of borehole heat exchangers for the Earthquake Research Center building at KIGAM. In order to validate the performance of a double U-tube borehole heat exchanger system, long-term temperature monitoring is performed with fiber optic distributed temperature sensing (DTS) and thermal line sensor (TLS) methods. The basis of DTS method is given in Hutig et al.(1993), Förster et al. (1997) etc. The principle of fiber optic DTS consists in filtering the Stokes and anti-Stokes

1) Korea Institute of Geoscience and Mineral Resources, Groundwater & Geothermal Division
E-mail: boshim@kigam.re.kr
Tel : (042)868-3055 Fax : (042)868-3358
2) Korea Institute of Geoscience and Mineral Resources, Groundwater & Geothermal Division
E-mail: ylee@kis.kigam.re.kr
Tel : (019)208-3889 Fax : (042)868-3358
3) Korea Institute of Geoscience and Mineral Resources, Groundwater & Geothermal Division
E-mail: khc@kigam.re.kr
Tel : (042)868-3055 Fax : (042)868-3358
4) Korea Institute of Geoscience and Mineral Resources, Groundwater & Geothermal Division
E-mail: song@kigam.re.kr
Tel : (042)868-3175 Fax : (042)868-3358

components out of the back scattered light. The measurement equipment is DTS-SR from Sensornet Ltd.; the accuracy of the instrument is ±1°C and a resolution less than 0.1°C can be reached. The fiber optic range is up to 5 km and the temperature range is -20 to 600°C depending on the sensing cable used. Accuracy is controlled by the fiber-specific calibration function, whereas the available resolution and precision depends on the specific material properties of the optical fiber used (Großwig et al., 1996). Thermal line sensing data is used to test the validation of the temperature variation with the optical fiber DTS. The accuracy of the thermal line sensor is 0.5°C (for -10 to +85°C) and the resolution is 0.065°C.

Monitoring and collecting temperature data are an initial part of the long-term efficiency validation study of geothermal heat pump (GHP) system. Additionally, thermal transfer monitoring at the borehole heat exchanger and the observation borehole is useful to determine boundary conditions.

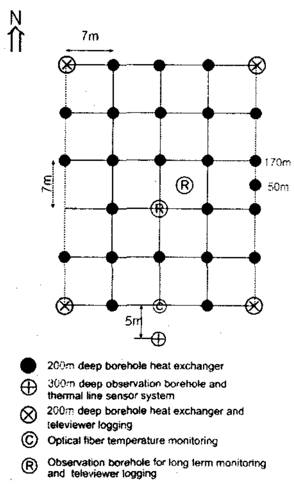


Fig. 1. Schematic layout of sensing method and location for double U-tube heat exchanger and observation boreholes in KIGAM study site.

2. Method

Fiber optic cables are attached on the surface of an inlet and an outlet pipe of double U-tube and the tube is installed in a 200m deep borehole. The detailed borehole heat exchanger system is described in Fig. 2 and the monitored temperature data are compared to that of reference probe of DTS and amended accordingly for temperature calibration. The each space resolution of fiber optic DTS and TLS is 0.5m and 2m, respectively. Therefore the temperature is compared in every 2m depth space.

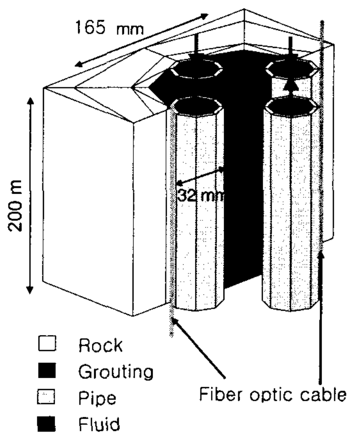


Fig. 2. Schematic diagram of the double U-tube borehole heat exchanger system and the installed fiber optic cables (signorelli, et al.).

3. Results

3.1 Observation borehole

A series of hydrogeothermal in-situ survey and lab experiments are performed to determine thermal properties of rocks. In-situ thermal conductivity estimated from the thermal response test is 3.28 W/m-K. The value is about 10 % higher than 2.98 W/m-K obtained from lab experiments.

Slow ground water flow velocities in large scale aquifer systems generate a characteristic set of temperature-depth curves. The recharge regions have temperature curves concave toward the temperature axis, while the upflow regions of the system have temperature curves convex toward the temperature axis. The extent of curvature depends on depth and size of aquifer circulation.

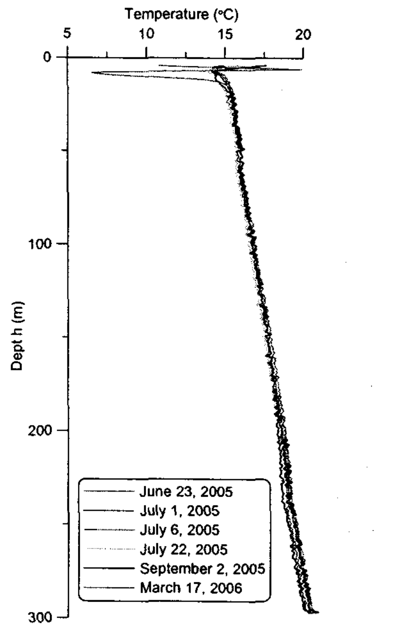


Fig. 3. Temperature versus depth profile by fiber optic DTS in the 300 m deep observation borehole.

Fig. 3 is six temperature-depth profiles measured from June 23, 2005 to March 17, 2006 in the 300m deep observation borehole (Fig. 1). There is no abrupt change or curves in temperature-depth and temperatures at the same depth, but different time, are less than 1°C. The small fluctuation in temperature-depth profiles seem to be caused by the white noise of the instrument. The thermal gradient between 220-250m depth interval shows slight difference compared to other intervals. The temperature difference at the same depth is considered as ground water effect and calibration error of the DTS instrument.

The average porosity measured on core samples from the depth of 63, 107, 212, and 301m is 0.79%; the hydraulic conductivity is about 10^{-6} ~ 10^{-7}m/sec except a few highly fractured depth ranges. According to the above hydraulic characteristics, we consider that the temperature-depth profiles do not seem to be dependent on ground water flow effect.

3.2 Borehole heat exchanger

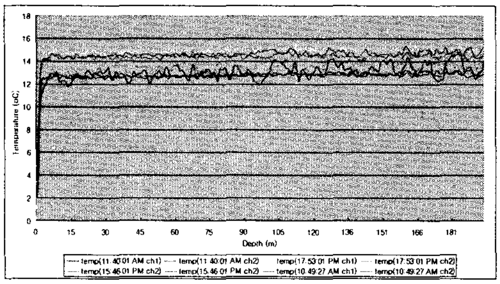
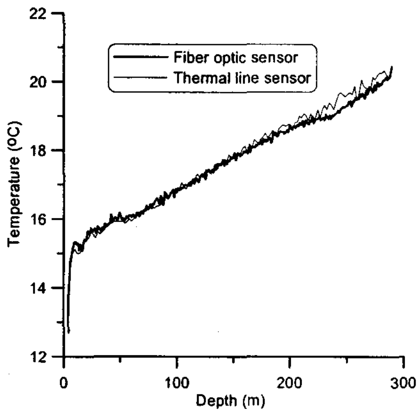


Fig. 4. Temperature distributions along a borehole heat exchanger with fiber optic DTS at several different points of time from January 7 to February 10, 2006.

Fig. 4 represents temperature distributions in a borehole heat exchanger in depth. During the GHP operation, temperatures are decreased more than 1°C and temperatures are highly fluctuated because of the effect of circulation water in the u-tube. When the system is stoped the amplitude is reduced less than 0.3°C and temperatures are slowly recovered to surrounding ground temperature. Temperatures on the each surface of the the inlet and outlet pipe are almost same at each measurement time and shows similar fluctuation shapes. The reason is considered as the large part of the attached fiber optic cable is separated from the u-tube surface in the borehole when the grouter is injected in high pressure.

3.3 Validation test

Fig. 5 represents temperature-depth profiles (a) and the temperature difference (b) between two applied sensing methods in every 2m deep at the observation borehole. In Fig. 5b the temperature difference from surface to the depth of 50m does not represent any trend but other depth ranges show the slope of temperature difference. The maximum difference is 0.5°C and the difference starts to be decreased at the depth of about 250m (Fig. 5b).



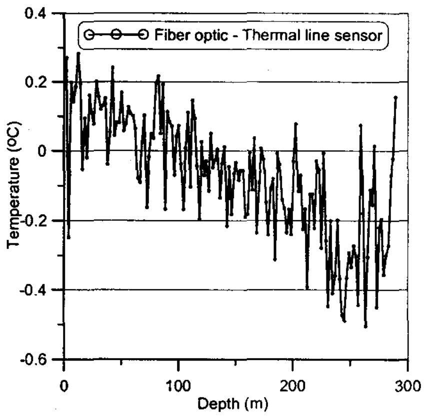


Fig. 5. Temperature distributions by fiber optic DTS and TLS (a), and temperature difference (fiber optic DTS - TLS) versus depth profile (b) in a 300m deep observation borehole on March 17, 2006.

4. Conclusion

During the GHP operation the amplitude of the fiber optic DTS temperature variation is about 2°C and the shape is irregular because fiber optic DTS shows some temperature fluctuation when the fiber optic cable is disturbed by the fluid circulation. However when the geothermal heat pump operation is stopped, the amplitude is decreased less than 0.3°C and temperature is regressed to a thermal gradient line. For the case of permanently installed system fiber optic DTS is very useful. By comparing with TLS, fiber optic DTS shows good accuracy and reliability. The fiber optic DTS represented long-term and short-term temperature changes in the borehole heat exchanger.

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