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Evaluation of fiber optic distributed temperature sensing in characterization of borehole fractures: a laboratory experiment

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Mapping of bedrock fractures in boreholes and the contribution of main fractures to groundwater flow have long been a significant challenge in the geosciences field. Advanced techniques such as formation micro-imager (FMI) are able to detect the location of downhole fractures and to characterise their properties, such as aperture and orientation. However, these techniques have not been designed to estimate flow from individual fractures and are, in many cases, economically unjustified.

In recent years, Fiber Optic Distributed Temperature Sensing (DTS) has been used to detect the location of active fractures and their contribution to groundwater flow, however; the technique has not been evaluated in a controlled environment and the limitations of the technique have yet to be identified.

For that reason, a fractured rock borehole with active fractures was simulated in a lab-scale experiment. A structure with two fractures was built in a cylindrical configuration around the borehole and placed inside a cylindrical reservoir. A coiled fibre optic cable was inserted in the centre of the borehole. In order to simulate groundwater interactions, water with distinct temperature was added to the reservoir. During tests, water from the borehole in the centre was pumped out of the system, while the fiber optic DTS recorded the temperature response. The location of the artificial fractures and their contribution to the flow rate were determined through analysis of the measured temperature data.

The results show that for the experimental setup, the locations of the fractures are most easily detected from the early times of the temperature response. As the water with different temperature from the reservoir flows into the borehole, it changes the borehole temperature starting from around the fracture locations. With time, this anomaly disappears and the borehole temperature reaches a new steady state condition. The contribution of each fracture to the pumping flow can then be identified from a combination of early time temperature responses and the new steady state temperature inside the borehole. The experiment also revealed that for certain combinations of parameters (temperature difference between water in borehole and fracture, pumping flow rate and aperture of the fracture), there exists a threshold below which fracture locations and flow rates cannot be accurately detected by measuring the temperature response.