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Hydraulic fracture monitoring: Integrated analysis of DAS, pumping information, and microseismicity

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Summary

Hydraulic fracturing is a well-stimulation technique employed to extract hydrocarbons from unconventional reservoirs by increasing their permeability and productivity with the creation of fractures. The geometry, orientation, and propagation of the created fractures can help identify potential completion issues during hydraulic fracturing operations and help in the design of more efficient unconventional reservoir completions, which is why the monitoring of these fractures during treatment is important. Low frequency DAS (LF DAS) is a new technology that enables continuous, real-time measurements along the entire length of a fiber optic cable, it presents a promising prospect for hydraulic fracture monitoring due to its characteristics and its ability to record strain perturbations of the medium, due to fracture propagation, which provides critical constraints on hydraulic fracture geometry.

In this study, we analyzed low frequency DAS strain fronts for all stages of one hydraulic fracturing treatment with their corresponding pumping curves and microseismicity. We also employed the PKN model as a diagnostic tool to determine whether things went according to plan during injection. This integration of records will give us a better understanding of the information about hydraulic fractures present in LF DAS, comprehension of the interactions between hydraulic fractures, strain changes, injection rates, and microseismicity, and a more complete interpretation of the fracturing treatment completion.

Theory

DAS is a type of distributed optical fiber sensor; these sensors use light to obtain information of the medium and they can obtain a measurement at every point in the fiber as the fiber is the sensor (Molenaar & Cox, 2013). DAS operates by sending coherent laser pulses from the interrogator unit to the fiber cable at constant intervals. These pulses of light experience scattering by interacting with small, natural inhomogeneities present in the cable. This scattered light returns to the interrogator unit, where the phase is measured. This process is also known as backscattering. Any vibroacoustic disturbance that affects the optic fiber produces variations in the phase of the backscattered light. These phase variations in the returned signal provide measurements of the strain the fiber cable is subjected to, and, by recording the time of its arrival, it determines the position at which each component of the backscattered light was generated (Fernandez-Ruiz et al., 2020).

Recently it was demonstrated that the low-frequency DAS data can be used to measure small and gradual variations along the fiber caused by the opening, closing and propagation of fractures during hydraulic stimulation of a well. This data can be used to constrain hydraulic fractures geometry; length, density, width, propagation speed and azimuth, by analyzing the DAS strain front patterns (Jin & Roy, 2017; Ugueto et al., 2019). To use low-frequency DAS to monitor hydraulic fracture geometry during stimulation the fiber is installed and cemented in a monitor well close to the well being treated, this well is usually horizontal (Jin & Roy, 2019). Figure 1a shows an example of the low-frequency DAS response for one hydraulic fracture, acquired from a single treatment stage during well stimulation, as recorded in the monitoring well. This is called a DAS strain front; the y-axis is measured depth and the x-axis is time, the red color indicates extension while blue indicates compression. The fracture signal resembles the shape of a dragonfly with a heart-shaped tip, that represents the fracture hit. Figure 1c displays the pumping curves; bottomhole pressure and the slurry rate, these curves help to make correlations between strain changes and injection characteristics during the stimulation process in the stage, as well as to obtain information on the timing and extent of communication between the treated and monitored well (Karrenbach et al., 2017).

Methodology

For the first part of the study the fracture characteristics present in the LF DAS data and pumping curves were picked to obtain estimations of the number of fractures created, fracture propagation speed, and fracture trajectory. These characteristics are FBP (formation breakdown pressure), fracture hit time and fracture hit measured depth. The difference in times between the FBP and the Frac hit are used to calculate the fracture propagation speed, the separation between the treated well and the monitoring well is divided by the difference in time between those two points. The frac hit measured depths are plotted in the monitoring well and connected with lines to the corresponding stage cluster on the treated well. This creates a fracture connection map where the deviation angle of the fracture propagation direction is shown.

In the second part, the length and trajectory of the microseismic clouds of every stage were analyzed to obtain an idea of how long the fractures are and how they propagated. After that the microseismic events were projected onto the strain fronts as a function of the time of their occurrence. Figure 1b shows an example of a strain front with its characteristics picked out and with the microseismic events on top of it. The microseismicity concentrates on top of the dragonfly and happens in a continuous manner from the start until just after the end of injection.

For the last part, the PKN fracture model was computed using data obtained from the LF DAS records, geomechanical and completion parameters from the fracturing treatment, to calculate the expected fracture propagation speed and length. Then, trajectory of the fracture obtained from the fracture connection map was combined with the fracture length of the PKN model and compared to the microseismic cloud length and trajectory. This analysis offers a baseline to determine if the LF DAS and microseismic results are within what was expected from the treatment or if something unexpected occurred during the injection.

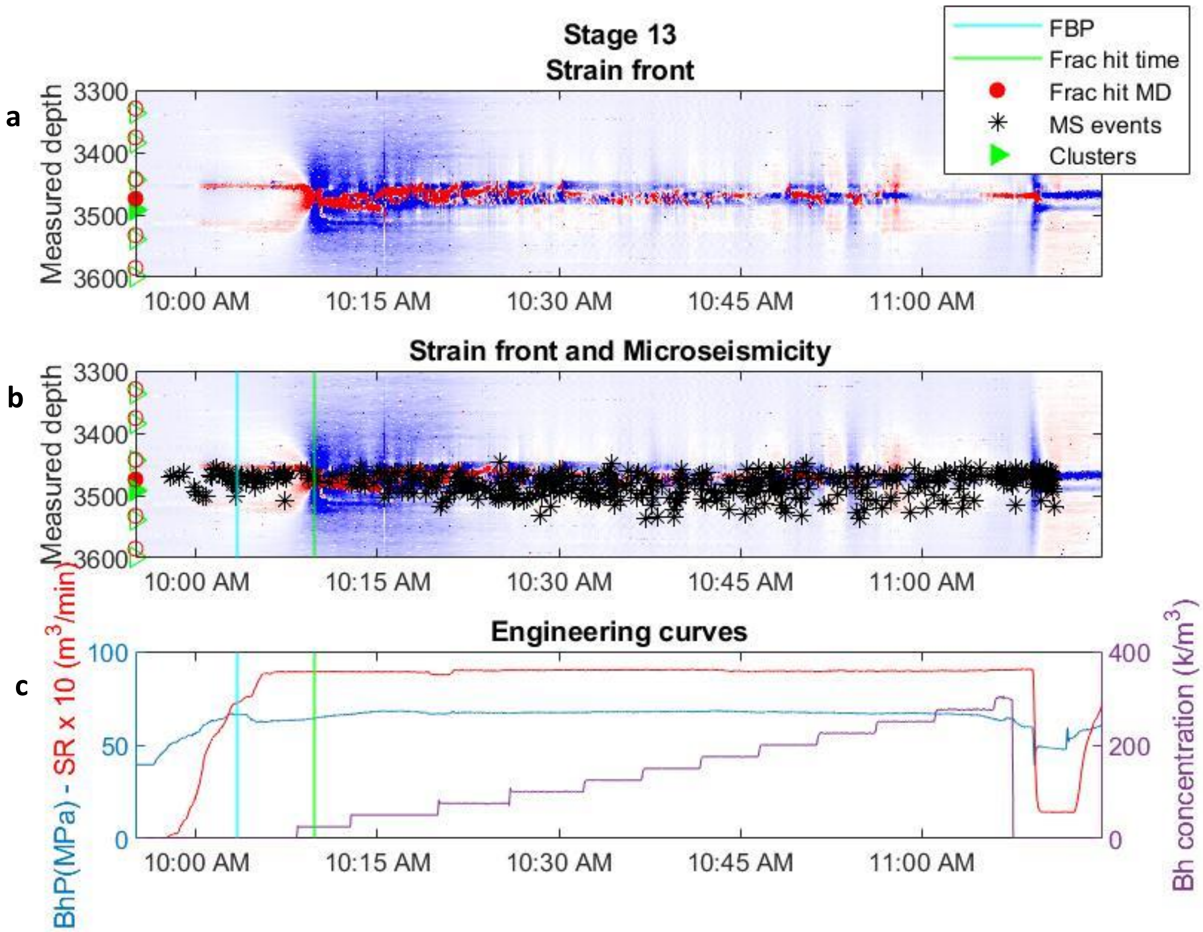

Figure 1. Strain front of one stage and its pumping curves. a) LF DAS strain front of a single stage from an offset well, the x-axis is Time, and the y-axis is Measured Depth (MD), red indicates extension and blue compression strain. b) Strain front with its characteristics picked out and the microseismic events on top, Formation Breakdown Pressure is the blue line and frac hit time the green line, pink circle represents the frac hit measured depth, microseismic events are the black stars and the clusters are shown by the green triangles on the right. c) Pumping curves with FBP and frac hit time picked out, the slurry rate is the blue curve, and the bottom hole pressure is the orange curve.

Results

From this study, we learned that DAS data analysis can benefit from being supported by other diagnostic tools. The integrated observations give us estimations on fracture propagation speed, length, and trajectory. These integrated observations show good agreement between them in many cases, however in some cases, they exhibit modest to poor agreement, this gives us an idea that maybe something unexpected happened during the stage. The following conclusions can be drawn from this integrated analysis.

Ideal cases have the heart-shaped tip in the strain fronts and the formation breakdown pressure peak is easily identified. Their propagation speed is reasonable, and their azimuths propagate perpendicular to the treated well. The microseismicity overlays on top of the fracture strain signal on the strain fronts and is continuous from the start of the injection until the end of it. The fracture growth is fairly described by the PKN model. The PKN fracture trajectory agrees with the trajectory of the microseismicity cloud. The complex cases are missing at least one of the ideal cases characteristics.

In our results we found that the hydraulic fractures of this treatment propagate mostly perpendicular to the treated well and they seem to be smaller but propagate faster in later stages. The absence of the heart-shaped tip in the strain fronts means that the fracture intercepting the monitoring well was already there. The antenna signals present in some stages come from previous stages, they are the reopening of fractures. The fractures that propagate with an inclination to the treated well are due to the existence of other fractures or weakness planes in the formation that diverted the fracture or because the cluster failed to create a fracture and the fluid propagated along the well until it found a fracture to move through. The comparison of the DAS strain fronts and the microseismicity shows that in most cases there is good agreement between the fracture strain signal and the microseismic events as the microseismicity happens at the same azimuth as the strain signal and it occurs continuously from the start of the injection to just after the treatment stops, otherwise it would mean that the isolation did not work as expected and the fluid is going to previous stages.

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