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Time-Frequency Analysis of Treatment Pressure

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Summary

We analyse hydraulic fracture treatment pressure using a time-frequency representation to gain insight into the dynamic nature of how a hydraulic fracture interacts with the rock mass. We simulate pressure fluctuations using a numerical model and study field cases from the Cardium and Duvernay Formations. We also analyse the pressure decay of a diagnostic fracture injection test performed within the Duvernay Formation. Various underlying physical process are presented which may produce pressure fluctuations and are studied by integrating pressure observations with microseismic data. Through analysis of these datasets in a pressure frequency framework, a theory of hydraulic fracture growth is presented. We further discuss how pressure frequency analysis may provide engineering parameters such as hydraulic fracture length and aperture, hydraulic fracture complexity, dynamic in-situ stress distributions and relative system permeability.

Introduction

The motivation of this study arises from the hypothesis that deformation in the subsurface is controlled by an increase in fluid pressure and subsequent rupture of a fracture. If the deformation is hydro-mechanically coupled, then fracture dilation and constriction results in pressure fluctuations which can be observed at the wellbore. Essentially, the fluid filled wellbore acts as a pressure probe into the dynamic behaviour of hydraulic fracture growth. If microseismic events are hydraulically coupled to the main hydraulic fracture, then slip or opening events could correlate to fluctuations in treating pressure from dilation or constriction of fractures within the reservoir. Furthermore, as the hydraulically connected system dilates, resonances within the open fracture network would be expected.

The relationship between treating pressure and hydraulic fracture growth has been proposed by various authors, however definitive links have been difficult to measure due to complicating factors during treatment such as changes in rate, changes in fluid properties and wellhead measurement (Downie et al., 2015). We circumvent some of these issues by analysing the entire time series of the pressure treatment data rather than simply picking a few representative points during the hydraulic fracturing process. For example, metrics such as average treatment pressure, breakdown pressure and instantaneous shut in pressure distil periods of the treatment stage into single values but miss some of the subtleties that arise due to physical processes at play during hydraulic fracture growth.

Theory and Method

Seismic events associated with fluid movements in faults or hydraulic fractures often develop in spatial temporal clusters or swarms which follow a pressure transient front originating at a point of elevated fluid pressure (Shapiro and Dinsk, 2009; Diehl et al., 2017). However, in unconventional reservoirs such as shales, these pressure diffusion fronts may occur episodically as faults or other structural control causes the fluid pressure front to become permanently or temporarily arrested. Goertz-Allmann et al. (2017) describe how microseismic clusters do not follow an expected continuous pressure diffusion, but are activated episodically as fluid moves from one cluster into the basement rock along faults. Smaller scale structural heterogeneity such as natural fracture connectivity is seen to play a critical role in controlling fluid flow (Gale et al., 2014). Fractures are often not uniformly distributed within the reservoir and display a marked lateral and vertical heterogeneity which can be quantified through mechanical stratigraphy studies (Laubach et al., 2009; Slatt and Abousleiman, 2011; Cooke et al., 2006).

The episodic movement of fluid within the earth and associated seismicity has been observed in completely natural systems as well. Sibson et al. (1975) describe a fault pumping cycle where shear stresses build up around a fault which contributes to rock mass dilation, thus lowering the fluid pressures in response to the increase in fracture porosity. Because the fluid pressures are lowered, an inflow of fluid into the fault zone occurs. The inflow of fluid results in an increase in pressure which triggers an earthquake. With the collapse of the rock mass during the earthquake, fluid is pumped along the fault and the cycle is then set up to repeat. A representation of this episodic spatial-temporal behaviour of fluid flow and associated microseismicity is captured in Figure 1.

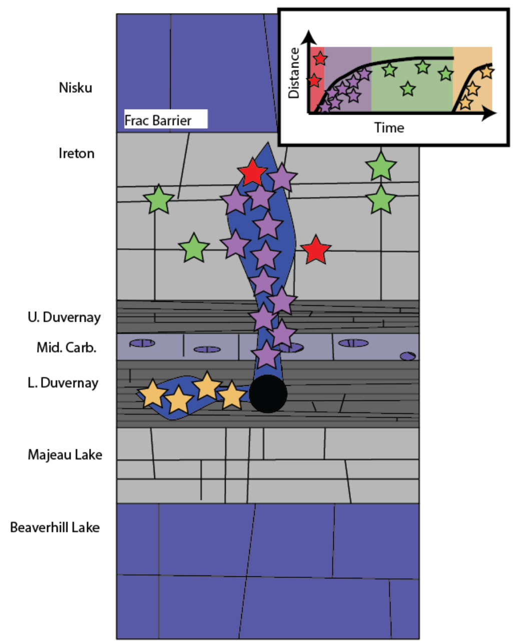

Figure 1. Schematic representation of hydraulic fracture growth through the Duvernay Formation exhibiting spatial-temporal clustering controlled by geomechanical facies. Microseismic events are illustrated as stars and are plotted on a time-distance plot with corresponding events shown in the sub-surface.

In order to assess the frequency content of the treating pressure, we employ a short time fourier transform on the treatment data. Resonances within the hydraulic fracture are attributed to result from a Krauklis wave (Krauklis, 1962), with fundamental frequency f_0, hydraulic aperture h, rock shear modulus μ, frac length l, fluid density ρ and s to p wave velocity ratio γ (Tary et al., 2014)

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{h\mu\pi^3}{l^3\rho}(1-\gamma^2)}. \quad (1)$$

Examples

We present hydraulic fracturing cases from the Duvernay and Cardium formations. In the Cardium Formation, frequency resonances are well developed and indicate a relatively simple hydraulic fracture which is independently corroborated through microseismic interpretation (Figure 2).

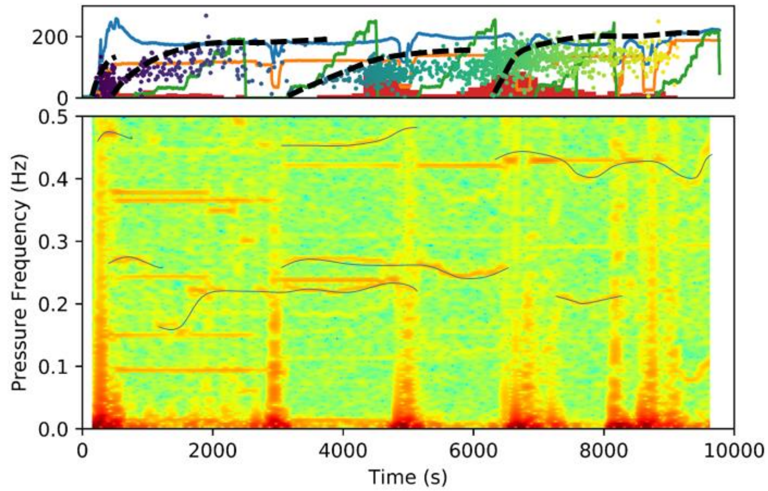

Figure 2. Pressure frequency analysis of a Cardium Formation treatment stage. Top) Distance of microseismic event from perf cluster and treatment parameters showing spatial-temporal clustering behaviour. Bottom) Time-Frequency representation of the treating pressure time series with example frequency trends highlighted.

Conclusions

Pressure frequency analysis provides an unusual way to observe hydraulic fracture behaviour on data which is generally collected yet not fully analysed. This analysis technique is particularly useful when combined with other data analysis such as microseismicity, treatment curves and pressure transient analysis. We identify signals in a time-frequency domain and show how they can be used to identify deformation and fluid movement in the sub surface. Certain trends are consistent between treatment stages and reveal the underlying physical processes at play during the hydraulic fracture growth.

Acknowledgements

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