An Improved DFIT Methodology: A Primrose Case Study

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Summary

Thermal in-situ recovery caprock integrity requires minimum in-situ stress values to be determined confidently. In-situ stresses are a first order effect on hydraulic fracturing initiation, propagation and containment. Primrose and Wolf Lake (PAW) has 25 years of commercial Thermal operations including CSS, SAGD and Steamflood. Significant field observations exist. This material will highlight an improved DFIT interpretation methodology and will cover

- DFIT Shut-in and flowback cycles
- Caprock field observations
- Numerical modeling of DFIT fracture behavior
- Considerations of G function compliance versus tangent closure approaches

For DFIT interpretation Canadian Natural uses a combination of flow regime identification on Bourdet derivative plots and the compliance method on the G-Function plots to pick the fracture closure pressure (FCP). These two methods routinely provide consistent results, therefore increasing technical rigor. This approach follows the methodology introduced by Bachman et al. (2012) and Bachman et al. (2015).

Method

The compliance method for picking closure is based on a combination of theory, experience and modeling. A variable compliance behavior is observed in shale caprocks in CNRL's thermal development areas, which leads to significant difference between the compliance method and the alternative tangent method. Formations at Primrose where this behavior has been observed include the Clearwater sand, Clearwater shale and Colorado group shales. Illustrative field examples will be reviewed that shows the changing compliance behavior and the resultant difference in the interpreted fracture closure pressure using different methods.

Field Example

DFIT field examples will be presented, which demonstrate a FCP similar to the vertical stress using Bourdet derivatives with a consistent compliance interpretation.

Field experience

Field observations will be presented which independently confirm stress magnitude and orientation.

Modeling Support for Compliance Methodology

A coupled reservoir and geomechanical model was used to produce a synthetic response of a DFIT in a shale caprock to demonstrate the physical processes occurring during the fracture closure process of a fall-off.

A summary of the different flow geometries, regimes and their expected slopes is shown in **Figure 1**. Specifically the radial equivalent time is the basis for the Bourdet derivative (the key derivative plot in classic PTA), which will be discussed. This analysis and approach has been introduced and verified by Bachman (Bachman et al. (2012)[1] and Bachman et al. (2015)[2].

Expected Slopes for Flow Regimes on Log-Log Plots (Derived from Analytical Equations for the below flow regimes)

Log-Log	Wellbore Storage		Bilinear		Linear		Pseudo-Radial		Spherical		Nolte	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Log dP vs Log Δt	$1/1$	$1/1$	$1/4$	0	$1/2$	0	~x kPa per log(t_{er}) cycle		NM	0	$1/1$	$1/2$
Log dP/dt vs Log Δt (PPD)	0	0	$-3/4$	$-7/4$	$-1/2$	$-3/2$	$-1/1$	$-2/1$	$-3/2$	$-5/2$	0	$-1/2$
Log Δt(dP/dt) vs Log Δt (DT Log-Log Derivative)	$1/1$	$1/1$	$1/4$	$-3/4$	$1/2$	$-1/2$	0	$-1/1$	$-1/2$	$-3/2$	$1/1$	$1/2$
Log $\Delta t^{1/4}$ (dP/dt_{eb}) vs Log Δt (Bilinear Equiv. Time)	$1/1$	$2/1$	$1/4$	$1/4$	$1/2$	$1/2$	0	0	$-1/2$	$-1/2$	$1/1$	$3/2$
Log $\Delta t^{1/2}$(dP/dt_{el}) vs Log Δt (Linear Equiv. Time)	$1/1$	$2/1$	$1/4$	$1/4$	$1/2$	$1/2$	0	0	$-1/2$	$-1/2$	$1/1$	$3/2$
Log Δt_{er}(dP/dt_{er}) vs Log Δt (Radial Equiv. Time)	$1/1$	$2/1$	$1/4$	$1/4$	$1/2$	$1/2$	0	0	$-1/2$	$-1/2$	$1/1$	$3/2$
Log Δt(dP/dt_{en}) vs Log Δt (Nolte Equiv. Time)	$1/1$	$3/2$	$1/4$	$-1/4$	$1/2$	0	0	$-1/2$	$-1/2$	$-1/1$	$1/1$	$1/1$

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Expected Slopes Based on Synthetic Data using Analytical Equations

Figure 1: Flow Regime summary of expected slopes for PTA analysis for DFIT fall-offs

Model setup

The results of the reservoir and geomechanical model demonstrate the validity of the compliance method for interpreting the FCP. A rigorous flow regime identification workflow for interpreting the FCP shows that the end of Nolte flow indeed aligns with the change from an open fracture to a partially closed residual fracture behavior and is the best method to interpret the minimum total stress.

[1] Bachman, R. C., Walters, D. A., Hawkes, R. A., Toussaint, F., and Settari A: 2012. Reappraisal of the G Time Concept in Mini-Frac Analysis, SPE 160169

[2] Bachman R. C., Afsahi, B., and Walters, D. A: 2015. Mini-Frac Analysis in Oil sands and their Associated Cap Rocks Using PTA Based Techniques

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