Solid Earth Discussions

Solid Earth Discuss., author comment AC1
https://doi.org/10.5194/se-2021-1-AC1, 2021

Reply on RC1

Mostafa Gorjian et al.

Author comment on "An Analytical Framework for Stress Shadow Analysis During Hydraulic Fracturing – Applied to the Bakken Formation, Saskatchewan, Canada" by Mostafa Gorjian et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-1-AC1, 2021

We would like to thank the reviewers for their thoughtful comments and efforts towards improving our manuscript. Below is our response to the issues raised in the review:

- Introduction line 55: What is the specific objective of the study? The author mentioned "a better understanding of the combined effects of mechanical, thermo and poroelastic stress shadows during the process of hydraulic fracturing." But from the literature review, it is not clear what is the problem or gap in this area that this work is attempting to address. The paper's objective is not the same with the discussion and conclusion. The abstract needs to reflect clearly the objective(s) of the study.

Answer: The authors addressed two gaps related to Canadian Bakken Formation and stress shadow analysis: Lack of data specifically in core scale, and introducing the fast, simple, and realistic workflow.

The authors compiled/measured all the required data (e.g., thermal, hydraulic, mechanical properties, complete well logging set, etc.,.) for analyzing almost any geomechanical projects in the Canadian Bakken formation, and we have plan to put part of those data in the revised version. This lack of data was the first gap regarding Canadian Bakken Formation studied area.

Another gap was related to stress shadow analysis by itself. To the best of authors' knowledge, most of prior analyses did not take most of real field complexities (e.g., different hydraulic fracture treatment schedule (proppant and fluid type), well trajectory, geologic structure, leak-off, process zone stress, etc.,). This is the reason of having reasonable match between our workflow output and DFIT field data.

We will definitely elaborate on each of them in the revised version.

- The equations presented to the end of page 17 are all from the literature and well known. There is no need to present them all in the main body of the manuscript, as it distracts the reader to focus on the main objective of this work. If necessary they should be moved to the Appendix.

Answer: We will move the formulation to the appendix in the revised version.

- It is not clear at all, what is the new development in this work. Is it the algorithm which combines the use of the analytical methods and numerical simulations using Gohfer?

Answer: The new development of this work is introducing the workflow (toolbox) to calculate thermo-hydro-mechanical stress shadow in tandem with a fully coupled three dimensional numerical fracture simulator. Despite the limitations, which is inherent in any method, this workflow considers the real field complexities. This workflow is simple and fast, and yet reliable as the result was verified by field data. Some of the real field complexities which were considered in our workflow are as follow:

- *The rheological coupled behavior of frac fluid and proppant, the same as real treatment schedule. Rheological behavior of frac fluid was simulated based on the lab data, provided by service company.*
- *Calibration of treating pressure by modifying the frictional parameters such as pipe, and perforation friction, tortuosity factors.*
- *Considering the effect of real well-trajectory.*
- *Considering the real geological structure, which enables us to analyze horizontal heterogeneity.*
- *Determining type and amount of leak-off and PZS by analyzing DFIT test. The leak-off coefficient implicitly accounts for the existence of fissures, and secondary fractures around the hydraulic fracture. PZS is calculated by [i.e., ISIP-closure pressure], which is more realistic criteria for fracture propagation rather than fracture toughness, which is measured under dry laboratory condition.*
- *Updating fracture width according to proppant crushing strength at the end of the operation according to time lag.*
- *Verification of numerical simulation by applying pressure-matching technique.*
- *And etc.,*

To the best of authors knowledge, even measuring and compiling the data set for Canadian Bakken Formation is deemed as a new development, since lack of these data put hold on many major projects in this formation for more than a decade.

- What is the shortcoming or limitation of the cumulative stress shadow calculation method? For example. 1. The author assumed the i+1 stage stress shadow has no impact on the I stage stress shadow. 2. The author assumed the average value of fracture length and width.

Answer: As you mentioned in example 1 and 2. In our work, the effect of i+1 stage stress shadow on the stage i is not deemed important, since it was not simultaneous hydraulic fracturing.

- 1 Workflow: Clear discussions need to be given regarding the GOHFER software and how it accommodates stress shadow distribution (magnitudes and direction). Simple example to clarify how it works and validation of results should be given before presenting a complex 30 stage fracturing example.

Answer: We will cover it in revised version.

- 2 Mechanical stress shadow equation 1-4: There is no explanation of parameters such as E, E', , R, r, etc. It is not clear if it is proposed to modify the existing equation or solely reproducing the equations.

Answer: We proposed to modify the existing equation, by considering the fact that fracture leaves open after hydraulic fracture due to existence of the proppant layers. The proposed equations consider the effect of propped fracture, as well.

- 3 Thermo-elastic Stress Shadow: Phie (effective porosity) is better to be shown as Φ.

Answer: we will correct it in the revised version.

- Line 310: In the case study part. The author mentioned the results of sensitivity analysis from other research, but there is no citation. These results are not generally known.

Answer: We will cite it in a revised version.

- Line 330: Which figures in the Appendix are results of ‘’0 MPa for the thermo-elastic and 0 for 330 the poro-elastic” are not mentioned.

Answer: The authors meant the stress shadow at a point corresponding to Teta = 90° and R = fracture stage spacing for each stress shadow mechanism.

Figures A.2.b & B.2.b

- Line 350: It will be useful to show the direction of the stresses in Figure 12 using arrows in Figure 1. That will help to understand why the stage 3 fracture orients 11 degree.

Answer: We will try to accommodate it in the revised version.

- Line 400: figure 18 (a) is not induced shear stress, it is minimum horizontal stress.

Answer: We will correct it in the revised version.

- It is important to show the results of GOHFER simulation, I didn’t see how GOHFER was used and what are the outcomes. No explanations are given on how GOHFER adopts and utilizes the stress distribution to predict the fracture geometry and orientation.

Answer: we will show the results of verified GOHFER simulation, with explanation in the revised version.

- There is no explanation on how to obtain the total stress shadow from each stage.

Answer: We will explain it in the revised version.

- Figure 21. The orientation of each fracture is not clear. It looks like each fracture is parallel to the other and no stress shadow effect.

Answer: The red dashed lines are only the visual guide to show the location of each stage. We will try to fix it in the revised version. Fractures are not parallel in reality, and stress shadow effect is considered.

- There is a discussion on microseismic events on the early page but no further explanation in the main paper except one-page appendix. How the results of multistage fracturing simulations presented and the stress shadow effect was validated against microseismic data?

Answer: Comparison of the lateral extents of the zones of microseismic activity monitored at well L (Figure C-1) against the predicted extents of shear failure zones for various scenarios of natural fracture orientation, used to validate (Table 2).