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Reply on RC2

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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-AC2, 2021

We truly appreciate the reviewer for the comments! Please find our responses as follow:

An Analytical Framework for Stress Shadow Analysis During Hydraulic Fracturing – Applied to the Bakken Formation, Saskatchewan, Canada

It is well written (as far as my English grammar knowledge allows) and deals with an interesting and up-to-date subject, that involves both the economic development of tight reservoirs and the environment protection in such activities (this might be a suggestion to the Authors, from the general point of view…).

Answer: Thanks for the positive comments!

Despite these premises, the manuscript in its present form in not suitable for publications.

It is based on the application of a series of equations that are difficult to be understood (and to easily justify). Results produced by the application of the proposed equations are then compared with well results though time (or space?).

Among my perplexities, here are some substantial ones:

The Authors should make explicit how did they obtain the proposed equations (1-9) from the cited reference (Pollard & Segall 1987). This is important, since it is the base of the work presented in the manuscript.

answer: We will explain the method in the revised version. The authors cordially ask the reviewer to refer to Appendix C of "Ge, J. (2011). Modeling and analysis of reservoir response to stimulation by water injection (Doctoral dissertation, Texas A & M University)". We need to cite this reference in the revised version, as well. It should be noted that one of the real field complexities which was considered by our toolbox is the effect of propped fracture due to the proppant layers remaining inside of the fracture after termination of each stage within the process of multi-stage hydraulic fracture. To do that, these equations were modified slightly.

The meaning of the term "Stage" is not enough explicit: does it refer to different time of application (line 280, Fig. 14) or does it represent a distance measure (Fig. 13)?

Answer: Stage is so common and broadly agreed-upon term in the hydraulic fracturing field. It means the interval, which is pressurized to create hydraulic fracture. In multistage hydraulic fracturing presented in our paper, stages are from the toe (end of the horizontal leg) to the heel (back to the vertical part of the well). Figures 13 and 14 show the stage spacing (distance) and time lag (the time between finishing one stage and starting the next stage) within multi-stage hydraulic fracturing in well S.

Computations are compared with experimental results that, as they maintain, strongly depend from the time lag between "stages". Yet the presented equations do not take into account for the time variable, with the exception of the Thermo-elastic model, where time is used as a mere computation of the amount of fluid injected (eq.12). Furthermore, the Authors demonstrated that this component is negligible in their computation.

On the other hand, the comparison between equations and experimental results deals with the relevance of the time lag between successive injection changes (stages, did I correctly understood?), that are not included in the used formulas.

Answer: Figure 3 is the algorithm that was developed in our work. The attributes of the hydraulic fracture are simulated by 3-D coupled numerical simulation and then those attributes are given to the stress shadow toolbox as an input to calculate stress shadow. The in-situ stress is updated then accordingly. It should be mentioned that leak-off data were real, and analyzed through field DFIT test in the studied area.We will definitely elaborate on this part in the revised version.

The Author should make explicit how did they arrive to the simplified formulas (45-46) from the proposed full form. Did they just summed the results from each stage by ignoring the dissipation/interference between stages? These formula contains fracture dimensions: how were they determined? Were they extracted from the experiment data, and how (line 444-446)?

- *We considered the effect of dissipation and interference between stages. Attributes of hydraulic fracture are obtained by doing 3-D coupled numerical modeling. Please refer to the answer 4. The reason for extracting fracture attributes from numerical modelling was to consider maximum real field complexities (e.g., different hydraulic fracture treatment schedule (proppant and fluid which were rheologically modelled by using lab data), well trajectory, geologic structure, leak-off, process zone stress, etc.,) and analytical model cannot reflect that level of complexities.*

In my opinion, there is a general questionable point in their analysis: stress produced by fluid injection strongly depends on the rate of injection due to fluid viscosity and rock/fluid interaction (e.g. friction). This factor should be taken into consideration when computing produced stress and stress shadows. Cited Pollard models are based on a static approach, that is change in the fracture dimensions (i.e. L) is not considered during the computations, as they modify stress by the produced work, and geometry. And the prediction of enlargement of fractures is one of the goal of the presented work.

- *Answer: As we mentioned before, proppant type and rheological behavior of fluid according to laboratory data were simulated. Treatment pressure was calibrated by modifying the frictional parameters such as pipe, and perforation friction, tortuosity factors. It is worth noting that even the effect of proppant embedment on the surface of fracture was considered in this workflow. We will elaborate on them in the revised version of this paper.*

The computed average width of fractures with respect to their extension seems too large for the proposed properties (line 294-295 and Tab. 1), with a width/length ratio of about 5.7 / 162 = 0.035 that is about 3 times what observed in nature (e.g. Walsh results). The authors should compare and comment on this.

Answer: This well was actually completed by 30-stages of hydraulic fracturing in the field, and each stage had 4 tonnes of proppant mixed with 32.9 m3 of fracture fluid (ELE-Stim for proppant stages and ELE-Stim 18cp for non-proppant stages) injected over a total time of 47 minutes for each stage. The ELE-Stim has initial viscosity of 111 cp and peak viscosity of 516 cp, and ELE-Stim-18cp has initial viscosity of 11 cp and peak viscosity of 18 cp. Having more viscous fluid rather than conventional 1 cp fluid (e.g., fresh water) results wider and shorter fracture.

As far as what mentioned, the manuscript requires a significant improvement before entering in the stage of a detailed and complete review.

Answer: We trust the foregoing answers are satisfactory, and we would greatly appreciate your reconsideration of our paper.