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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Evgenii Kanin

PhD Program: Petroleum Engineering

Title of Thesis: Asymptotic models of coupled geomechanics/fluid mechanics phenomena of hydraulic fracture growth

Supervisor: Professor Andrei Osiptsov
Co-supervisor: Professor Dmitry Garagash, Dalhousie University, Canada

Name of the Reviewer: Brice Lecampion

I confirm the absence of any conflict of interest	**Date: 01-08-2022**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

It is with pleasure that I present below an assessment of Evgenii Kanin thesis entitled "Asymptotic models of coupled geomechanics/fluid mechanics phenomena of hydraulic fracture growth".

This thesis consists of three main chapters, corresponding to four publications of which Evgenii is first author published in top-tier international journals. This testifies the quality of the work produced by the candidate. I appreciated that the candidate took the time to put in perspective his work, by re-arranging the content of these 4 papers into a readable thesis avoiding many repetitions between chapters. The work is of theoretical and numerical nature. The manuscript is extremely well written and the figures and illustrations of high quality. The organization of the manuscript is clear and to the point.

In his doctoral thesis, Evgenii has addressed by means of theoretical modeling some very important topics related to the modeling of hydraulic fracture propagation, with multiple applications toward well stimulation.

First, Evgenii has investigated in details the importance of pressure dependent leak-off on hydraulic fracture growth – this by first focusing on a travelling wave-like solution of a steadily moving semi-infinite fracture, then on the case of a an axisymmetric (finite) radial fracture: a simplified geometry of practical relevance. Although, the importance of pressure-dependent leak-off has been long recognized in the case where the reservoir is over-pressured, theoretical investigations have been lagging for a long time. Most HF simulators assume that the leak-off rate is constant and does not depend on the fluid pressure inside the fracture. Evgenii's work relax this assumption in accounting the pressure dependence of the leak-off rate, while maintaining the approximation of 1D diffusion flow in the rock formation perpendicular to the fracture faces. Evgenii's work therefore provides the first in-depth analysis of this effect. More importantly, he also quantified when the usual approximation of constant leak-off rate fails and when it is acceptable. A very important point.

Evgenii has then tackled two other interesting problems: first the interplay between leak-off in the formation (assuming a constant leak-off rate) and the possible occurrence of turbulent flow on the propagation of again 1) a semi-infinite hydraulic fracture, and 2) a radial hydraulic fracture. Although rather small in most cases, turbulent flow is enhanced in the presence of leak-off.

Finally, Evgenii has investigation the impact on HF growth of the viscoplastic rheology for the fracturing fluid. Indeed, a large number of fluids exhibit a viscoplastic behavior (i.e. must overcome a yield stress for the flow to start). Extending previous contribution, Evgenii has solved the problem of a radial hydraulic fracture driven by a Herschel-Bulkley rheology. Compared to the simpler power-law fluid cases, the solution has now two additional asymptotic regimes (at large times) related to storage/yield stress (an intermediate asymptotic regime visible in some cases) and leak-off/yield stress (the ultimate regime).

The work of Evgenii Kanin provide new important results for the mechanics of hydraulic fracture growth in permeable rocks driven by Newtonian and Non-Newtonian fluids. Note that the work is of a very rigorous nature, but Evgenii has made the effort to relate his mathematical solutions to practical configurations encountered in reservoir engineering practice.

I believe the manuscript is of outstanding quality and can be accepted as is.

However, I feel that some future perspectives are lacking in the final Conclusions of the thesis – what in the eyes of the candidate are the important problems to be tackled in the field of hydraulic fracture mechanics in the near future? This is an exercise that is important to ensure Evgenii develops into a fully independent scientist.

Brice Lecampion

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Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*