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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:** Dimitry Chuprakov, Schlumberger Moscow Research, Kirov, Russia.

| I confirm the absence of any conflict of interest | **Date: 14-07-2022** |
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| **Reviewer's Report** |
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The PhD dissertation work by Evgenii Kanin "*Asymptotic models of coupled geomechanics/fluid mechanics phenomena of hydraulic fracture growth*" is a well-written scientific work, which evidences scientific maturity of the author. The mechanics of hydraulic fracture propagation, as a big branch of rock mechanics, has been noticeably enriched by the present work. All three chapters, devoted, respectively, to the pressure-dependent leakoff, turbulent flows, and yield-stress fracturing fluid rheology, make noticeable contribution to this branch of mechanics, and must appear later in references of the corresponding books and papers.

Theory of fracture propagation in solids historically pays well-deserved attention to the phenomena at the tips, because this is where the criterion of fracture propagation is formulated. Evgenii has focused his work on a couple of "subtle" near-tip effects, namely, pressure-dependent leak off and leak in, yield-stress fluid rheology, and turbulent flow, which used to be ignored due to their apparent complexity. He has studied fluid mechanics phenomena in a radial fracture, which allowed him to observe qualitatively and quantitatively their impact on a finite fracture propagation. Such focus and thorough analytical study are obviously valuable. For investigation of semi-infinite and radial fractures, author employed powerful analytical apparatus of scaling and asymptotic methods, which are probably the only way to derive analytical solutions in such tough problems. That speaks about good mathematical skills of the author and his ability to make analysis of difficult nonlinear problems. Hence, scientific novelty and value of this dissertation are undeniable.

Speaking about practical application of this work, it is worth to note that for more than 50 years, simulations of hydraulic fractures in the oilfield industry were based on classical models with Carter leakoff and power-law viscous fluids. This work suggests a corrected description of leakoff and special consideration of that in a near-tip region, including turbulent flow effects, and yield-stress fluids. Such challenges to modification of commercial fracturing models may indeed exist in certain types of oilfield and mining operations, e.g., mini-frac tests, shallow fracturing, and gravel packing due to high leakoff or large fluid lag zone, where these effects may not be neglected.

Other good point of the work is that author clearly denotes new terms in the equation that need to be added for the pressure-dependent leakoff (Eqn. (3.31) on page 77). It must be helpful for those who wish to implement them into existing fracture models. The work contains many illustrations and plots showing the error due to ignoring the pressure dependent leakoff when it is high ($\psi = 10^{-1}$), or low ($\psi = 10^{-5}$).

There are also **few remarks (descending from major to minor)**, which I draw after reading chapters 2 and 3 (lack of my expertise in fluid mechanics does not allow me to properly comment chapters 4 and 5).

1. For derivation of pressure dependent leakoff in a near tip region author uses 1D diffusion equation. How 1D flow in a near-tip region can be justified, which, seems, must exhibit 2D flow more likely?
2. On page 27, the parameter $c_t$, which is conventionally denoted in literature as a *total compressibility*, is called fluid compressibility in the thesis. If this is indeed only a fluid component of compressibility as written, then why author neglects a rock skeleton compressibility component, and what $t$ index stands for in such case?
3. Semi-infinite fracture is introduced for convenient representation of a near-tip region of any finite fracture. As author works with both geometries, I would expect that author discusses which region of a radial fracture corresponds to the region of validity of the semi-infinite fracture analog.
4. Estimates of errors due to the PDL effect look diverse and vague in different parts of the work. For example, on page 91, in the description of the most severe effect of PDL with $\psi = 0.1$, the maximum error for the width is 38%, for the radius it is 61 %, and 13% for opening and pressure. At the same time, page 98 speaks about 5% for $\psi = 0.1$, which is much smaller. In conclusions, author talks about 10% deviation for realistic parameters corresponding to field values.
5. In Conclusions, it is very desirable to see quantitative estimates of such errors. It has many qualitative conclusions, e.g., "*the yield stress potentially results in notable deviations of the fracture parameters from the outcomes of the zero yield stress model*". Such "*notable deviations*" could be either subjective, or depend on the case. I suggest writing conclusions in a more measurable sense.
6. The model is not simple and will require quite a bit of work for implementation of the PDL effect into existing simulators. Is it possible to elaborate a convenient workaround or approximation of the PDL effect, for example, by the modification of the Carter leakoff coefficient?
7. In the dissertation, author decided to omit derivations of key equations and solutions. Instead, he included references to the published papers, e.g., Eqns. (2.5)-(2.6) on page 28, Eqn. (3.1) on page 38, Eqn. (3.16)-(3.17) on page 50. The most interesting for me numerical model of radial HF (e.g., Eqn. (3.34) on page 78) is referred to the paper for details. The dissertation is a self-dependent work, without limitation in size (as opposed to some journals) and can freely contain all necessary derivations used in the work for convenience of a reader.

In summary, all remarks above should not underestimate quality of the written dissertation. It is excellent, and Evgenii Kanin deserves a PhD degree in Petroleum Engineering.

**Provisional Recommendation**

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