

The impact of rock elastic parameters on the hydraulic fracturing process for Enhanced Geothermal Systems (EGS) in Poland

Author:

Rafał Moska, M.Sc.

Supervisor:

Krzysztof Labus, Prof.

Company Supervisor:

Piotr Kasza, Ph.D.

Abstract

Among the currently developing low-emission energy production technologies, Enhanced Geothermal Systems (EGS) exhibit some of the highest potential. These systems are created within so-called *hot dry rocks* (HDR) – a geological formations typically located at depths greater than 4000 meters, under conditions of high pressure and temperature. HDR are characterized by extremely low permeability and porosity and usually contain little to no water. As a result, their thermal energy cannot be transported to the surface in the same manner as in conventional geothermal systems. To address the limited natural fluid conductivity in HDR, artificial stimulation is employed to enhance their hydraulic conductivity, most commonly through hydraulic fracturing (HF) technology. This process creates a geothermal system in which a working fluid circulates in a closed loop: it is first injected into the reservoir through an injection well, heated as it flows through artificially created or reactivated fractures within HDR, and then extracted to the surface where its heat is utilized for thermal and/or electrical energy production. The cooled fluid is then reinjected into the reservoir, completing the cycle. EGS projects have been developed worldwide since the 1970s, with commercial power plants currently operating in countries such as France and Germany. In Poland interest in this unconventional branch of geothermal energy has been increasing since the early 21st century, leading to the implementation of scientific projects and the publication of numerous studies. Despite the wide research scope of some of these efforts, their outcomes have not been directed toward the development of HF-related technological elements tailored to Polish hot dry formations. This doctoral dissertation aims to address that specific research gap.

The research activities undertaken in this dissertation can be divided into two main parts: (1) laboratory investigations on rock samples collected from prospective EGS regions in Poland, preceded by an extensive literature review focused on key elements of HF technology in EGS, and (2) numerical simulations of HF treatments, combined with the assessment of the impact of rock elasticity parameters on hydraulic fracture geometry.

The conducted literature review examined the most significant EGS projects carried out worldwide, with particular attention paid to their geological, petrophysical, and tectonic parameters, as well as the HF technologies employed. This analysis enabled the identification

of HF treatment features typical of EGS, fracture geometries within reservoirs, and the operational parameter ranges used in those projects. These findings were compared to the conditions characteristic of promising formations in Poland. The results of this study were published in *Energies* (Moska et al., 2021).

A complementary review was also conducted, expanding the analysis of prospective EGS areas in Europe to include the Baltic counties (Lithuania, Latvia, Estonia) and comparing their geological conditions with those in Poland. This work was published in *Energies* (Moska et al., 2023).

The next part of the work involved laboratory testing of core samples obtained from three geologically prospective EGS areas in Poland: the Karkonosze region, the Gorzów Block, and the Mogilno-Łódź Trough. Collected samples were characterized in terms of petrophysical and petrographic properties. Results of geomechanical testing, performed using ultrasonic methods under reservoir conditions on a research setup modified by the doctoral candidate, were also presented. Additionally, it was demonstrated how the brittleness index, traditionally used in the oil and gas industry, can be applied to assess the susceptibility of these formations to hydraulic fracturing. These studies were published in *Advances in Geo-Energy Research* (Moska et al., 2024).

Supplementary studies of the samples thermal parameters were also performed, along with numerical simulations in two areas: (1) the temperature distribution and cooling extent during long-term heat extraction, and (2) the chemical reactions occurring during thermal energy production. These simulations provided the basis for evaluating the EGS potential in western Poland. This analysis was published in *Energies* (Labus et al., 2025).

The final stage of the dissertation involved numerical simulations of hydraulic fracturing treatments, based on data acquired during the earlier research phases. Using two geologically distinct potential EGS locations in Poland, the influence of rock elasticity parameters (specifically Young's modulus and Poisson's ratio) on fracture geometry was analyzed. Sensitivity analyses of fracture geometry and conductivity in response to variations in these parameters were also performed. The results of this work were published in *Energies* (Moska et al., 2025).

The findings from the entire body of research, including testing and simulation, indicate that the analyzed rocks exhibit petrophysical properties characteristic of petrothermal EGS formations. The impact of Young's modulus and Poisson's ratio on hydraulic fracture geometry in these formations is generally limited, however, their influence on fracture conductivity may significantly affect the performance of geothermal systems in sedimentary rocks. Intervals with higher Young's modulus and brittleness index are more promising for EGS development in sedimentary formations. In contrast, in magmatic formations, sections with lower Young's modulus and brittleness index, possibly representing natural zones of weakness, are more likely to be preferentially stimulated during HF treatment.

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