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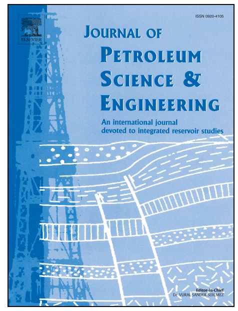

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Pore Pressure Effects on Fracture Net Pressure and Hydraulic Fracture Containment: Insights from an Empirical and Simulation Approach

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A B S T R A C T

Pore pressure and its relationship with fracture net pressure has been reported qualitatively from both field and experimental observations. From a modeling perspective, the ubiquitously used pseudo 3D (P3D) models that are based on linear elastic fracture mechanics (LEFM) do not include the effect of reservoir depletion (or overpressure). Models that utilize effective stress as propagation criteria with a cohesive zone description, introduce the pore pressure directly into the simulation and hence can potentially capture the effect of pore pressure on fracture propagation. This work investigates the effect of pore pressure on hydraulic fracturing net pressure and geometry using empirical and numerical simulation approaches. We carried out an analysis of more than 400 datafrac injections spanning a wide range of geological ages and depositional environments in order to investigate the relationship between observed net pressure and reservoir pore pressure. The net fracture propagation pressure from the fracture treatment analysis was seen to be correlated with the effective stress in the reservoir. Fracture propagation simulations were performed using a coupled finite element – finite difference fracture simulator. The code uses a cohesive zone model (CZM) to describe fracture propagation. Four different effective stress scenarios were used to study the effect of effective stress on net pressure. The simulation results closely match the empirical relation between net pressure and effective stress as obtained from the analysis of actual frac treatment data. It is observed from the simulations that the magnitude of the effective stress also has an effect on the fracture geometry with a high effective stress leading to wider, shorter and more radial fractures. The derived empirical correlation is hence useful as a fracture design parameter. The datafrac net pressure diagnostics workflow in the pseudo 3D models can incorporate local tip pore pressure as a new pressure matching parameter. The pore pressure effect can thus explain high net pressures routinely observed in frac operations and also as a containment mechanism.

1. Introduction

Pore pressure changes affect the minimum stress, which results in well known effects on fracture propagation pressure and fracture height growth. Field fracturing data had qualitatively shown that hydraulic fracturing net pressure observed from frac jobs performed in depleted reservoirs are much higher than was initially reported from treatments done in virgin reservoir condition (Shaoul et al, 2003). It was also observed that the closure stress in the pay has decreased on depletion. Schmitt and Zoback (1989) conducted laboratory tests on the effect of pore pressure on tensile failure. Bruno and Nakagawa (1991) presented theoretical analysis based on Griffith strain energy release criteria that suggested that tensile fracture is controlled by general effective stress. Experiments performed by them in rocks with induced pore pressure gradients showed that fracture orientation is biased towards regions of higher pore pressure or lower effective stress and the fracture initiation pressure is less when fracture tip is in the vicinity of these regions. It was argued that the observed differences in pore pressure magnitude around the crack tip (local pore pressure) and its effect on fracture orientation and direction was supportive of an effective stress law for tensile failure in porous rocks. Visser (1998) also performed a series of experiments on the pore pressure effect on extensile fracturing of saturated porous materials. Reconciling high observed net pressure with model net pressure has been an issue in fracture modeling for decades. The magnitude of net pressure during hydraulic fracturing is influenced by multiple factors and this is depicted in Fig.1. A high net pressure can be explained by linking its dependence to simple physical parameters like injection rate, rock properties, fluid viscosity etc. However more complex mechanisms may also be at play like hydraulic fracture interaction with natural fractures, multiple fracture propagation and growth through layer interfaces. The commonly used pseudo 3D fracture models that use stress intensity factor based criteria for the fracture propagation problem do not explicitly include pore pressure. Recent experimental work indicates that the LEFM approach for fracture propagation is not always valid and a cohesive zone description is necessary (van Dam et al, 2001, 2002). Such cohesive zone models (CZM) would then use effective stress at the tip exceeding tensile strength as a propagation criterion which introduces the effect of pore pressure. It is worth investigating this relatively simple effect in order to explain high observed net pressure and its influence on fracture geometry. This paper attempts to quantify the effects of this simple mechanism by comparing net pressure from actual fracture treatment data to that predicted using a coupled cohesive zone model.