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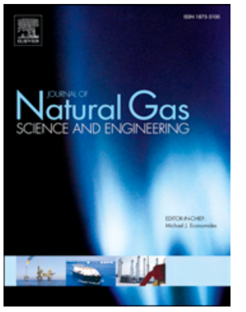

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Laboratory Visualization of Fracture Initiation and Propagation Using Compressible and Incompressible Fracturing Fluids

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Abstract

Homogeneous, rock-like materials are fractured in this experimental study using a viscous liquid (glycerin) and nitrogen gas to provide a fundamental insight on the effect of using compressible gases compared to hydraulic fracturing fluids. The fracturing process in the experiments are captured using sequences of high resolution images as well as a novel application of Digital Image Correlation for crack detection. We show that fractures propagate through test specimens in a gradual manner when induced by glycerin at various injection rates. In contrast, nitrogen injection induces instantaneous fractures, which we attribute to its compressible nature and ultralow viscosity. The specimen breakdown pressure is also shown to be markedly lower for nitrogen fractures compared to glycerin fractures. The significantly higher pore pressure distribution and induced tensile stresses associated with nitrogen injection are demonstrated through numerical simulations of the laboratory experiments. Moreover, an experimental evidence of fluid lag when fractures are induced with viscous fluids is provided.

Keywords: Hydraulic fracturing, gas fracturing, nitrogen fracturing, breakdown pressure, injection rate, fracture propagation experiments

1. Introduction

Hydraulic fracturing operations in the field are predominantly carried out using water-based fluids such as slickwater, gelled water, and/or hybrid fluids. However, there is often a desire in many applications to minimize or eliminate water usage in fracturing treatments driven by logistics, such as water scarcity or government regulations, environmental concerns or well productivity optimization. From a productivity standpoint, many benefits are realized by minimizing the amount of water used in fracturing: (1) a lower volume of water is to be recovered from the formation after fracturing; (2) gel damage associated with fracturing is lower; (3) relative hydrocarbon permeability damage caused by capillary retention or phase trapping of fracturing water is minimized; (4) permeability damage caused by swelling or migrating clays and fines in water-sensitive formations is reduced; and (5) severe proppant embedment into fracture walls caused by rock softening from the exposure of water is alleviated (AlTammar 2014).

Using nitrogen as a fracturing fluid can be an effective alternative to water-based fluids. Initial field applications of nitrogen fracturing were reported by Abel (1981) and Freeman et al. (1983) in shale formations. Although nitrogen is mostly used without proppant due to its low viscosity, Gottschling et al. (1985) showed that small amounts of proppant can be utilized in nitrogen fracturing to improve well production. Grundmann (1998) also described a successful application of cryogenic nitrogen treatment that relies on exposing a warm shale formation to an extremely cold nitrogen and hence, inducing thermal tensile cracks that could be further extended into the formation by high nitrogen injection pressure. More recently, Wozniak et al. (2010) reported the superior performance of nitrogen fracturing in multi-fractured, horizontal wells in the Lower Huron Shale as compared to water-based fracturing fluids. Despite the early recognition and application of nitrogen fracturing, limited research has been published on the fundamental mechanisms of gas-induced fractures and their unique characteristics as