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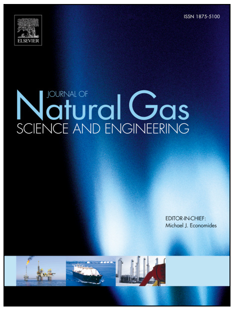

Field data provide estimates of effective permeability, fracture spacing, well drainage area and incremental production in gas shales

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Field data provide estimates of effective permeability, fracture spacing, well drainage area and incremental production in gas shales☆

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Abstract

About half of US natural gas comes from gas shales. It is valuable to study field production well by well. We present a field data-driven solution for long-term shale gas production from a horizontal, hydrofractured well far from other wells and reservoir boundaries. Our approach is a hybrid between an unstructured big-data approach and physics-based models. We extend a previous two-parameter scaling theory of shale gas production by adding a third parameter that incorporates gas inflow from the external unstimulated reservoir. This allows us to estimate for the first time the effective permeability of the unstimulated shale and the spacing of fractures in the stimulated region. From an analysis of wells in the Barnett shale, we find that on average stimulation fractures are spaced every 20 m, and the effective permeability of the unstimulated region is 100 nanodarcy. We estimate that over 30 years on production the Barnett wells will produce on average about 20% more gas because of inflow from the outside of the stimulated volume. There is a clear tradeoff between production rate and ultimate recovery in shale gas development. In particular, our work has strong implications for well spacing in infill drilling programs.

Keywords: hydrofracturing, shale gas, fracking, energy resources, scaling laws

1. Introduction

Natural gas from hydraulically fractured mudrock formations continues to attract attention as a major source of energy for the future. Commonly known as shales, mudrocks are layers of fine–grained sediment which typically lie at a depth of $2-3$ km and have the geometry of a sheet: they extend laterally over hundreds of kilometers and are about $30-90$ m thick. Shale gas is stored in nanometer scale, poorly connected pores (Loucks et al., 2009) and as such is not accessible without hydraulic fracturing, or stimulation. This process involves drilling one or more horizontal wells along the mudrock layer, injecting large volumes of pressurized water into reservoir rock at multiple points along the well, known as hydrofracture stages, propagating fluid–driven fractures into the rock and propping the fractures open with sand. Hydraulic fracturing ultimately creates a highly permeable, multiscale network of hydraulic fractures, reopened natural fractures, faults and shear failures. Gas seeps through the rock and is collected by this network, quickly flows within the fractures, reaches the wellbore and is produced. Tens of thousands of US shale wells have been hydraulically fractured, and potential for development on all other continents is also considerable (Birol, 2012).

Shale development is decided primarily based on long-term production forecasts and reserve estimates, which depend upon many independent reservoir and stimulation variables. For horizontal gas wells with multiple fracture stages, considerable modeling effort has been devoted over the past two decades to extract these variables from data on time dependence of production (Wattenbarger et al., 1998; Anderson et al., 2010; Nobakht et al., 2012; Silin and Kneafsey, 2012; Patzek et al., 2013; Virués et al., 2013; Walton and McLennan, 2013). Existing models can infer certain combinations of these variables, but cannot determine each variable uniquely. In particular, characteristic spacing of the connected fracture network responsible for production ("fracture spacing" from here on) and effective permeability of unstimulated shale (matrix and natural fractures) have not been obtained independently of one another. Wattenbarger et al. (1998), Anderson et al. (2010), Nobakht et al. (2012) and Virués et al. (2013) have extracted from production data the product $A\sqrt{k}$, where $2A$ is total fracture surface area and k is effective permeability of unstimulated shale, but k or A could not be estimated individually; Patzek et al. (2013) have extracted the ratio d^2/k, where d is fracture spacing, but k or d could not be obtained uniquely. As a result, current estimates of long-term production and fracture spacing rely on presumed values

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