Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 6 (2017) 276–282

Structural Integrity Procedia

www.elsevier.com/locate/procedia

XXVII International Conference "Mathematical and Computer Simulations in Mechanics of Solids and Structures". Fundamentals of Static and Dynamic Fracture (MCM 2017)

Magistral and fractal regimes of the hydro-fracturing

Paderin Grigory[a], Shel Egor[b] *

[a]*Leading specialist, Gazpromneft-NTC, Saint-Petersburg 190000, Russian Federation*
[b]*Leading specialist, Gazpromneft-NTC, Saint-Petersburg 190000, Russian Federation*

Abstract

The paper describes the specific difference between two fracture growth regimes, when it forms the radial fracture network (fractal regime) and when it forms one big fracture in certain direction (magistral regime). A continuum model is used, which represents the fracture network in the media with the permeability tensor, rapidly increasing with the fracture appearance. The fracture front instability is shown, linked with the Saffman-Taylor instability, even in isotropic case. By analogy with Saffman-Taylor instability in porous media, the fractal nature of the fracture network is derived. The dimensionless parameters of fracture front speed and anisotropy are found, which would help to numerical and experimental modeling of the reservoir.

Keywords: geomechanics; hydro fracturing; Saffman-Taylor instability; piezoconductivity; fractals; fracture network; tensile strength; stimulated volume

1. Introduction

Hydrofracturing is one of the main methods to increase oil and gas production in the petroleum industry. Hydraulic fracturing of the reservoir was especially important in the extraction of non-traditional reserves, such as shale gas and shale oil. In this application, hydraulic fracturing, ideally, should not only enhance the production rate, but also enlarge the total amount of hydrocarbon production. In this regard, it is commonly believed that during fracturing in non-traditional reservoirs, a branched network of cracks is formed, which spreads in all directions from the well and occupies a certain volume, called the stimulated volume. This assumption oppose to the assumptions

* Corresponding author. Tel.: +7-911-170-4549.
E-mail address: Shel.EV@gazpromneft-ntc.ru

10.1016/j.prostr.2017.11.042

about crack growth in traditional reservoirs, such as PKN (Perkins 1961, Nordgren 1972), KGD (Khristianovic 1955, Geertsma 1969), Pseudo3D (Adachi 2010) and Planar3D (Clifton 1979), where it is believed that the crack extends along one trunk plane perpendicular to the minimum rock stresses.

This contradiction in the literature is often explained by the different properties of the reservoirs, like brittleness. The problem is that the definition of brittleness in these works varies, and hence it is not a strictly defined quantity.

In contrary to that opinion, in this paper it is shown that "brittleness" is not the main factor for the nature of crack propagation. The leading role in the propagation regime of a fracture, network (also called here fractal, see below) and the magistral, is played primarily by parameters such as the viscosity of the fracturing fluid, permeability, the injection rate and the anisotropy of the horizontal rock stresses.

It also will be shown that in both traditional and non-traditional reservoirs both regimes are possible. With a low anisotropy of the rock stresses, in any case, the fractal regime will be performed, and, at high anisotropy, the magistral regime will start.

To describe the propagation of a fracture system, a continual model of double porosity is used, in which the matrix has a finite porosity and very low permeability, and the fracture system has high permeability and low porosity. Such approaches were used, for example, in Li 2012, and in various other papers.

2. Mathematical model

The following laws are used to consider the propagation of a fluid. First, it is the law of conservation of mass:

$$\frac{\partial \rho}{\partial t} + \nabla_i(\rho v_i) = 0 \tag{1}$$

And secondly, it is Darcy's law, written in a tensor form:

$$v_i = -\frac{k_{ij}\nabla_j p}{\mu} \tag{2}$$

The fluid here is assumed to be Newtonian, although the law can be generalized to power-law rheology.

Also, the equation for the porosity deformation is used:

$$dV = Vc_t dp \tag{3}$$

Here V is the pore volume of the porous medium, c_t is the total compressibility of the porous volume.

To obtain the equation for pressure, the Darcy law should be substituted into the law of conservation of mass. After this, all quadratic terms with respect to the pressure gradient are neglected in the expression. The dependence of viscosity on pressure is also neglected. Hence, the equation could be obtained:

$$\frac{\partial p}{\partial t} + \frac{(\nabla_i k_{ij})\nabla_j p}{\mu} + \frac{k_{ij}(\nabla_i \nabla_j p)}{\mu} = 0 \tag{4}$$

It is worth noting that the term with the permeability derivative remains, since in the case of fracture propagation, this derivative can be significant.

3. Isotropic case, uniform model

Consider a well in a layer that is under isotropic rock stresses in the horizontal plane. In this case, the fracture network from the well will spread radially in all directions, with equal probability in each direction. This