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Hydraulic Fracture Geometry Modeling Techniques for Extracting Unconventional Reservoirs

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read, reviewed and approved the final manuscript.

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ABSTRACT

This study aims to provide a comprehensive review of all hydraulic fracture geometry modeling techniques available in the conventional and unconventional reservoirs. We are introducing a comparison study between major available hydraulic fracture modeling techniques, advantages, and disadvantages of each one according to the latest related studies. The study includes the three general families of models: 2D models, pseudo-3D models, and fully 3D models. Consequently, the results of this work can be used for selecting the proper model to simulate or stimulate the reservoir to enhance oil recovery using hydraulic fracturing. Also, these results can be used for any future updates related to hydraulic fracturing stimulation based on the comparisons that were conducted.

Keywords: Hydraulic fracture; models; modeling techniques.

1. INTRODUCTION

Libya holds the seventh place world reserve of the unconventional oil [1] with large resources of 26 bbl. This huge energy is still out of hand and needs to be extracted. According to the latest unconventional oil extraction technology; hydraulic fracturing is considered the only

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available way to extract shale hydrocarbons that use efficiently to stimulate and enhance oil and gas production from unconventional reservoirs.

Hydraulic fracturing is a technology that has been in practice since the late 1940s to improve production from the hydrocarbons reservoirs. Hydraulic fractures are manufactured flow paths through which hydrocarbons efficiently extracted from low permeability rocks [2]. The fracture is constructed by the planned injection of high-pressure fluid to overcome the resistance of rocks to open those paths through it, which in turn achieves economic production rates. Many parameters must be considered to get successful hydraulic fractures such as (stress, young's model, poison's ratio, fracture toughness, pressure, composite layering effect). There are three general families of models that can be applied to predict, and interpret how a hydraulic fracture can be initiated and propagated, which are two-dimensional models (2D models), Pseudo three dimensional models (P-3D models), and fully three-dimensional models.

2. 2D MODELS

This type of model combines elastic fracture mechanics, fluid transport in the fracture, fluid leak-off from the fracture, and material balance in the fluid, and proppant to calculate appropriate prediction to the created fracture geometry, and the resulting proppant distribution. 2D models are closed-form analytical approximation assuming constant fracture height. In this type of modeling family, there are the following major models [3].

2.1 Perkins-Kern-Nordgren (PKN)

The PKN model has an elliptical shape at the wellbore. The maximum width is at the centerline of this ellipse, with zero width at the top and bottom. PKN model applies for deeply penetrating fractures, appropriate in low permeability reservoirs, and for a fracture length much larger than the fracture height; Fig. 1 shows the PKN model [4].

2.2 Kristitianovich-Zheltov Geertma-Deklerk (KGD)

The KGD model is a 90º turn of the PKN model and is particularly applicable to approximate the geometry of fractures where the fracture height is much larger than the fracture length. Thus, it should not be used in cases where long fracture lengths are generated.

The shape of the KGD fracture implies equal width along the wellbore, in contrast to the elliptical shape (at the wellbore) of the PKN model. This width profile results in larger fracture volumes when using the KGD model instead of PKN model for a given fracture length. KGD model relates better to short very high conductivity fractures in high permeability reservoirs; Fig. 2 shows the PKN model [4].

2.3 The Radial Model

The radial model or sometimes referred to as penny shaped model is a limited case were fracture height, h_f is double the fracture length, x_f.

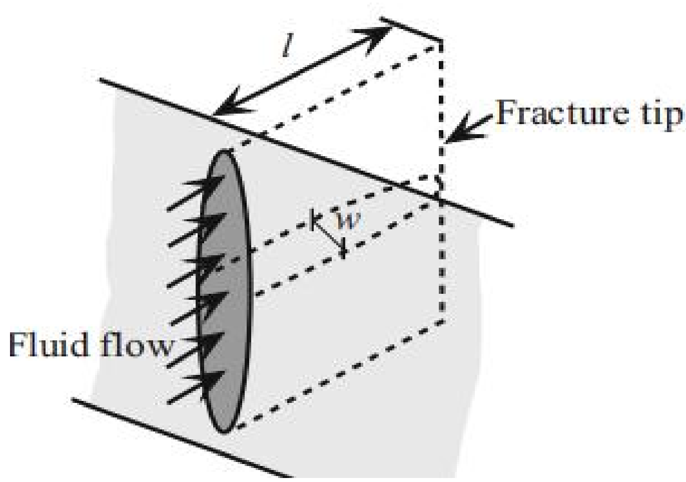

Fig. 1. PKN model

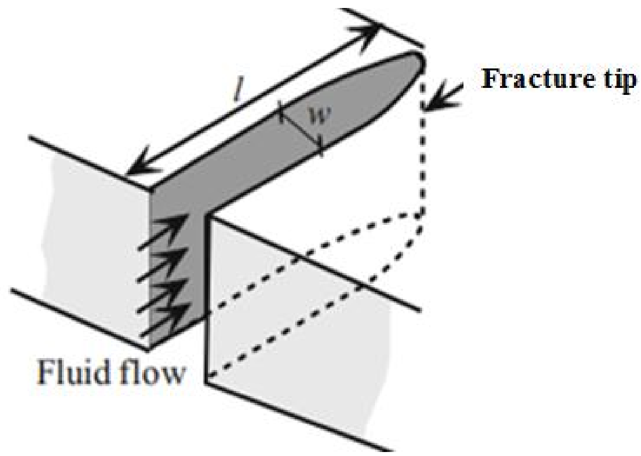

Fig. 2. KGD model

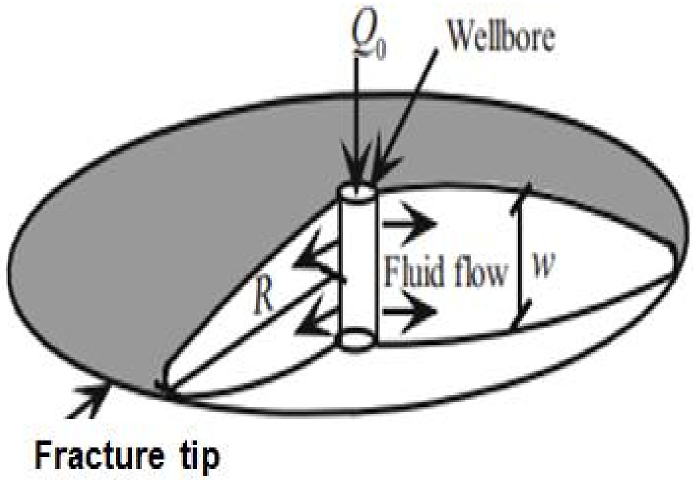

Fig. 3. Radial model "Penny-shaped Fracture"

When the formation is thick enough or the fracture is small enough that no vertical barriers to fracture growth are felt, the fracture created is approximately circular and the radial or penny shaped model is appropriate. Is limiting case were fracture length; h_f = 2 x_f. Fig. 3 shows the PKN model [4].

3. PSEUDO 3D MODELS (P-3D MODELS)

In order to idealize fracture growth in multi-layered formation, most use pseudo-three-dimensional (P3D) models.

P-3D models allow simultaneous lateral and vertical fracture height migration along the fracture path, and this migration depends on the stress contrast between the target and adjoining intervals. The basis of P-3D models is the coupling of a two-dimensional description of vertical growth (PKN) model with one-dimensional lateral propagation. The height variation along the fracture length can be considered linear or parabolic. The key for P3D modes to give a more realistic prediction of fracture geometry and dimensions is to have a complete and accurate data set that describes the layers of the formation to be fracture treated, plus the layers of rock above and below the zone of interest. In most cases, the data set should contain information on 5 to 25 layers of rock that will or possibly could affect fracture growth. [5] developed a very elegant system of equations to describe fracture growth in multilayered formations by neglecting the hydrostatic effect of fluid inside the fracture such a model is considered less expensive to develop, requires less computing time, and is easier to use, but it is not as accurate as a numerical simulator.

4. 3D MODELS

A fully 3D fracture propagation with fully 2-dimensional fluid flow. The fracture is discretized, and within each block calculation are done based on the fundamental laws and theories of Linear elastic fracture mechanics with the effects of complex fluid flow patterns inside fracture [6].

Fully 3D model, require significant amounts of data to justify their use, and are extremely calculation intensive, and are outside the scope of applications of vast majority of hydraulic fracture treatments. However fractures in horizontal and highly deviated wells may require full 3D modeling due to fracture initiation, usually aligned with the well trajectory, is likely to be different from direction propagation.

The following are the major fully 3D models available:

4.1 3D Hydraulic-Fracturing Simulator, Frac Pro

Which is a 3D fracture design and analysis software widely used in the industry for predicting fracture behavior. This modeling was performed to evaluate fracture length as a function of reservoir permeability [7].

4.2 3D Hydraulic-Fracturing Simulator, GEOFRAC

This 3D is described that implicitly couples the solution of the fracture boundary movements with that of the fluid pressure and fracture width profiles over the fracture face [8].

4.3 3D Analysis of Fracture Propagation Resulting from Composite Layering Effect

This 3D model uses composite layering effect CLE to predict in 3D space the shape of a hydraulic fracture [9].

There are multiple mechanisms controlling fracture propagation through the formation (fracture containment). These include complex geologic layering, heterogeneity in formation rock properties, high fluid leakoff, the presence of natural fractures, and the presence of layers of high permeability [8].

CLE reflects the resistance of the fracture growth through layer interfaces [10]. As a fracture tip grows through layer interfaces, some of these interfaces may become partially debonded and the fracture may start growing again at a local weakness offset from the original path. The consequence of composite layering is a loss of leverage along the fracture height, resulting in a significant decrease in the vertical growth rate. The model impact of this parameter in the model is that the fracture height is exchanged for fracture half-length [10] and [9].

Fig. 4 depicts the CLE effect on fracture height growth. Determination of this value of CLE helps in the model calibration and matching net pressures where additional height confinement is required other than the conventional mechanisms such as stress

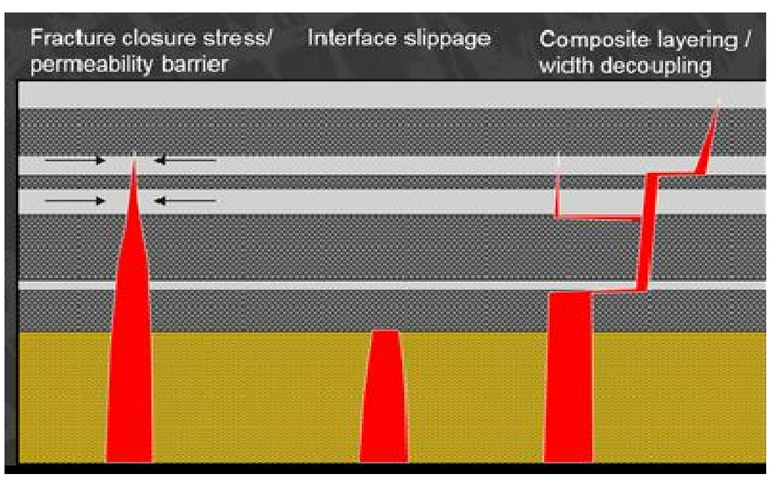

Fig. 4. Composite Layering Effect (CLE) mechanism

contrast, modulus contrast, fracture toughness, and permeability [11].

$\mathrm{X} = 10^{\mathrm{C}}$; C: constant; C = $\frac{\log_{10}^{\mathrm{I}} - \log_{10}^{\mathrm{a}}}{\mathrm{b}}$

X = CLE value

= Height to Length ratio

a, b = given constants;

(a = 0.9978, b = 0.4349), [9].

5. CONCLUSION

Two-dimensional models are closed from analytical approximation assuming constant fracture height. In this type three models have been used.

1. For fracture length much larger than the fracture height PKN model is considered appropriate approximation. PKN model applies for deeply penetrating fracture appropriate in low permeability reservoir.
2. For fracture length much smaller than the fracture height KGD model is preferred. KGD model relates better to short very high conductivity fractures in high permeability reservoirs.
3. When the formation is thick enough or the fracture is small enough that no vertical barriers to fracture growth are felt, the fracture created is approximately circular and the radial or panny-shaped model is appropriate.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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