operating modes of the reactor-regenerator unit without the need for long experiments, which makes it possible to flexibly respond to changes in the composition of feedstock and market demand for oil products.

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IMPROVING THE EFFICIENCY OF HYDRAULIC FRACTURING THROUGH FRACTURE GEOMETRY MODELLING

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Hydraulic fracturing is considered to be one of the most used methods of enhancing oil recovery in Russia and beyond. It involves the creation of tensile cracks known as hydraulic fractures at specific intervals in the wellbore to increase hydrocarbon access in the reservoir.

These fractures are characterized by their height (*h*), length (*x*) and width (*w*). The ratio between the area of a fracture and that of an open hole wellbore is calculated using the formula below:

$$\frac{4x_f h}{2\pi r_w h} \approx \frac{x_f}{r_w} \qquad (1)$$

Where x_f − fracture half-length, r_w − wellbore radius and h − fracture height.

Fractures are longer than the radius of the wellbore in which they are created, as well as the fracture area in contact with the reservoir rock compared to the area of the wellbore.

Mechanical Properties

In-situ stresses and the stress profile of a formation are necessary parameters needed in confining a fracture treatment in the productive interval during its design. The in-situ stresses control fracture orientation that is vertical and horizontal, its azimuth, height growth, width, treatment pressure and fracture conductivity.

Fractures grow perpendicular to the direction of the minimum in-situ stress; thus, stress direction can affect well-placement and spacing decisions [1]. The figure below illustrates the effects of stresses on fracture propagation.

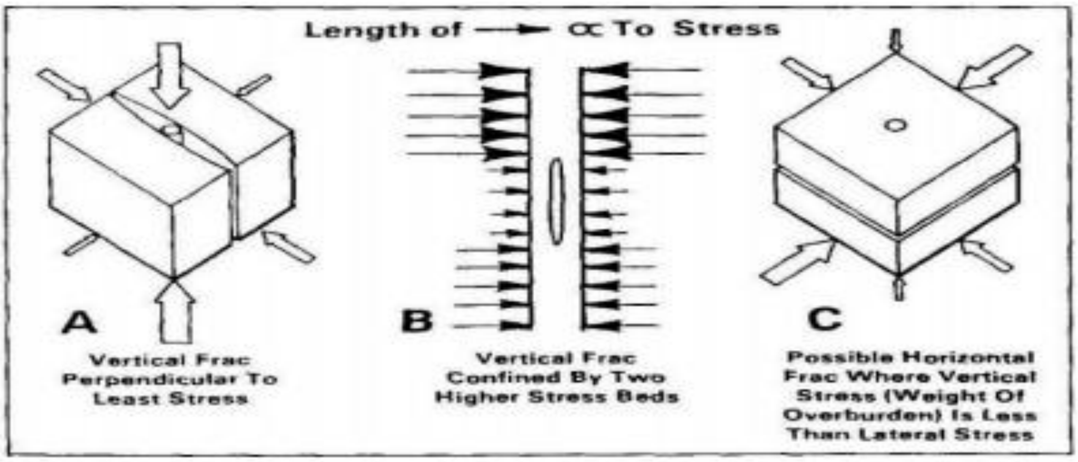

Fig. 1 Effect of stress field on fracture propagation (John L. Gidley, 1990)

Fracture Models

The different kinds of hydraulic fracture models, necessary for calculation of the fracture geometry include:

- **2D Models:** Perkins-Kern Nordgren (PKN), Khristianovich- Geertsma-DeKlerk (KGD)
- **Pseudo-3D Models:** MFRAC, StimPlan, e-StimPlan and FracCade
- **Lumped Parameter Models:** FracPro, FracPro-PT
- **3D Models:** GOHFER, N-StimPlan, Terra-Frac

The fracture for PKN models has the shape of ellipse, where its height is constant and the fracture length (x) is significantly larger than the fracture width ($2x_f$>h_f). Perkins and Kern developed their model for non-Newtonian fluids and included turbulent flow, however the fluid flow rate is assumed to be governed by the basic equation for flow of a Newtonian fluid in an elliptical section as in equation (2) (Lamb, 1932):

$$\frac{dp}{dx} = -\frac{64q\mu}{\pi h_f w^3} \tag{2}$$

where p –pressure, x – distance along the fracture, and μ – fluid viscosity.

The PKN width equation is shown in equation (3) below:

$$w_{w,o} = 3.27\left(\frac{\mu q_i x_f}{E'}\right)^{1/4} \tag{3}$$

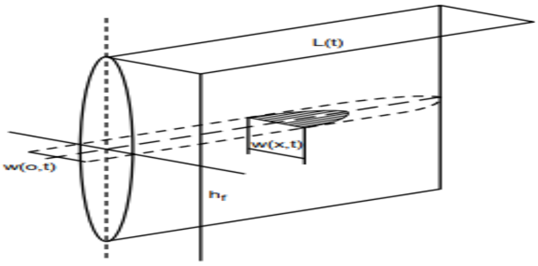

Fig.2 PKN geometry for 2D fracture [2]

For the Khristianovich and Zheltov fracture geometry model, the horizontal plane strain assumption is relevant for short fractures with length significantly lower than height, i.e. $2x_f$< h_f. Other assumptions include:

i. The formation is an infinite, homogeneous, isotropic, linear elastic medium characterized by Young's modulus E, Poisson's ratio ν and fracture toughness K_{IC}.

ii. The horizontal sections of the crack are the same and to use the two-dimensional statement of the problem of elasticity when describing rock deformation and its destruction. Fracture width according to KGD is calculated by the formula below.

iii. The fracture tip is a cusp-shaped.

The formula below is the KGD width equation and it is calculated by:

$$w_w = \left(\frac{336}{\pi}\right)^{1/4} \left(\frac{\mu q_i x_f^2}{E' h_f}\right)^{1/4} = 3{,}22\left(\frac{\mu q_i x_f^2}{E' h_f}\right)^{1/4} \tag{3}$$

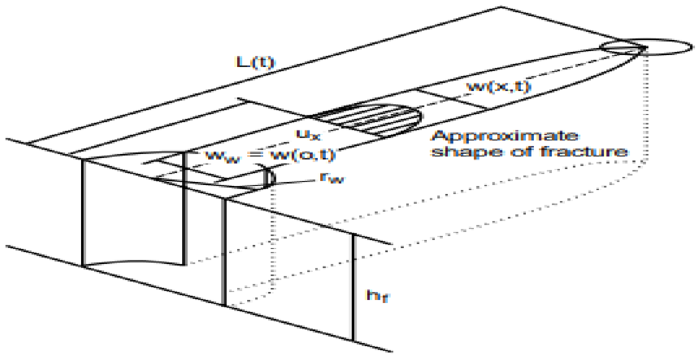

Fig. 3 KGD geometry for 2D fracture [1]

Pseudo-3D and 3D Models

P-3D models modify the 2D PKN models by idealizing fracture growth in formations with multiple layers. The term "pseudo" is given to them because they do not take into consideration the variation of fracture geometry in a three-dimensional space. Common fracture growth models used in commercial fracturing simulation software are the Pseudo 3D and Planar 3D models. Pseudo 3D models are divided into two types: Lumped P3D [3] and Cell-based P3D [2].

Lumped P3D models are parametric, and the result of modeling the geometry of the hydraulic fracture with they normally have a convex fracture profile, consisting of two semi-ellipses. The advantage of Cell-based P3D models is that they allow to numerically solve the elasticity equation in separate cells into which the fracture is divided along the length, as well as to simulate one-dimensional transfer of the mixture of fluid and proppant.

Models of the Planar 3D class are more complex from a mathematical point of view, but more perfect from the point of view of physical formulation [5]. Available simulators for P-3D and 3D models are FracPro, Fracade, GOHFER and others.

Fracture Geometry Simulation for Field X

Modeling an "optimal" hydraulic fracture requires a multidisciplinary approach to data collection, data evaluation and evaluation of reservoir properties, including its lithological structures. A seismic log data from Field X was analyzed and entered into the simulation program FracPro. Table 3 shows the fracture design parameters and criteria used to simulate the desired fracture length of 100 m. The proppant used is Yixing LT and the fluid injection rate is 4 m^3 / min.

Table 1

Fracture design and criteria parameters

Slurry Fluid	HL_2% KCL
Proppant Type	Yixing-Lt2040
Desired Fracture Length (m)	100,00
Injection Rate (m3/min)	4,0
Pumping Rate (m^3/min)	4,00
Min Conc for Propped Frac (kg/m^2)	0,98
FcD Goal	10,0
Fracture Half-Length Increment (m)	9,14
Max TSO Net Pressure Increase (MPa)	6,89
Max Proppant Concentration (kg/m3)	2 397
Multiple Fracs Considered Conductive (%)	100

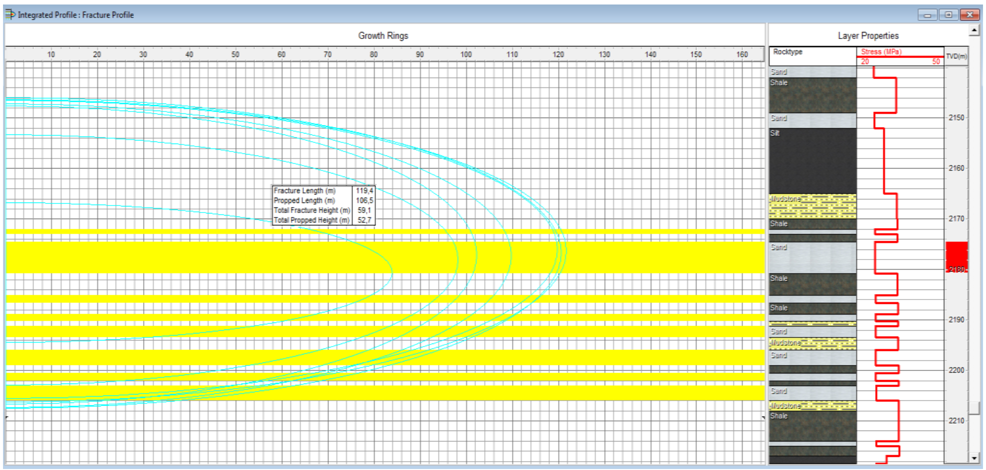

Fig. 4

The length of the fracture is 119.4 m, the total height is 59.1m. The length of the fracture filled with proppant is 106.5 m, the height is 52.7m.

Figure 5 shows the proppant filled fracture profile with layer parameters including their permeabilities. Also shown is the proppant concentration measured in kg / m^2.

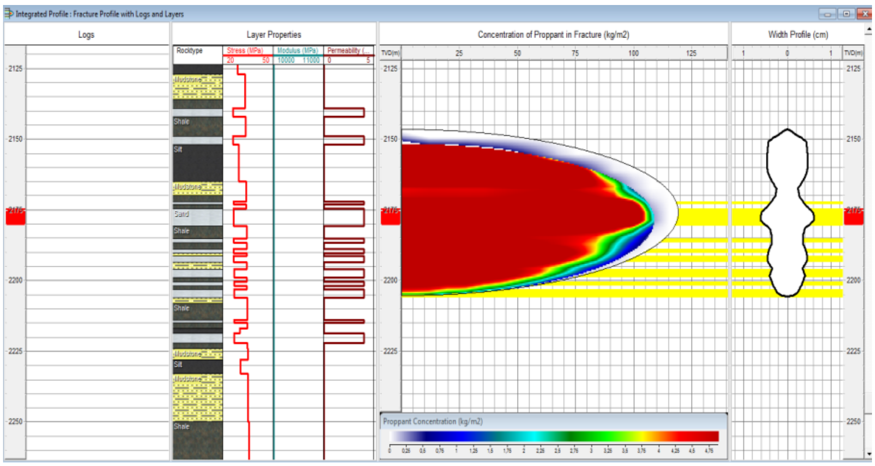

Fig. 5

Table 2 summarizes the details of fracture geometry obtained after simulation. All reported values refer to the entire fracture system at a model time of 720.00 min (end of stage 1). The values are reported for the end of the last pumping stage.

Table 2

Fracture Half-Length (m)	280	Propped Half-Length (m)	0
Total Fracture Height (m)	127	Total Propped Height (m)	0
Depth to Fracture Top (m)	2 094	Depth to Propped Fracture Top (m)	2 178
Depth to Fracture Bottom (m)	2 221	Depth to Propped Fracture Bottom (m)	2 178
Equivalent Number of Multiple Fracs	1,0	Max. Fracture Width (cm)	3,32
Fracture Slurry Efficiency**	0,00	Avg. Fracture Width (cm)	1,78

The fracture created in the well '231' is considered optimal, since the fracture height covered a sufficient part of the pay zone and grows deeply into the zone, therefore, after the main treatment of hydraulic fracturing, an increase in the hydrocarbon access is assured hence increase in productivity.

It is obvious that the crack propagates in the area of minimal stress. The shape of the width profile shown is also stress dependent. Fractures tend to remain in vertical low stress regions that effectively "seal in" or "catch" the fracture and keep it from breaking into higher stress rock.

Staying in the formation is highly desirable, as staying in the zone of interest maximizes oil production and minimizes the waste of hydraulic fracturing energy on unproductive rocks.

The profile also shows that the proppant is concentrated in most of the fracture, which indicates the significant increase in permeability in the fracture zone, hence its conductivity, therefore, increases the flow of hydrocarbons into the wellbore and subsequently increases the efficiency of reservoir modeling and oil production.

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SOURCES OF CARBON DIOXIDE FOR MISCIBLE DISPLACEMENT ENHANCED OIL RECOVERY IN THE SIBERIAN REGION OF THE RUSSIAN FEDERATION

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Industrial applications of CO_2 have recently been considered as an environmentally attractive and economically viable alternative to enhancing oil recovery as well as reducing greenhouse gas emissions. Unlike other gases, CO_2 as a displacement agent produces a significant increase in the oil recovery coefficient. Under laboratory conditions, with unlimited miscibility, the oil displacement coefficient can reach 97%.

Carbon dioxide is a non-flammable greenhouse gas, chemically consisting of a carbon atom and two oxygen atoms with a molar mass of 44.01 g /mol and a concentration of 0.03-0.04% in air. Its density under normal conditions is 1.98 kg / m^3 (1.5 times heavier than air). Carbon dioxide dissolves in oil 4 -10 times better than in water. In 1m^3 of oil at a pressure of 10 MPa and a temperature of 27ºC, 250-300 m^3 of CO_2 is dissolved.

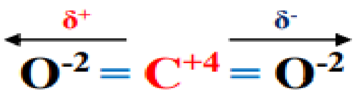

Fig.1 Molecular structure of carbon dioxide

Today, projects to increase oil recovery using CO_2 in Russia seem to be the most economically promising option for carbon capture and storage. Therefore, the assessment of the CO_2 sources that enable these projects to be implemented is of paramount importance. Sources of carbon dioxide can be divided into natural and man-made.

The Russian Federation as of 2017 had confirmed a total of four natural deposits of CO_2, namely; Astrakhan, West Astrakhan, Pomorskiy and North Gulyaev, with a total carbon dioxide reserve of 601.6 billion tons/m^3 and an average of 13.9 % concentration of CO_2.

In Western Siberia, as a rule, the concentration of carbon dioxide in oil associated gases does not exceed 1 %, but in some cases, there are accumulations with a significant content of carbon dioxide. Thus, the CO2 content at the Veselovskiy field reaches 85 %, at the Mezhovskiy field - 97 %, and at the Samutnel field-76.7%.