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Numerical Simulation on Controlling and Optimizing of Fracture Behaviors for Hydraulic Fracturing in Low Permeability Formation

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Abstract

The key technologies used to unlock the unconventional resources now a days are horizontal drilling and single or multi-stage fracturing. It's often verified with utilization of micro-seismic data, hydraulic fracturing in shale reservoirs typically created highly complex fracture network due to their complex geology and activation of pre-existing natural fractures that can't be realistically captured when the classic planner bi-wing fracture models are implemented.

In this paper, a data set of reservoir properties, petro-physical properties and fracture treatment is used to build a new, advanced, and improved simulation model, which shows the improved methods for maximizing the production of oil and gas. The main factors that are investigated and that result in the main effect on fracture behavior are flow rate, proppants type and fracturing fluid.

Fracturing behavior, it's controlling and optimizing are the main factors used to enhance production. FracproPT software is used, which shows the effect of proppant, the flow rate and fracturing fluid.

A comparison (between a real and simulation model) is shown, since the stimulated well's production can be enhanced as a better simulated models should be implemented in future well's stimulation.

A final fracture treatment that achieves maximum fracture length, fracture width and fracture height are determined to be optimal.

In this work, laboratory data is presented for various fracturing fluids with different surface activity pumped into the assembly chamber. Recent fracture treatments have been successfully utilizing a slick water treatment consisting of water and dry polymer with and without surfactant (Tri-ethanol Amine- TEA). Commonly used surfactants as well as a microemulsion system are evaluated in this study.

Results from simulations show that the optimal fracture geometry and fracture conductivity based on pumping limitation is obtained at an injection rate of 100bpm, gel loading of 50ppg and proppant size of 20/40 mesh sand. This paper brings new understanding of fracture behavior in reservoirs and serves as a guide for improved hydraulic fracturing practices.

Keywords

Fracturing, Fracture behavior, FracproPT Software, Fracture geometry, Proppants, Simulation modeling, Fracture growth

1. Introduction

The process of initiation and propagation of hydraulic fracture by pumping specially designed fluid at relatively high flow rate and pressure is one of the techniques from other several techniques to create fracture in the targeted zones.

There are variety of reasons for desiring fractures in earth's crust, mainly includes, the enhance recovery of oil and gas, re-injection of drilling or other wastes, to measure in-situ stress, to enhance well water production and recovery of geothermal energy. The range of these fractures varies from a few meters to hundreds of meters and regarding the cost/investment on the operation is about the portion of total development cost. The hydraulic fracture geometry can surely be predicted and controlled with great accuracy where the in-situ stress includes the direction and is aligned with one of the far-filed principal stresses. However, the hydraulic fracture geometry is usually more difficult and complex to model for the wellbores that are not aligned with such direction (deviated wells), especially close to wellbores where the stress field around the well have different value from far-filed stress. It's difficult to predict the actual hydraulic fracture geometry from the data available on the field because it's mainly existing in pressure curves form, therefore a simulation method is used to predict the directions, locations, and extent of these fractures.

There are various circumstances of main factors that really make able the facture operation to be completed safely and in time. But of course, the experience of the field in this job cannot be neglected. The best engineer or the team is not even able to make or take decisions without having the entire related informant to pertain the job. The monitoring and analyzing system of hydraulic fracturing, that has ability to collect the data during the operation/job and that data if used for real time simulation play major role to make improvements.

1.1 Background of Simulation

Hydraulic fracturing is a complex non-linear mathematical problem that involves the mechanical interaction of the propagating fracture with the fluid dynamics of the injected slurry. Several assumptions are commonly made to render the problem tractable: plane fractures, symmetric with respect to the wellbore; elastic formation; linear fracture mechanics for fracture propagation prediction; power law behavior of fracturing fluids and slurries; simplification of fracture geometry, and its representation by few geometric parameters; etc. The reader is referred to the SPE Monograph Volume 1211 for a detailed description of the governing equations. Although the models predict "trends" of treating pressure behavior~ they may not always reliably predict the observed behavior for a given treatment. This discrepancy has been attributed to many complex interactions of the injected fluids with the formation that are not well understood.

1.2 Fracture Models

This section describes the individual fracture models that were used in this comparison. Short descriptions of the models were provided by the modelers or by the companies who ran commercially available models. Fracture models are used to understand and predict how materials crack and break under stress. These models are crucial in fields like engineering, materials science, and geophysics. When it comes to fracturing modeling specifically for geometric structures, the approach can vary based on the nature of the material and the complexity of the geometry.

2. Development of Simulation Model

To build a model to simulate, detailed data is required from the field that can be used and implemented in the software to get some better and improved results. As discussed in previous chapter; after importing field data in the software (real data) and then changing its parameters, we can get some results of extended results of fracture and for better growth of fracture geometry.

In this paper, field data is imported and by changing its parameters we can generate a 3D model with some better results. Below are the detailed data, which is used for modelling and as a result new fracture profile and fracture geometry is generated (i.e. its length, width, and height).

2.1 The Proppant and Fracture Conductivity

2.1.1 Proppant Conductivity

To complete the fracture treatment, proppants are used to keep the fractures open. These proppants are highly conductive propped fractures, that serve and allow conduit flow of reservoir fluid from the reservoir rock into the wellbore and then to the surface. Ideally, the proppants may able to provide the large fracture conductivity with negligible pressure drop within the fracture during the time of production, but in real, this may not be possible, because of the facts of practical and economic concern (Gidley et al, 1989).

The first ever material used a proppant was River sand, since the inspection of hydraulic fracturing in 1950's (RP-56, 1953). Since that time, different types of material are used as proppant. Most of the proppant agent that are successfully used, include Sand, intermediate strength proppants (ISP) ceramics, high strength proppants (such as sintered bauxite and Zirconium oxide, Economides and Nolte, 1989) and resin coated. Below is the table which shows the different size of sand particles that are commonly used as a proppant agent in fracturing job. These sand sizes are specified by American Petroleum Institute (API) and are shown in Table 1.

Table 1 Different size of sand particles

Mesh Range Designation	Range (μm)
Primary Sizes	
12/20	850 to 1700
20/40	425 to 850
40/70	212 to 425
6/12	1700 to 3350
Alternates Sizes	
8/16	1180 to 2360
16/30	600 to 1180
30/50	300 to 600
70/140	106 to 212

2.1.2 Fracture Conductivity

The fracture conductivity or permeability can be referred to as the measure of ability of fracture that transmits the fluid. The formula used to calculate the fracture conductivity is as:

$$F_{cd} = K_f w_f \left(K l_f\right)(1 - D) \qquad Eq.\ 1$$

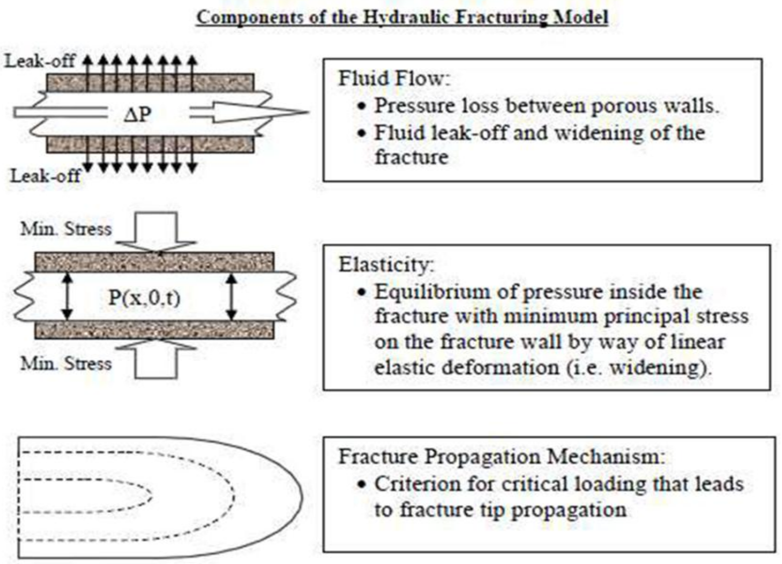
Where,

K_f = The fracture permeability,
W_f = Average fracture width when closed on proppant,
K = Reservoir permeability,
L_f = Fracture half-length and
D = Amount of damage to fracture permeability

The main purpose of the proppant agent in the fracturing job is to keep the wall of fracture apart, while creating path between the reservoir fluid and wellbore. This requires unrestricted linear flow with the fracture to the wellbore and to achieve this, there must be a larger order of magnitude of fracture permeability and conductivity than that of formation itself.

2.2 Conventional Hydraulic Fracturing Theory

Fracturing models typically consists of three basic components: a fluid flow model; a rock deformation model; and a fracture propagation criterion (Fig. 1). The fluid flow model describes the pressure losses and pressure distribution along the fracture, and leak-off into the surrounding porous media when a fracturing fluid is injected. The rock deformation model predicts the response of the fractured surface to hydraulic loading.



Components of the Hydraulic Fracturing Model

Fluid Flow:
- Pressure loss between porous walls.
- Fluid leak-off and widening of the fracture

Elasticity:
- Equilibrium of pressure inside the fracture with minimum principal stress on the fracture wall by way of linear elastic deformation (i.e. widening).

Fracture Propagation Mechanism:
- Criterion for critical loading that leads to fracture tip propagation

Fig. 1 Components of a conventional hydraulic fracture model (Martinez, 2012)

2.2.1 Fracture Mechanics Fundamentals

Most failure criteria theories derive from the work done by Griffith (1921), who proposed that the existence of minute cracks in the material act as stress concentrators. When a crack propagates in a medium, a part of the elastic energy of the medium is released to create new fractures. Subsequent modifications of Griffith's theory led to more general loading conditions in terms of measurable parameters called “stress intensity factors” (Martinez, 2012). These studies, along with many other following contributions led to the origin of the classic theory of fracture mechanics. In the case of fracture propagation in a rock, it is assumed that loading and deformations have a linear relation, and that propagation of the fracture occurs in brittle fashion before considerable non-linear features are apparent. This assumption of linear elasticity is combined with the principles of classic fracture mechanics in what is known as Linear Elastic Fracture Mechanics (LEFM). In LEFM, the concept of plane strain is often used to reduce the dimensionality of the problem.

From the work done by Sneddon (1973), it is well known that the pressurized crack in the state of plane strain has an elliptical width distribution.

$$w(x) = \frac{4p_o}{E'}\sqrt{c^2 - x^2} \qquad Eq.\ 2$$

Where, x is the distance from the center of the crack, c is the crack half length, and is the constant pressure exerted on the rock. From the above equation, the maximum width at the center can be solved as shown below.

$$w(x) = \frac{4p_o}{E'} \qquad Eq.\ 3$$

This indicates a linear relationship between crack opening induced and the pressure exerted. When the concept of a pressurized crack is applied to hydraulic fracturing, is replaced by net pressure, , which is the difference between the pressure inside the fracture and the minimum principle stress acting from outside, trying to close the fracture (Economides et al., 2002).

According to Griffith (1921), the presence of defects in the rock (cracks, soft inclusions, etc.), have the effect of intensifying the magnitude of any applied load. The intensification effect is the result of a compromise between the surrounding loads, the geometry of the defect, and the mechanical properties of the medium and is called a stress intensity factor. The stress intensity factor for a pressurized line crack is given by:

$$K_I = p_o c^{\frac{1}{2}} \qquad Eq.\ 4$$

Where is the crack half length, and is the constant pressure exerted on the rock. It can be observed that the stress intensity factor at tip of the fracture is proportional to pressure opening the fracture and the square root of fracture half length (Martinez, 2012).

2.2.2 Fracturing Fluid Mechanics

The most important property of fracturing fluids is apparent viscosity. Apparent viscosity is defined as the ratio of shear stress to shear rate. Based on the trend of the rheological curve, we can classify the types of fluids (Fig. 2). These rheological curves can be used to calculate the pressure drop for a given flow condition. Rheological properties of the fracturing fluids are mainly dependent on chemical composition, temperature, and several other factors like shear history (Economides et al., 2002).

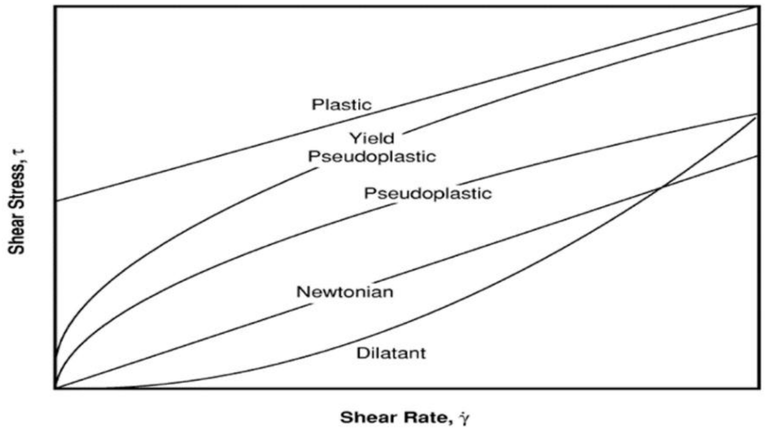


Fig. 2 Typical rheological curve (Economides et al., 2002)

Typically, the flow condition of fracturing fluids is laminar flow with two limiting geometries. Slot flow occurs in a channel of rectangular cross section when the ratio of the major dimension to the minor dimension is extremely large. Ellipsoid flow occurs for an elliptical cross section with an extremely large aspect ratio.

2.2.3 Fracture Propagation Models

Fracture propagation models combine elasticity, fluid flow, material balance, and any additional propagation criterion. If the fluid injection schedule is known, the fracture propagation should predict the evolution of fracture geometry with time and wellbore pressure. Initially there were two original 2-D models: the PKN and KGD models. Each represents a set of different assumptions in deriving the analytical solutions. Based on these models, several other models were developed.

2.2.4 Radial Model

Radial fractures occur when the fracture initiates and grows (horizontal fractures in a vertical well or transversely vertical fractures in a horizontal well). either case the minimum principal stress is perpendicular to the fracture (Zeng, 2002). The radial length (radius of the fracture) R, and the width W_w, of the KGD radial fracture can be seen below:

$$R = \sqrt{\frac{q_{I(4w_w+15S_p)}}{30\pi^2 {C_z}^2}\left(e^{s^3} erfc(S) + \frac{2}{\sqrt{\pi}} S - 1\right)} \qquad Eq.\ 5$$

$$W_w = 2.56\left(\frac{\mu q_i R}{E'}\right)^{1/4} \qquad Eq.\ 6$$

Where,

$$S = \frac{15 C_L \sqrt{\pi}}{4W_w + 15S_p} \qquad Eq.\ 7$$

For the case with no fluid leak-off, the above equation can be approximated as:

$$R = 0.52\left(\frac{E {q_I}^3}{\mu}\right)^{1/9} t^{4/9} \qquad Eq.\ 8$$

$$W_w = 2.17\left(\frac{\mu^2 {q_I}^3}{E'}\right)^{1/9} t^{1/9} \qquad Eq.\ 9$$

After considering fluid leak-off, approximation for the radial model is:

$$R = \frac{1}{\pi}\left(\frac{{q_i}^2 t}{C_L}\right)^{1/4} \qquad Eq.\ 10$$

$$W_w = 2.56\left(\frac{\mu q_i R}{E'}\right)^{1/4} \qquad Eq.\ 11$$

All 2D fracture propagation models assume a planar fracture. In non-radial models, the fracture is assumed to extend vertically to the full height of the pay zone and remain within the pay zone. In the radial fracture models, the fractures are assumed to initiate from a point source and propagated without restrictions. While these assumptions greatly simplify the solution for fracture geometry, they do not always represent reality.

3. Methodology

The workflow procedure (Fig. 3) followed in this study to simulate the fracture geometry using experimental design and response surface methodology is primarily divided into two stages. The first stage focuses on identifying the significant variables affecting the fracture geometry. This stage was conducted in three phases, each phase incorporating progressively more complex assumptions about geology. The second stage of the study uses the three most significant variables identified in the first stage to quantify a functional relationship between them and the predicted fracture geometry using Box-Behnken experimental design and response surface methodology. The workflow used in this study is as follows:

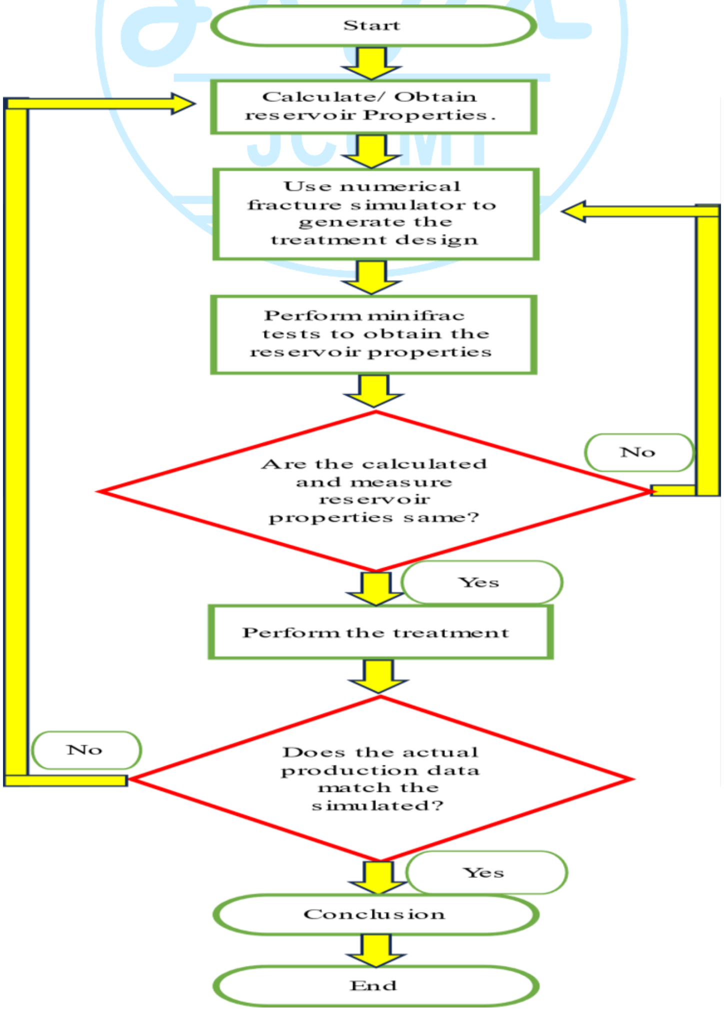


Fig. 3 Flowchart describing the workflow used in this study

3.1 Significant Parameter Identification

FracproPT software, a pseudo 3D fracture propagation model was used in this study. This simulator effectively determines the fracture treatment schedule for a known desired fracture length. After inputting the reservoir geology, mechanical properties, proppant type/size, fracturing fluid type, and the desired fracture length, FracproPT generates several treatment schedules and selects the treatment schedule with the predicted fracture length as close as possible to the desired estimate. As discussed earlier, pseudo 3D models have improved accuracy when compared to 2D models and they require less computational time/input data as compared to full 3D models. The FracproPT PT predictions can overestimate the fracture geometry in shales as it neglects stress shadowing, stress anisotropy and natural fractures. Table 2 shows the fracture geometry variables for the modeling of fracture.

Table 2 Seven fracture geometry variables modeled in this study

S#	Dependent/ Controllable parameters	Symbol
1	Width at the top of the fracture, in	*width_top*
2	Width at the middle of the fracture, in	*width_mid*
3	Width at the bottom of the fracture, in	*width_bot*
4	Fracture length, ft	*fracture_length*
5	Propped length, ft	*propped_length*
6	Fracture height, ft	*fracture_height*
7	Propped height, ft	*propped_height*

3.2 Hydraulic Fracturing Simulation

Hydraulic fracturing (or "fracking") simulation is a specialized field within geomechanics, and reservoir engineering used to model and predict the behavior of fractures induced in subsurface rocks by injecting fluids at high pressure. These simulations are critical for optimizing the extraction of resources like oil and natural gas and for managing environmental impacts. Here’s a comprehensive overview of hydraulic fracturing simulation:

- *Key Components of Hydraulic Fracturing Simulation*

A. Geomechanically Modeling

Concept: Models the stress and strain in the rock formation. Understanding the geomechanically properties of the rock helps in predicting how fractures will propagate.

Key Parameters: Rock strength, in-situ stress, pore pressure, and rock elasticity.

Tools: Finite Element Analysis (FEA), Finite Difference Methods (FDM), and continuum mechanics-based software.

B. Fracture Propagation

Concept: Predicts how fractures initiate, grow, and interact with each other and the surrounding rock. This includes the geometry of the fractures and their propagation paths.

Key Parameters: Stress intensity factors, fracture toughness, and the effect of fluid pressure on fracture growth.

Tools required for the simulation are Hydraulic fracturing simulators and specific software like FRACPRO or TNO’s TOUGH2.

C. Proppant Transport

Concept: Simulates the distribution and placement of proppants within the fractures to keep them open after the fluid pressure is reduced.

Key Parameters are Proppant concentration, particle size, and settling velocity.

Tools required for proppant transportation are Particle transport models and discrete element methods (DEM).

3.3 Special Concerns for Fracturing Design in Shale Reservoirs

3.3.1 Reservoir Characterization

A careful study of the reservoir is necessary to understand the complexities in shale reservoirs and evaluate the possible candidate wells. Reservoir characterization will help us in determining the increase in production, water inflow, cross flow between formation layers, and availability of sufficient pressure support (Crabtree, 1996). The geologic properties like size of reservoir, type of reservoir and the drainage area are needed to decide the well spacing and the optimum length of horizontal well. The formation lithology affects the fracture height containment and fracturing fluid selection. Clay content and its distribution affect the permeability of the rock and are necessary to design fracturing fluid additives (Nolte and Economides, 1989). Fracture orientation depends on the fault pattern in the formation and in-situ stress field.

3.3.2 Horizontal Well Design

The reservoir rocks at a certain depth are subjected to an in-situ stress field. This field can be represented by three principal stress vectors (vertical and two horizontal components). The fracture always propagates in the direction perpendicular to the least principal stress (Economides et al., 2012). The horizontal well is preferred to be placed in the direction perpendicular to the maximum principal stress to achieve maximum reservoir contacted by the transverse fractures. Therefore, understanding the in-situ stress orientation can help in determining the orientation of horizontal well.

Other factors such as reservoir geology, reserves to be developed per well, production rates expected per well, future well intervention requirements, surface logistics, and environmental impacts also affect the horizontal well design.

4. Hydraulic Fracturing Simulation

This research resulted and was carried out by commercially used fracturing software called FracproPT. This FracproPT system was designed especially for engineers to provide comprehensive tools for designing hydraulic fracture and analysis. The utilization of actual treatment data is the key theme for this software which separates FracproPT from other competing products.

4.1 FracproPT Software

FracproPT Software (Fig. 4) uses measured values of flowrate, proppant concentration, and fluid rheology parameters to calculate the pressure drop down a wellbore of variable deviation and diameter, and the time histories of the fracture growth and the net fracture pressure are calculated.

FracproPT models the convection and settling of proppant in a fracture. Proppant convection is a process whereby heavier treatment stages (e.g., proppant stages) displace rapidly downward from the perforations to the bottom of the fracture. Those stages are then replaced by the pad, or by low-concentration proppant stages. Initial Laboratory and computer simulations indicate that proppant convection may be the dominant mechanism in propped-fracture stimulations. The main goals of FracproPT can be described as:

1. To determine the areal penetration (radius and length)
2. To determine the geometry of fracture
3. The complexity of fracture
4. Opening width of created hydraulic fracture.

Fig. 4 shows the major work and outline of what FracproPT can do and how we can utilize it.

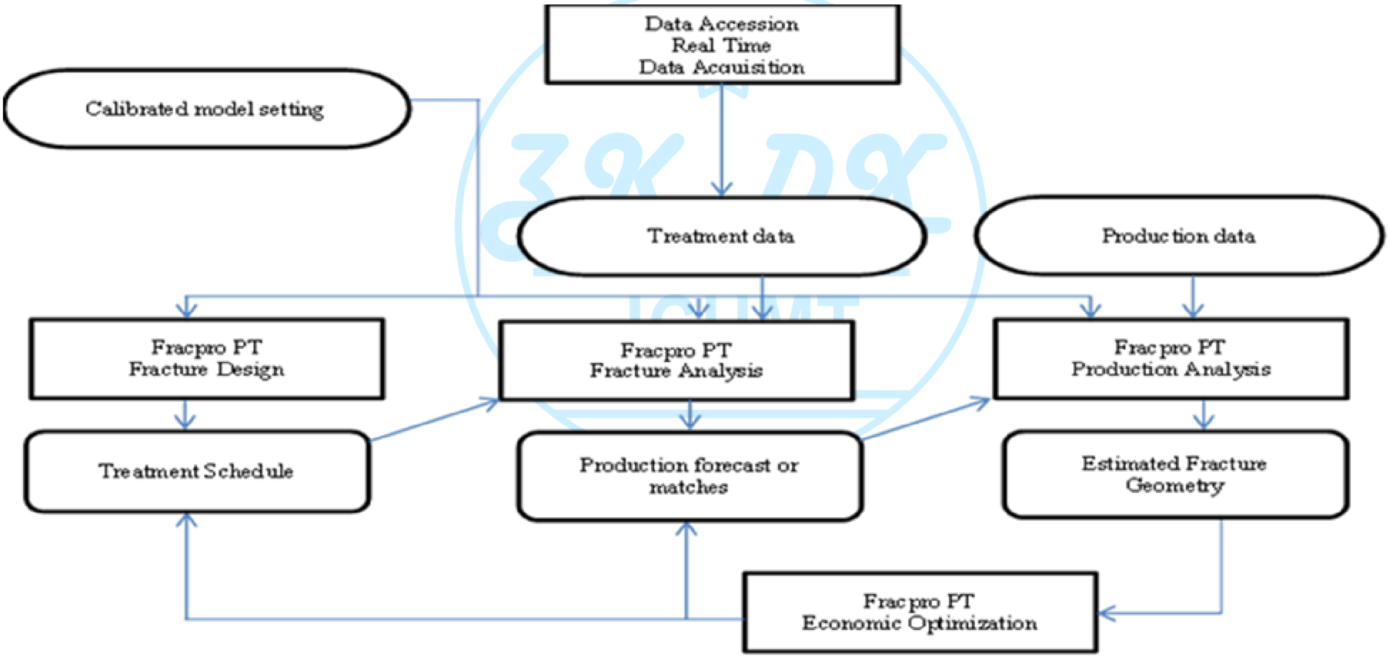


Fig. 4 Details of FracproPT Software

4.1.1 Setting Up of Software

The main factors used to set up the software to start or carry out the simulation in very accurate and proper manner. Following are two major steps:

I. Accession of data
II. Modeling of Hydraulic fracture

4.1.2 Accession of Data

The system of accession collects and saves the data from the treatment. Several different types of data are available (collected). These available data is then managed in proper manner and used according to linked to each other (i.e. back-to-back)

Data acquisition (DATACQ) computer is used, so that data can be saved, and the data can easily be available at the computer where the program/software is installed.

After the data is acquired, it’s then sleeted, compressed, and fed into the treatment base model. All previously monitored jobs, design and other major parameters can be kept in data base for future refer, record generation or re-running of model and of comparison.

The main information that kept in data base is:

- Data for treatment of selected channel
- Final job design, fluid type and proppant type.
- The reservoir parameters
- Information of well, i.e. well name, treatment data, formation etc.

4.1.3 Modeling of Hydraulic Fracture

The targeted formation (i.e. the Stimulated formation) plays major role in the control and growth of hydraulic fracture behaviour. For example: the large difference of magnitude in the horizontal stress in the formation, the growth expecting of thin fracture is in one direction. The FracproPT software is helpful in a way that it allows users to import types of fracture growth behaviour which may be unique to certain formations.

In FracproPT, to simulate the fracture growth behaviour, a model of 2D shear-decoupled is used. As a result of introducing composite layering effect, longer confined hydraulic fracture are predicted in 2D shear-decoupled model. FracproPT software is widely used now days for modelling, testing, and improving fracturing to enhance production. The main factors that affect the fracture behaviour can be named as fracture slurry, proppants, and flow rate (pressure). Combination of these three main factors may result in different direction and growth of fracture.

There are different types of proppants available but each of these must be used and mixed carefully with properly design slurry to achieve proper results.

Field data is used in the model to build new advanced and modified models to get more beneficial/improved results compared to previous ones.

4.2 Real-Time Fracture Analysis

The prediction of any hydraulic fracture simulation, to achieve with confident, require fracturing pressure (the fracturing fluid pressure above of the closure stress) which is predicted by the model must be match with the fracturing pressure that is observed in the treatment.

However, due to completed inability to match observed net fracturing pressure, the two dimensional and conventional three-dimensional fracturing models can be dismissed. The accurate knowledge of bottomhole pressure ($P_{bottomhole}$) is required to determine observed net fracturing pressure.

If bottomhole pressure can't be measured directly, then it can be calculated by using the formula as:

$$P_{bottomhole} = P_{surface} + P_{head} - P_{friction} \qquad Eq.\ 12$$

Where,

$P_{surface}$ = The treatment pressure measured at surface,
P_{head} = Hydrostatic weight of fluid in well, and
$P_{friction}$ = Head loss due to friction in the pipe.

When the bottomhole pressure is known or calculated, the net fracturing pressure can be calculated by subtracting closure stress ($P_{closure}$) and pressure loss because of perforation (P_{perf}) or near-wellbore friction ($_{Pnear\text{-}wellbore}$) from the bottomhole pressure ($P_{bottomhole}$). It can be defined as by using formula:

$$P_{net} = P_{bottomhole} - P_{closure} - P_{perf\ or\ near-wellbore} \qquad Eq.\ 13$$

To predict the net fracturing pressure in FracproPT, it uses the measured proppant concentration, fluid flow, reservoir description and fluid rheology.

This predicted net fracturing pressure can be then compared in history matching process, to observe the value of net pressure described in Eq.13.

The simulator re-run until the observed and predicted pressure gets matched with each other (The simulator re-run after implementing some known or certain unknown properties of reservoir upon which the pressure responds and of course, on this pressure response, the growth of fracture depends on this pressure response).

The better the pressure match will result in the best estimation of fracture extent and proppant placement. And for sure, if the bottomhole pressure and closure stress is known more accurately then the more precisely and true net pressure in the fracture can be calculated which results in the more precise fracture-geometry prediction.

4.3 Fracturing Fluid Selection

Fracturing fluids play a vital role in reaching the designed stimulation goals. These fluids are mainly used to provide the necessary pressure to initiate and propagate the fracture. Apart from this, the fracturing fluids also transport the proppant into the fracture to prevent the fracture closure. Based on the wide range of reservoir properties like permeability, porosity, pressure, temperature, material composition and other aspects, four different types of fracturing fluids have been developed for different reservoir conditions--water-based fluids, oil-based fluids, foams, and emulsions. Designing a fracturing fluid depends on several variables like stress anisotropy, pumping rate, and fluid-rock reactivity. Fluid and core measurements help us determine the necessary additives to prevent formation damage. Fracturing fluids should also exhibit low friction loss during pumping and be as economical as practical. In shale reservoirs, massive volumes of fracturing fluid are required as large reservoir volumes are stimulated. Even though the low viscosity of water-based fluids makes it easy to invade shales with ultralow permeabilities, they have very low proppant carrying capacity. Whenever the proppant carrying capacity is of high priority, more viscous fluids are used. An ideal fracturing fluid in shale reservoirs should have low viscosity in early stages, and the viscosity should increase whenever higher proppant concentration is needed. Table 3 shows details parameters of different fluids used in the simulation of hydraulic fracturing operation in research.

Table 3 Details of parameters used in simulation model

Fluid Name	**SLICKWATER**	**Fresh water**	**HL_WG-19_20_1**	**HL_FG_22**
Description	SLICKWATER (20#/1000 GAL OF GEL IN WATER)	Fresh water	20#/1000 WG-19 (GUAR)	22#/1000 WG-31 (GUAR) 7.5#/M GelSta
Initial Viscosity (cp)	3.97	0.244	4.73	761.6
Initial k' (lbf·s^n/ft^2)	1.200e-04	5.100e-06	1.180e-04	0.040
Viscosity @ 4.0 hours (cp)	3.97	0.244	0.618	119.0
k' @ 4.0 hours (lbf·s^n/ft^2)	1.200e-04	5.100e-06	1.332e-05	0.003
Base Fluid Specific Gravity	1.000	1.000	1.01	1.01

Four different fluids are used in these simulation models, i.e. slickwater, freshwater, HL_WG-19_20_1 and HL_FG_22. Freshwater and slickwater are used for initial propagation of fracture in the formation, whereas two different types of fracturing fluids are used to carry proppants to the created fractures in the reservoir.

4.4 Proppant Selection

Proppants are solid particles that flow into the induced fractures to keep the fractures from closing. Proppant type, size and concentration determine the flow capacity of the induced fracture networks (Crabtree, 1996). Sand is the most used proppant in shale reservoirs, particular smaller size ranges like 100 mesh. Resin-coated sand proppants are used when the proppants are expected to be subjected to high compressive strengths. Ceramic proppants are used when very high proppant strength and thermal resistance are required (King, 2010). Proppant selection is mainly dependent on the following parameters. Table 4 shows the detailed of proppant properties used in the simulation modeling.

Table 4 Properties of Proppants used in simulation model

Proppant Name	**Ottawa2040**	**Ottawa1630**
Proppant Coating	None	None
Cost ($/lb)	0.0	0.070
Bulk Dens (lbm/ft^3)	95.90	93.60
Packed Porosity	0.420	0.434
Specific Gravity (sg)	2.65	2.65
Turbulence Coeff a	1.45	0.930
Turbulence Coeff b	0.750	0.060
Diameter (in)	0.023	0.029

The proppants used in this modeling with no coating on it. The values of proppatns used in the model are mentioned in Table 5.

Table 5 Proppant parameters

Parameter	**Value**	**Default**
Minimum Proppant Concentration (lb/ft^2)	0.20	0.20
Minimum Proppant Diameter (in)	0.0080	0.0080
Minimum Detectable Proppant Concentration (ppg)	0.20	0.20
Proppant Drag Effect Exponent	2.0	8.0
Proppant Radial Weighting Exponent	0.3750	0.2500
Proppant Convection Coefficient	10.00	10.00
Proppant Settling Coefficient	1.00	1.00
Quadratic Backfill Model	ON	ON
Tip Screen-Out Backfill Coefficient	0.50	0.50
Stop Model on Screen out	ON	ON
Reset Proppant in Fracture after Closure	ON	ON

5. Results and Comparison

Data is collected from experimental work hydraulic fracturing operation which was performed in laboratory. A real field data is used to investigate the use of effect of different fracturing fluid along with proppants at different injection rates. The Given below are the results and differences between the stimulated well and simulation. The growth of fracture can be enhanced, and the production of oil and gas can be maximized by changing different parameters while performing fracturing job. The main parameters include are flow rate, proppants, and fluid type.

Fig. 5 shows the response of pressure in the chamber for the creation of fracture while performing an experiment. The rise in pressure shows the buildup of the pressure and drop in pressure shows the creation of fracture within the sample. Also, the sufficient length of fracture can be achieved by continuous injection of fracturing fluid.

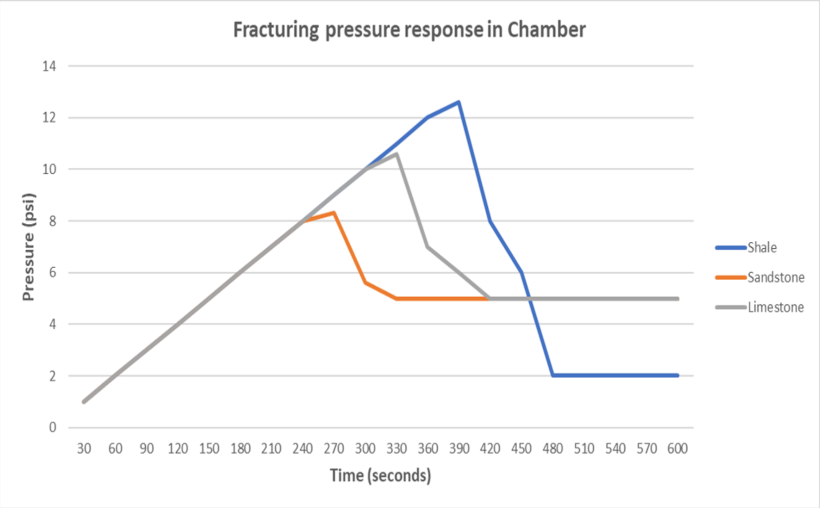


Fig. 5 Pressure behaviour in the chamber

Fig. 6 shows the geometry of fracture created in the chamber in response to the pressure behaviour shown in Figure 3.

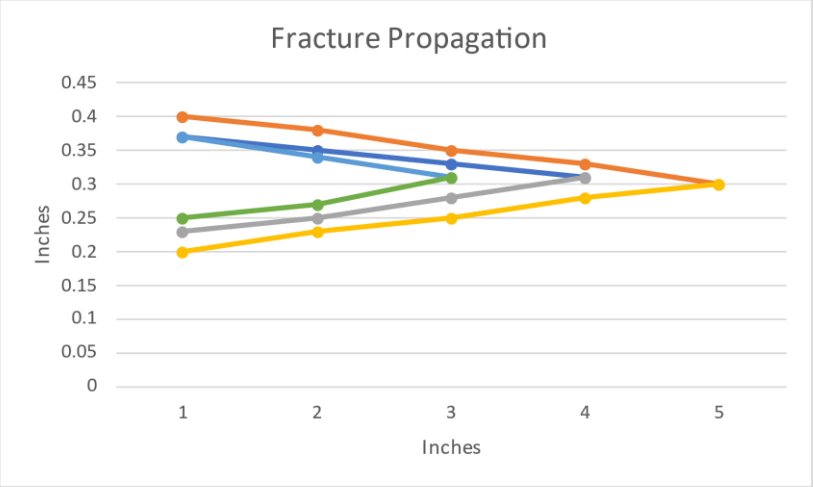


Fig. 6 Fracture length

Given below (Fig. 7) are the results and differences between the stimulated well and simulation. The growth of fracture can be enhanced, and the production of oil and gas can be maximized by changing different parameters while performing fracturing job. The main parameters include are flow rate, proppants, and fluid type.

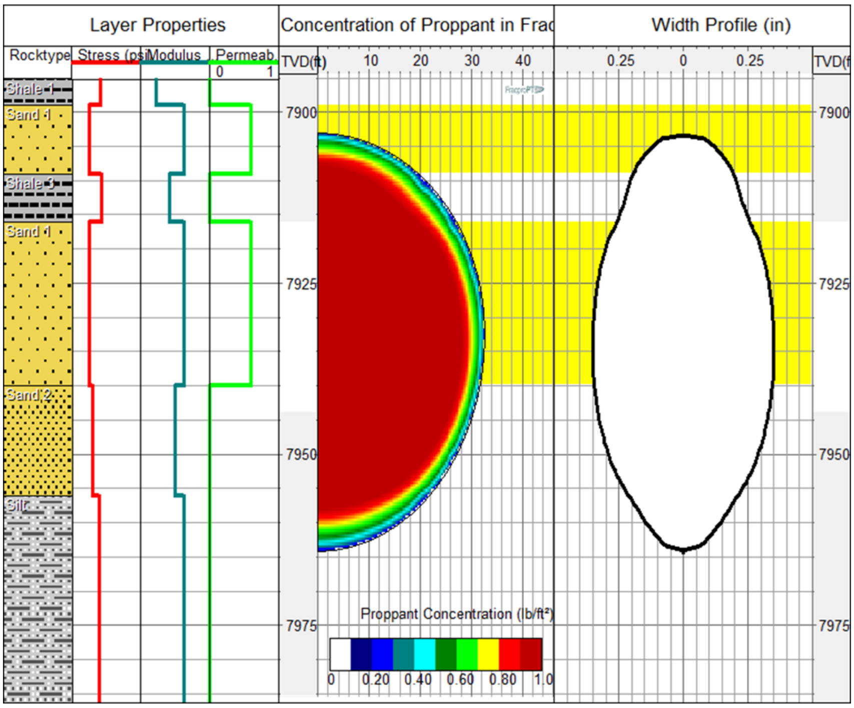


Fig. 7 Concentration of Proppant in Fracture

Fig. 8 shows the treatment design of the fracturing operation in the simulation. Treatment design is the comprehensive process of injection of fresh water, the slurry, the fracturing fluid and proppants concentration. The fracture growth (length and geometry) is controlled by proper designing of fracture treatment.

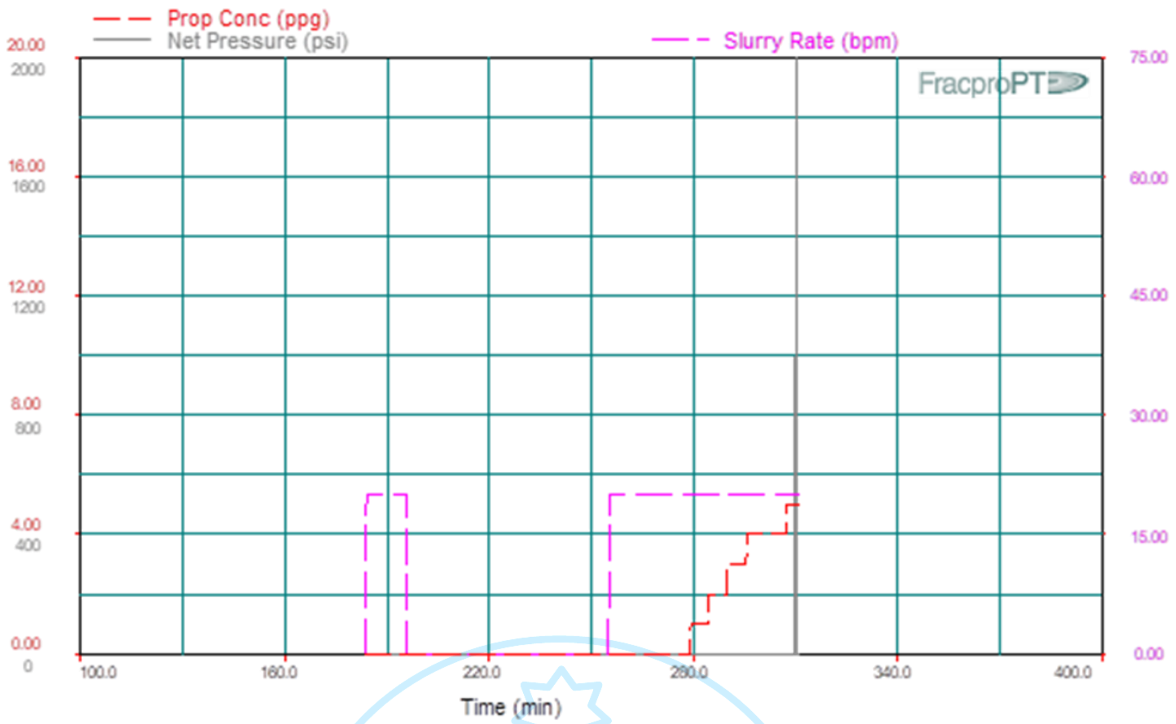


Fig. 8 Designing of simulation model for fracture treatment

Fig. 9 shows the creation of fracture length within the formation by exerting a continuous pressure of injection form the surface. The higher length of fracture length is achieved by exerting a constant pressure of slurry and fracturing fluid from the surface.

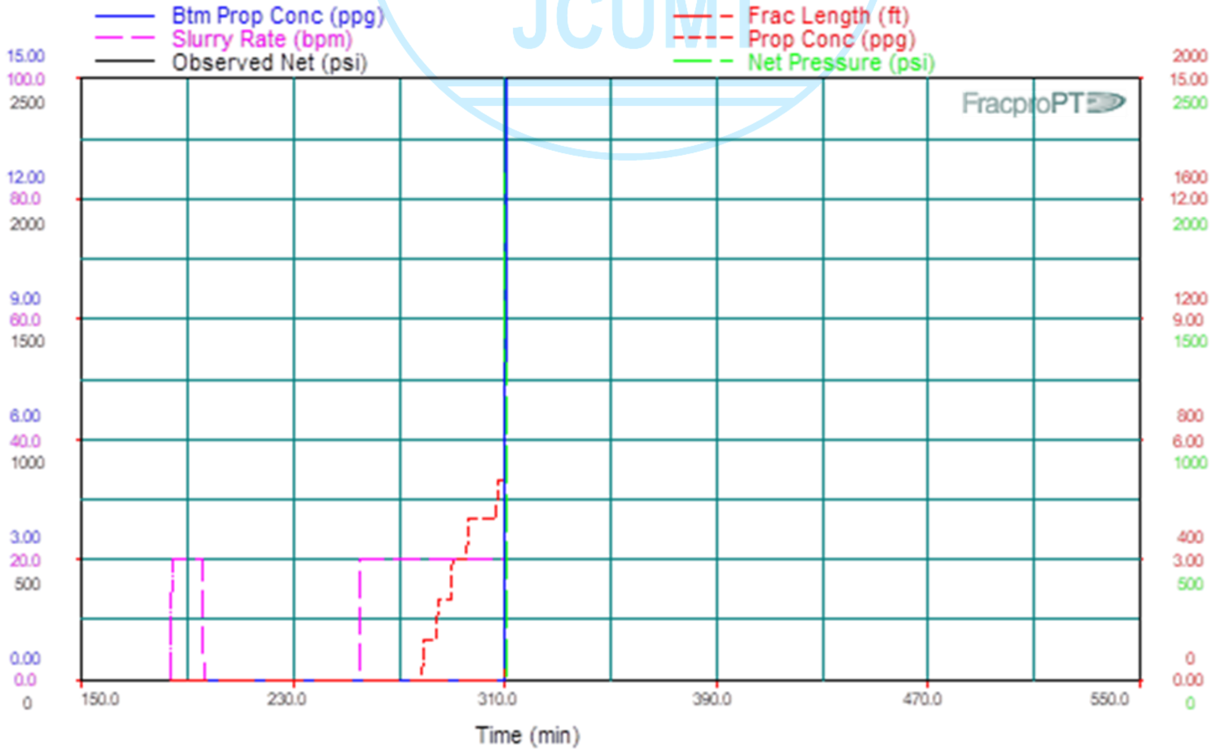


Fig. 9 Exerting a constant pressure to achieve a sufficient fracture length

Fig. 10 shows the behaviour of net injection pressure exerted for the creation of fracture within the formation and to achieve sufficient length of the fracture.

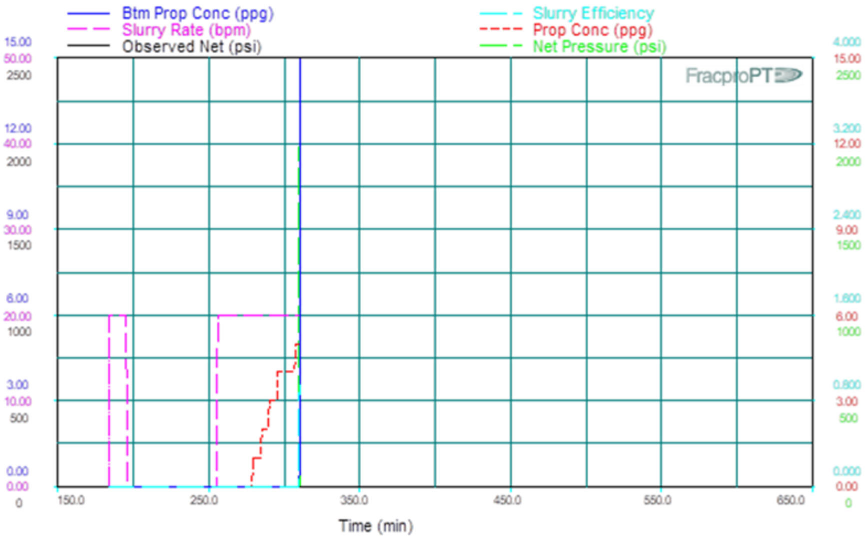


Fig. 10 Behavior of Net injection pressure

Fig. 11 (a and b) shows the proppant concentration used for the injection within the created fracture of the formation. High concentration is required to completely fill the created fracture. However, small proppants are used initially, and then large proppants are used.

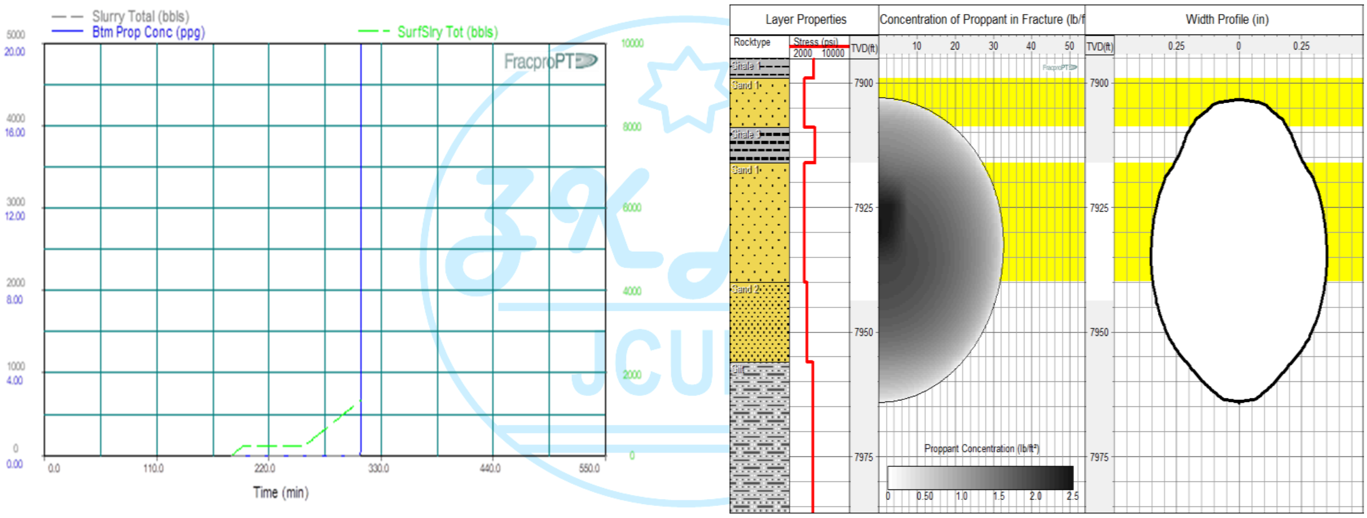


Fig. 11 (a)-left and 8(b)-Right Concentration of Proppant in Fracture

Fig. 12 shows the fracture conductivity of the created fracture. Large size proppants have high conductivty, whereas, small proppants have less proppant conductivity.

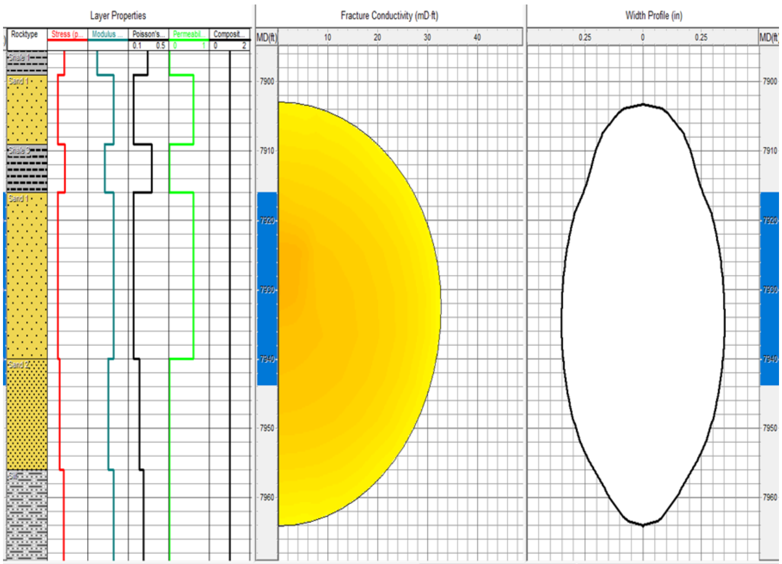


Fig. 12 Fracture Conductivity

Fig. 13 (a and b) shows the response of layers and formation stress on the width of the created fracture in the formation.

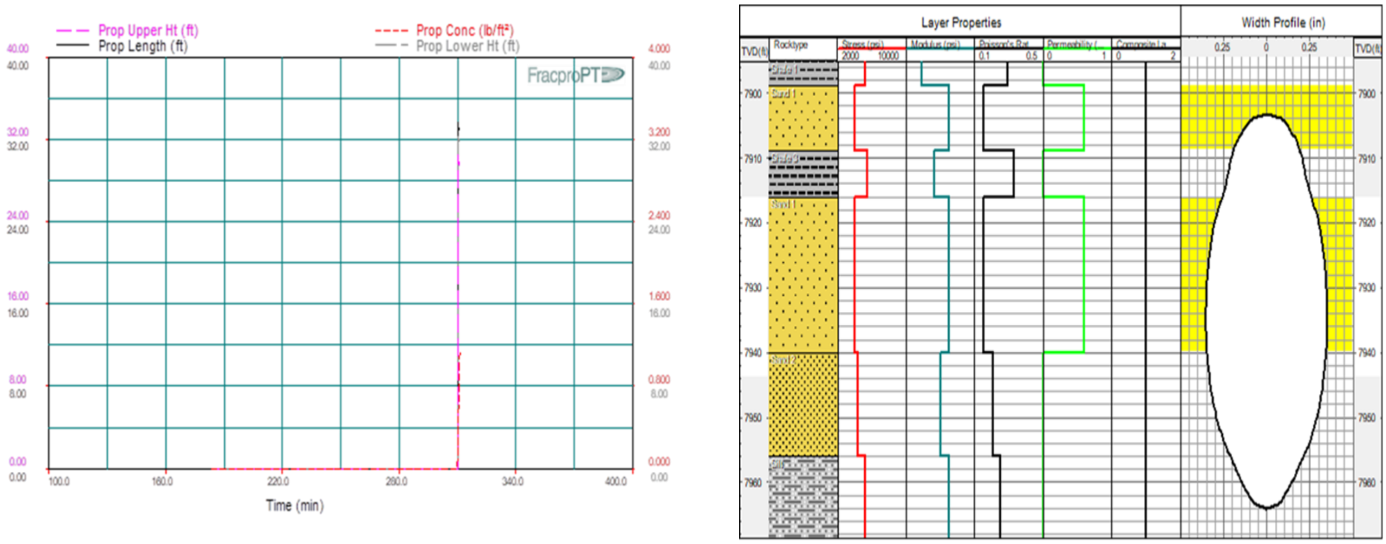


Fig. 13 (a)-Left and 10(b)-Right Response of formation stress on fracture growth

Fig. 14 shows the response of different forces of formation to the injection rate of the fracturing fluid and slurry.

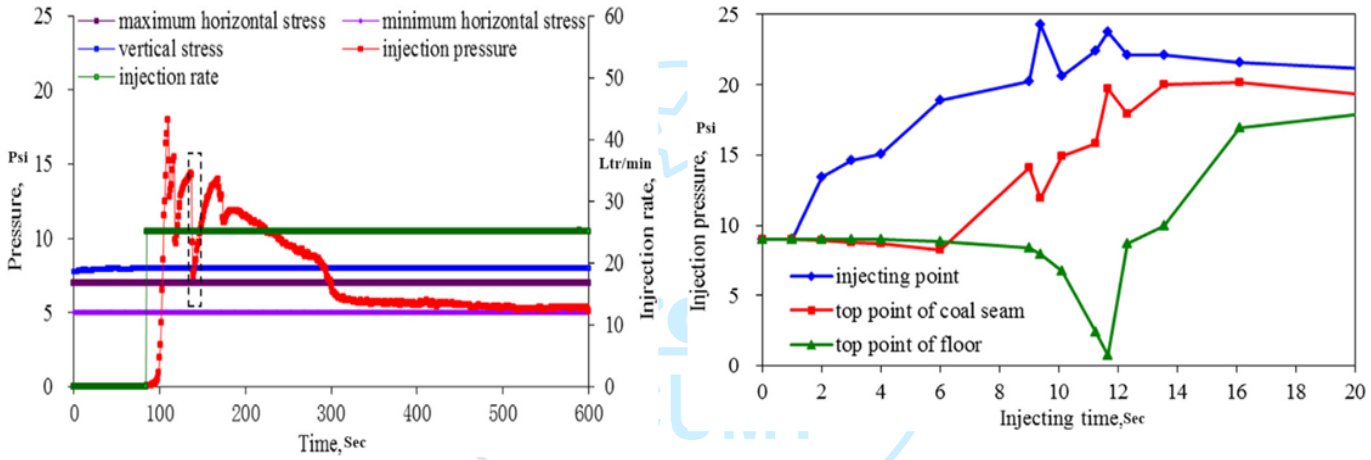


Fig. 14 Response of formation stresses

Fig. 15 shows the volume fraction of proppant slurry used in the fracture simulation to simulate the fracturing operation in FracproPT software.

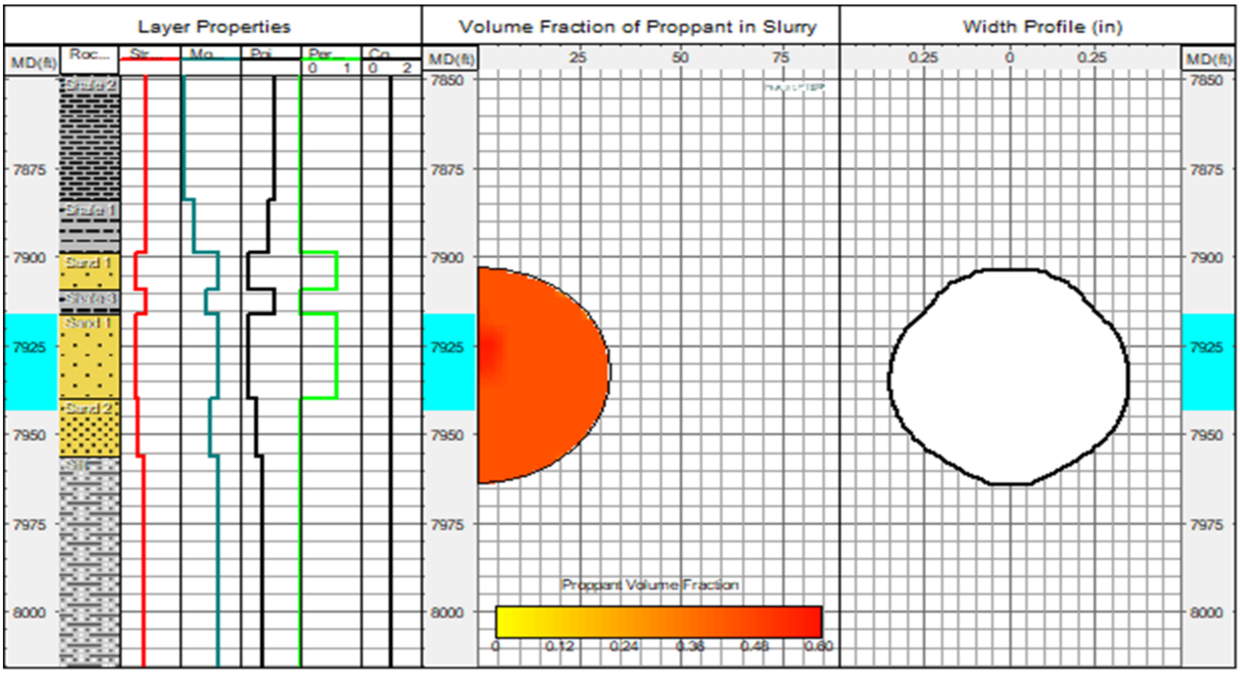


Fig. 15 Volume of proppant fraction and width profile of created fracture

6. Conclusion and Recommendations

6.1 Conclusion

Effective Hydraulic fracture stimulation is essential to technology to produce and maximize the production of oil and gas from the reservoir. A simulator that is capable of modelling single, multiple, and fully 3D hydraulic fractures has been built. It could maintain the consistent geometry representation of fracture geometry throughout the analysis.

Additions and enhancements in simulator and modelling are still in progress, in order to allow the modelling of more complex problems and also to increase the speed, accuracy and efficiency of the simulator.

From the study, we can conclude as following:

1. One of the very useful methods for estimating and creating the fracture dimensions and geometry is modelling the growth of hydraulic fracture in the reservoir zone.
2. Careful analysis of observed data from hydraulic fracturing treatment has revealed the inadequacy of conventional fracturing model approaches in predicting created hydraulic fracture dimension and geometry.
3. With increase of volumetric injection rate, the created fracture length increases.
4. Volumetric injection rate has a direct effect over fracture width. Increasing the injection rate serves to increase the net pressure, fracture volume and expands the fracture width.
5. Calculations from the same model with different options give a useful comparison of the importance of all the additional physical mechanisms that are continuously being added to the models to explain the wide variety of pressure responses observed in different reservoirs. Such options give the completion engineer considerable flexibility, but also difficult choices of when various options should be used.
6. These comparisons show that differences in calculated fracture lengths can be large, as much as a factor of three difference. Fracture heights, for the multi-layer cases, can differ by more than 50%. Net pressures also differ by a factor of two. At the end, still more field cases and comparative studies are required to pursue people to trust the reliability of the results.

In particular, the comparison of the result between the production history and the new approach in this work needs to be performed in a more exhausting way.

6.2 Recommendations

Simulation helps us enhance the understanding, behaviour, and response of the subsurface by using different real data from the original field and to observe the behaviour of same formation at different parameters. There are two primary recommendations that could be suggested for the future work on this study.

1. It would be beneficial to perform this same type of study for different input conditions. This case was chosen because it was a realistic field situation for which detailed data were available. Other warranted cases are those where there are minimal stress contrasts and where the stress contrasts are extremely large.
2. The pressure-history matches that were performed at the Fracture Propagation Modeling Forum provided many interesting results but were not suitable for documentation because there was no simple way to compare the various models. However, a comparison of pressure-history matches would be of value.

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