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Hydrocarbon Production Department

DISSERTATION

To obtain the Master's degree

Option: Professional Production

Presented by:

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-TITLE-

Pillar Hydraulic Fracturing Using Pulsed or Cycled Proppant Fracture (Conductor Frac)

Publicly defended on: 08 / 06 / 2022

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Dedication

For every beginning there is an end, and what is beautiful in any end is success.

I dedicate this modest work, fruit of very long years of work to the light of my life, and the source of my happiness to ***my very dear parents.***

To my hero my dear ***father****, for his encouragement, his support, especially for his love and sacrifice so that nothing hinders the progress of my studies.*

To the only woman in my life who suffered so much to make me what I am, who always gives me the hope of living, and who has never stopped her Prayers for me: ***My dear Mother****.*

To my three lovely sisters: my soul ***IKRAM****, my dear* ***IMAN***

and my twin ***FADOUA***

My kind brother ***AHMED***

My best Iraqi friend ***MUSTAFA***

And finally to my pretty coworker ***NOUR***

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This study is wholeheartedly dedicated to my beloved parents,

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my source of inspiration who continually provide their moral, spiritual, emotional, love, support…

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and my classmates who made this

journey easier and more fun.

NOUR

Abstract:

After an oil or gas well is drilled, the wellbore pressure is reduced to less than the oil or gas bearing formation. This higher formation pressure forces the oil or gas to the wellbore, where it then travels to the surface. Sometimes, the flow of oil or gas (well production or productivity) is too small for the operator to make any profit. If the reservoir does contain enough oil or gas to make it commercially sufficient, then the problem may be formation damage near the wellbore caused during the drilling process or be a formation with low permeability (ability to allow flow). In either case, the flow needs to be stimulated.

Stimulation treatments include acidizing to restore the initial permeability and hydraulic fracturing to create a new path in the naturally low permeability formations.

Halliburton recommended a new technology in the production enhancement, which is the Pillar hydraulic fracturing (conductor Frac) to enhance the fracture conductivity in the formation with a high risk of screen-out.

Key words: Pillar, conductor, hydraulic fracturing, production enhancement, screen-out.

Résumé :

Après le forage d’un puits de pétrole ou de gaz, la pression de puits est réduite moins que le pétrole ou le gaz portant la formation. Cette pression de formation force le pétrole ou le gaz de déplacer alors au puits ou à la surface. Parfois, l'écoulement d'huile ou de gaz (production du réservoir ou index de productivité) est trop petit pour que l'opérateur fasse tout bénéfice. Si le réservoir contient assez d'huile ou de gaz pour le rendre commercialement suffisant, alors le problème peut être un colmatage de formation près du puits causé pendant le processus de forage ou être une formation avec une perméabilité naturellement faible (capacité à l'écoulement). Dans l'un ou l'autre cas, l'écoulement doit être stimulé.

Les traitements de stimulation incluent l’acidification matricielle pour restaurer la perméabilité initiale et la fracturation hydraulique pour créer un nouveau chemin dans les formations de perméabilité naturellement faible.

Haliburton a recommandé une nouvelle technologie dans l’amélioration de production qui est la fracturation hydraulique des piliers (conductor Frac) pour augmenter la conductivité des fractures dans des formations qui ont un grand risque du screen-out.

Mots clés : Piliers, conductivité, fracturation hydraulique, amélioration de production, screen-out.

تلخيص:

بعد حفر بئر نفط أو غاز، يتم تقليل ضغط حفرة البئر إلى أقل من تكوين محمل النفط أو الغاز. يؤدي ضغط التكوين العالي هذا إلى دفع النفط أو الغاز إلى جوف البئر، حيث ينتقل بعد ذلك إلى السطح. في بعض الأحيان، يكون تدفق النفط أو الغاز (إنتاج البئر أو الإنتاجية) صغيرًا جدًا بحيث لا يتمكن المشغل من تحقيق أي ربح. إذا كان المكمن يحتوي على ما يكفي من النفط أو الغاز لجعله كافيًا تجاريًا، فقد تكون المشكلة هي تلف المناطق المنتجة بالقرب من حفرة البئر أثناء عملية الحفر أو يكون مكمنا ذا نفاذية منخفضة (القدرة على السماح بالتدفق). في كلتا الحالتين، يجب تحفيز التدفق

تشمل معالجات التحفيز بالحموضة لاستعادة النفاذية الأولية والتكسير الهيدروليكي لإنشاء مسار جديد في التكوينات منخفضة النفاذية بشكل طبيعي

أوصت شركة هاليبرتون بتقنية جديدة في تحسين الإنتاج وهي التكسير الهيدروليكي العمودي (التكسير الموصل) لتعزيز موصلية الكسر في المكمن مع وجود مخاطر عالية من السكرين اوت

.كلمة مفتاحيّة: عمود، التوصيل، التكسير الهيدروليكي، تعزيز الانتاج، سكرين-اوت

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Nomenclature

q: oil flow in downhole conditions (bbl/d).

k: permeability (md).

h: tank height (ft).

μ: oil viscosity (cp).

Pr: reservoir pressure (psi)

Pwf: dynamic background pressure (psi)

re: drainage radius (ft)

rw: radius of the well (ft)

S: total skin.

ks: permeability of the damaged zone.

rs: radius of the damaged area (ft).

P: layer pressure (psi).

Cm: matrix compressibility.

Cb: Compressibility of porous rock.

α≈ 1

σH'= effective horizontal stress (PSI).

σ tect= tectonic stress contribution (psi).

Hmax: maximum horizontal stress.

Hmin: minimum horizontal stress.

ρ = the density of the formations overlaying the target reservoir (lb/ft3),

D = depth to the target reservoir (ft).

α = Biot's poroelastic constant (dimensionless),

P = pore (reservoir) pressure (psi).

δ : stress (psi).

ε : strain

Pbd : formation break down pressure (psi)

Psi : Surface injection pressure, (psi).

Ph: hydrostatic Pressure. (psi).

Pbd: Formation break down pressure (psi).

ΔPf: frictional pressure drop, (psi).

ΔPf: Frictional pressure drop (psi).

ρ: density of fluid (g/cm3).

D: tubing diameter, (in).

L: Tubing length, (ft).

ISIP: instantaneous shut in pressure (psi).

Qv = Volume flow rate, at standard conditions of 14.73 psia and 60 deg F (Sm3/h).

C = Orifice flow constant

hw = Differential pressure, inch water at 60 Deg F (psi).

Pf = Absolute Upstream Static Pressure. (psi).

Fb = Basic orifice factor

Fr = Reynolds number factor

Y1 = Upstream expansion factor

Fpb = Pressure base factor = 1, as Pb = Pst = 14.73 psia is assumed

Ftb = Temperature base factor = 1, as Tb = Tst = 60 deg F is assumed

Ftf = Flowing temperature factor.

Fgr = Real gas relative density factor.

Fpv = Super compressibility factor.

Fa = Orifice thermal expansion factor

WHP: wellhead pressure (psi).

GasSG: Gas specific gravity (psi).

Abbreviations :

HMD: Hassi Messaoud

CP : Closure pressure

Pnet: Net pressure

PNP: Plug and Perforate completion system

CT: coiled tubing

BACS: Ball-Activated completion system

CTACS: Coiled-Tubing-Activated completion system

CBL: Cement bond log

Dos: Design of Service

Bpm: baril per minute.

SRT: spill response team

PDL: pressure decline leak-off.

GOR: Gas oil ratio.

Chk: choke.

PBU: pressure build up.

PILLAR HYDRAULIC FRACTURING USING PULSED OR CYCLED PROPANT FRACTURE (CONDUCTOR FRAC)

General Introduction

Energy is the one that makes a country developed, to meet future energy demand of the Algeria advancement in oil and gas industry is inevitable. The primary objective of exploration and production companies is to increase the production and ultimate recovery. Hydraulic fracturing is one of the oldest methods followed in oil and gas industry to increase recovery of oil, still continuing, and going to meet the energy demand. Hydraulic fracturing includes a lot of engineering, and equipment's, which is highly sensitive and errors or miscalculations could lead to failure of project, abandonment of well, damage of formation etc. so that operations are to be done with extreme care.

Hydraulic fracturing is the process in which fractures in rocks below the earth's surface are opened and widened by injecting chemicals and liquids at high pressure, used especially to extract oil and Natural gas and one of the primary engineering tools for improving well productivity. This is achieved by placing a conductive channel through near wellbore damage, bypassing this crucial zone and extending the channel to a significant depth into the reservoir to further increase productivity, to alter the fluid flow in the formation.

In this project, we will discuss about the well stimulation, hydraulic fracturing and types, along with different fluids used in the fracking process including water, proppants and chemicals. We will also discuss about the "the Pillar hydraulic fracturing (conductor frac)" proven by HALLIBURTON who owns the first patent of this technology introduced in 1971 and its application in Algeria's field in 2012.
The aim of the Conductor Frac is to increase the conductivity of the fracture significantly realized while reducing the consumption of water and the proppants. It creates open ways inside the fracture allowing hydrocarbons to rather cross the stable channels than to cross the proppants. Finally, we will discuss about the fracturing jobs, design, well test results and construction of the AZSE-21 well located in REGGANE region.

How can this technology reduce or eliminate the screen-out cross on the entire high stressed formations?

To better understand our work, this dissertation structured on three chapters

- The first Chapter presents an overview about the hydraulic fracturing types, fluids and equipment's used to accomplish the fracking job.

- The second chapter illustrate the study case of AZSE-21 well located in REGGANE region and the process of the conductor frac technology.

Finally, general conclusion illustrates a main point about the evolution of conductor frac and a summary of the results are respected and investigate.

CHAPTER ONE:

GENERALITIES IN

HYDRAULIC FRACTURING

CHAPTER ONE: GENERALITIES IN HYDRAULIC FRACTURING

I. 1.History of Hydraulic Fracturing:[1]

- 1947 The first attempts at hydraulic fracturing.
- 1949 (March 17), The first two commercial fracturing attempts, in Stephens County, Oklahoma.
- In the mid1950s, 3000 jobs per month were being completed.
- In the 10 years that followed, more than 1.2 billion pounds of sand were pumped into wells within the United States.
- 25 years after the first fracturing jobs, treatments averaged about 37,000 gal of fluid and 45,000 lb. of proppant.
- By 1981, more than 800,000 treatments had been performed. By 1988, this had grown to exceed 1 million. About 35 to 40% of all currently drilled wells are hydraulically fractured.

I. 2. Hydraulic fracturing:

Hydraulic fracturing or, as it is commonly called, “fracking”, is a well stimulation technique that has been employed in the oil and gas industry since 1947, used for accessing natural gas and oil in tight geologic formations. Very low permeability formations such as tight sandstone, shale tend and some coal beds and to have fine grains (limited porosity) and few interconnected pores (low permeability). In order for natural gas or oil to be produced from low permeability reservoirs, individual molecules of fluid must find their way through a tortuous path to the well. Without hydraulic fracturing, this process would produce too little oil and/or gas and the cost to drill and complete the well would be could not be justified by this low rate of production**.[2]**

The process of hydraulic fracturing is intended to create new fractures in the rock as well as increase the size, extent, and connectivity of existing fractures, so the hydrocarbons and other fluids can flow more easily from the formation rock, into the fracture, and ultimately to the wellbore. Hydraulic fracturing is a well-stimulation technique used commonly in low-permeability rocks. A similar technique is used to create improved permeability in underground geothermal reservoirs**.[3]**

Hydraulic fracturing treatments are designed by specialists and utilize state-of-the-art software programs.

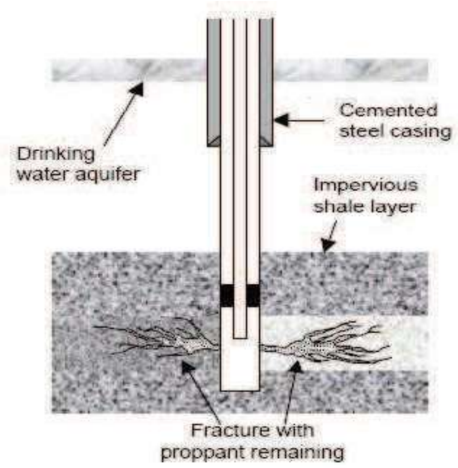


Figure I.1: hydraulic fracturing.[4]

I. **3. Objective:[1]** The operations of hydraulic fracture can be carried out on a well for one (or several) of the five following reasons:

- To avoid the damages, close to the well and to restore a well with its productivity natural.
- To prolong a conducting way in a formation and to thus increase the productivity

beyond natural level.

- to modify the flow of the fluids in the formation.
- Increase the rate at which the well is capable of producing oil or gas.
- Increase the economically recoverable reserves for a well

Fracturing consists of the injection of a treatment fluid at a pressure higher than the fracturing pressure of the formation, thus opening channels with very high permeability, in which the effluent can flow much more easily, which increases well throughput and productivity.

I. **4. Increase production: [5]**

The hydraulic fracturing aims to increase (or restore) the permeability, and by consequent, the productivity and flow of production in the horizontal wells and them vertical wells.

Darcy's equation: $$Q = \frac{kh\,(Pr - Pwf)}{141.2\ B\ \mu\,[\ln\frac{re}{rw} + S]} \quad \text{(I.1)}$$

Stimulation aimed at increasing Q by:

- Bypassing near wellbore formation damage.
- Create large effective wellbore radius (rw’).
- Change the flow pattern.

I. *4.1. Bypass the damage:* [5]

- There are certain activities that cause damage near the wellbore which lead to reduction in productivity. The drilling operation itself causes damage to the formation as the solids and fluids of the drilling fluids, as well as the fines produced due to the drilling operation, invade the formation and reduce the formation permeability and the ability of the oil and gas to flow to the wellbore. Sometimes the drilling fluid is not chemically compatible with the formation and it damages the wellbore. In cases when the formation is damaged chemically, matrix treatment is preferably used to improve productivity, but sometimes it doesn’t work. When this happens, hydraulic fracturing is used to bypass damage (Economides & Nolte, 2000).
- Bypassing flow effects that increase the skin (s) e.g. near wellbore formation damage.

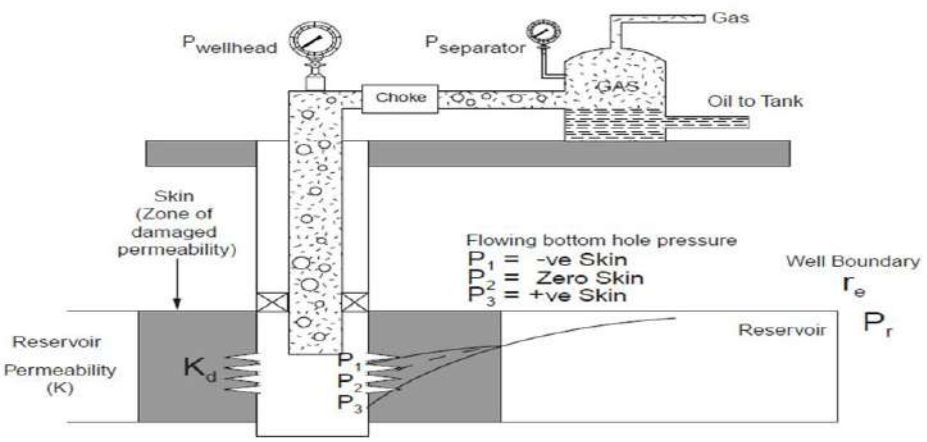


Figure I.2: Highly conductive fracture results in a negative skin.[5]

I. 4.2. Create large effective wellbore radius:[5]

increasing the wellbore radius (rw) to an effective wellbore radius (r’w).

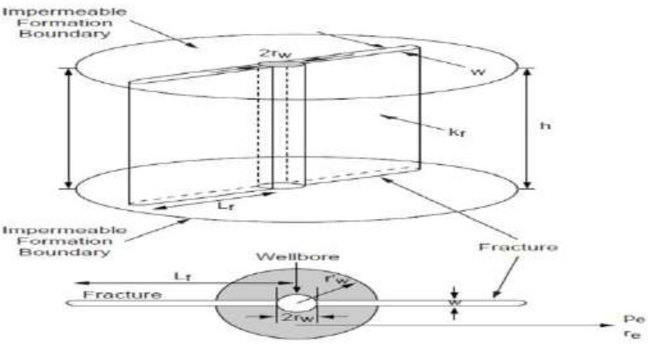


Figure I.3: large effective wellbore radius [5]

I. 5. Hydraulic fracturing process:[6]

Once the drilled well and the formwork installed until the target depth, of the holes or the perforations are bored in the oil string in order to create entrance points allowing the fluid fracturing and the agent of supporting in suspension to penetrate in one or more targeted hydrocarbon zones. The number and the orientation of the perforations given in advance and are conceived in order to enable them to cross any natural network of fractures which can conceal the tank (later, these same perforations will make it possible gas to penetrate in the well).

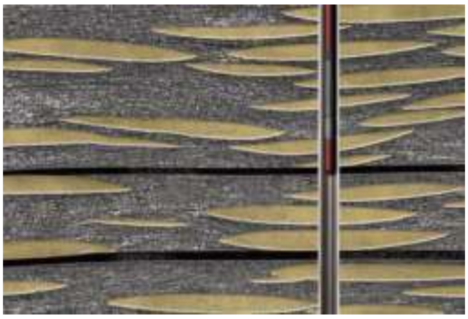


Figure I.4: Hydrocarbons from small, scattered reservoirs (Halliburton, 2008)

The equipment used for purposes of hydraulic fracturing then is installed on the surface and is connected to the well of drilling in order to carry out treatment by fracturing. This process consists mainly of four stages:

Stage 1: Exercise of a pressure on the container using a fluid in order to generate the creation of a fracture.

Stage 2: Increase in the size of the fracture thus created by continuous pumping of fluids in one or more fractures.

Stage 3: Pumping of agents of supporting in the fracture in the form of mud mixed with the fluid of fracturing.

Stage 4: Stop of pumping repression of the fluids of fracturing in the well so allowing their recovery, while leaving the agent of supporting in place in the tank.

The fluid fracturing is pumped into the production casing, through the perforations (or open hole), and into the targeted formation at pressures high enough to cause the rock within the targeted formation to fracture. In the field, this is known as "breaking down" the formation.

As high-pressure fluid injection continues, this fracture can continue to grow, or propagate. The rate at which fluid is pumped must be fast enough that the pressure necessary to propagate the fracture is maintained. This pressure is known as the propagation pressure or extension pressure. As the fracture continues to propagate, a proppant, such as sand, is added to the fluid. When pumping is stopped, and the excess pressure is removed, the fracture attempts to close. The proppant will keep the fracture open, allowing fluids to then flow more readily through this higher permeability fracture.

During the hydraulic fracturing process, some of the fracturing fluid may leave the fracture and enter the targeted formation adjacent to the created fracture (i.e. untreated formation). This phenomenon is known as fluid leak-off. The fluid flows into the micropore or pore spaces of the formation or into existing natural fractures in the formation or into small fractures opened and propagated into the formation by the pressure in the induced fracture.

As one would expect, the fracture will propagate along the path of least resistance. Certain predictable characteristics or physical properties regarding the path of least resistance have been recognized since hydraulic fracturing.

In the field, the process is called the **"treatment" or the "job."** The process is carried out in predetermined stages that can be altered depending on the site-specific conditions or if necessary, during the treatment. In general, these stages can be described as follows.

a) ***Pad:*** The pad is the first stage of the job. The fracture is initiated in the targeted formation during the initial pumping of the pad. From this point forward, the fracture is propagated into the formation. Typically, no proppant is pumped during the pad.

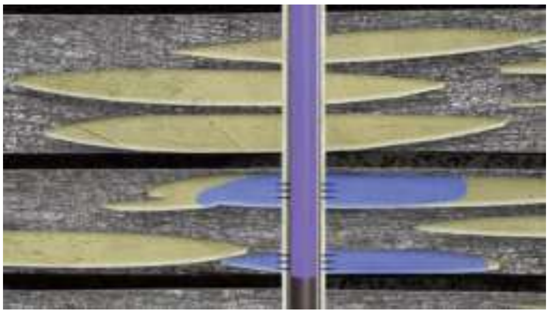


Figure I.5: Fluid is pumped with pressure after perforation (Halliburton, 2008)

b) ***Proppant Stages (slurry stage):*** After the pad is pumped, the next stages will contain varying concentrations of proppant. The most common proppant is ordinary sand that has been sieved to a particular size. Other specialized proppants include sintered bauxite, which has an extremely high crushing strength, and ceramic proppant, which is an intermediate strength proppant.

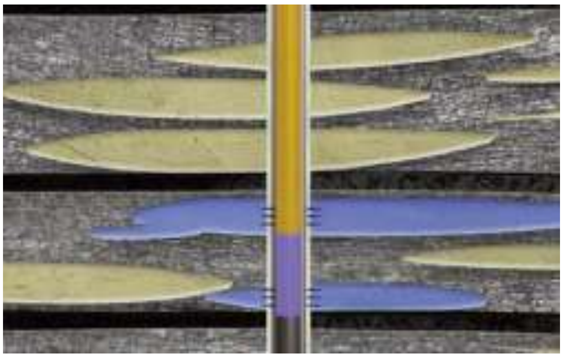


Figure I.6: Fluid carrying proppant is pumped in to the fracture (Halliburton, 2008)

c) ***Displacement (flush stage):*** The purpose of the displacement is to flush the previous sand laden stage to a depth just above the perforations. This is done so that the pipe is not left full of sand, and so that most of the proppant pumped will end up in the fractures created in the targeted formation. Sometimes called the flush, the displacement stage is where the last fluid is pumped into the well. Sometimes this fluid is plain water with no additives, or it may be the same fluid that has been pumped into the well up to that point in time.

In wells with long producing intervals (e.g. horizontal wells), this process may be done in multiple stages or cycles, working from the bottom to the top of the productive interval. Staging the treatments allows for better control and monitoring of the fracture process.

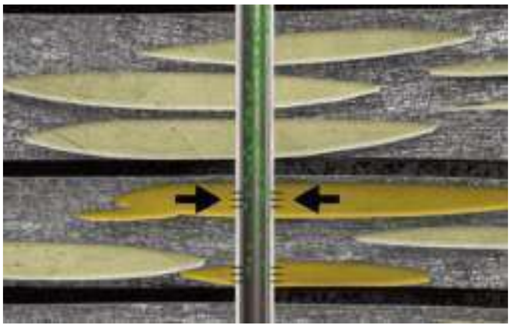


Figure I.7: Hydrocarbon production begins after the treatment (Halliburton, 2008)

The Figure I.7: shows that the hydraulic fracturing process is finished and the well is cleaned and ready for production.

The design of fracture treatment is a complex task, which involves analysis, planning, experience and rigorous observation of different stages in the entire process.

I. 6. Surface equipment:[7]

• ***Pumping units****:* This pumping unit makes pumping the treatment fluid possible at very high pressures.

• ***Blender:*** The Blender allowed the proppants to be mixed with water and additives.

• ***LFC Hydration Unit:*** LFC is an oil-based polymer blend, we mix it with water using the hydration unit to better prepare our gel.

• ***Cabinet for treatment monitoring:*** Necessary for monitoring and recording data during processing.

• ***Tree saver (well insulation tool):*** It is equipment that allows the treatment fluid to be pumped at a surface treatment pressure higher than that of the well.

• ***The Frac Tank:*** The frac tank is a reservoir where water is stored, this water is necessary for gel preparation. The storage capacity per tank is 20,000 Gallons, the number of tanks that must be available depends on the volumes planned for the operation.

• ***Proppant storage tank:*** Proppant has to be stored on location, ready for use. It has to be kept clean and dry, and must be delivered to the blender smoothly and quickly.

In addition to all of the above equipment, there are also other equipment such as: Lab Van, flowmeters, pressure gauges and high-pressure treatment lines.

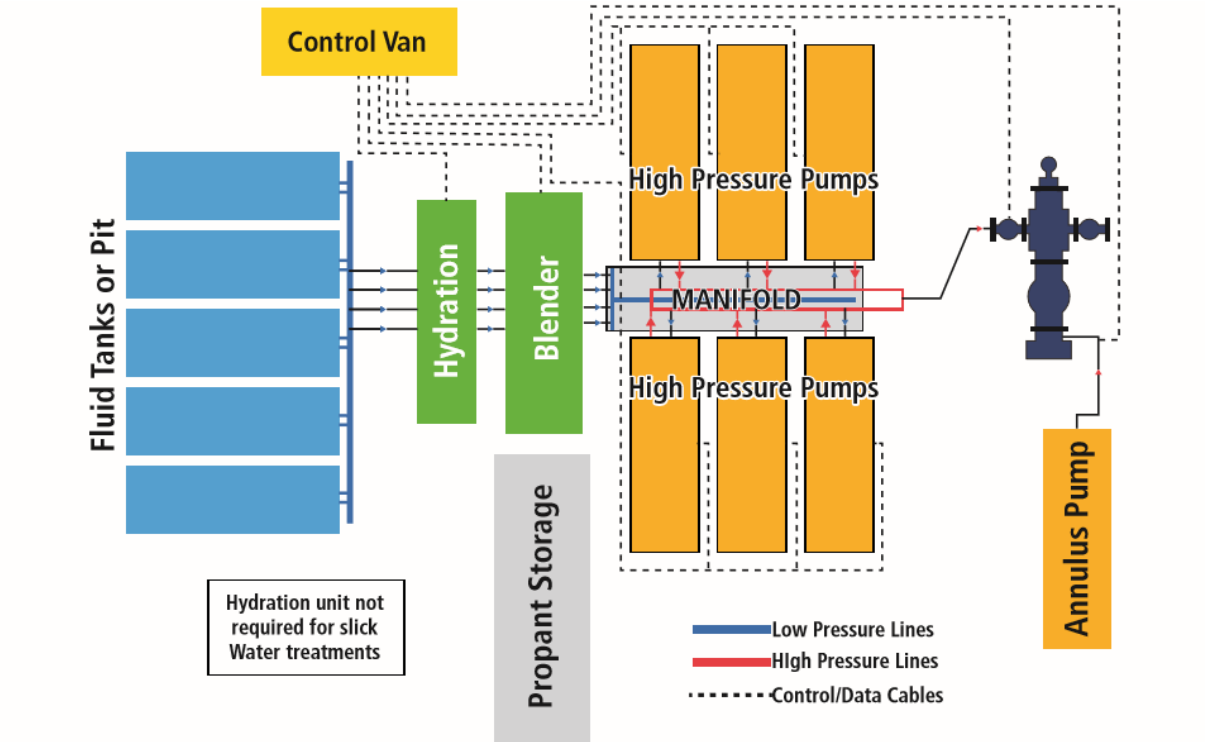


Figure I.8: **Hydraulic fracturing surface equipment.[7]**

I. 7. Matrix Acidizing:[8]

1. ***Sandstone:*** In treating Sandstone Matrix the injected fluids have to "dissolve/disperse" the damage itself to restore the natural permeability.
2. ***Limestone:*** In treating Limestone Matrix, the damage is bypassed and the natural flow capacity is restored by the creation of some highly conductive wormholes.

➢ ***Major Effects:***

- Dissolves/Disperses Damage.
- Restores Permeability.

➢ ***Minor Effects:***

- Minor Stimulation.

3. Limestone:

➢ ***Major Effects:***

- Enlarge Flow Channels/Fractures.
- Disperse Damage by Dissolving Surrounding Rock.
- Creation of Highly Conductive Wormholes.

I. **8. Propped frac:** Propped hydraulic fracture well stimulation should only consider when:

- Sufficient recoverable Reserves.
- Sufficient reservoir Pressure.
- Low Permeability (less than 10 mD).
- Oil/Water and Oil/Gas contacts not very close.
- Good cementation.

I. **9. Conventional Hydraulic Fracture (vertical and horizontal):[5]**

An induced fracture propagates vertically in the direction perpendicular to minimum horizontal stress.

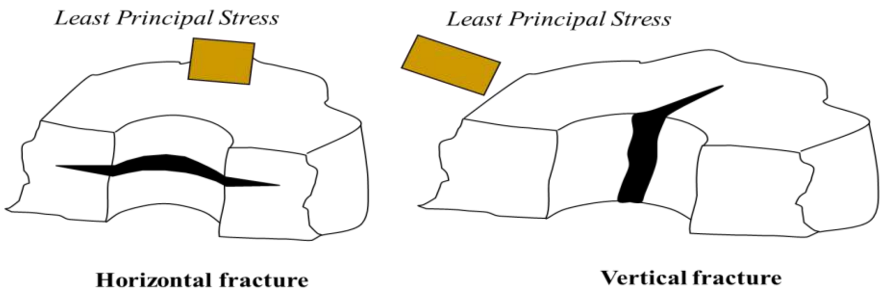


Figure I.9: vertical and horizontal fracture.[5]

I. ***9.1. Vertical and Horizontal Fracture:[8]***

- Basic hydraulic fracturing techniques are the same for horizontal and vertical wells.
- The type of the fracturing treatment is predominately determined by the nature of the formation that being treated.

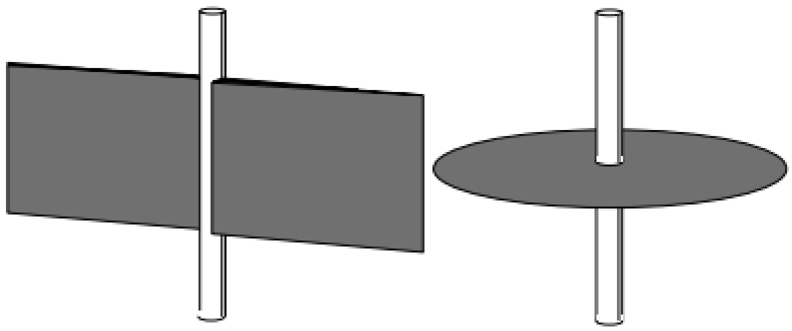


Figure I.10: vertical and horizontal fracture.[8]

-Vertical fracture plane is perpendicular to earth's surface due to overburden stress being too great to overcome.

- Horizontal fracture with a pancake like geometry. Usually associated with Shallow wells of less than 3,000 ft. depth

• **Rule-Of-thumb:**

– Frac Gradient < 0.8 psi / ft ------→ Vertical Fracture.

– Frac Gradient > 1.0 psi / ft ------→ Horizontal Fracture.

Figure I.11: Vertical Hydraulic Fracture

I. 10. Fundamentals of Hydraulic Fracturing:[6]

I. 10.1. Constraints:[22] Generally, the formations are subjected to various constraints, which join between them to maintain these rocks in states of compression:

- Total principal contraints (σi). (Figure 2).
- Effective principal constraints (σi).

These constraints are dependent between them by the following relation:

- $\sigma i = \Sigma i - \alpha P \; (I = 1, 2, 3)$ .... (I.2)
- $\alpha = 1 - \frac{Cm}{Cb}$ .... (I.3)

With:

- P: layer pressure.
- Cm: matrix compressibility.
- Cb: Compressibility of porous rock.
- $\alpha \approx 1$

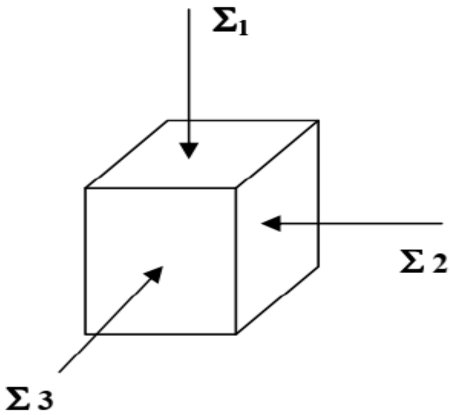


Figure I.12: constraint model.[22]

I. ***10.2. In-situ stresses:*** **[5]** There are three principle earth stresses oriented at right angles to one other. These are: vertical stress v), maximum horizontal stress (max) or intermediate stress and minimum horizontal stress (min). In a three-dimensional stress regime, a fracture will propagate parallel to the greatest principal stress and perpendicular to the least principal stress. A description of three principal in-situ stresses is given in the following sub-sections:

A. horizontal stress:

The vertical stress is translated horizontally through the Poisson ratio (v).

$$\sigma H' = \left(\frac{v}{1-v}\right) \sigma v' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.4)}$$

where: σH’= effective horizontal stress (PSI).

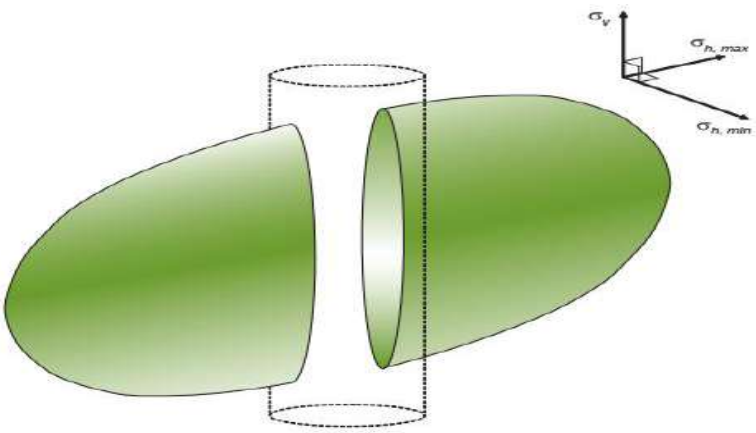
Poisson’s ratio is a rock property which is defined as the ratio of lateral unit strain to the longitudinal unit strain in material which is stressed in one direction without any failure or rupture. For sand stones it is approximately equal to 0.25, implying that the effective horizontal stress is approximately one – third the effective vertical stress. The absolute horizontal stress, σH would be equal to the effective stress plus αp

$$\sigma H - \sigma H' + \alpha p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.5)}$$

Due to tectonic loading, the horizontal plane stress varies with direction. The above horizontal stress is the minimum horizontal stress, the maximum horizontal stress is

$$\sigma H.max = \sigma H'.min + \sigma tect \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.6)}$$

Where: σ tect= tectonic stress contribution (psi).



FigureI.13: Fracture propagation perpendicular to the minimum horizontal stress.

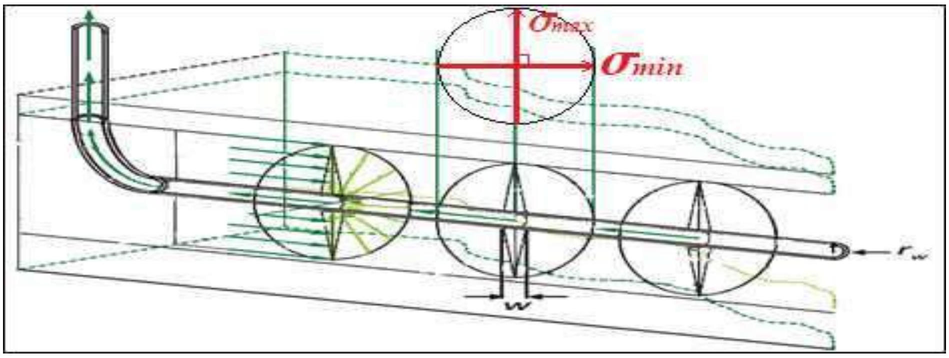


Figure I.14: form and the orientation of the fracture according to the constraints (σ) in a horizontal well.[9]

B. vertical stress:

The absolute vertical stress, σv in psi corresponds to the weight of the overburden, and is given by:

$$\sigma v = \rho D/144 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.7)}$$

where:

ρ = the density of the formations overlaying the target reservoir (lb/ft3),

D = depth to the target reservoir (ft).

In a porous medium, the weight of the overburden is carried by both the grains and the fluid within the pores. Accordingly, an effective stress, σv’, is defined as

$\sigma v' = \sigma v - \alpha p$…………………………………………… (Π.8)

where:

α = Biot's poroelastic constant (dimensionless),

P = pore (reservoir) pressure (psi).

I. 10.3. Poisson's ratio &Young Moduls : [10]

- **Young's Modulus:**
- **:** is a measurement of stress over strain. Simply put, when hydraulic fracturing occurs, Young's modulus can be referred to as the amount of pressure needed to deform the rock. Young's modulus measures a rock's hardness, and the higher the Young's modulus, the stiffer the rock. A higher Young's modulus will help to keep the fractures open. $E = \delta / \varepsilon$………………………………… (I.9)

δ : stress (psi).

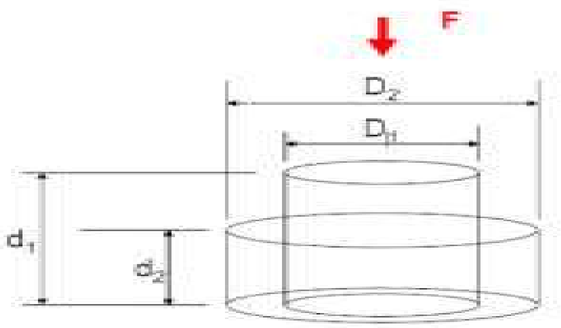
ε : strain

- **Poisson's Ratio:** Poisson's ratio measures the deformation in material in a direction perpendicular to the direction of the applied force. Poisson's ratio changes from layer to layer, the best formations to hydraulically fracture have the lowest Poisson's ratios.

$\upsilon = \varepsilon 2 / \varepsilon 1$…………………………………………. (I.10)

$e1 = (L1 - L2) / L1$………………………………... (I.11)

$e2 = (d1 - d2) / d1$…………………………………… (I.12)



FigureI.15: compression deformation.[10]

I. *10.4. Formation Fracturing Pressure:*

Formation fracturing pressure is also called breakdown pressure. It is one of the key parameters used in hydraulic fracturing design. The magnitude of the parameter depends on formation depth and properties. Estimation of the parameter value begins with in situ stress analysis.

Based on a failure criterion, Terzaghi presented the following expression for the breakdown

$$Pbd = 3\ \sigma H.min - \sigma H.max + T0 - P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.13)}$$

Where:

Pbd : formation break down pressure.

σH.min = min horizontal stress (psi).

σH.max= max horizontal stress (psi).

a. Pressure of Treatment:

$$Psi = Pbd - Ph + \Delta Pf \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.14)}$$

Where :

Psi : Surface injection pressure, psi.

Ph: hydrostatic Pressure. Psi.

Pbd: Formation break down pressure.

ΔPf: frictional pressure drop, psi.

b. Frictional pressure drop (Economides and Nolte, 2000):

$$\Delta Pf = \frac{518\ \rho 0.79\ Q1.79\ \mu 0.207}{1000\ D4.79} L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(I.15)}$$

ΔPf: Frictional pressure drop.

P: density of fluid (g/cm3).

Q: injection rate (bbl/min).

µ: fluid viscosity (cp).

D: tubing diameter, (in).

L: Tubing length, (ft).

I. 11. Fracture Geometry Models:

I. ***11.1. The PKN model:*** **[11]** The PKN model is used for long fractures of limited height and elliptical vertical cross-section. This model is applied to the fractures in vertical plane. It has an elliptical shape at the wellbore with a maximum width at the center.

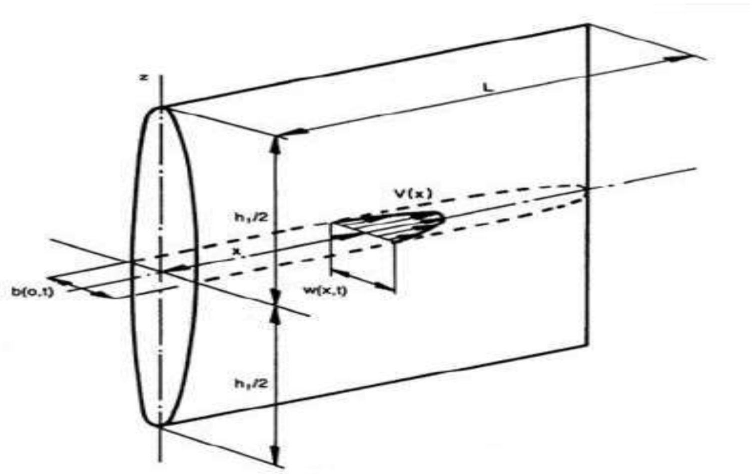


Figure I.16 PKN Fracture Schematic Diagram.[11]

I. ***11.2. the KGD model:[12]*** fracture height is fixed and width is proportional to fracture length. This model also assumes constant width against height and slippage at the formation boundaries.

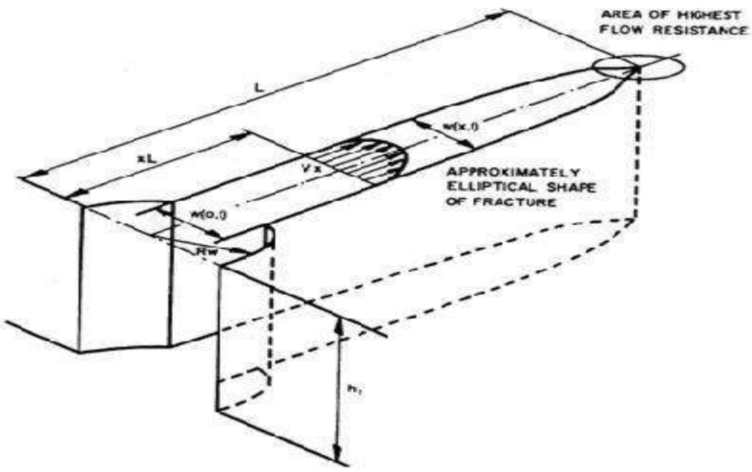
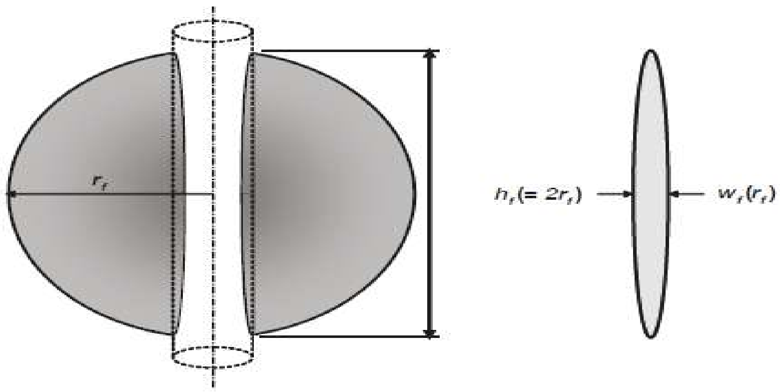


Figure I.17: KGD Fracture Schematic Diagram.[11]

I. ***11.3. radial:[12]*** Various radial models have been developed, but in each one the height is assumed to be directly related to the fracture length, such that hf = 2rf (the radius of the fracture). In this model, fracture width is proportional to fracture radius.



FigureI.18: radial fracture model.[12]

I. **12. Fracturing fluids:[5]** The fracturing fluid is composed of 99.5% of water and sand, the remaining 0.5% is made up of additives.

The three main functions of Frac fluid are:

- Initiate and propagate the fracture.
- Developpe fracture width.
- Transport proppant throughout the length of the fracture.

I. **12.1.** ***Fracturing Fluid Requirements:***

- **Compatibility with formation rock and fluids.**
- **Viscosity**
  – Required for proppant transport.
  – Controls fracture net pressures.
  – Determines fracture geometry (via fracture width).
- **Friction**
  – Reduce surface treating pressures.
- **Fluid Loss**
  – Proper fracture design.
  – Determines fracture geometry (via efficiency).

FigureI.19: fracturing fluid.[5]

I. ***12.2. Types of Fracture Fluids [5]:***

- **Water-based fluids:**
– Linear gels (*slick water *gelled water).
– Cross-linked fluids.
- **Oil-based fluids:**
- Crude oil.
- Gelled oil.
- Cross linked oil.
- **Multiphase or foamed fluids:**
– N2 and CO2 foams.
– Binary foams.
- **Viscoelastic Surfactants:**
– Non-polymeric fracture fluids (Clear FRAC).

I. ***12.3. Fracturing fluid additives [5]:*** Fluid additives are materials used to produce a specific effect independent of the fluid type:

- Polymers (GUAR "HPG/CMG/CMHPG"
- Crosslinkers.
- Breakers.
- PH control.
- Friction reducer.
- Clay stabilizers.
- Iron control.
- Corrosion inhibitors.
- Surfactants.
- Fluid loss additives.
- Bactericides.

I. 13. Proppant: Important parameter affecting fracture conductivity:

• The physical properties of the proppants

• Proppant concentration in the fracture

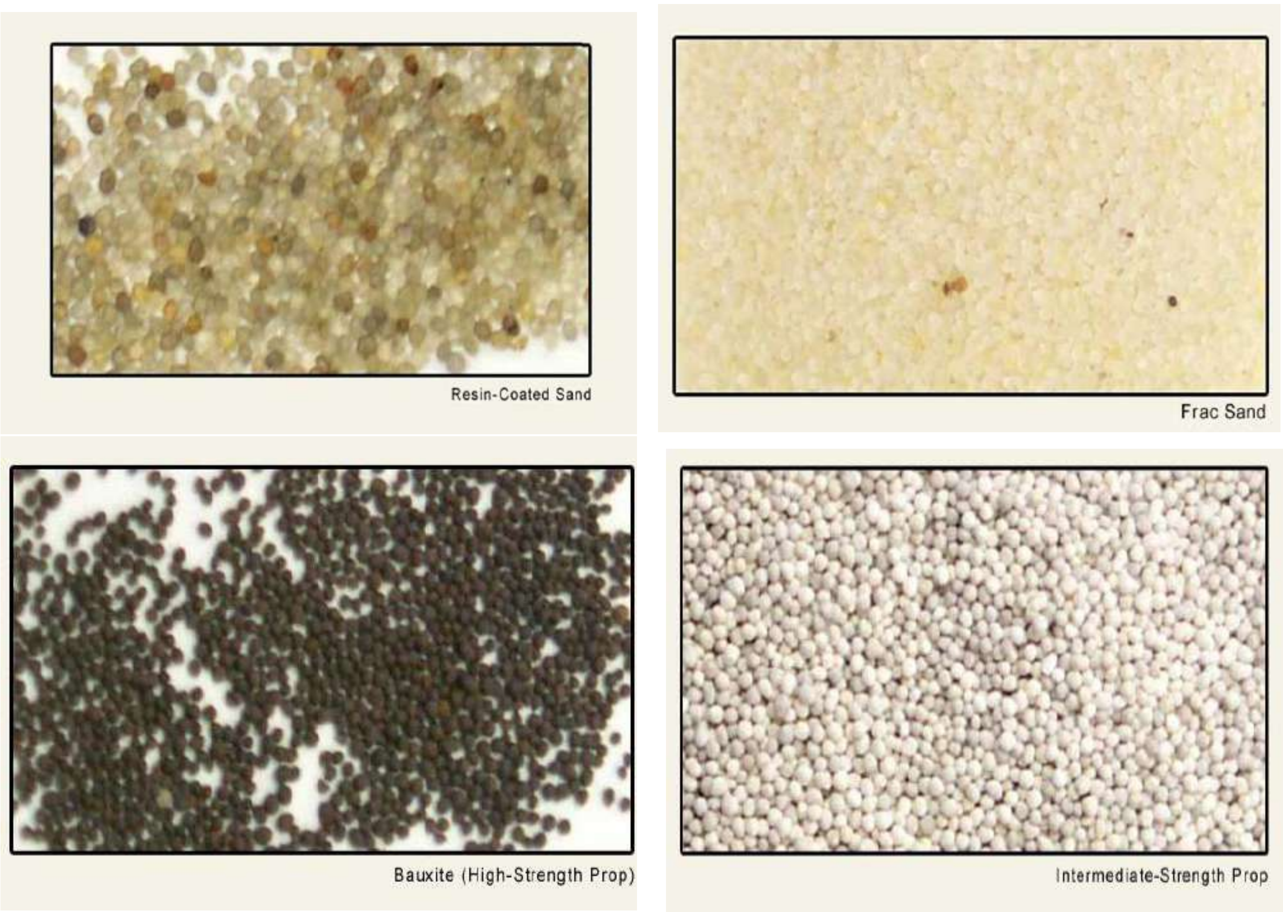
• Closure stress

• Fracture width after closure

• Contaminants (residue).

I. 13.1. Type of proppant:[8]

- **Sands:**
  - Ottawa - monocrystalline
  - Brady (Hickory) - polycrystalline
  - Colorado
  - Arizona
- **Resin-Coated Sands:**
  - Pre-cured - adds strength to sand.
  - Curable - locks the grains together



FigureI.20: types of proppant [5]

I. ***13.2. Proppant sizes:[5]*** 12/20; 16/30; 20/40; 40/70.

FigureI.21: proppant sizes [5]

I. ***13.3. Selection Proppant:***

- Perforating diameter should be six (6) times diameter of proppant.
- Fracture width should be five (5) times diameter of proppant.
- Use small mesh proppant at higher closure pressures.

I. **14. Hydraulic fracturing chronology:[7]**

I. ***14.1. injection test:*** It consists of injecting a fluid such as; treated water, brine, or crude in a fracturing regime to:

- Check if the formation absorbs the fluid (hence, the name of the Injection test).

- Determine the fracturing gradient.

This test is performed in two steps:

• **Step test:** (evolution of the propagation pressure). It consists in injecting fluid into the well at increasing flow rates in stages of equal duration and this until the breaking of the rock, after fracturing, the flow rate is kept constant in order to determine the evolution of the propagation pressure as well as the profile injection.

• **Constant flow test:** (determine areas of fluid absorption). The test consists of pumping fluid (water at 2% KCl) at a constant rate until the rupture, the rate is kept constant for a determined time, in order to allow the fracture to propagate. Pumping is stopped to record the pressure drop (Fall off). During pumping, PLT passes are made to determine the areas of fluid absorption, this test is repeated at different flow rates to ensure the assessment of the height of the fracture.

I. *14.2. Mini frac tests (Data Frac, Shadow Frac):[7]*

The minifrac is designed to be as close as possible to the actual treatment, without pumping any significant volumes of proppant. The minifrac should be pumped using the anticipated treatment fluid, at the anticipated rate. It should also be of sufficient volume to contact all the formations that the estimated main treatment design is anticipated to contact. A well planned and executed minifrac can provide data on:

- fracture geometry.
- rock mechanical properties, and fluid leak off.
- information that is vital to the success of the main treatment.

The minifrac includes two tests:

• **Step rate test:** This test determines the Fracture Extension Pressure (FEP). It consists first of injecting the base fluid (treated water) at a low rate, then gradually increasing this rate in increments, and maintaining it for a sufficient time until the pressure stabilizes (5 to 10 min). All of this must be accompanied by a continuous recording of the pressure.

This makes it possible to draw two curves P as a function of Q and the intersection between them gives us the pressure of extension of the fracture after projection on the pressure scale.

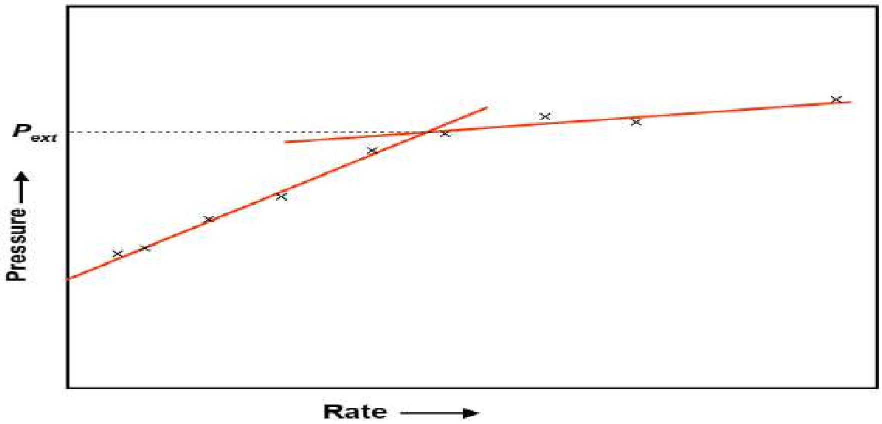


Figure I.22: Step rate test [7]

- **Pressure decline test:**

This test consists of creating a mini-fracture in the formation with the same fluid as that proposed for the main treatment. It is divided into two stages:

- Mini frac step, which makes it possible to determine the propagation model.
- Fall-off step or pressure drop after mini frac, which determines:

- The efficiency of the treatment fluid (η).
- Fluid filtration (CL).
- The geometry of the fracture (width, length, and thickness).

This test consists first of injecting the fluid into the formation at the rate of the main treatment proposed, and maintaining it until 10 to 15% of the total volume proposed for the treatment is pumped. Then stop the injection and close the well to enter the second phase, which is the fall-off, allowing the pressure at the bottom to drop.

I. **14.3. The main treatment [7]:** It is divided into three stages:

- Injecting a Pad.
- Slurry injection.
- Flush displacement.

I. **14.4. Clean-out of wells after treatment:**

The moment of disgorging is determined by the change in the pressure at the wellhead after the treatment. The well is opened when the pressure is stable.

- This process is then repeated until all stages are fractured.

I. **15. Pressure decline analysis:[7]**

I. **15.1. *Break down Pressure:*** this is the pressure required to initiate the fracture, so it must exceed the minimum stress of the hole.

I. **15.2. *Instantaneous shut-in pressure (ISIP):***

ISIP = Final injection pressure - Pressure drop due to friction ……………… **(I.16)**

I. **15.3. *Fracture gradient:***

$$\text{Fracture Gradient} = \frac{\text{ISIP}}{\text{FORMATION DEPTH(FT)}} \quad \textbf{(I.17)}$$

I. **15.4. Net Fracture Pressure (ΔPnet):** Net fracture pressure is the additional pressure within the frac above the pressure required to keep the fracture open. It is an indication of the energy available to propagate the fracture.

ΔPnet = ISIP - Closure Pressure……………………………………… **(I.18)**

I. **15.5. closure pressure (Pc):** The calculation of the closure pressure (CP) is essential, in fact it corresponds to the minimum horizontal stress (σh). The value of (σh) is an essential data to determine the parameters of the fracture.

Fracture closure pressure is the fluid pressure needed to initiate the opening of a fracture. This is not the same as the breakdown pressure, which is the fluid pressure required to initiate a fracture in intact rock.

Closure pressure is equal to the minimum in-situ stress because the pressure required to open a fracture is the same as the pressure required to counteract the stress in the rock perpendicular to the fracture. Closure pressure is determined from the G-Function or the Sqrt(t) plot.

I. **15.6. Fluid efficiency:** The fracture volume is divided by the total volume pumped. It can be determined by Nolte's Function G method.

Fluid Efficiency = $\frac{GC}{2 + Gc}$ ……………………………………………………... **(I.19)**

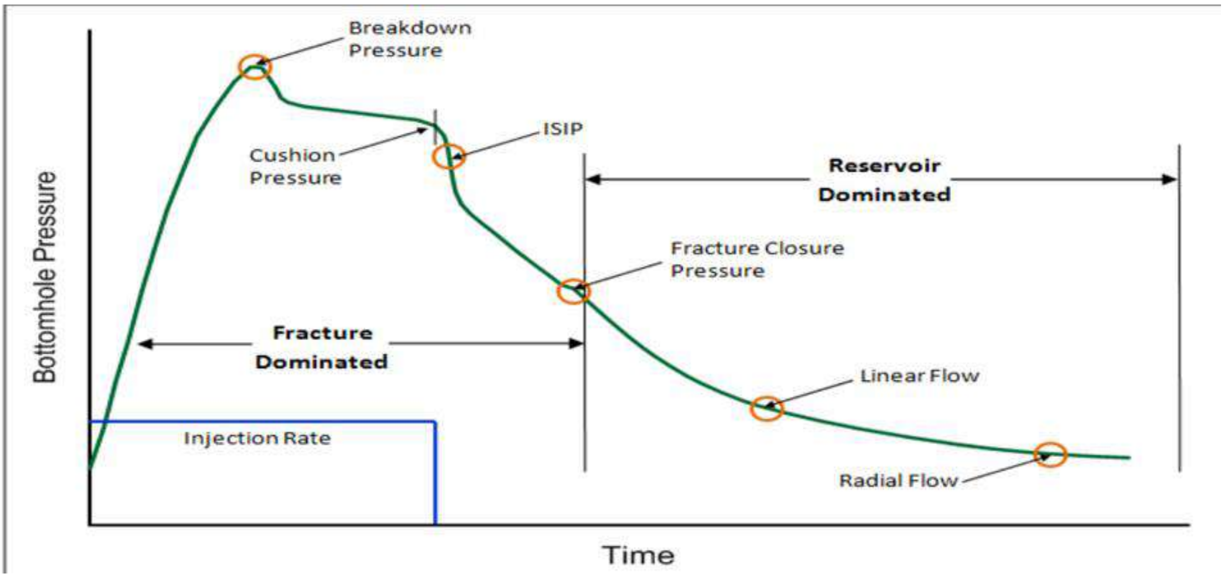
Gc is the G-function time at fracture closure

I. **15.7. Formation leak off characteristics and fluid loss coefficients or Filtration coefficient:** we can calculate it by a simple relation:

Total pumped volume (%) = Filtration coefficient (%) + Fluid efficiency (%0)………. **(I.20)**

I. **15.8. Propagation pressure:** This is the pressure necessary for the fracture to propagate.

I. **15.9. Fracture closure pressure (FCP):** this is the pressure necessary to keep the fracture open. It is almost equal to the minimum horizontal stress.



FigureI.23: Idealized pressure curve for a Mini Frac test.[7]

I. 15.. 10. G-function method:[11]

The Closure pressure is calculated based on the G-function method using these formulas:

- $G(\Delta tD) = \frac{16}{3\pi}\left[(1 + \Delta tD)\exp\frac{3}{2} - (\Delta tD)\exp 3/2 - 1\right]$ ………… $[UB]$ … **…. (I.21)**
- G(ΔtD) = 4/π [(1 + ΔtD) sin−¹ (1 + ΔtD) ½ + (ΔtD) ½− π/2] ……. [LB]……... **(I.22)**

Where:

$\Delta tD = \frac{\textit{Shutin Time}}{\textit{Pumping time}} = \frac{\Delta t}{tp}$ … … … … … … … … … … … … … … … … … **……… (I.23)**

After the shut-in, we draw the plot $PBH = (G(\Delta tD))$ and $G\ dp/\ dg = F(G(\Delta tD))$ …… **(I.24)**

I. 15.11. square root:[7]

Fracture closure can be identified by the peak of the first derivative on the sqrt(t) plot, which corresponds to an inflection point on the pressure curve. The semi-log derivative behaves similar to the G-Function Analysis. A user-defined (Sqrt(t)) analysis line may be added to the sqrt(t) plot to help identify the point of inflection.

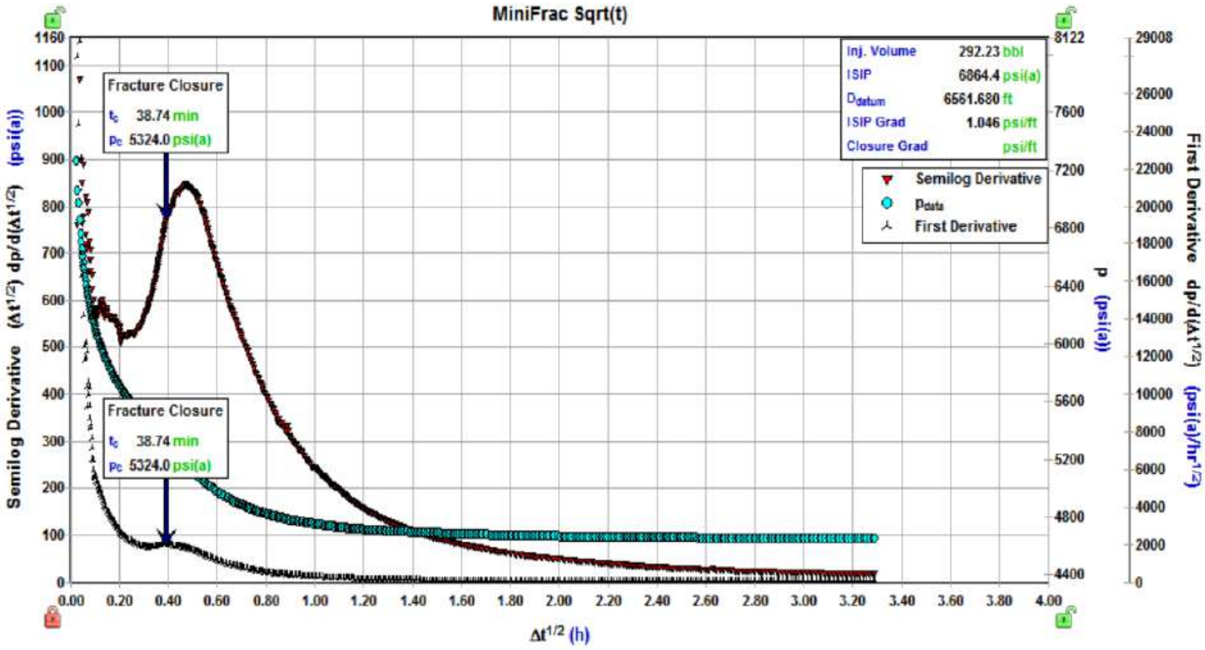


Figure I.24: Pressure evolution versus Square Root Time [11]

I. 15.12. Nolte and Smith analysis [11]:

This method analyzes the expected response of pressure formation during fracture propagation. Nolte and Smith then established a curve of pressure versus time on a Log-Log graph, their analysis results are shown in the table associated with the following figure:

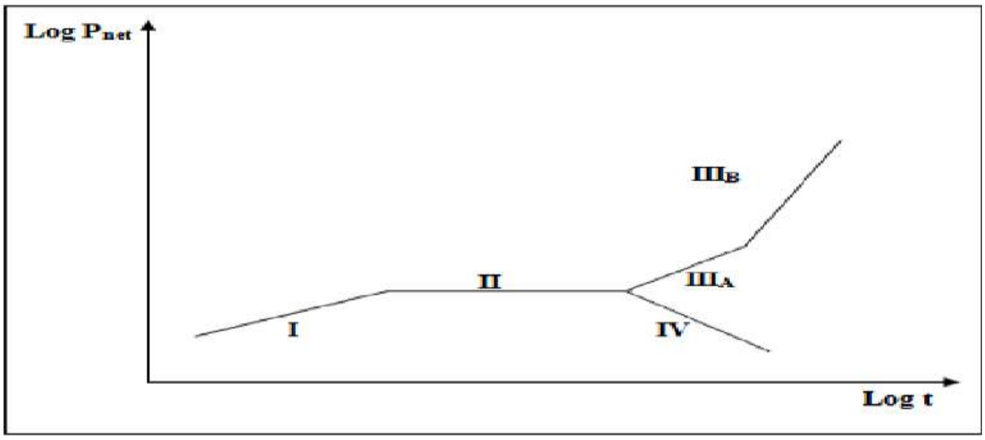


Figure I.25: Propagation pressure curve as a function of time. [11]

Table I-1: curve analysis results:[7]

Row index	Approximate slope	Interpretation
I	1/8 to ¼	The fracture extends in length and slightly in height, So it spreads according to the PKN model
II	0	The increase is regulated by an increase in height in barriers or by natural fissure openings, So the fracture spreads radially
IIIA	1	Extension restriction and width increase (W)
IIIB	2	Extension restriction (on only one active side)
IV	Negative	Height increase in another low stress area. (screenout) both models, KGD and Radial can be considered.

Table I-1: curve analysis results

I. 16.Hydraulic fracturing techniques for unconventional resources:

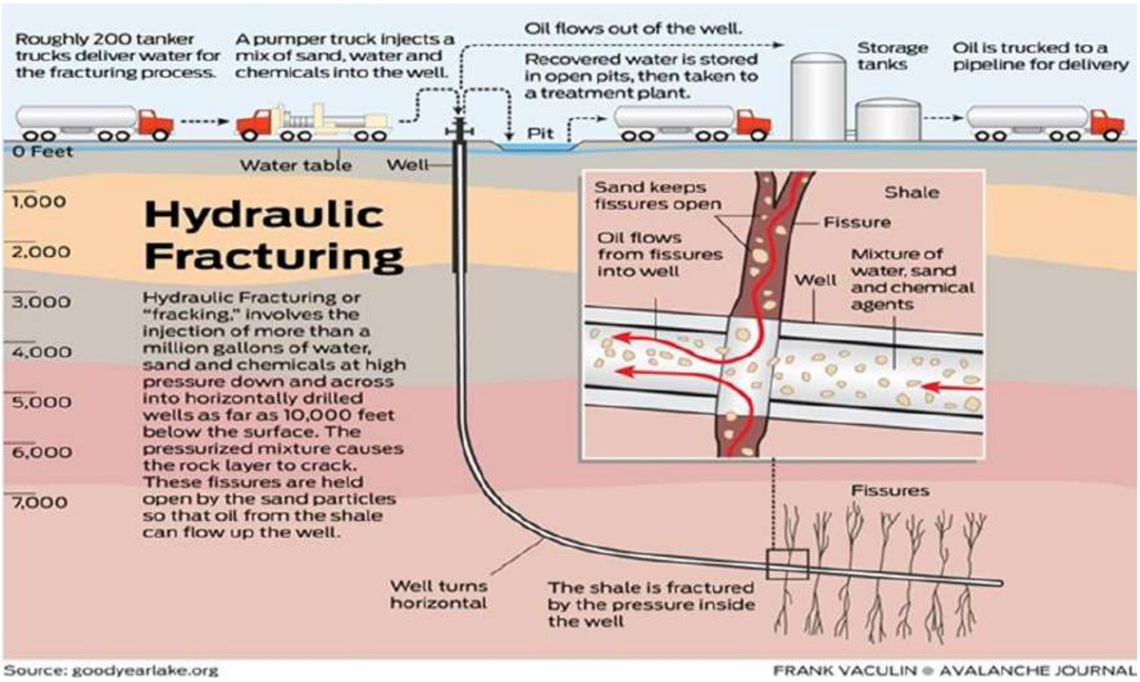
I. 16. 1. Multistage Hydraulic Fracturing:

Hydraulic fracturing becomes critical for taking advantage of shale and tight reservoirs. Natural gas production has tremendously increased in the past decade mainly contributed by unconventional gas reservoirs, and is expected to continue to grow. This is largely related to the effectively use of multistage hydraulic fracturing technology and horizontal drilling.

Multistage hydraulic fracturing involves multiples fracture spaced at a characteristic distance between fractures. This distance can be attempted by placing one fracture per stage. Hence, the distance between fractures is designed to be the distance between stages.

Multistage fracturing is a commonly used stimulation operation usually performed on low permeability formations. The complex formations and extreme conditions require several individual zones to be completed and fractured to access the entire horizontal interval.

Multistage horizontal wells plays a significant role in the economical production from conventional and unconventional reservoirs. Drilling multistage horizontal wells have increasingly become a common approach for developing potential reservoirs due to significant cost, time, and environmental savings, which shows the viability of this technique in the future.



FigureI.26: Hydraulic fracturing, natural gas, shale oil and environmental concerns [13]

I. 17. Unconventional resources:

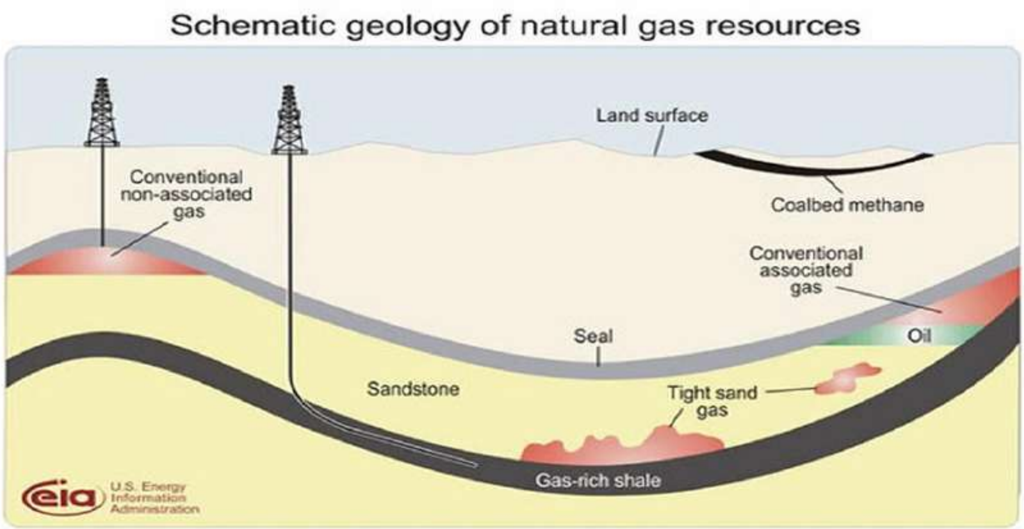
I. *17.1. Shale Gas*:

Shale gas, existing in sedimentary basin, has a very good development potential for its wide distribution, and it is the ideal energy resource in addition to oil and gas. Due to its special mechanism of aggregation, it cannot be extracted by conventional method. With the development of the shale gas drilling technology, horizontal well fracturing technology can improve the single well production with the greatest degree during the development phase of shale gas. It is evaluated as an important way to the development of shale gas.

Researching a large number of the current fracturing cases of shale gas horizontal well, two methods are commonly used: one is cable perforation and pumping bridge plug (referred to here as plug-and-perforate) and the other is opening the fracturing sliding sleeve by dropping-down balls with different sizes in proper order (referred to here as BDFS).

I. 17.2. Tight Gas:[13]

Tight gas is natural gas trapped within a rock with extremely low permeability typically limestone or sandstone. This is not to be confused with shale gas, which is natural gas trapped within shale formations. Tight gas is considered to be an unconventional source of natural gas because it requires significant hydraulic fracturing a much more extensive process to access the gas. This is because the low permeability of the rock (meaning the pores within the stone are poorly connected), makes it difficult for the gas to travel through them.



FigureI.27: schematic geology of natural gas resources.

I. 18. Horizontal wells:[14]

A horizontal well is a type of multi-directional drilling technique that drills with an inclination of at least 80 degrees to enhance reservoir performance. The horizontal technique is used as an alternative method for drilling oil and gas in situations where vertical wells are impossible or the shape of the reservoir is difficult to access.

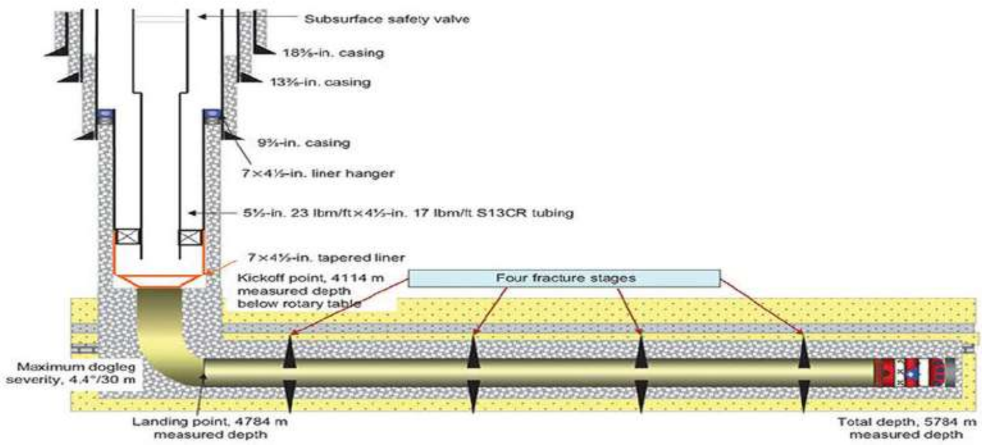
Although horizontal wells are expensive to excavate compared to vertical wells, they are preferred due to their efficiency in increasing oil field production. When combined with hydraulic fracturing, it is estimated that horizontal drilling can cost up to three times more per foot than vertical drilling. Horizontal drilling is used to reach targets lying below adjacent lands and even increase the productivity of a well.

Listed below are several reasons for using horizontal wells when drilling oil and natural gas:

- Reach difficult target.
- Drain a wide area.
- Improve well productivity in a fractured reservoir.

Horizontal drilling is used as part of the hydraulic fracturing process in the development of low-permeability rocks. The rocks contain a large amount of gas and it is difficult to locate the reservoir in these rocks using the traditional vertical wells due to the tiny pore spaces in the low-permeability rocks.

To stimulate the productivity of the rocks, exploration companies drill horizontally through the low-permeability rock unit. Hydraulic fracturing is then used to produce an artificial permeability, which is a compound of water, chemicals, and guar gum into the shale. The force of the injections props the shale open, creating cracks and fissures that allow large volumes of petroleum and gas to be extracted.



FigureI.28: Horizontal well design [14]

I. 18.1. Fracturing technology for horizontal well: [15]

The shale gas horizontal well fracturing has become the main mode of the exploitation of shale gas efficiently. The fracturing methods and processing steps are directly related to the production and the quality of the follow-up operations.

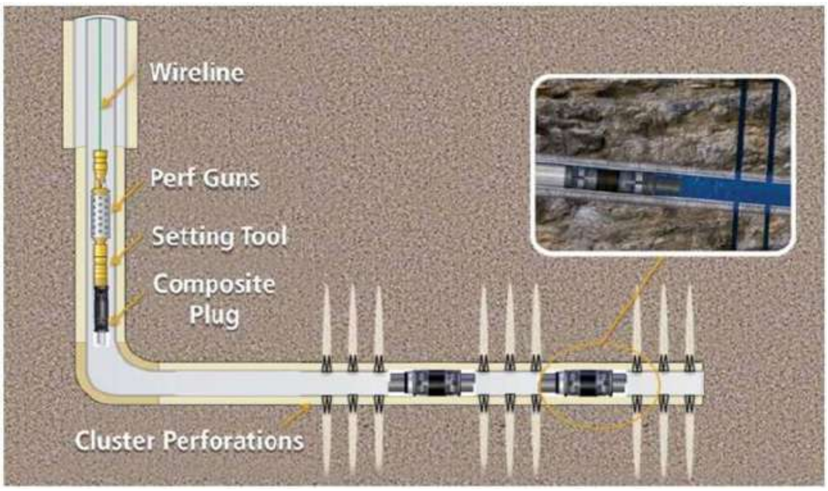
There are generally three main multistage fracturing methods for shale gas horizontal well:

a. Plug and Perforate completion system (PNP):[15]

The first method is the hydraulic fracturing technique using cable perforation and composite bridge plug separation.

While using plugging-and-perforating segmentally, composite bridge plug is used to separate fracturing segments.

After the bridge plug is pumped into the borehole, the casing over the bridge plug will be perforated by setting logging cable. Then hydraulic fracture is implemented on the borehole of the cased well, and finally, the CT is used to drill out the plug to starting production. However, the technique requires a high-pressure performance for the casing, and the service life of hydraulic fracturing tool is also limited, which makes it hard to drill plug for the long horizontal section. And the comprehensive cost is higher.



FigureI.29: Wellbore diagram of a plug and perf completion system [15]

ADVANTAGES:[16]

- Matured technology with designs available of the shelf**.**

- Efficient deployment and perforation guns.
- Matured technology to remove bridge plugs.
- Full bore casing access to well total depth.

DISADVANTAGES:[16]

- Repeated wire line or coiled-tubing interventions.
- The time between fracturing treatment stages to set bridge plugs and perforate the next zone.
- Fracture control requires good cement quality and detonation of perforating charges.
- Cementing can clog natural fractures in the horizontal section.
- Friction in the perforating tunnel may result in higher pumping pressure.

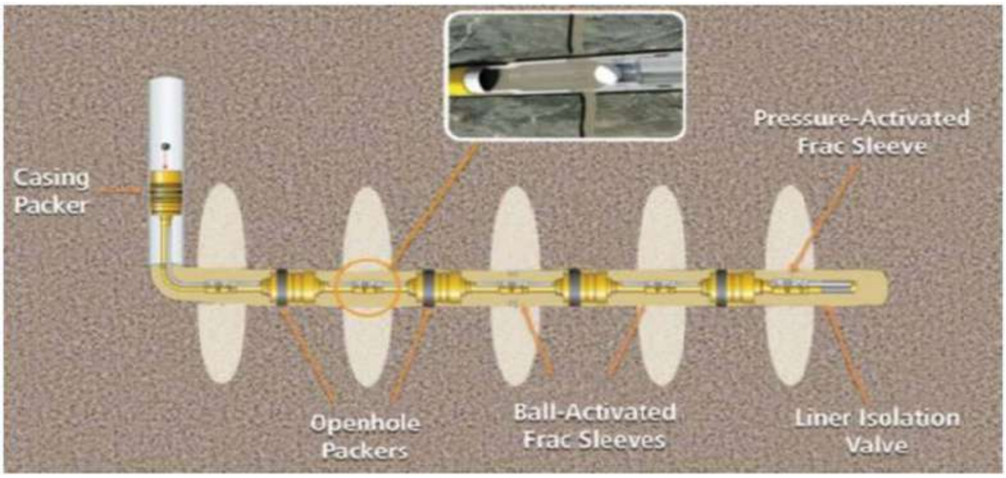
b. Ball-Activated completion system (BACS):[15]

The second method is the multi stage fracturing technology of pitching slip sleeve.

Usually, the sliding sleeve is opened in different sections by dropping balls with different diameters through hydraulic packers.

This method does not require perforation and has no pollution to the layer, but the maximum fracturing layers are limited by the number of balls that are allowed to throw in Meanwhile, the ball seat impacts the diameter of oil channel, which does not benefit the following workover operation.

Moreover, the technique is just a single process that cannot be applied to selective production. When the packing interval is too short, the cross strata phenomenon may appear and the gas coning may be out of control.



FigureI.30: Ball-Activated fracturing completion system [15]

ADVANTAGES:[16]

The advantages of open hole multi-stage fracturing systems address are most applicable to horizontal well construction and completion operations. These advantages are not as significant for vertical wells.

The advantages are:

- No cement is required for formation isolation.
- No perforating in required between stages.
- Reduces operating time between stages.
- External packers and sleeves provide isolation between stages and access without perforating.
- Sleeves may be opened and closed as access and diversion is required.

DISADVANTAGES:[16]

- The number of stages in a horizontal well is limited by sizing of available balls and ball seats.
- Directional drilling and well tortuosity make setting the liner string at program depth in horizontal well challenging.
- Make up of a long lower completion string with many tools is not required.
- Multistage frac operations are more complex compared to the plug and perf method.
- Surface limitations will likely dominate operations and time savings of ball and sleeve system not achieved.

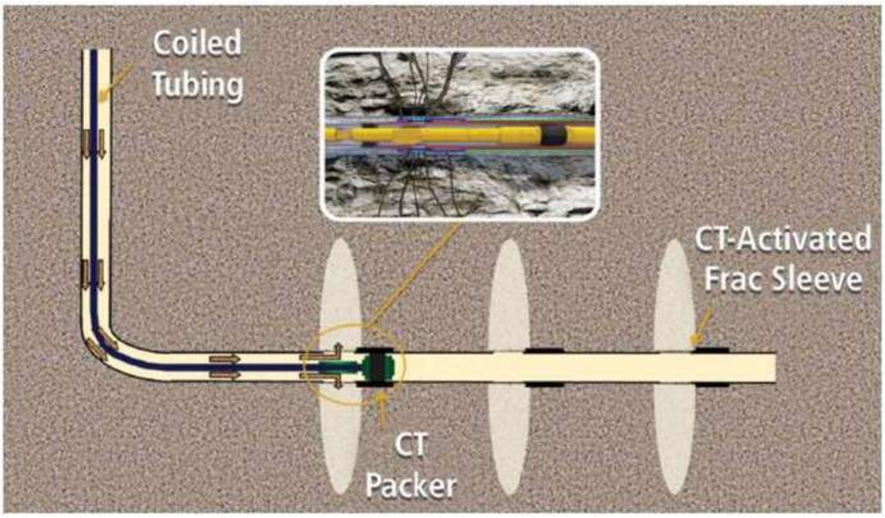
c. Coiled-Tubing-Activated completion system (CTACS):[15]

The third method is the multistage fracturing technique with switchable cementing sliding sleeve.

First, the sliding sleeve should be put on the position of the oil layer selectively, and then it will be opened by switch tool carried by drill pipes, tubing, or CT after well cementation. Finally, the fracturing operation can be carried out with the same pipe string.

The technique allows the fracturing operation to be finished continuously at a time and no perforation and extra packer layer are required, which saves the operation time and cost. After the fracturing, the space of the casing is unobstructed which brings convenience to the following workover operations.

Since the sliding sleeve can be opened or closed for many times, it will improve operation efficiency greatly, and it can also open or close fracturing sliding sleeve in proper order, which can meet the technical requirements on shale gas well multi-layer hierarchical reformation and selective exploitation.

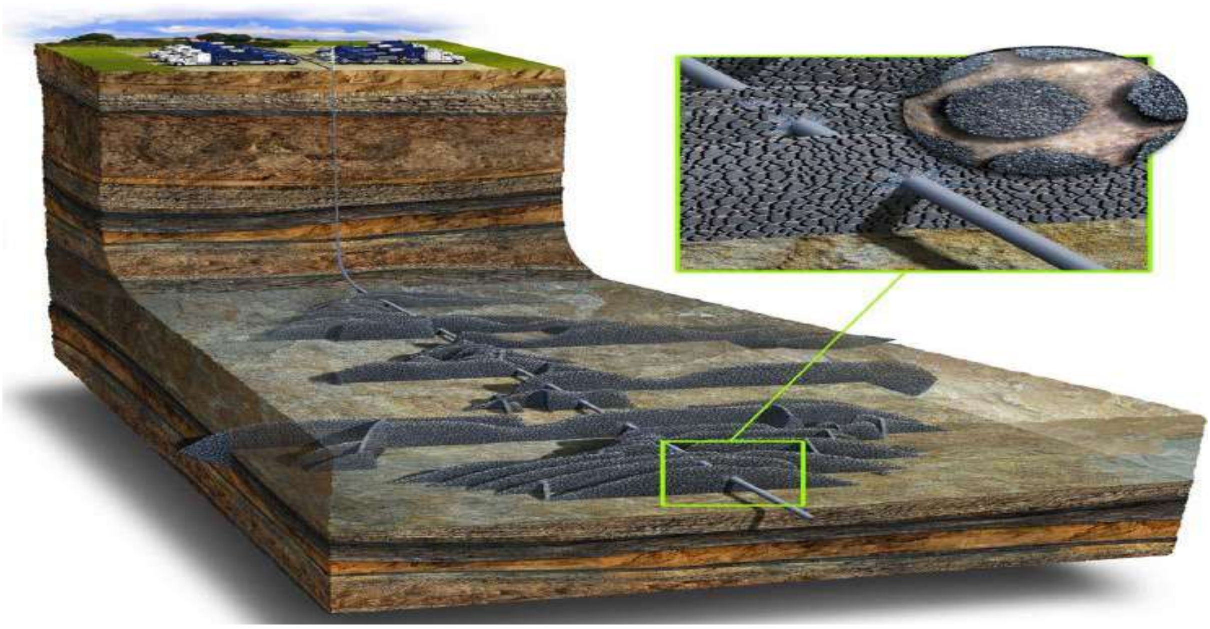


FigureI.31: Coiled-Tubing-Activated completion system [15]

I. 19. Pillar hydraulic fracturing (conductor frac):

a. Objective:[17]

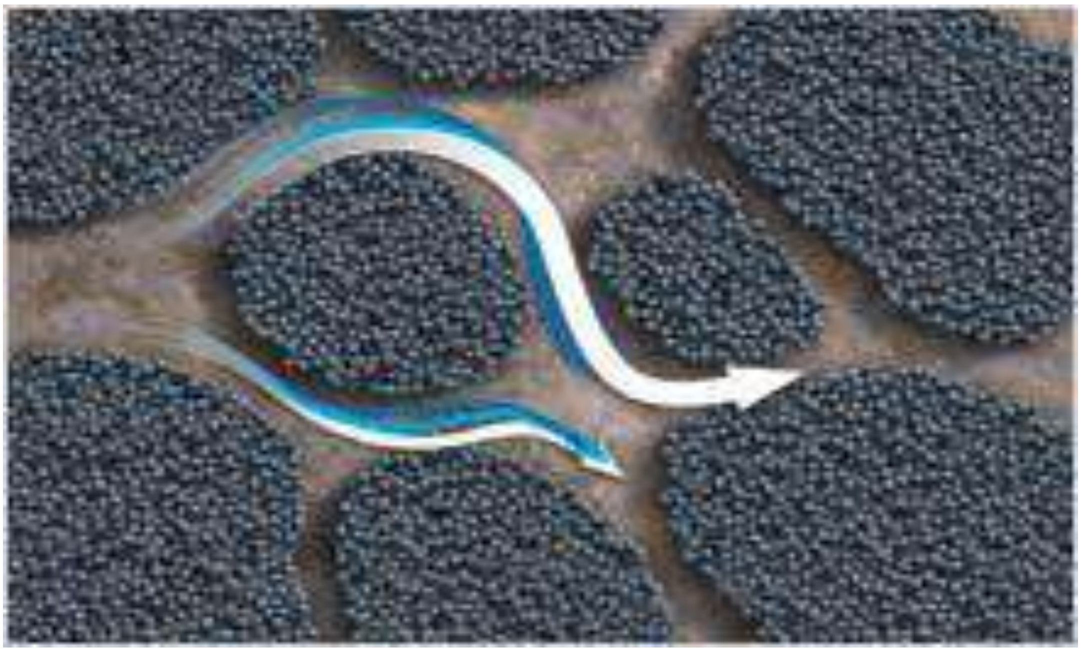
The aim of the pillar fracturing technique was to achieve the highest possible fracture conductivity to enhance water injectivity for reservoir pressure maintenance.



FigureI.32: conductor frac [23]

b. Creation of conductivity:[17]

This technique creates infinite conductivity channels with proppant distributed within the fracture as aggregates or groups separated by clean fluid. These proppant groups function as pillars to hold the fracture open and help enable fluid flow in the open channels between proppant pillars. The conductivity of a partially open fracture with proppant pillars can be several orders of magnitude greater than that of a conventional fracture filled with proppant after closure. After a pillar style hydraulic treatment, the propping agent remains in the fracture grouped to form pillars because of the sticky resin that was applied to the proppant just before being blended (intermittently) into the fluid system that was pumped during the treatment. This helps the grains in the resulting pillars to adhere together and help prevent the fracture from entirely closing, forming open conduits for fluid flow. The overall success of this fracturing stimulation treatment depends on the sequenced pumping technique, allowing the propping agent to form proppant aggregates during their placement into the formation.



FigureI.33: disposition of the proppants by the technique of pillar frac.

c. Conductivity Enhancers:

- ***Sand Wedge TM:[18]***

The conductivity enhancement additives came as a direct result of research to find a liquid proppant flowback control additive. The Sand Wedge materials that were produced and are continuously being improved were found to have the unique property of improving the flow of fluids through proppant. There are two type (Sand Wedge TM NT and Sand Wedge TM SM).

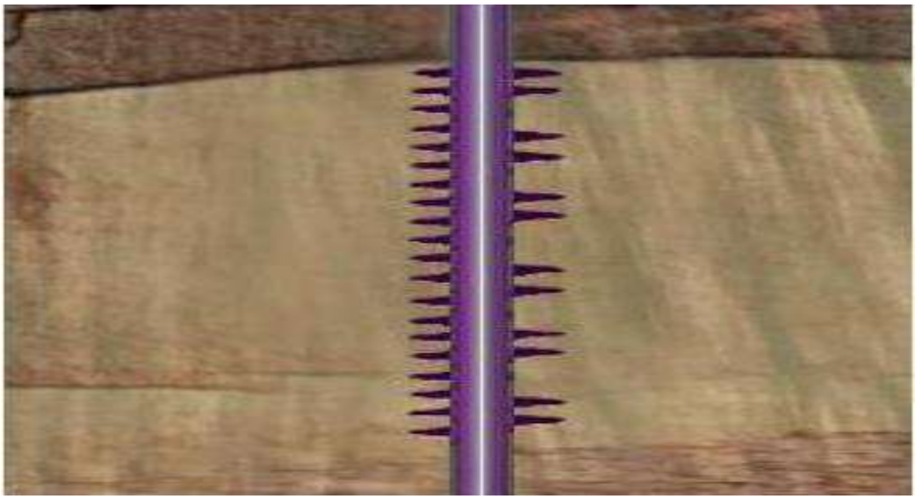
d. Location of the perforations:[19]

The first stage and the success of stimulation by hydraulic fracturing should be started with the choice of the arrangement and the positioning of the perforations. Perforations are the means of communication between the tank and the well in other term the perforation is control enters the fracture and the well. In a traditional treatment, the perforations are generally placed in a continuous interval useful height. In a treatment of fracturing with drainage canals, a heterogeneous system of perforations made up of beams of perforations separated by not perforated intervals.

Compared to the system of perforation used for the traditional treatments, the strategy of perforation used in the technique of fracturing to channels (conductor) is generally conceived to cover most of the height of the fracture, which is important to obtain a more uniform distribution of the pillars of proppants through the height and to obtain the geometry optimal of the channels.

The density of the perforations and their dephasing are generally the same ones as those used for a traditional work. The total number of perforated holes is preserved, or perhaps slightly reduced as illustrated on the **FigureI.34**. It is also important to mention that the effects of the zone close to the well such as tortuosity can also facilitate creation of the channels in the direction of growth of the fracture.

However, these effects cannot be envisaged and are difficult to diagnose and with to quantify correctly. For this reason, the heterogeneous system of perforation is only reliable method which is recommended to separate the impulses from proppant in smaller ingots and to support the uniform distribution of the pillars through the fracture.



FigureI.34: Perforations of conductor frac on the line and conventional on the left.[19]

e. Reduce the risk of screen out:[20]

This technique mitigates the risk of undesired screen out by reducing the proppant volume compared to a conventional job. Moreover, the initial production of the well revealed a significant improvement while the long-term performance showed a stabilized trend. Based on these outcomes, the use of this technique could face a fast increase within the Algerian market, considering also possible refracturing interventions on older wells.

f. Pumping schedule:[21]

The program of pumping of the pillar method is based on a program conventional the principal difference is that proppant it is delivered in short impulses during the treatment, each stage has a dialogue of proppant given, it can y have some pulse repetition frequency. There are two types of impulses:

Impulse of proppant (dirty) and clean impulse of fluid (clean). Two impulses adjacent “an impulse of proppant and one of clean fluid” form a cycle. Impulses are characterized by a concentration (which is in connection with the stage to which they belong) and the duration. The last stage of a treatment by pillar requires the addition continuous of an agent of supporting such as it would be carried out in a conventional treatment. drank this stage, called the stage of tail (tail-in training course), is to ensure a stable connection, uniform and reliable enters the channeled fracture and the well. It is important to conceive one tail-in training course enough runs to prevent it from having a significant negative impact on total conductivity of fracture.

CHAPTER TWO:

CASE STUDY [AZSE-21]

II. 1. Executive Summary/Project History:

- AZSE-21 was drilled in Q3-2017 to drain Ged-B reservoir that showed a commercial gas production in the nearby exploratory wells.
- The well was drilled as deviated hole (S-Shape). The surface and sub-surface distance between two wells is 425m and 275m respectively.
- Four PBU were performed during well history, and all confirmed a positive skin. All the PBU's were analyzed, and the overall history exhibited improving in mechanical skin with time from +7 to +2.0.
- The high total skin could be attributed to one or more of the following:
  - ✓ Inefficient clean-up
  - ✓ The perforation was exposed to brine for long time before flow back the well. The brine has corrosion inhibitor, which could react with the formation and cause damage.
- The final PBU interpretation concluded that the pressure derivative is matched with two barriers at distance 48m and 445m away from the well. Both expected to be faults but asper CUSTOMER geologists both barriers confirmed as a lithology change only from ductile sandstone to a tight sandstone.
- Due to a high KH & porosity of reservoir, a high leak off is expected during stimulation treatment.
- The CBL/VDL log indicates a fair to good cement quality in front of the perforations and **bad** cement quality upward. Therefore, Temperature log after MiniFrac is mandatory to confirm propagation in the zone of interest.
- The design was made based on the experience of the previous Fracked wells in the field.
- The treatment designed with two scenarios:
  - ✓ SC-1 Conventional with 190,500 lbs total proppant up to 8ppg at 35bpm.
  - ✓ SC-2 Conductor Frac with 131,138 lbs total proppant up to 8ppg at 30bpm.
- Based on MiniFrac analysis and templog, the treatment will be re-designed accordingly to reflect to actual conditions and the decision will be made whether to go with SC-1 or SC-2.
- Due to a high KH & Perm, a high leak off is expected, therefore, a conductor Frac is recommended as contingency plan to mitigate the risk of screen out and enhance well conductivity and productivity as well.
- Both Ged-4 & Ged-5 units confirmed depleted, therefore both layers should be in low stress zone (less FG) and the fracture initiation will be easier on both zones. The Ged-3 & 2 proved tight and not depleted thus both layers will be as barrier upward. The fracture

expected to be confined in the zone of interest (Ged-4 & 5). Following the well objective, a moderate fracture half-length should be enough to bypass the skin damage (improve the skin to -5). The reason behind the massive job even the well has a very good KH & Perm is to improve the skin to -5 which is the target with aim to enhance well productivity.

- No issue with water production.
- The present Design of Service (DoS) is applicable for this field. AZSE-21 well activities are based on information provided by CUSTOMER for this scope of work requesting for proposal DOS-ALG-HAL-CUSTOMER-PE-21-77. The final redesign will be validated after the Minifrac analysis to reflect actual conditions.

II. 2. Well technical data

a. *Well data section:*

- **Completion:**

Table II.1: completion data.

Name	Measured Depth (RT-MD)	Outer Diameter in	Inner Diameter in	Linear Weight (lbm/ft)	Grade
Cemented casing	0-3,775	9 5/8”	8.535	53.5	P-110
Liner	3,629 – 4,100	7”	6.094	32	P-110
Tubing	0-3,811.13	4 ½”	3.798	15.1	VM 895 13CR / VT
Packer	3,781.55	HALL Hydraulic/Permanent	-	-	/

- **Perforations:**

Table II.1: perforation data

Name	Top MD (m)	Bot MD (m)	Top TVD (m)	Bot TVD (m)	Shot Density (spf)	Number of Perfs	Phase (DEG)	Hole Diameter (in)
Ged-B	3,934	3,950	3,934	3,950	6	318	60	0.234

Name/Depth (ft)	Pore Pressure (psi)	BHST (°F)	Frac Gradient (psi/ft)
GED-B	3,858 – 5,352	265	-

II. 3. Well Schematic:

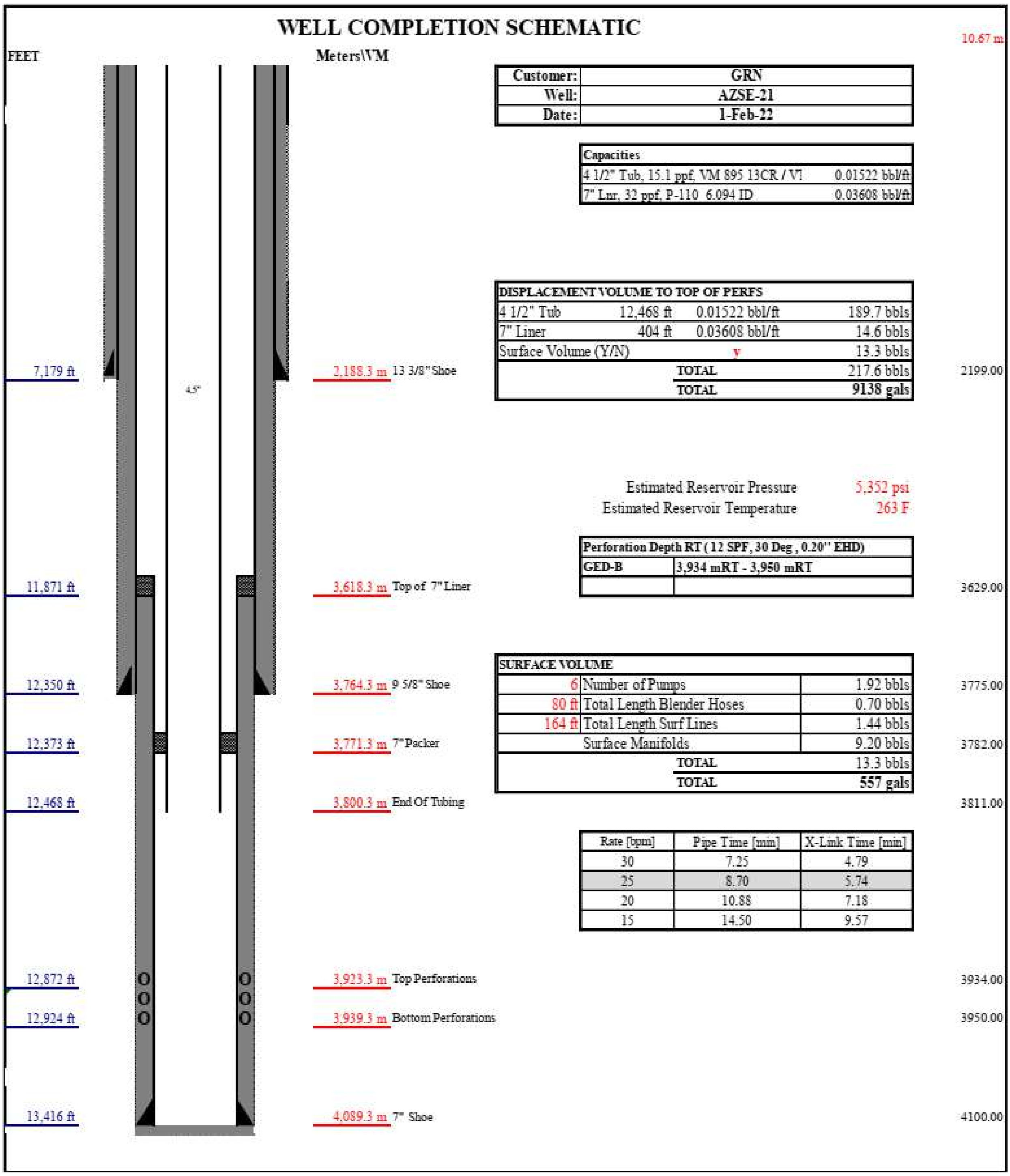


Figure II.1: well completion schematic.

II. 4. Job Objectives:

The objective of the Hydraulic fracturing treatment is to place a propped fracture in the units Gedennian B reservoir based on its geo-mechanical and Petro-physical characteristics. The fracture will help increasing the production potential of the well and drain the hydrocarbons from the Gedennian layer by connecting the wellbore to the clean zone in the reservoir and creates a conductive path to formation fluid.

II. 4.1. Surface Pressure Limitation:

Tubing Burst Pressure (4.5", 15.1 ppf, VM 95 13 CR,)	12450 psi
Tubing Burst Pressure at 80%	9960 psi
Packer Depth	12373 ft
Tubing Clean Fluid Density	8.34 ppg
Annulus Fluid Density	10.26 ppg
Surface Annulus Pressure during inj.	2500 psi
Proppant Absolute Volume	0.0347 gal/lb

	Clean	1 ppg	2 ppg	3 ppg	6 ppg	7 ppg	8 ppg
Proppant Concentration (ppg)	0	1	2	4	6	7	8
Fluid Density in Tubing (ppg)	8.34	9.03	9.67	10.84	11.87	12.34	12.79
Hydro in Tubing at Packer Depth (psi)	5366	5808	6221	6972	7637	7941	8229
Hydro in Annulus at Packer Depth (psi)	6602	6602	6602	6602	6602	6602	6602
For Tubing at Surface, Max WHP	12460	12460	12460	12460	12460	12460	12460
For Tubing at Packer Depth, Max WHP	13695	13253	12840	12089	11425	11120	10832
Max Surface Pressure at Screenout (psi)	12460	12460	12460	12089	11425	11120	10832

- CUSTOMER and Service Company engineer to meet and agreed that maximum allowable surface pumping pressure should not exceed the pumping clean fluid and proppant laden according with calculations at 8 ppg.
- Collapse and Burst Pressure calculations were for 4.5”, VM 895 13CR / VT,15.1 lb /ft. String with 80% safety factor applied. Maximum 12,460-psi surface treating pressure can be achieved when pumping clean fluid and maximum 10,832 psi at 8ppg, when 2,500 psi annulus pressure applied. Taking on consideration the well integrity concerns confirmed by CUSTOMER team, the kickout pressure will be limited to 9,000 psi for Proppant stages (up to 8ppg).

II. 5. Engineering Hydraulic Fracturing Design Process:

II. 5.1. Preliminary Frac Design:

Preliminary Frac Design is a guideline to the type of treatment that will be performed and it contains a Minifrac, and Main treatments design requested by the customer and based on the Log, reservoir and well data obtained from CUSTOMER as well as previous experiences in similar field/reservoirs in Algeria. Following the Minifrac analysis and temperature logs, the main treatment may be reviewed to reflect actual conditions. The justification for the job design will be based on the risk associated with reaching the primary job objectives.

The fracture design simulation was made using commercially fracture simulator **FracproPT**. The objective is to hydraulically fracture the Gedinnian B reservoir to enhance the well productivity.

The treatment designed with two scenarios:

1. SC-1 Conventional with 190,500 lbs total proppant up to 8ppg at 35bpm.
2. SC-2 Conductor Frac with 131,138 lbs total proppant up to 8ppg at 30bpm.

a. Scenario 1 treatment: conventional frac:

The first scenario was made with conventional frac and the results are illustrated in the tables below:

➢ **Injection and Minifrac pumping schedules:**

Stage description	Treated Water (gal)	Linear Gel 40# (gal)	Hybor 40# (gal)
Injection			
Load Well	8,500		
Breakdown	3,000		
Shut-In			
Step Down Rate	5,000		
Minifrac			
Pre-Pad		1,000	
Pad			10,000
Displacement		8,500	

Table II.3: Injection and Minifrac pumping.

➢ **Main treatment pumping schedules:**

MAIN TREATMENT	Treated Water (gal)	Linear Gel 40# (gal)	Hybor 40# (gal)	Proppant (lbs)
Pre pad		1,000		
Pad			10,000	
Pad+BV-CF*			5,000	250
Pad			15,000	
1 ppg SLF			8,500	8,500
2 ppg SLF			8,000	16,000
3 ppg SLF			4,000	12,000

4 ppg SLF			4,000	12,000
4 ppg SLF			6,000	24,000
5 ppg SLF			6,000	30,000
6 ppg SLF			6,000	36,000
7 ppg SLF			4,000	28,000
8 ppg SLF			3,000	24,000
Flush		8,200		
TOTALS	16,500	18,700	89,500	48,500 lbs 30/50 HSP 143,000 lbs 20/40 HSP 250 lbs Biovert

Table II.4: Main treatment pumping

Notes:

- The treatment pumping schedule will be reviewed following the diagnostic injection tests and temperature log and altered if required.
- 100 mesh sand will be available on location to be used within the Pad stage if needed to mitigate the excessive fluid loss.
- Flush volume will be updated on location taking into consideration the real surface volumes.
- Biovert CF are optional depending on formation leakoff after the Minifrac analysis.

➢ **Fracpro PT Main Treatment Design Result:**

Description	Measures
Propped Half-Length (m)	103.2
Total Propped Height (m)	38.0
Depth to Propped Fracture Top (m)	3,918.7
Depth to Propped Fracture Bottom (m)	3,956.7
Avg. Fracture Width (in)	0.261
Avg. Proppant Concentration (lb/ft²)	2.85
Avg. Conductivity (mD·ft)**	2,653.0

Table II.5: Fracpro PT Main Treatment Design Result

- **Conventional Frac Main Treatment Plot:**

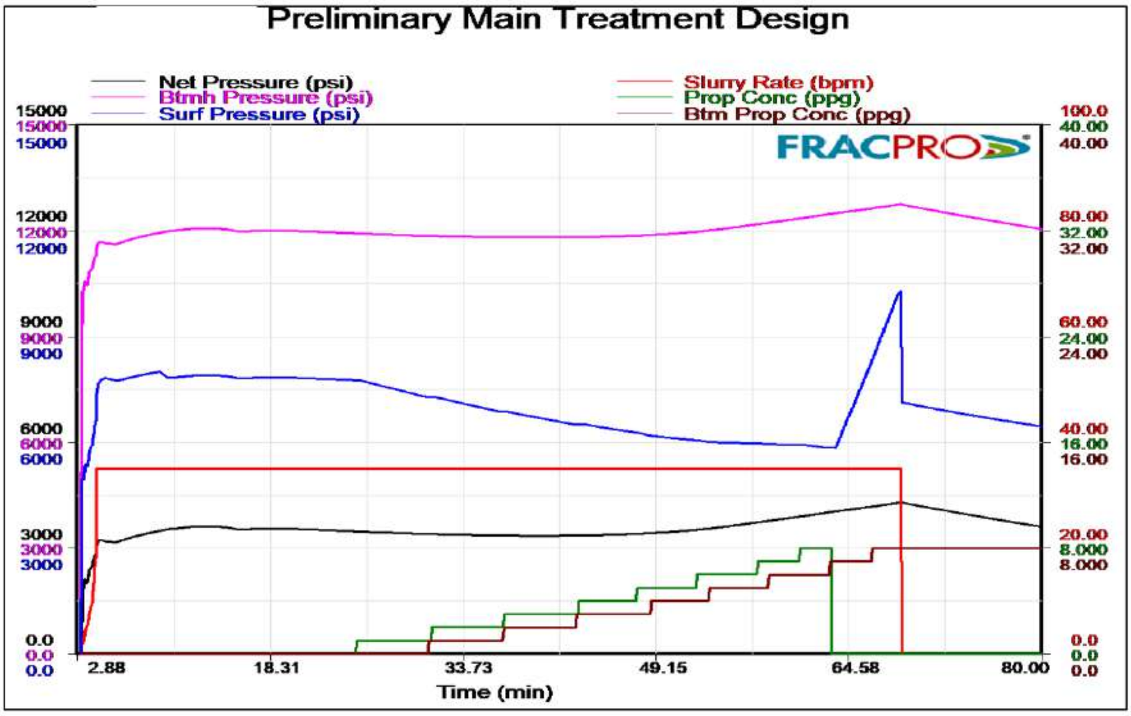


Figure II.2: preliminary Conventional Frac Main Treatment Plot

- **Fracture Geometry**:

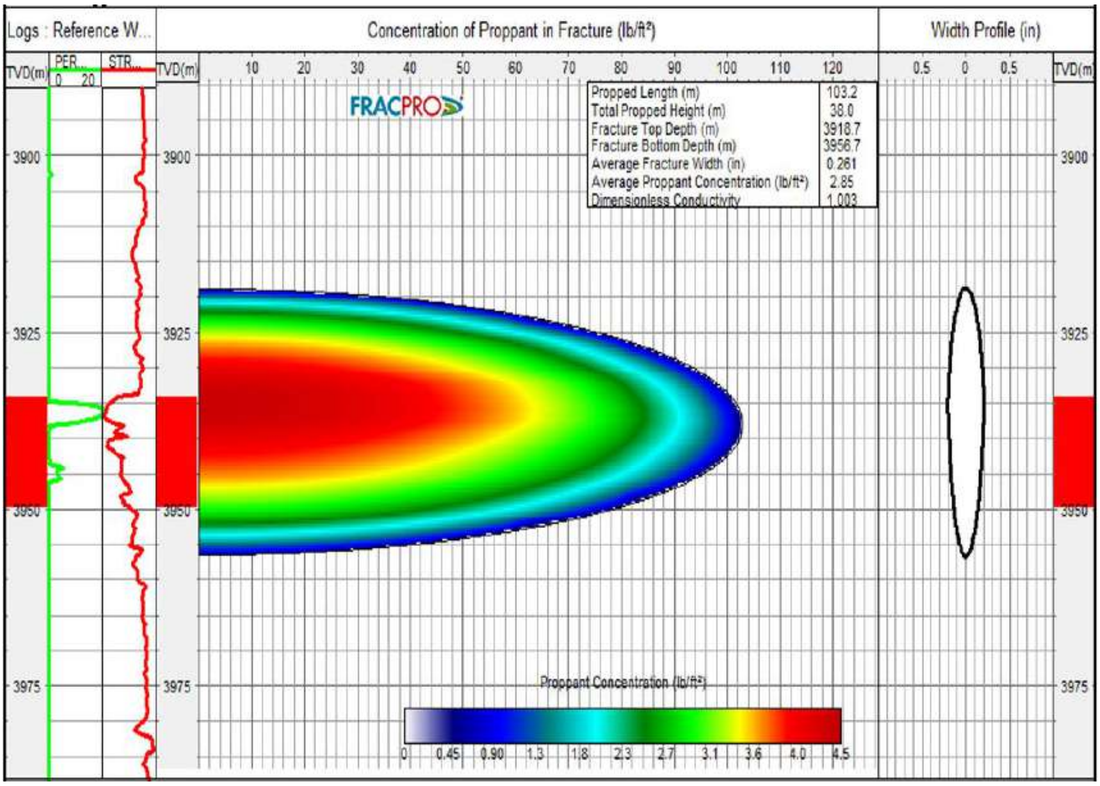


Figure II.3: Fracture geometry

b. Scenario 2 treatment: conductor frac

The second scenario was made with conductor frac and the results are illustrated in the tables below:

➢ **Injection and Minifrac pumping schedules:**

Stage description	Treated Water (gal)	Linear Gel 40# (gal)	Hybor 40# (gal)
Injection			
Load Well	8,500		
Breakdown	3,000		
Step Down Rate	5,000		
Minifrac			
Pre-Pad		1,000	
Pad			10,000
Displacement		8,500	

Table II.6: Injection and Minifrac pumping

➢ **Main treatment pumping schedules:**

MAIN TREATMENT	Treated Water (gal)	Linear Gel 40# (gal)	Hybor 40# (gal)	Proppant (lbs)
Pre-Pad		1,000		
Pad+BV-CF*			30,000	250
1 ppg SLF			8,500	8,500
Spacer			5,355	
2 ppg SLF			5,508	11,001
Spacer			2,520	
3 ppg SLF			2,752	8,251
Spacer			2,520	
3 ppg SLF			2,752	8,251
Spacer			4,095	
4 ppg SLF			4,121	16,502
Spacer			4,095	
5 ppg SLF			4,121	20,628
Spacer			4,095	

6 ppg SLF			4,121	24,753
Spacer			2,520	
7 ppg SLF			2,752	19,252
7 ppg SLF			2,000	14,000
Flush		8,200		
TOTALS	**16,500**	**18,700**	**101,827**	**25 lbs BV-CF* 27,752 lbs 30/50 HSP 104,386 lbs 20/40 HSP**

Table II.7: Main treatment pumping

Notes:

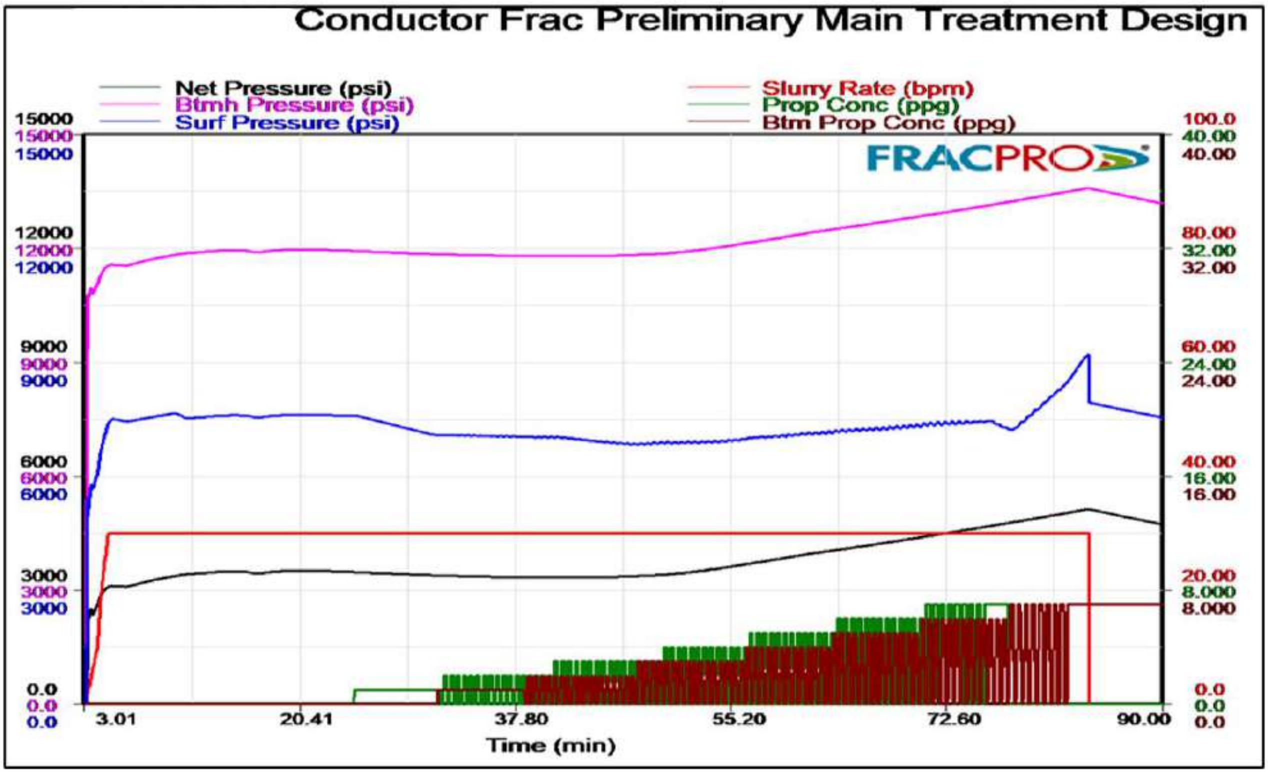
- The treatment pumping schedule will be reviewed following the diagnostic injection tests and temperature log and altered if required.
- 100-mesh sand will be available on location to be used within the Pad stage if needed to mitigate the excessive fluid loss.
- Flush volume will be updated on location taking into consideration the real surface volumes.
- Biovert CF are optional depending on formation leakoff after the Minifrac analysis.

➢ **Fracpro PT Main Treatment Design Result:**

Description	
Propped Half-Length (m)	**97.6**
Total Propped Height (m)	**35.0**
Depth to Propped Fracture Top (m)	**3.920.5**
Depth to Propped Fracture Bottom (m)	**3,955.5**
Avg. Width on Proppant (in)	**0.651**
Avg. Proppant Concentration (lb/ft²)	**2.24**
Avg. Conductivity (mD·ft)**	**85,661.2**

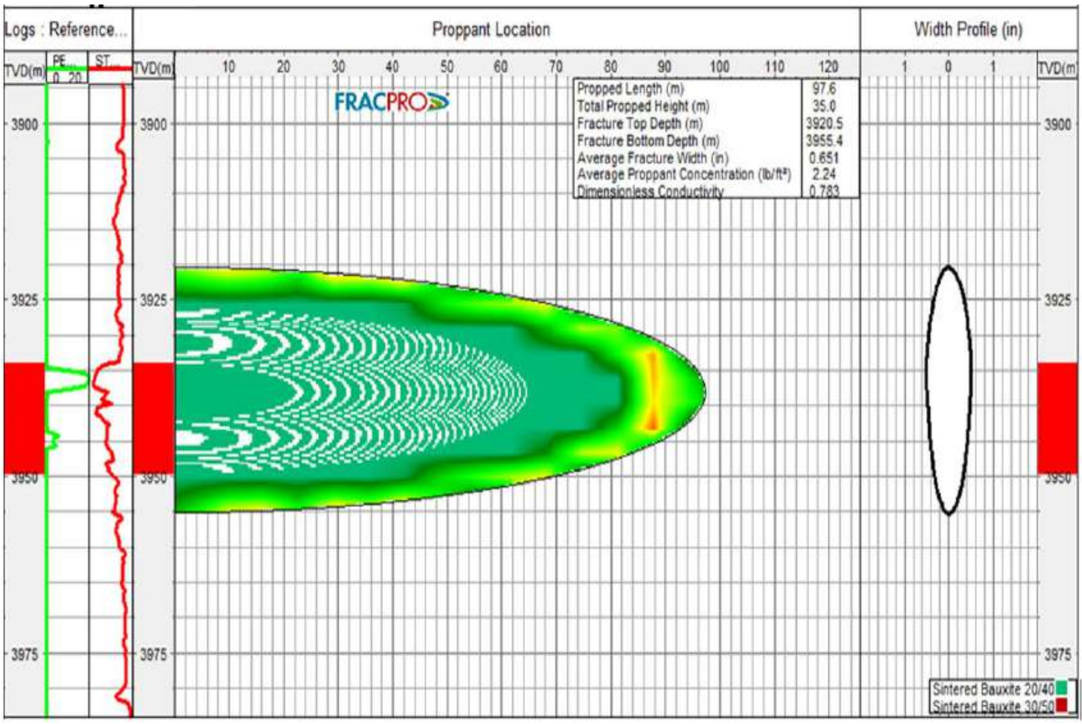
Table II.8: Fracpro PT Main Treatment Design Result

- **Conductor frac Main treatment plot:**



FigureII.4: conductor frac main treatment plot.

- **Fracture Proppant Location**



FigureII.5 : fracture proppant location.

- **Interpretation :**

- Perform injection test and diagnostic pumping to evaluate and calibrate the target formation
- Run the temperature log to correlate the minimum created fracture height
- Perform the propped Main Treatment as per final design
- The recommended fracturing fluid system is 40 lbs Hybor base fluid.
- Delayed cross-linked gel system containing:
    - 30/50 HSP proppant
    - 20/40 HSP proppant
- The main treatment designs are only preliminary in nature and will be revised after a Minifrac has been performed on this well.
- In actual frac design, the Pad is representing around 34% of total volume. Just in presence of high leak off, increase this Pad amount with the combination of Biovert CF and 100-mesh sand into the slugs.
- A progressive increase of surface pressure as it shown at Conventional Frac Main Treatment Plot which indicates the occurrence of the screen-out.

- **Recommendation:**

The Conductor Frac Technology is still highly recommended for this formation as per the gathered information about this challenging field to minimize the premature screen-out tendency and pump the treatment to completion (will be discussed after Minifrac evaluations).

II. 5.2. Minifrac Test:

On January 26th & 27th 2022, an Injection Test, step Rate test (Up/Down) and Minifrac were performed in the Gedinnian B formation on AZSE-21 in field of Algeria. The Minifrac was conducted to collect information to aid in the Main Fracturing treatment design and execution. A summary of these tests volumes, rates and pressures are presented in **Schedules III.7.**

Stage Description	Fluid Description	Planned Volume (gal)	Actual Volume (gal)	Slurry Rate (bpm)		Surface Press. (psi)	
				Avg	Max	Avg	Max
Load the well	Treated Water	9,000	2,683	6.4	10.8	3,057	3,236
Break Down	Treated Water	3,000	11,470	22.6	35.3	6,002	9,152
Shut-in	-	-	-	0	0.0	0	0
Step Rate Test	Treated Water	5,000	14,884	15.0	34.5	4,660	9,117
Shut-in	-	-	-	0	0	-	-
Pre-PAD	40# Linear Gel	1,000	1,985	14.8	29.5	519	1,359
PAD	40# HYBOR H	12,000	11,993	34.8	35.2	6,442	7,542
Flush	40# Linear Gel	9,138	9,247	34.9	35.2	6,133	6,274
Shut-In		-	-	-	-	-	-

Table II.9: Mini frac test

The Injection Test was started by checking the wellhead pressure that was recorded at 2,946 psi, then followed by loading the well with treated water starting with a minimum rate of 2 bpm using HPP. Then the pumping rate was increased gradually to 35bpm without noticing any Breakdown signature **(Figure breakdown test)**. A total volume of 14,153 gals of treated water was pumped. After the injection test a step Rate test (Up/Down) was performed ahead the Minifrac in order to get the fracture extension pressure, furthermore the dominating friction along the treating path **(Figure SRT)**. A summary of the **SRT(spill response team)** results are presented in **Schedules II.10.**

Beta Factor:	1.01
Pipe Friction:	3,934 psi
Entry Friction:	3,172 psi
K_{Entry}:	90.10
Perf Friction:	1,090 psi
K_{Perf}:	0.91
NWB Friction :	2,082 psi
K_{NWB} :	353.48

Table II.10: summary of the SRT results.

The Minifrac was started by checking the wellhead pressure that was recorded at 60 psi, followed by injection of the Pre-pad stage with HPP where the treating rate was brought up gradually and stabilized at 35 bpm were a total of 1,985 gals of 40# linear gel were pumped.

The pumping was carried on with the Pad stage of 11,993 gals Hybor H4.0420 Cross-linked Gel. The Minifrac was displaced with 9,247 gals of 40# linear gel (Fig 6). At the end of the displacement, the pumps were shut down and the pressure decline was monitored to obtain the Minifrac ISIP, frictions, closure pressure, net pressure and fluid efficiency. The Minifrac shut-in pressure decline analysis is presented in **schedules II.9.**

		Minifrac	Minifrac Analysis
Reservoir Injection Fluid:		Hybor H 40#	Hybor H 40#
Volume Injected:	(gal)	11,993	
Avg. Injection Rate:	(bbl/min)	35	
BH Last Pumping Pressure	(psi)	10,407	
BH ISIP (1)	(psi)	9,351	
Bottom hole Friction	(psi)	1,056	
Fracture Gradient:	(psi/ft)	0.72	
Closure Gradient:	(psi/ft)	0.55	
Closure Pressure:	(psi)		7,103
Fluid Efficiency:	(%)		20.54/22.41 %
Net Pressure:	(psi)		2,248

Table II.11: The Minifrac shut-in pressure decline analysis.

- **(1)** Water hammer effects mask the ISIP; the reported ISIP is extrapolated from the trend of shut-in pressure decline curve to the time of shutdown.

Note: The collected data from the Minifrac was then modeled using the FracProPT fracture design simulator. The FracProPT model match was then used to help design the Main Treatment. The FracProPT Minifrac Match is displayed in Figures 11, 12, and the FracProPT Main Treatment Design is displayed in Figures 13 and 14.

Injection test Plot:

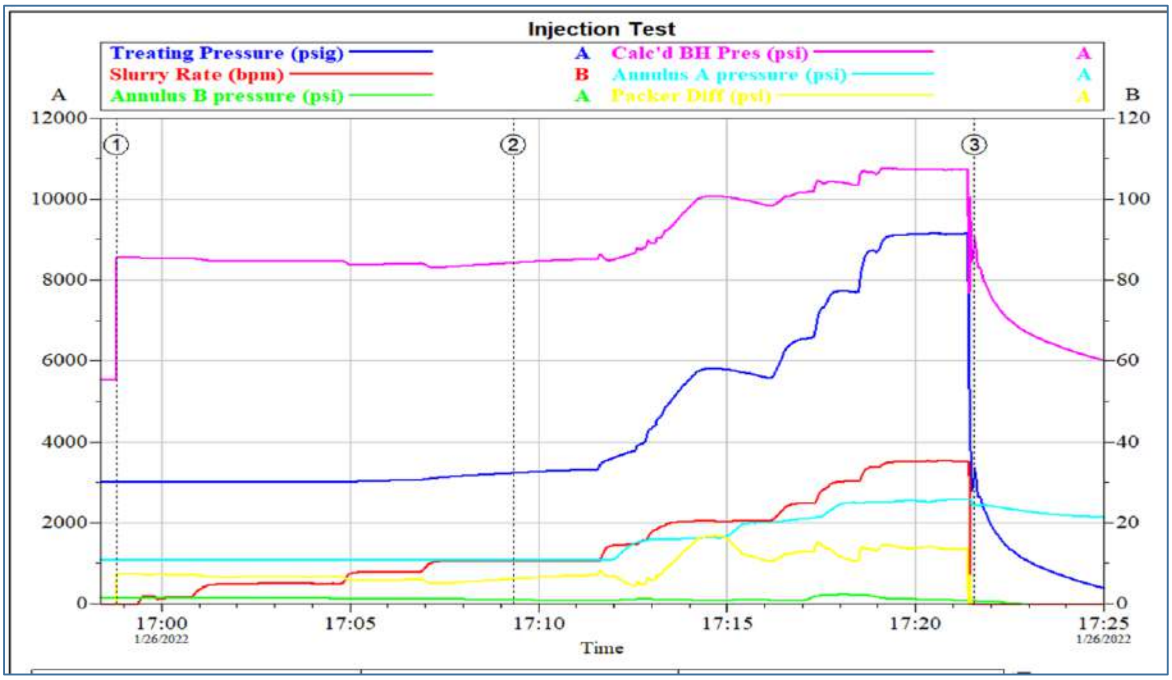


Figure II.6: Injection Test Plot.

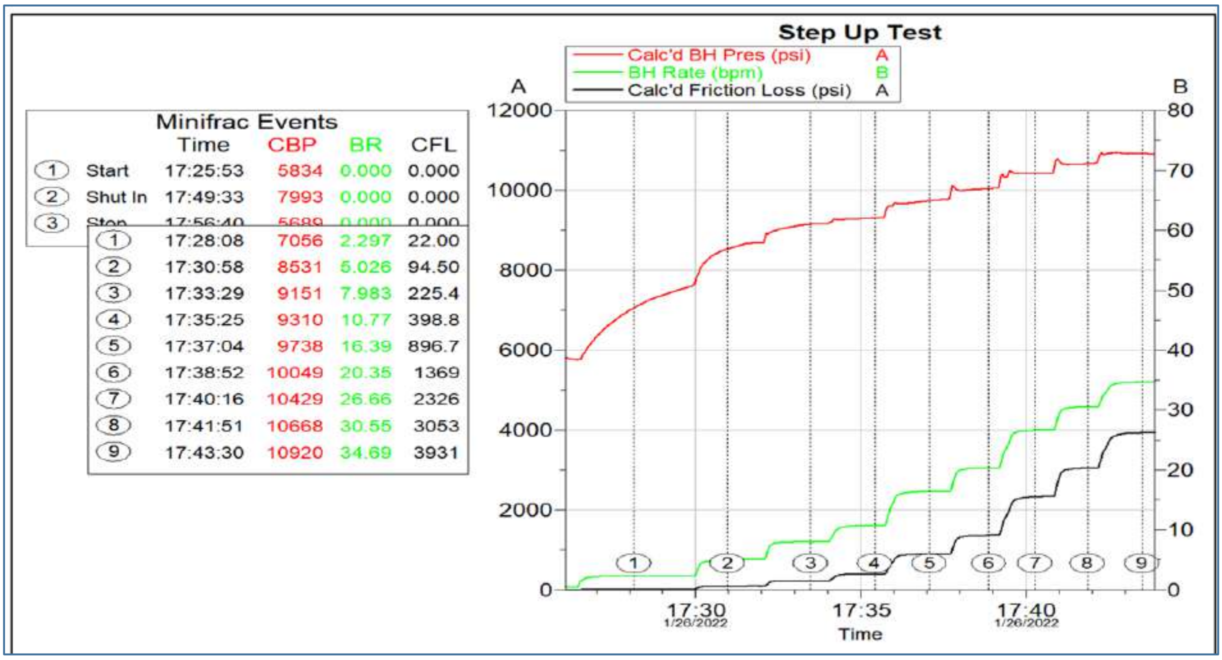


Figure II.7: Step Up Rate Test

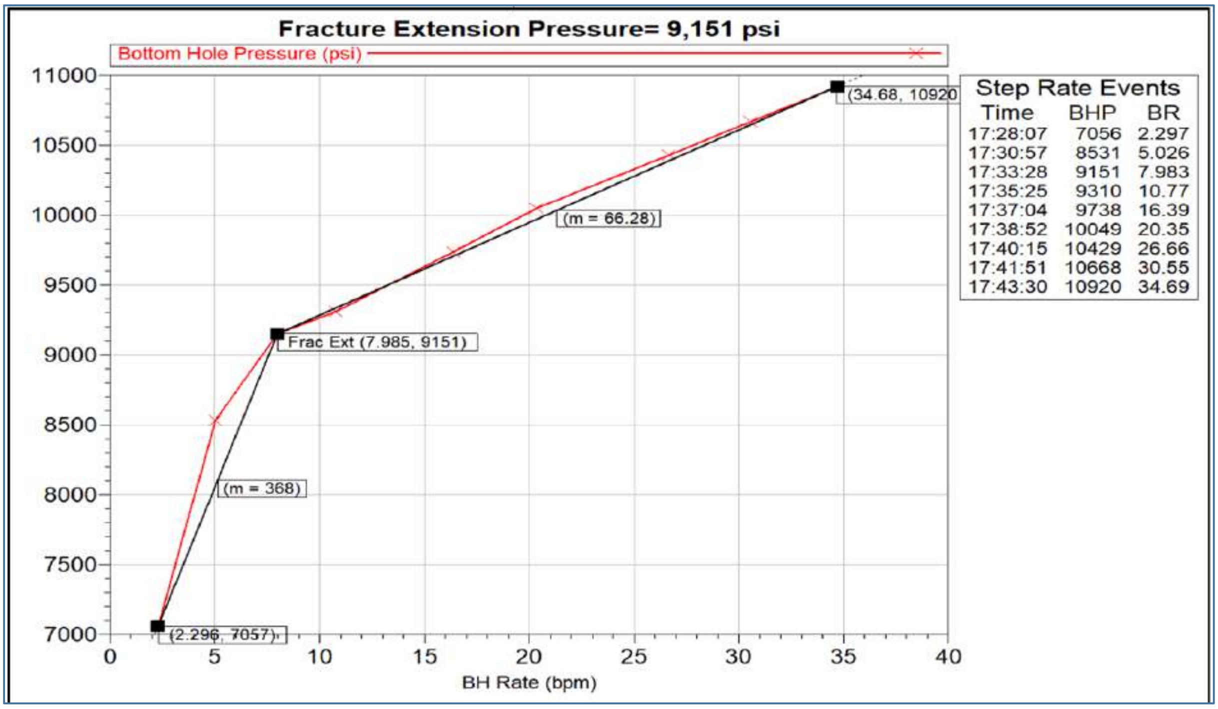


Figure II.8: Fracture Extension Pressure.

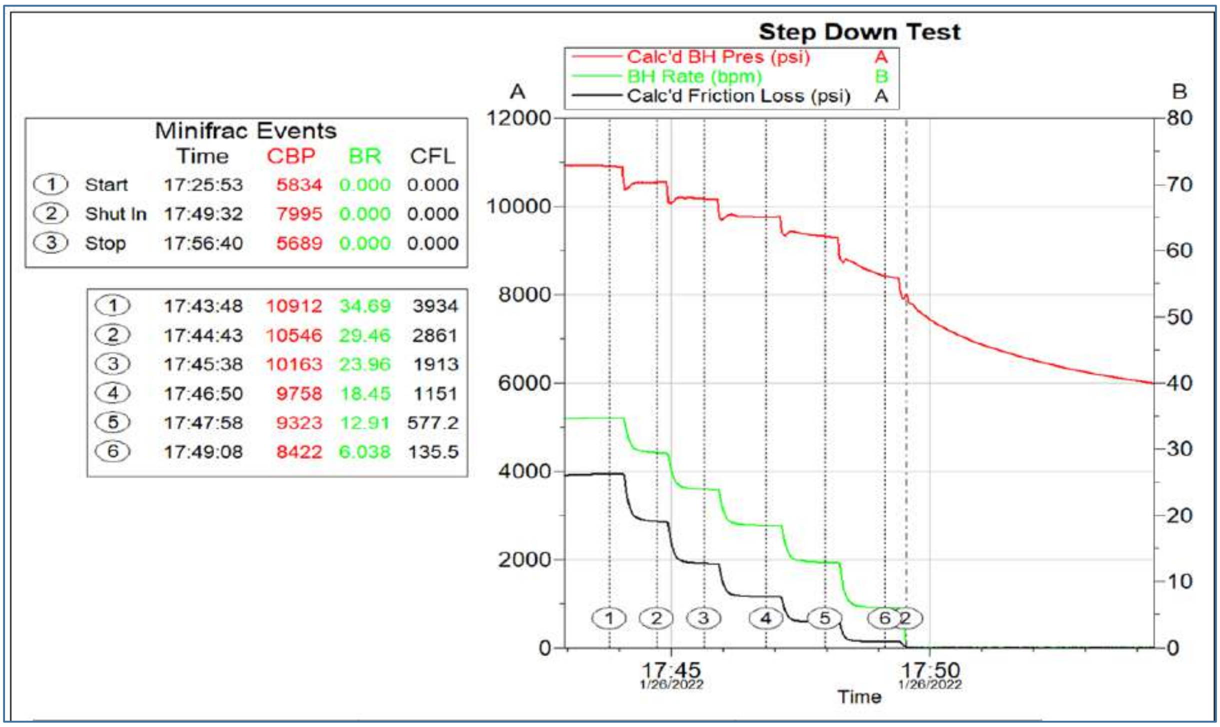


Figure II.9: Step Down Rate Test.

- **Minifrac Analysis:**

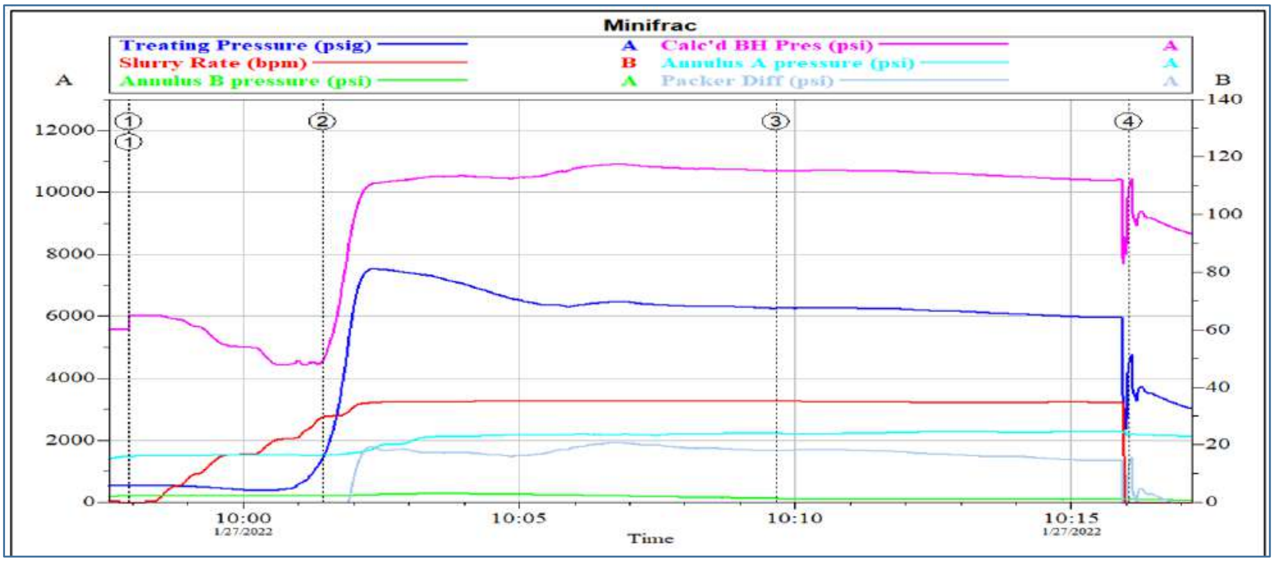


Figure II.10: Mini frac analysis.

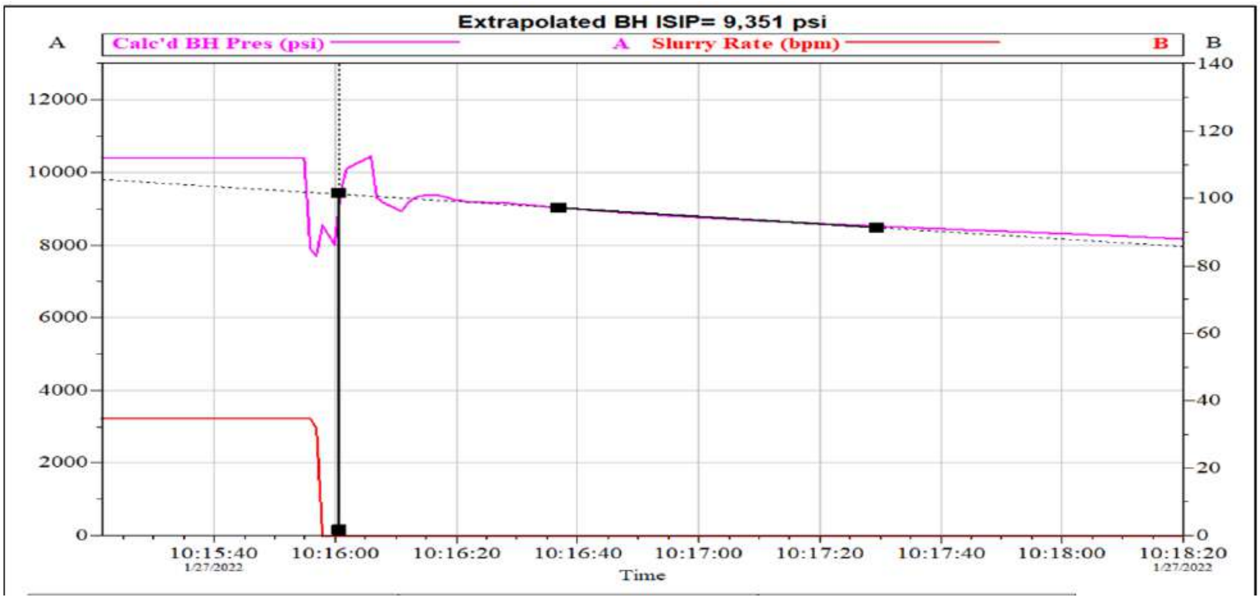


Figure II.11: Minifrac ISIP.

The Minifrac shut-in pressure decline was analyzed using G-Function, Square root, methods (Figures 8 & 9), The conservative closure was picked at 7,103 psi with a corresponding fluid efficiency of 22.41%. The analysis from G-function indicated a PDL of 2,248 psi.

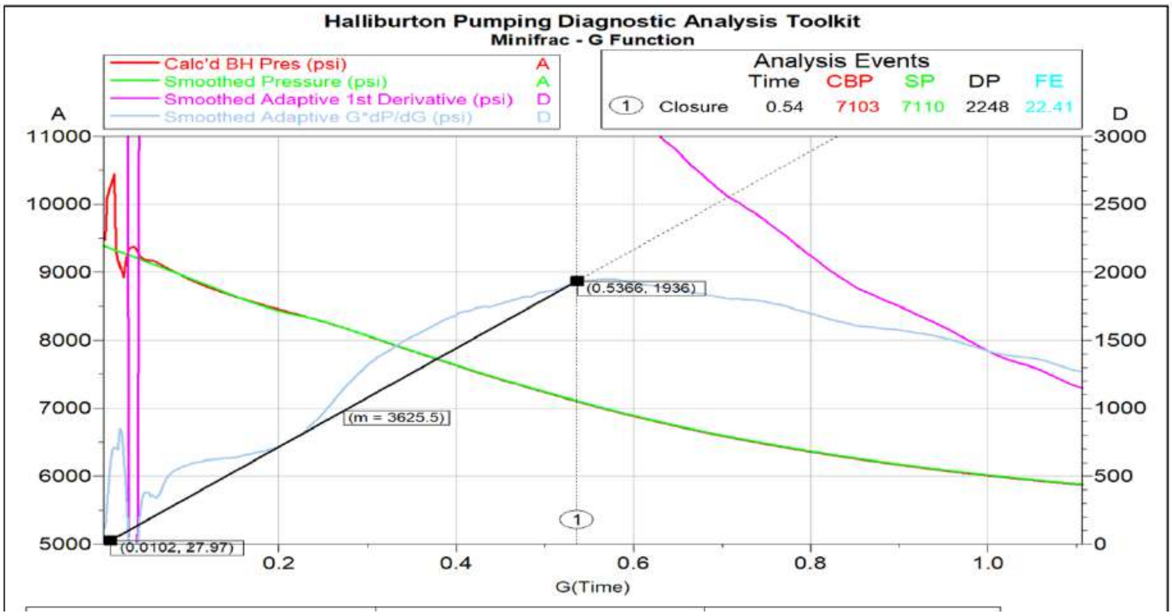


Figure II.12: Minifrac G Function Analysis.

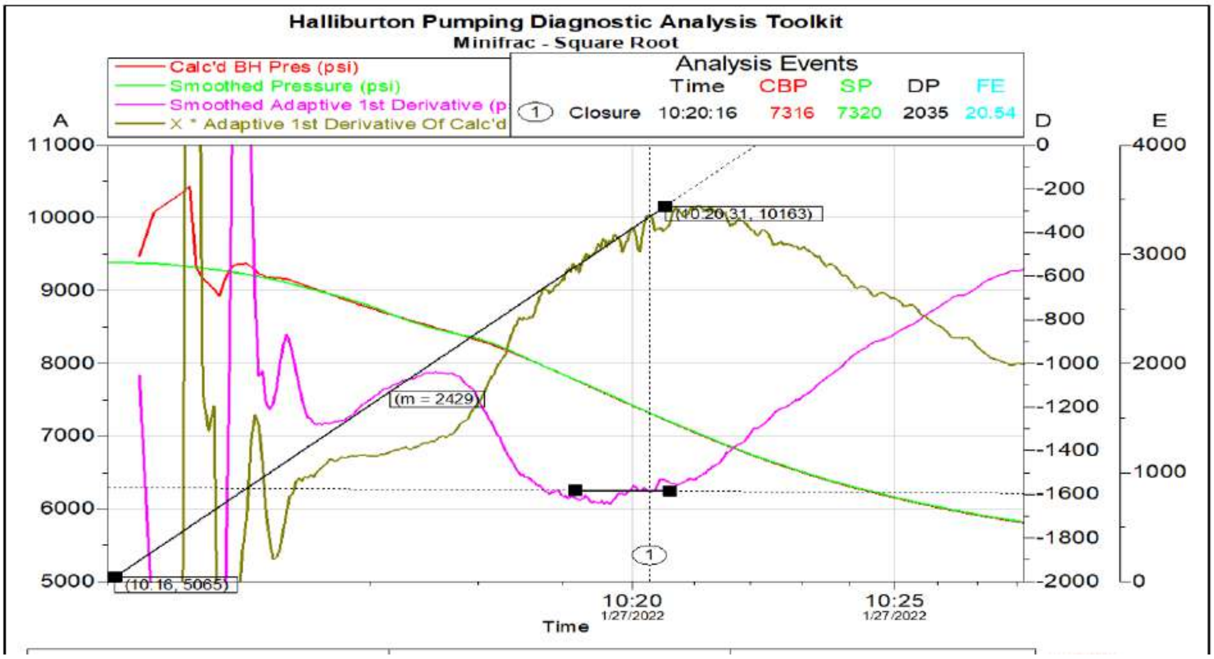


Figure II.13: Minifrac Square Root Analysis.

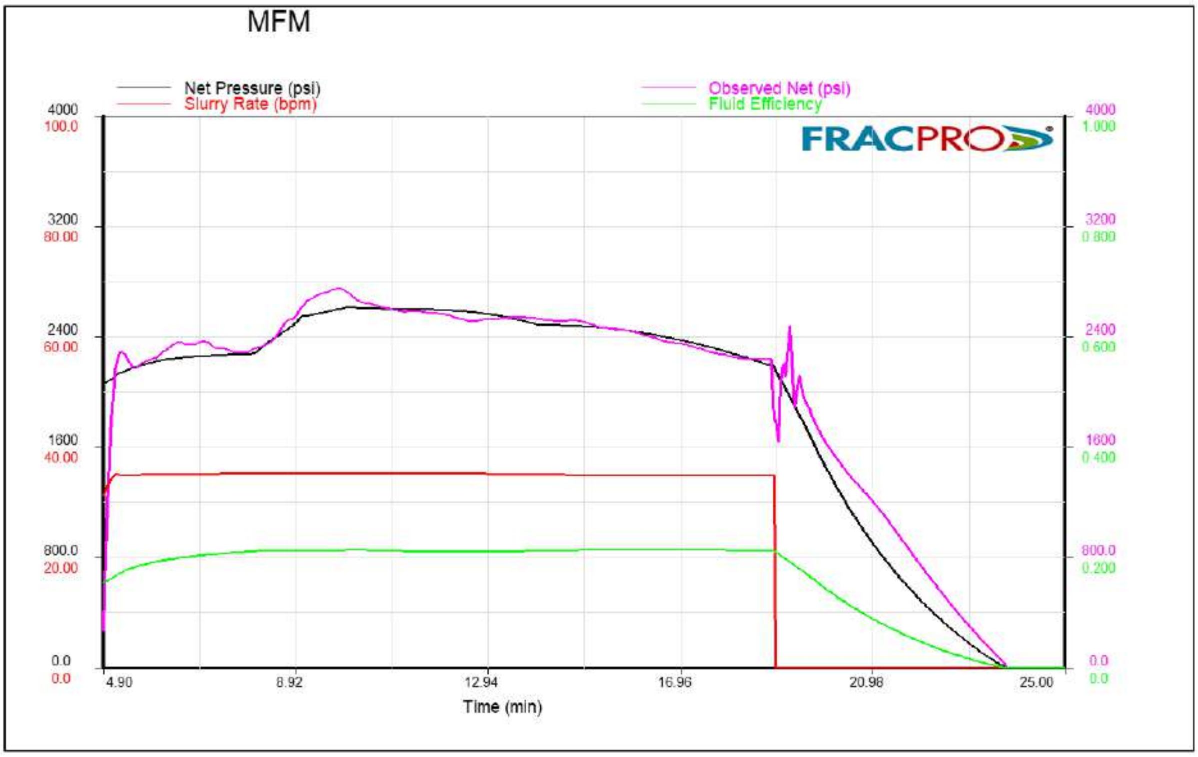
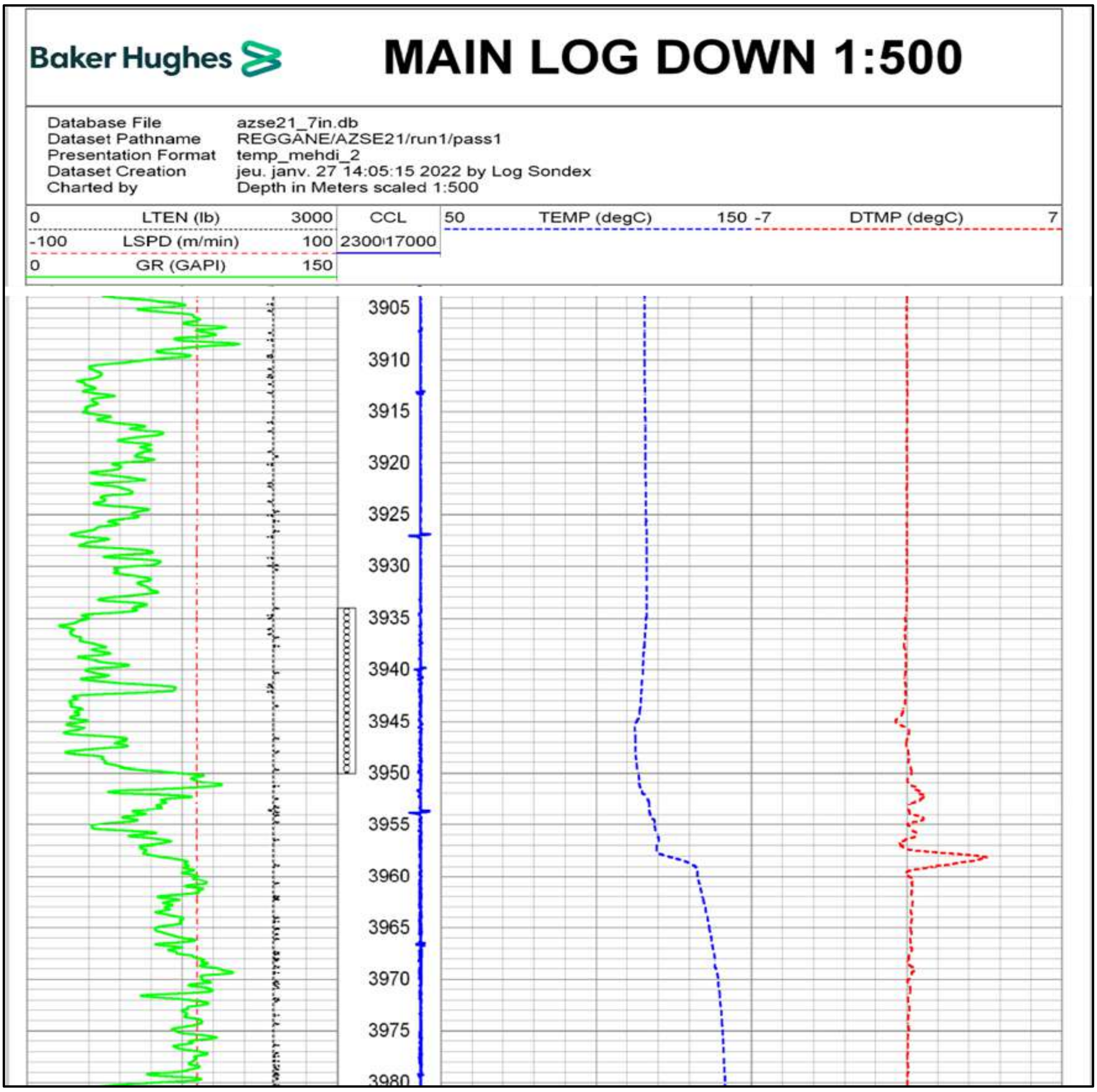


Figure II.14: FracProPT Minifrac Match.

Description	
Fracture Length	60.8 m
Total Fracture Height	38.1 m
Fracture Top Depth	3,930.7 m
Fracture Bottom Depth	3,968.7 m
Average Width	0.196 in

Table II.12: FracProPT Minifrac Match Geometry.

- **Temperature log Test:**



FigureII.15: Temperature Log.

- The temperature log shows the fracture propagation from 3,932 downward to 3,968 mRT where a main cooling is in front of the lower part of the perfs interval. The Temperature signature indicates a confined fracture.

II. 5.3. Main treatment:

The Main Treatment was performed on January 29th, 2022. Summaries of the main treatment data are presented in Tables II-1 & II-2. The Main Treatment plots are presented in Figures 15 and 16.

The main treatment was started by checking the well head pressure that was recorded at 80 psi, then start loading the well with 40# linear gel using HP pumps with minimum rate of 2 bpm brought up to 30 bpm. A total volume of 2,474 gals 40# Linear Gel was pumped before starting the cross-linkers and establish the treating rate. **The pre-pad stage was followed by three Pad stages and a 1 ppg 30/50 HSP Prop Slug of Hybor H4.0420 as below:**

- First Pad of 3,030 gals of Hybor H4.0420.
- Second Pad + BioVert with 5,213 gals of Hybor H4.0420.
- 1 ppg 30/50 HSP Prop Slug with 2,013 gals of Hybor H4.0420.
- Third Pad of 20,022 gals of Hybor H4.0420.

The PAD stages followed by 7 prop stages and spacers pumped unconventionally as below:

- 1 ppg stage using 30/50 HSP proppant in 1 repeat using 10,025gallons of Hybor 40#.
- Spacer then 2 ppg stage using 30/50 HSP proppant in 16 pulses using 8,702gallons of Hybor 40#.
- Spacer then 3 ppg stage using 30/50 HSP proppant in 14 pulses using 12,324gallons of Hybor 40#.
- Spacer then 4 ppg stage using 30/50 HSP proppant in 12 pulses using 10,865 gallons of Hybor 40#.
- Spacer then 4 ppg stage using 20/40 HSP proppant in 9 pulses using 7,838 gallons of Hybor 40#.
- Spacer then 5 ppg stage using 20/40 HSP proppant in 7 pulses using 6,182 gallons of Hybor 40#.
- Spacer then 6 ppg stage using 20/40 HSP proppant in 5 pulses using 4,555 gallons of Hybor 40#.
- Spacer then 7 ppg stage using 20/40 HSP proppant in 4 pulses using 3,738 gallons of Hybor 40#.
- Spacer then 7 ppg tail-in stage using 20/40 HSP proppant in 1 pulse using 1,892gallons of Hybor 40#.

The Main treatment was under displaced with 8,887 gals of 40# linear gel (Fig 15). The main fracturing treatment placed 125,187 lbs (66,140 lbs of 30/50 HSP & 59,047 lbs of 20/40) proppant into the formation at a maximum bottom-hole concentration of 8.10 ppg. Approximately 4,651 lbs of 20/40 HSP was left in the wellbore.

- **Fluid Volume Summary:**

Stage Description:	Treated Water (gal)	40# Linear Base Gel (gal)	Hybor-H 40# (gal)
Breakdown/ Injection Test			
Load the Well	2,683		
Breakdown	11,470		
Step-Up Step-Down Rate Test	14,884		
MINIFRAC			
Pre-Pad		1,985	
Minifrac			11,993
Displacement		9,247	
MAIN TREATMENT			
Pre-Pad		2,474	
Pad			30,0272
Proppant Fluid			66,122
Displacement		8,887	
TOTALS	**29,037**	**22,592**	**108,387**

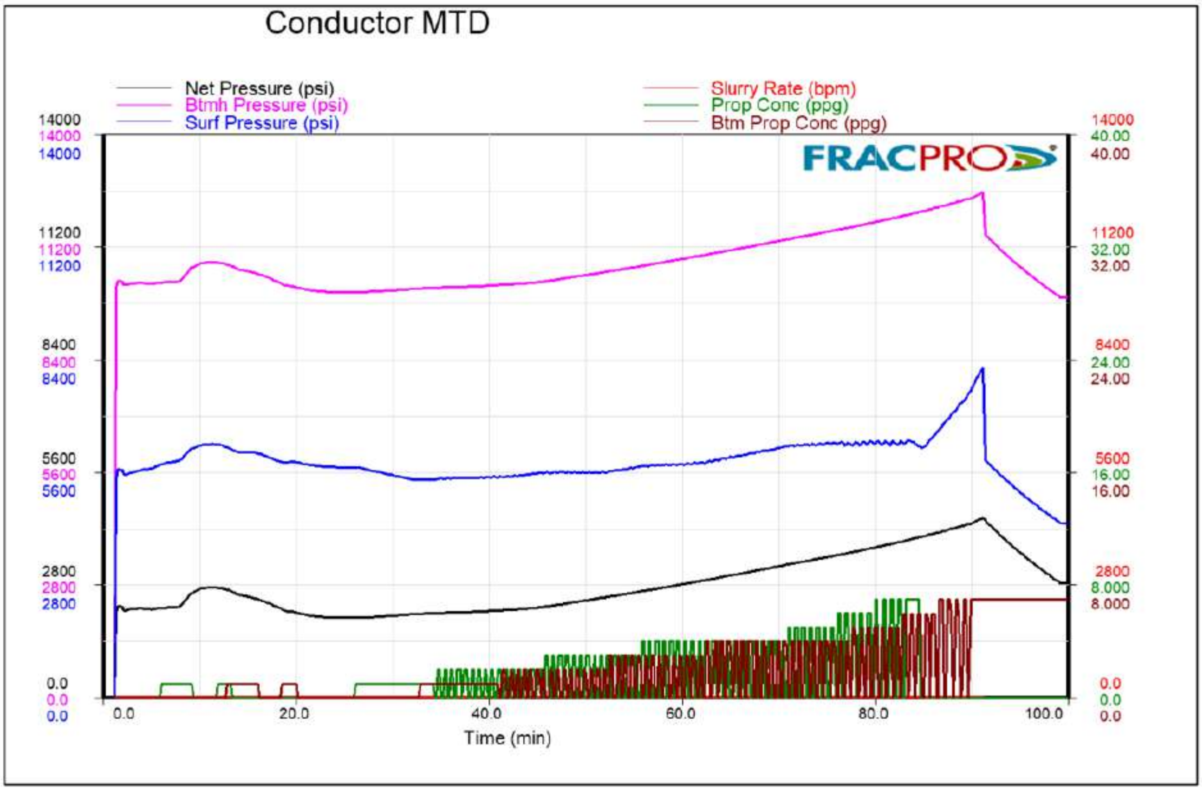
Table II.13: Fluid Volume Summary.

- **Main Treatment:**

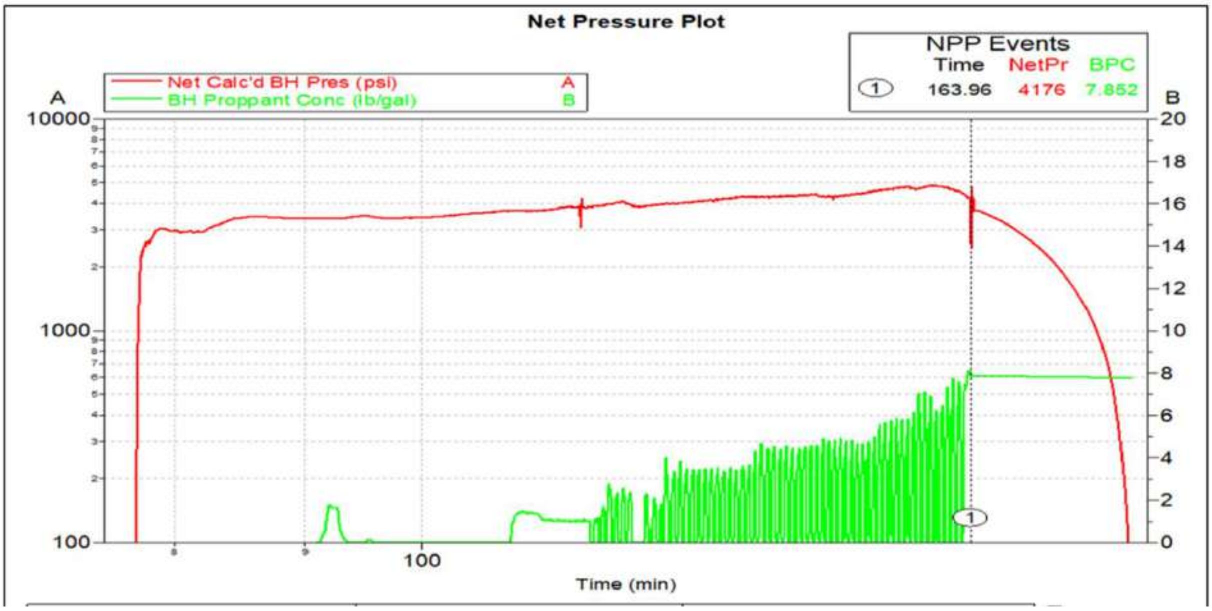
Description	
Propped Fracture Length	99.6 m
Total Propped Height	41.4 m
Propped Fracture Top Depth	3,927.4m
Propped Fracture Bottom Depth	3,968.7 m
Average Proppant Concentration	1.25 lbs/ft2
Average Fracture Width	0.248 in
Average Proppant Conductivity	86,441.7 mD-ft

Table II.14: FracProPT Main Treatment Review.

- **Conductor Main treatment design plot:**



FigureII.16: Conductor Main treatment design plot.



FigureII.17: Main Treatment Net Pressure.

- **FRACPRO MAIN TREATMENT REVIEW:**

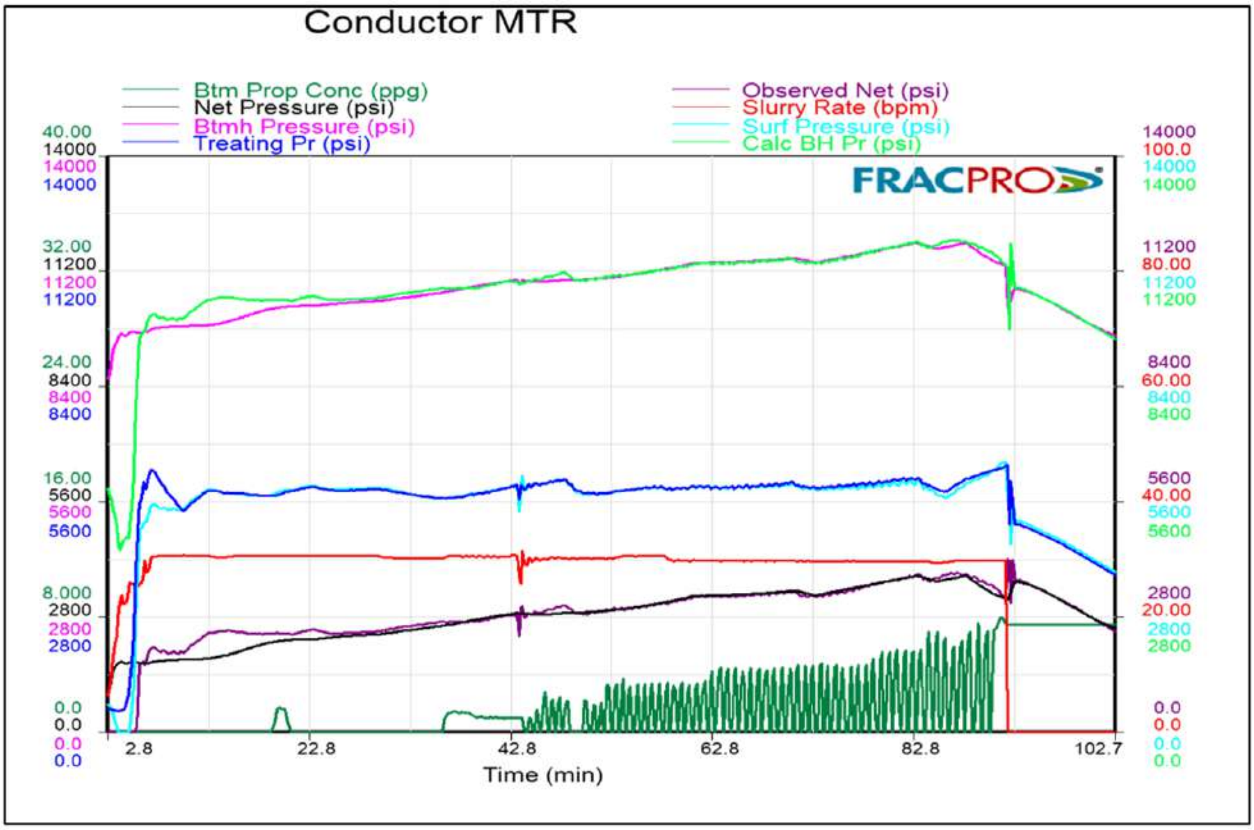


FIGURE II.18: FRACPRO MAIN TREATMENT REVIEW.

- **PROPPANT LOCATION:**

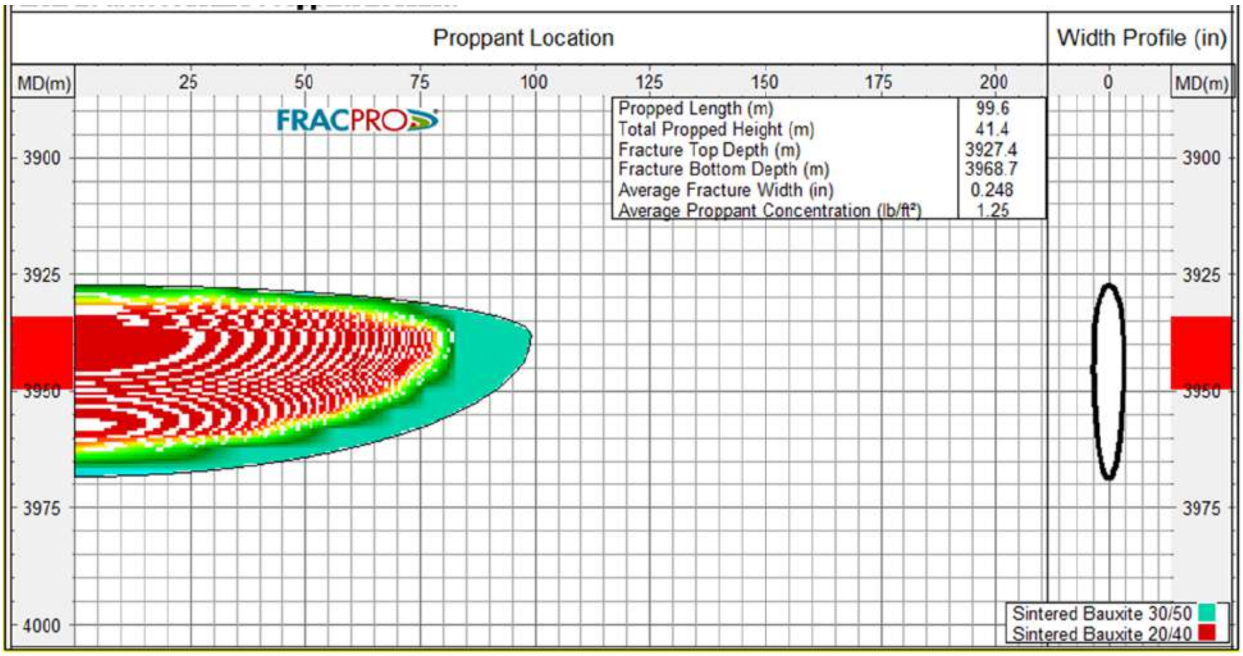


Figure II.19: PROPPANT LOCATION.

- **FracProPT Output:**

FracPro 2019

Hydraulic Fracture Analysis

- **Fracture Geometry Summary*:**

Fracture Half-Length (m)	100	Propped Half-Length (m)	100
Total Fracture Height (m)	41	Total Propped Height (m)	41
Depth to Fracture Top (m)	3,927	Depth to Propped Fracture Top (m)	3,927
Depth to Fracture Bottom (m)	3,969	Depth to Propped Fracture Bottom (m)	3,969
Equivalent Number of Multiple Fracs	0.8	Max. Fracture Width (in)	0.44
Fracture Slurry Efficiency**	0.28	Avg. Fracture Width (in)	0.25
		Avg. Proppant Concentration (lb/ft^2)	1.25

Table II.15: Fracture Geometry Summary.

** All values reported are for the entire fracture system at a model time of 101.90 min (end of Stage 137 Shut-in after Main frac flush)*

*** Value is reported for the end of the last pumping stage (Stage 136, Main frac flush).*

- **Fracture Conductivity Summary*:**

Avg. Conductivity** (mD·ft)	86,441.7	Avg. Frac Width (Closed on prop) (in)	0.115
Dimensionless Conductivity**	0.74	Ref. Formation Permeability (mD)	4.55
Proppant Damage Factor	0.50	Undamaged Prop Perm at Stress (mD)	216,608
Apparent Damage Factor***	0.00	Prop Perm with Prop Damage (mD)	108,304
Total Damage Factor	0.50	Prop Perm with Total Damage (mD)	108,304
Effective Propped Length (m)	100	Proppant Embedment (in)	0.003

Table II.16: Fracture Conductivity Summary.

** All values reported are for the entire fracture system. Actual conductivity could be lower if equivalent multiple fractures have been modeled*

*** Total Damage Factor and Proppant Embedment have been applied*

**** Apparent Damage due to non-Darcy and multi-phase flow*

- **Fracture Pressure Summary*:**

Model Net Pressure** (psi)	3,233	BH Fracture Closure Stress (psi)	7,103
Observed Net Pressure** (psi)	3,237	Closure Stress Gradient (psi/ft)	0.550
Hydrostatic Head*** (psi)	5,655	Avg. Surface Pressure (psi)	5,809
Reservoir Pressure (psi)	5,990	Max. Surface Pressure (psi)	6,546

Table II.17: Fracture Pressure Summary.

** Averages and maxima reported for Main Frac stages.*

*** Values reported for the end of the last pumping stage (Stage 136, Main frac flush).*

**** Value reported for clean fluid*

- **Operations Summary*:**

Total Clean Fluid Pumped (bbls)	2,565.5	Total Proppant Pumped (klbs)	130.3
Total Slurry Pumped (bbls)	2,666.6	Total Proppant in Fracture (klbs)	127.2
Pad Volume (bbls)	1,665.6	Avg. Hydraulic Horsepower (hp)	4,244
Pad Fraction (% of Slurry Vol)**	67.7	Max. Hydraulic Horsepower (hp)	4,983
Pad Fraction (% of Clean Vol)**	69.3	Avg. Btm. Slurry Rate (bpm)	29.0
Primary Fluid Type	Hybor-H 40#	Primary Proppant Type	30/50 HSP
Secondary Fluid Type	Linear Gel 40#	Secondary Proppant Type	20/40 HSP

Table II.18: Operations Summary.

** Averages and maxima reported for Main Frac stages. Totals reported for all injections combined.*

*** Based on following volume ratio of stage types: Main frac pad / (Main frac pad + Main frac slurry) and excluding flush.*

II. 6. Well test analysis:

The main purpose of this test is to measure the production rate, all the same, this test makes it possible to obtain other parameters characterizing the crude such as, the GOR, the oil density, the gas density, the temperature of oil as well as the salinity of the water. The results obtained from this test are shown in **schedules II.18**.

II. 6.1. Method of Gas Rate Measurement:[31]

- ***Gas Rate Calculations***: $Qv = C \times \sqrt{(hw \times Pf)}$ ……………………….**(II.1)**

where:

Qv = Volume flow rate, at standard conditions of 14.73 psia and 60 deg F

C = Orifice flow constant

hw = Differential pressure, inch water at 60 Deg F

Pf = Absolute Upstream Static Pressure.

- ***Orifice flow constant*:**

C = Fb × Fr × Y1 × Fpb × Ftb × Ftf × Fgr × Fpv × Fa × (unit conversion factor)…..**(II.2)**

where:

Fb = Basic orifice factor

Fr = Reynolds number factor

Y1 = Upstream expansion factor

Fpb = Pressure base factor = 1, as Pb = Pst = 14.73 psia is assumed

Ftb = Temperature base factor = 1, as Tb = Tst = 60 deg F is assumed

Ftf = Flowing temperature factor = $\sqrt{(1 / Tf1)}$

Fgr = Real gas relative density factor = $\sqrt{(1 / SG)}$

Fpv = Super compressibility factor = $\sqrt{(Zst / Zf1)}$,as Zb = Zst is assumed

Fa = Orifice thermal expansion factor

$$\textit{Choke Gas Rate} = \frac{0.60537 * 0.83 * (\frac{(Chk/64)^2}{2}) * \Pi * WHP}{(GasSG * (WHT + 460))^{0.5}} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(II.3)}$$

II. 6.2. Surface Data:

Date - Time	Production rate measurement (est gas rate) Sm3/h	Production volume measurement (gas v) Sm3
31-01-2022 08:15	10541	6644
31-01-2022 08:30	10349	9145
31-01-2022 08:45	10304	11721
31-01-2022 09:00	10301	14296
31-01-2022 09:15	10322	16877
31-01-2022 09:30	10334	19460
31-01-2022 09:45	10343	22046
31-01-2022 10:00	10354	24634
31-01-2022 10:15	10365	27226
31-01-2022 10:30	10375	29819
31-01-2022 10:45	10391	32417
31-01-2022 11:00	10426	35024
31-01-2022 11:15	10456	37638
31-01-2022 11:30	10463	40253
31-01-2022 11:45	10484	42874

31-01-2022 12:00	10497	45499
31-01-2022 12:15	10506	48125
31-01-2022 12:30	10519	50755
31-01-2022 12:45	10533	53388
31-01-2022 13:00	10541	56024
31-01-2022 13:15	10545	58660
31-01-2022 13:30	10558	61299
31-01-2022 13:45	10589	63947
31-01-2022 14:00	10605	66589

Table II.19: surface data.

- **Flow test Plots:**

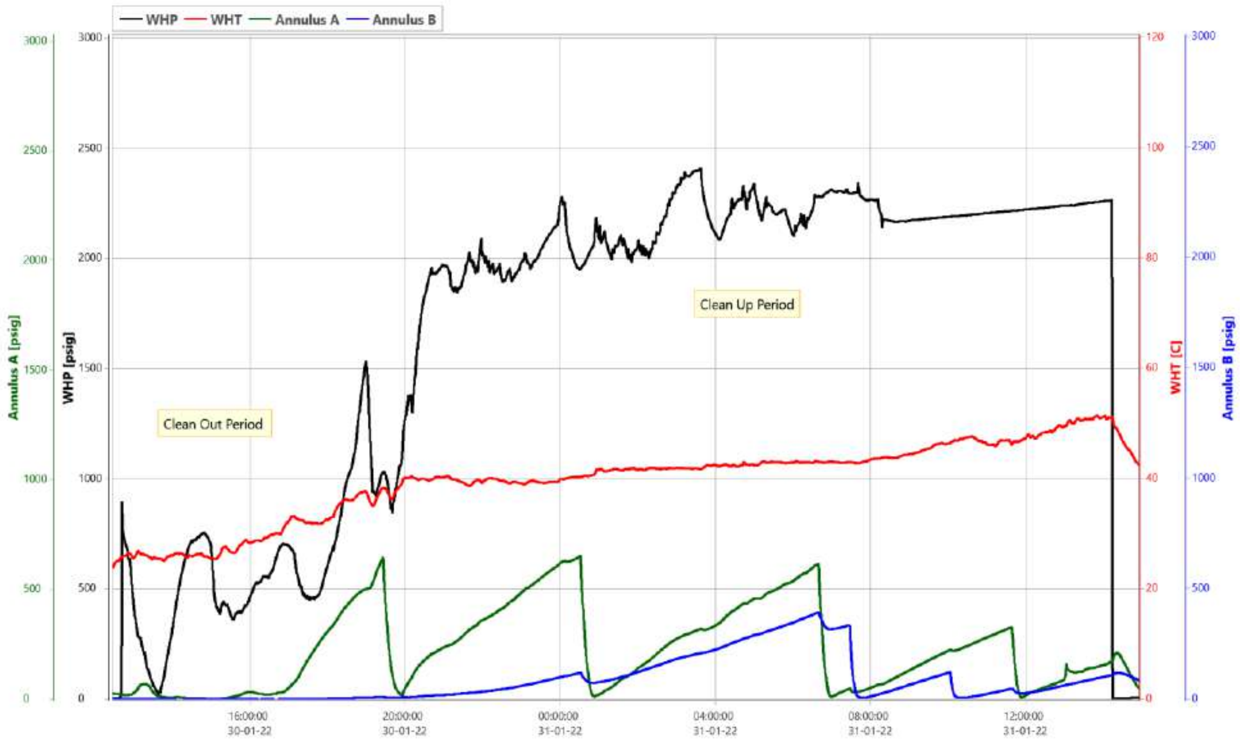


Figure II.20: flow test plot1.

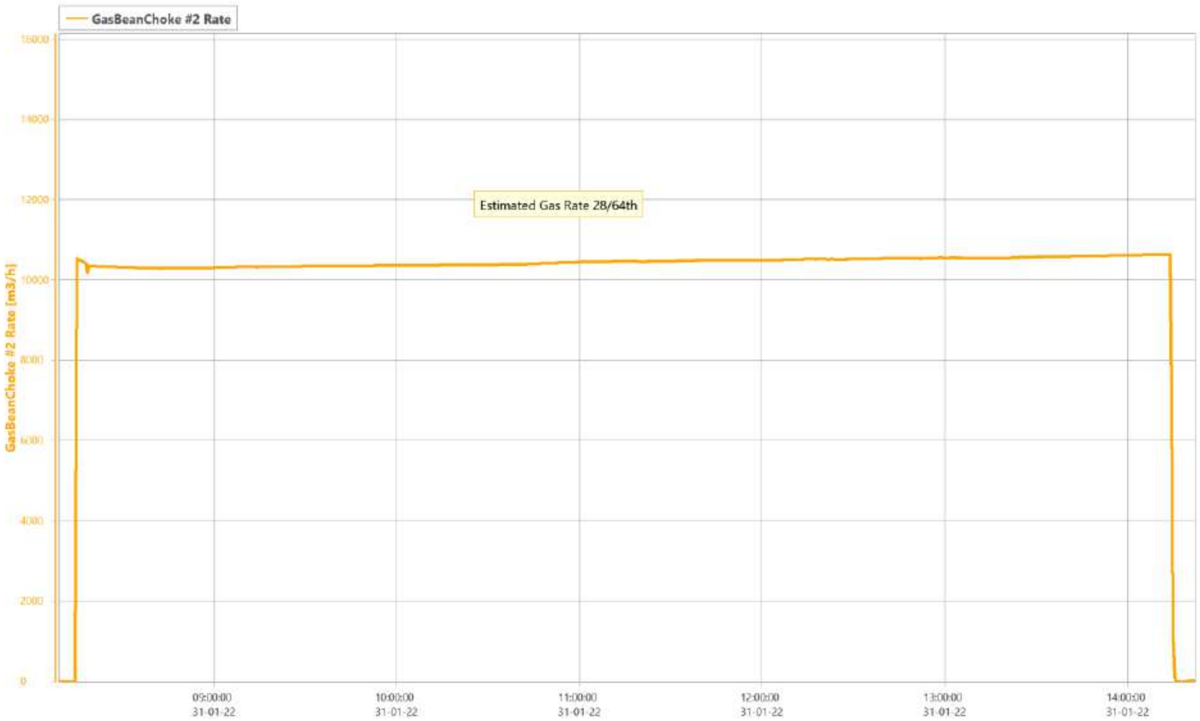


Figure II.20: flow test plot2.

		Well Parameters		Flowrates			Ratios		Separator Parameters		
Date	Choke	WHP	WHT	Cond	Gas Est. Gas Rate	Water	GOR	WC	Static	Diff P	Orifice
dd/mm/yy	/64"	psig	°C	m^3/h	Sm^3/h	m^3/h	Sm^3/m^3	%	psig	inw	in
31-Jan-2022	28	2207	47	N/A	10446	N/A	N/A	N/A	N/A	N/A	N/A

Table II.20: Flow Tests Report Summary.

II. 6.3. Well test interpretation:

According to the well test results, the following interpretations can be mentioned:

- A gradual increase in flow from 10541m3/h up to 10605m3/h corresponds to an increase in volume from 6644Sm3 up to 66587Sm3 in one day, which shows the efficiency of this operation.
- A slight increase in flowing temperature is mainly in clean out/up period due to the flow back.

- The variation of the volume values is directly proportional to the production flow values.

II. 7. JOB DISCUSSIONS:

- Both Minifrac and Main Treatments were executed safely without any HSE incident.
- The temperature log shows the fracture propagation from 3,932 downward to 3,968 mRT where a main cooling is in front of the lower part of the perfs interval. The Temperature signature indicates a confined fracture.
- The Minifrac Analysis (G-Function) showed a PDL, where the chosen closure was picked at 7,103 psi. with a high net pressure of 2,248 psi which is confirmed by a confined fracture by the temperature Log signature, and a very low fluid efficiency of 22.41% which reflects the PDL observed from the analysis.
- The Step-Up rate test showed a fracture extension of 9,151 psi, where a step-Down rate test indicated a dominating perf friction with a β factor of 1.01.
- The main treatment design was performed based on the injection test and Minifrac analysis to reflect the actual formation leak-off.
- Since we have a very high risk of premature screen out, Halliburton recommends using Conductor frac technology to reduce the premature screen out tendency and pump the treatment to completion.
- Due to the high leak-off, The PAD volume was increased, where BioVert CF was added to increase the fluid efficiency and limit the fluid loss across the fracture.
- The BioVert® CF material was pumped during the Pad stages to address the formation leak off issue and limit the fluid loss.
- The main fracturing treatment placed 125,187 lbs (66,140 lbs of 30/50 HSP & 59,047 lbs of 20/40) proppant into the formation at a maximum bottom-hole concentration of 8.10 ppg. Approximately 4,651 lbs of 20/40 HSP was left in the wellbore.
- All the samples taken during both the Minifrac and the main treatment were completely broken.
- After the welltest analysis, the conductor frac technology has increased the production flow with **64Sm3/h**, and the volume with **60000Sm3** compared with the initial values in one day.

General Conclusion:

Our dissertation aims to highlight the hydraulic fracturing efficiency in oil and gas wells, where we have devoted our work to the new technology used in Halliburton under the name pillar hydraulic fracturing (conductor frac).

our study on AZSE-21 well located in REGGANE region, was to achieve the highest possible fracture conductivity and was ended with the increase of the production flow.

this study allowed us to extract some very essential points:

- The conventional fracturing technique is an effective technique despite the appearance of very advanced techniques such as developed by Halliburton "conductor", it was very interesting to significantly increase the conductivity of the reservoir (permeability). The use of expedite makes it possible to give the structure of Proppants and internal fracturing create a high conductivity drain.
- The conductor frac technology is still highly recommend for this formation as per the gathered information from Minifrac and previous experiences in this challenging field to minimize the premature screen-out tendency and pump the treatment to completion as proved in this job.
- The conductor frac was proposed based in the previous experience in Algeria field and as well in this field, where we had almost the same circumstances and we were able to pump the treatment to completion.
- the Pillar hydraulic fracturing (conductor Frac) improve to enhance the fracture conductivity in the formation with a high risk of screen-out.
- A good conductivity confirms the success of the operations for the well.
- For the economic aspect, the technique is very expensive, so the right choice of candidate wells allows us to reduce the costs while increasing oil and gas production.
- this technology reduces or eliminate the screen-out cross on the entire high stressed formations.

Recommendations:

For the good course of an operation of stimulation by hydraulic fracturing, certain recommendations are to be taken into account with knowing:

- To descend a log of temperature right after the “breakdown test” or the “dated frac” for to have an idea on the zone of the tank which absorbed the fluids injected. This operation in the case of becomes very recommended presence of an undesirable fluid close to tank to be stimulated, in the case of a position rather close to the shoe of casing, or that presence of a bad cementing.
- The conductor fracturing method is recommended at the level of the field of Reggane, and a sight satisfaction of all the necessary conditions and many advantages, which are gets (very high conductivity).
- Based on these outcomes, the use of this technique could face a fast increase within the Algerian market, so we recommend the application of pillar hydraulic fracturing in the high stressed formations tight/shale gas, considering also it possible re-fracturing interventions on older wells.

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Appendix :

1) **Fracturing fluids & conditions for their use:[24]**

Base fluid	**Fluid type**	**Main composition**	**Used for**
Water based	Linear fluid	Gelled water Guar <HpG, HEC, CMHPG	Short fractures, Low temperatures
	Crosslinked fluids	Crosslinker +GUAR, HPG, CMHPG, CMHEC	Long fractures, High temperatures
Foam based	Water based foam	Water and foamer+N2 or CO2	Low pressure formations
	Acid based foam	Acid and foamer +N2	Low pressure, water sensitive formations
	Alcohol based foam	Methanol and foamer + N2	Low pressure formation with water blocking problems
Oil based	Linear fluids	Oil, galled oil	water sensitive formations, short fractures
	Crosslinked fluids	Phosphate ester gels	Water sensitive formations, long fracture
	Water external emulsions	Water + oil + emulsifier	Good for fluid loss control

2) Well Logs & Stress Profile:

- **CBL/VDL plots:**

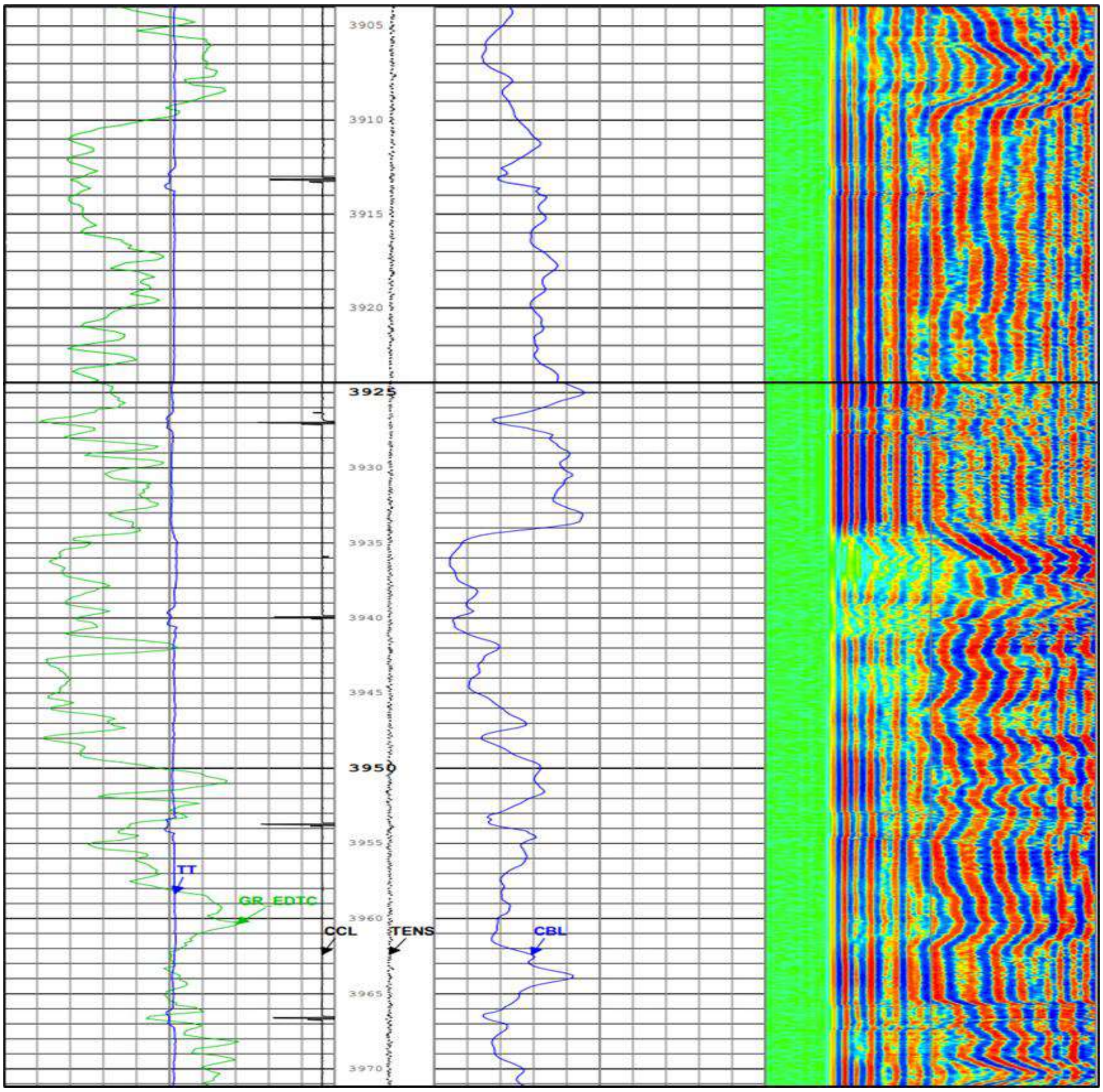

Figure 1: CBL/VDL plots.

5) **Main Treatment Volume, Rate, and Pressure Summary**:

Stage Description	Planned Clean Volume (gal)	Actual Clean Volume (gal)	Slurry Rate (bpm)		Tubing Press (psi)		Calc'd BH Press (psi)	
			Avg	Max	Avg	Max	Avg	Max
Pre-pad	1,000	2,474	13.2	25.7	721	2,519	10,333	10,499
Pad-1	3,000	3,030	28.3	30.6	5,696	6,377	10,545	10,571
Pad-2+Biovert	5,000	5,213	30.7	30.7	5,658	6,096	10,513	10,563
1 ppg Prop Slug	2,000	2,013	30.5	30.6	5,843	5,879	10,503	10,510
Pad-3	20,000	20,022	30.6	30.7	5,849	5,964	10,597	10,789
SLF 1	10,000	10,025	30.3	30.7	5,778	5,910	10,855	11,305
Spacer	420	427	30.7	30.7	5,714	5,721	11,031	11,165
SLF 2	428	539	30.5	30.6	5,712	5,727	11,048	11,169
Spacer	420	403	30.6	30.6	5,741	5,751	11,031	11,165
SLF 2	428	391	30.5	30.6	5,761	5,779	11,048	11,169
Spacer	420	402	30.6	30.6	5,782	5,789	11,031	11,165
SLF 2	428	501	30.4	30.6	5,783	5,798	11,048	11,169
Spacer	420	443	30.6	30.6	5,808	5,816	11,031	11,165
SLF 2	428	444	30.4	30.5	5,807	5,831	11,048	11,169
Spacer	420	444	30.6	30.6	5,840	5,848	11,031	11,165
SLF 2	428	461	30.5	30.6	5,841	5,860	11,048	11,169
Spacer	420	402	30.5	30.6	5,871	5,880	11,031	11,165
SLF 2	428	463	30.4	30.5	5,885	5,897	11,048	11,169
Spacer	420	422	30.5	30.5	5,912	5,919	11,031	11,165
SLF 2	428	64	30.5	30.5	5,920	5,920	11,048	11,169
Spacer	420	64	30.5	30.5	5,920	5,920	11,031	11,165
SLF 2	428	64	30.5	30.5	5,921	5,921	11,048	11,169
Spacer	420	85	30.5	30.5	5,922	5,922	11,031	11,165
SLF 2	428	64	30.5	30.5	5,924	5,924	11,048	11,169
Spacer	420	64	30.5	30.5	5,927	5,928	11,031	11,165
SLF 2	428	64	30.5	30.5	5,930	5,931	11,048	11,169
Spacer	420	85	30.5	30.5	5,934	5,935	11,031	11,165
SLF 2	428	64	30.5	30.5	5,937	5,938	11,048	11,169
Spacer	420	64	30.5	30.5	5,941	5,942	11,031	11,165

PILLAR HYDRAULIC FRACTURING USING PULSED OR CYCLED PROPANT FRACTURE (CONDUCTOR FRAC)

SLF 2	428	64	30.5	30.5	5,944	5,945	11,048	11,169
Spacer	420	64	30.5	30.5	5,947	5,948	11,031	11,165
SLF 2	428	85	30.5	30.5	5,952	5,953	11,048	11,169
Spacer	420	64	30.6	30.7	5,956	5,957	11,031	11,165
SLF 2	428	43	30.7	30.7	5,960	5,961	11,048	11,169
Spacer	420	452	30.7	30.7	5,973	5,982	11,031	11,165
SLF 2	428	702	29.1	30.7	5,855	6,218	11,048	11,169
Spacer	420	355	30	30.2	6,000	6,159	11,031	11,165
SLF 2	428	449	29.2	29.6	5,904	5,955	11,048	11,169
Spacer	420	416	30	30.1	6,013	6,021	11,185	11,397
SLF 3	434	359	29.6	29.8	5,973	6,010	11,213	11,424
Spacer	420	416	30.1	30.2	6,045	6,052	11,185	11,397
SLF 3	434	538	30	30	6,013	6,023	11,213	11,424
Spacer	420	416	30.1	30.1	6,044	6,051	11,185	11,397
SLF 3	434	429	30.1	30.1	6,045	6,065	11,213	11,424
Spacer	420	438	30.3	30.3	6,086	6,095	11,185	11,397
SLF 3	434	464	30.2	30.3	6,086	6,106	11,213	11,424
Spacer	420	438	30.3	30.3	6,129	6,143	11,185	11,397
SLF 3	434	428	30.2	30.3	6,116	6,130	11,213	11,424
Spacer	420	417	30.2	30.3	6,129	6,138	11,185	11,397
SLF 3	434	485	30.1	30.2	6,038	6,050	11,213	11,424
Spacer	420	417	30.2	30.2	5,989	6,021	11,185	11,397
SLF 3	434	448	30.1	30.2	5,887	5,896	11,213	11,424
Spacer	420	436	30.2	30.2	5,868	5,876	11,185	11,397
SLF 3	434	449	30.2	30.2	5,809	5,812	11,213	11,424
Spacer	420	438	30.2	30.3	5,819	5,822	11,185	11,397
SLF 3	434	448	30.1	30.2	5,812	5,819	11,213	11,424
Spacer	420	438	30.2	30.3	5,821	5,822	11,185	11,397
SLF 3	434	428	30.2	30.2	5,794	5,806	11,213	11,424
Spacer	420	436	30.2	30.3	5,813	5,817	11,185	11,397
SLF 3	434	449	30.1	30.2	5,800	5,813	11,213	11,424
Spacer	420	437	30.2	30.3	5,827	5,838	11,185	11,397
SLF 3	434	448	30.2	30.2	5,836	5,849	11,213	11,424
Spacer	420	438	30.3	30.4	5,858	5,864	11,185	11,397

SLF 3	434	453	30.5	30.6	5,861	5,869	11,213	11,424
Spacer	420	444	30.7	30.7	5,878	5,887	11,185	11,397
SLF 3	434	473	30.6	30.7	5,885	5,896	11,213	11,424
Spacer	420	402	30.7	30.7	5,907	5,915	11,423	11,509
SLF 4	443	474	30.5	30.7	5,903	5,916	11,438	11,536
Spacer	420	441	30.6	30.7	5,926	5,935	11,423	11,509
SLF 4	443	467	30.6	30.7	5,931	5,943	11,438	11,536
Spacer	420	442	30.7	30.7	5,954	5,959	11,423	11,509
SLF 4	443	462	30.6	30.7	5,943	5,952	11,438	11,536
Spacer	420	442	30.6	30.7	5,963	5,976	11,423	11,509
SLF 4	443	462	30.6	30.7	5,947	5,959	11,438	11,536
Spacer	420	442	30.7	30.7	5,976	5,983	11,423	11,509
SLF 4	443	476	30.3	30.7	5,919	5,964	11,438	11,536
Spacer	420	432	30	30.1	5,932	5,949	11,423	11,509
SLF 4	443	450	29.8	29.9	5,900	5,915	11,438	11,536
Spacer	420	452	29.8	29.9	5,944	5,958	11,423	11,509
SLF 4	443	467	29.8	29.9	5,928	5,949	11,438	11,536
Spacer	420	452	29.8	29.8	5,951	5,963	11,423	11,509
SLF 4	443	467	29.7	29.8	5,935	5,952	11,438	11,536
Spacer	420	452	29.8	29.8	5,976	5,988	11,423	11,509
SLF 4	443	468	29.8	29.8	5,958	5,980	11,438	11,536
Spacer	420	431	29.9	29.9	5,993	6,009	11,423	11,509
SLF 4	443	467	29.8	29.8	5,956	5,972	11,438	11,536
Spacer	420	452	29.8	29.9	5,973	5,986	11,423	11,509
SLF 4	443	448	29.8	29.8	5,938	5,962	11,438	11,536
Spacer	420	452	29.8	29.8	5,962	5,975	11,423	11,509
SLF 4	443	465	29.8	29.8	5,926	5,950	11,438	11,536
Spacer	420	452	29.8	29.9	5,956	5,969	11,460	11,593
SLF 4	422	441	29.8	29.9	5,931	5,947	11,482	11,654
Spacer	420	410	29.8	29.9	5,967	5,985	11,460	11,593
SLF 4	422	444	29.8	29.8	5,933	5,955	11,482	11,654
Spacer	420	427	29.8	29.9	5,979	5,991	11,460	11,593
SLF 4	422	444	29.8	29.8	5,953	5,972	11,482	11,654
Spacer	420	428	29.8	29.8	5,992	6,006	11,460	11,593

PILLAR HYDRAULIC FRACTURING USING PULSED OR CYCLED PROPANT FRACTURE (CONDUCTOR FRAC)

SLF 4	422	425	29.8	29.8	5,956	5,979	11,482	11,654
Spacer	420	429	29.8	29.8	5,994	6,007	11,460	11,593
SLF 4	422	443	29.8	29.8	5,977	5,989	11,482	11,654
Spacer	420	429	29.8	29.8	6,005	6,022	11,460	11,593
SLF 4	422	444	29.8	29.8	5,984	5,998	11,482	11,654
Spacer	420	409	29.8	29.8	6,011	6,027	11,460	11,593
SLF 4	422	464	29.8	29.8	6,005	6,020	11,482	11,654
Spacer	420	430	29.8	29.8	6,033	6,048	11,460	11,593
SLF 4	422	446	29.8	29.8	6,017	6,035	11,482	11,654
Spacer	420	427	29.8	29.8	6,051	6,065	11,460	11,593
SLF 4	422	446	29.8	29.8	6,046	6,061	11,482	11,654
Spacer	420	428	29.8	29.8	6,076	6,092	11,752	11,878
SLF 5	434	462	29.7	29.8	6,017	6,036	11,789	11,941
Spacer	420	427	29.8	29.8	5,988	6,006	11,752	11,878
SLF 5	434	437	29.7	29.7	5,955	5,975	11,789	11,941
Spacer	420	447	29.7	29.7	5,969	5,973	11,752	11,878
SLF 5	434	451	29.7	29.7	5,949	5,962	11,789	11,941
Spacer	420	447	29.7	29.7	5,945	5,979	11,752	11,878
SLF 5	434	450	29.7	29.7	5,934	5,944	11,789	11,941
Spacer	420	426	29.7	29.7	5,963	5,990	11,752	11,878
SLF 5	434	431	29.7	29.7	5,950	5,962	11,789	11,941
Spacer	420	447	29.7	29.7	5,980	6,006	11,752	11,878
SLF 5	434	450	29.7	29.7	5,964	5,976	11,789	11,941
Spacer	420	447	29.7	29.7	5,997	6,011	11,752	11,878
SLF 5	434	432	29.7	29.7	5,977	5,991	11,789	11,941
Spacer	420	447	29.7	29.7	6,009	6,032	11,861	11,943
SLF 6	456	465	29.7	29.7	6,001	6,020	11,881	11,963
Spacer	420	446	29.7	29.7	6,038	6,058	11,861	11,943
SLF 6	456	472	29.7	29.7	6,013	6,031	11,881	11,963
Spacer	420	443	29.7	29.7	6,054	6,078	11,861	11,943
SLF 6	456	454	29.7	29.7	6,028	6,052	11,881	11,963
Spacer	420	443	29.7	29.7	6,071	6,092	11,861	11,943
SLF 6	456	476	29.7	29.7	6,036	6,066	11,881	11,963
Spacer	420	427	29.7	29.7	6,088	6,106	11,861	11,943

SLF 6	456	482	29.7	29.7	6,068	6,093	11,881	11,963
Spacer	420	448	29.7	29.7	6,104	6,119	11,820	11,940
SLF 7	475	493	29.7	29.7	6,097	6,133	11,800	11,934
Spacer	420	445	29.7	29.7	6,132	6,151	11,820	11,940
SLF 7	475	485	29.7	29.7	6,117	6,145	11,800	11,934
Spacer	420	443	29.6	29.7	6,156	6,173	11,820	11,940
SLF 7	475	499	29.6	29.7	6,143	6,169	11,800	11,934
Spacer	420	424	29.6	29.7	6,155	6,175	11,820	11,940
SLF 7	475	501	29.7	29.7	6,148	6,187	11,593	11,625
Spacer	420	444	29.7	29.7	6,117	6,182	11,348	11,568
SLF 7 Tail-in	1,500	1,448	29.5	29.7	5,983	6,044	-	-
Flush	8,938	8,887	29.8	29.9	6,175	6,518	-	-
Shut-in	-	-	-	-	-	-	-	-

6) Gel Samples:

MiniFrac

Crosslinked Gel Samples	Broken Gel Samples
	

Main Treatment

Crosslinked Gel Samples	Broken Gel Samples