NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
THE DEPARTEMENT OF PETROLEUM AND NATURAL GAS ENGINEERING

HYDRAULIC FRACTURE MODELING IN A FINING UPWARD MIDDLE EAST CARBONATE RESERVOIR

M.Sc. THESIS

GRACE PREDY MOUANDA BAKA

Nicosia

JUNE, 2022

GRACE PREDY MOUANDA BAKA

HYDRAULIC FRACTURE MODELING IN A FINING UPWARRD MIDDLE EAST CARBONATE RESERVOIR

Nicosia June, 2022

NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
THE DEPARTEMENT OF PETROLEUM AND NATURAL GAS ENGINEERING

HYDRAULIC FRACTURE MODELING IN A FINING UPWARD MIDDLE EAST CARBONATE RESERVOIR

M.Sc. THESIS

GRACE PREDY MOUANDA BAKA

Supervisor
Prof. Dr. Salih SANER

Nicosia

JUNE, 2022

Approval

We certify that we have read the thesis submitted by Grace Predy MOUANDA BAKA titled **Hydraulic Fracture Modeling in a Fining upward Carbonate Reservoir** and that in our combined opinion it is a fully adequate, in scope and in quality, as a thesis for the degree of Master of Applied Sciences.

Examining Committee	Name-Surname	Signature
Head of the committee:	Prof. Dr. Cavit ATALAR	....
Committee Member:	Assoc. Prof. Dr. Kamil DİMİLİLER	....
Supervisor:	Prof. Dr. Salih SANER	....

Approved by the Head of the Department

27/04/2022

....

Prof. Dr. Cavit ATLAR

Head of Department

Approved by the Institute of Graduate Studies

...../...../2022

Prof. Dr. Kemal Husnu Can Baser

Head of the Institute

Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of institute of graduate studies, Near East University, I also declare that as required by these rules an conduct, I have fully cited and referenced information and data that are not original to this study.

Grace Predy MOUANDA BAKA

27/06/2022

Acknowledgments

It is often difficult to find the right words to express gratitude. Thank you, a term of inestimable semantic richness, is the only word that comes to mind. My sincere thanks to Near East University for giving me the opportunity to carry out my graduate studies in petroleum and natural gas engineering. I would like to thank Prof. Dr. Cavit ATALAR, the head of petroleum and natural gas department in Near East University, for agreeing to chair this jury and to examine this work rigorously. I express to you here the expression of my deep gratitude. A special mention is given to Prof. Dr. Salih SANER, my thesis supervisor who, through his rigor, his requirements, and his many advices, allowed me to carry out this work. Dear supervisor, be grateful. I would like also to thank Assoc. Prof. Dr. Kamil DİMİLİLER, committee member, for accepting to be among the examining Committee member and his contribution to improve this thesis. I warmly thank all the teachers of petroleum and natural gas department for their advices and contribution to this work. My thanks also go to my classmates for their assistance in this manuscript.

Grace Predy MOUANDA BAKA

Abstract

Hydraulic Fracture Modeling in a Fining Upward Middle East Carbonate Reservoir

MOUANDA BAKA, Grace Predy

M.Sc, Department of Petroleum and Natural Gas Engineering

June, 2022, 54 Pages

Using FRACPRO to study hydraulic fracturing to fracturing carbonate deposits in the Middle East is important for increasing the productivity of oil and gas in the region. FRACPRO is software for predicting fracture behavior and well productivity during reservoir fracturing.

The data used in this study, the purpose of which is to use FRACPRO to create a hydraulic fracturing model, analyze fracture geometry, proppant conductivity, and use different scenarios to select the case that gives the best estimate of final production to Increased productivity of these reservoirs were obtained from publications available in the literature.

The study focuses on a hydraulic fracturing design process and fracture analysis, including reservoirs parameters, fluid and proppant selection, and treatment planning. This study shows that the geometry of the fracture is dependent on the properties of the formation and its petrophysical properties, proppant conductivity tends to zero in high permeable layers. To fracture the all reservoir thickness of Arab-C in the Abqaiq field using Frac sand 20/40 it needs about 5.9klbs of proppant, 571.4bbls of clean volume and 577.8bbls of slurry. The average permeability before the fracture treatment is 30mD and after treatment, the average conductivity has considerably increased to 506.4mD-ft. Net pressure, fracture slurry efficiency and average fracture, fracture half-length width after treatment are respectively 300psi, 0.61, 0.179in, 152.1ft. At the end of the treatment, the generated fracture occures at the 7080.6ft from the surface and the total fracture thickness is 89.4ft.

Keywords: hydraulic fracturing, modeling, fining upward, carbonate reservoir.

ÖZET

Yukarı Doğru Orta Doğu Karbonat Rezervuarında İnce Bir Şekilde Hidrolik Kırılma Modellemesi

MOUANDA BAKA, Grace Predy

M.Sc, Petrol ve Doğal Gaz Mühendisliği Bölümü

Haziran, 2022, 54 Sayfa

Orta Doğu'daki karbonat rezervlerini kırmak için FRACPRO aracılığıyla hidrolik kırılma çalışması, bu alanda petrol ve gazın verimliliğini artırmak için çok önemlidir. FRACPRO, rezervuarı kırarken kuyunun verimliliğini ve kırılma davranışını tahmin etmek için kullanılan bir rezervuar yazılımıdır.

Bu rezervuarların verimlilik oranını artırmak için FRACPRO kullanarak hidrolik kırılma modelleri oluşturmayı, kırılma geometrilerini, propant iletkenliğini analiz etmeyi ve farklı senaryolar kullanarak optimum tahmini geri kazanımı (EUR) veren durumu seçmeyi amaçlayan bu çalışmada kullanılan veriler, bu rezervuarların verimlilik oranını artırmak. literatürdeki yayınlardan elde edilmiştir.

Çalışma, rezervuar parametrelerini, sıvı ve propant seçimini ve tedavi programını içeren bir hidrolik kırılma tasarım prosedürüne ve kırılma analizine odaklanmaktadır. Bu çalışmanın sonucu, kırılma geometrisinin kayanın doğasına ve petrofiziksel özelliklerine bağlı olduğunu, propant iletkenliğinin yüksek geçirgen katmanlarda sıfır olma eğiliminde olduğunu göstermektedir. Abqaiq sahasının tüm rezervuar kalınlığını Frac kumu 20/40 kullanarak kırmak için yaklaşık 5.9 klb proppanta, 571.4 bbl temiz hacme ve 577.8 bb bulamaca ihtiyaç vardır. Kırık tedavisi öncesi ortalama geçirgenlik 30mD'dir ve tedaviden sonra ortalama iletkenlik önemli ölçüde 506.4mD-ft'ye yükselmiştir. Net basınç, kırılma bulamacı verimliliği ve ortalama kırılma, kırık yarı uzunluk genişliği sırasıyla 300psi, 0.61, 0.179 inç, 152.1 ft'dir. Kırılma 7080.6 ft derinlikte görülür ve toplam kırılma yüksekliği 89.4 ft'dir.

***Anahtar Kelimeler*:** hidrolik kırılma, modelleme, yukarı doğru inceltme, karbonat rezervuarı.

Table of Contents

CHAPTER III

CHAPTER IV

CHAPTER V

List of Tables

List of Figures

List of Abreviatıons

Bbls: Barrel

Klb: Kilo pound

In: Inch

mD: milli Darcy

p_a: Pascal

E_{dyn}: Dynamic Young's modulus

E_{sta}: Static Young's modulus

υ_{sta}: Static Poisson's ratio

V_p: Compression velocity

V_s: Shear velocity

B_r: Brittleness

σ_n: Normal stress

σ_H: Maximum horizontal stress

σ_h: Minimum horizontal stress

ϕ: Porosity

K: Permeability

mD-ft: Milli-Darcy per foot

T_o: Tensile stress

P_i: Induce fracture pression

P_p: Pore press

CHAPTER I

Introduction

In petroleum industry, certain parameters such as permeability and porosity determine the productivity of the reservoir. In low permeability reservoir such as in tight and unconventional reservoirs, we cannot produce naturally a commercial amount of oil and it is a big challenge for the field to face.

Carbonate reservoirs exist in every continent and the majority of them is found in the Middle East, especially in the area of Arabian/Persian Gulf , in this area carbonate reservoir represent 80% and 90% respectively of oil and gas reserves (Total, 2009).

Nowadays the most common technique used to improve the permeability of tight reservoir is hydraulic fracturing. This technique consists of injecting a very high pressure fluid made up of water, proppant and chemicals into the reservoir in order to allow oil and gas to reach the surface at economic rates (Rahim, 2017).

Hydraulic fracturing is the process of breaking up rock formations with a water-based fluid. Generally, hydraulics is a subject of applied and engineering sciences that deals with the mechanical properties of liquids (Luca & Ulrik, 2015). There are four families of fracturing fluids: water-based fluids, oil-based fluids, acid-based fluids, and foam fluids.

When the fracturing the formation, the crack propagates perpendicular to the minimum horizontal stress. For a vertical well, the minimum horizontal stress can be estimated as follows:There are four families of fracturing fluid: water-based fluids, oil-based fluids, acid-based fluids and foam fluids.

When fracturing a formation, fractures propagate perpendicular to the minimum horizontal stress. In case of a vertical well, this minimum horizontal stress can be estimated as:

$$\sigma_x = \frac{\nu}{1-\nu}(\sigma_z - \alpha p_p) + \alpha p_p + \sigma_{ext} \tag{1}$$

Where:

ν: Poisson's ratio

σ_z: Overburden stress

α: Biot's poro-elastic constant

p_p: Reservoir pore pressure

σ_{ext}: Tectonic stress

Hydraulic fracturing is used in both vertical and horizontal wells in case of low permeability conventional reservoirs, unconventional tight reservoirs, and unconventional shale reservoirs. Figure 1 below shows horizontal versus vertical stimulation (Soliman, 2020). Hydraulic fracturing helps to improve the flow rate of oil and/or gas from low-permeability reservoirs, improve the flow rate of oil and/or gas from damaged wells, link the native fractures in a formation to the wellbore, decrease the pressure drop around the well to minimize sand production, improve gravel-packing and sand placement.

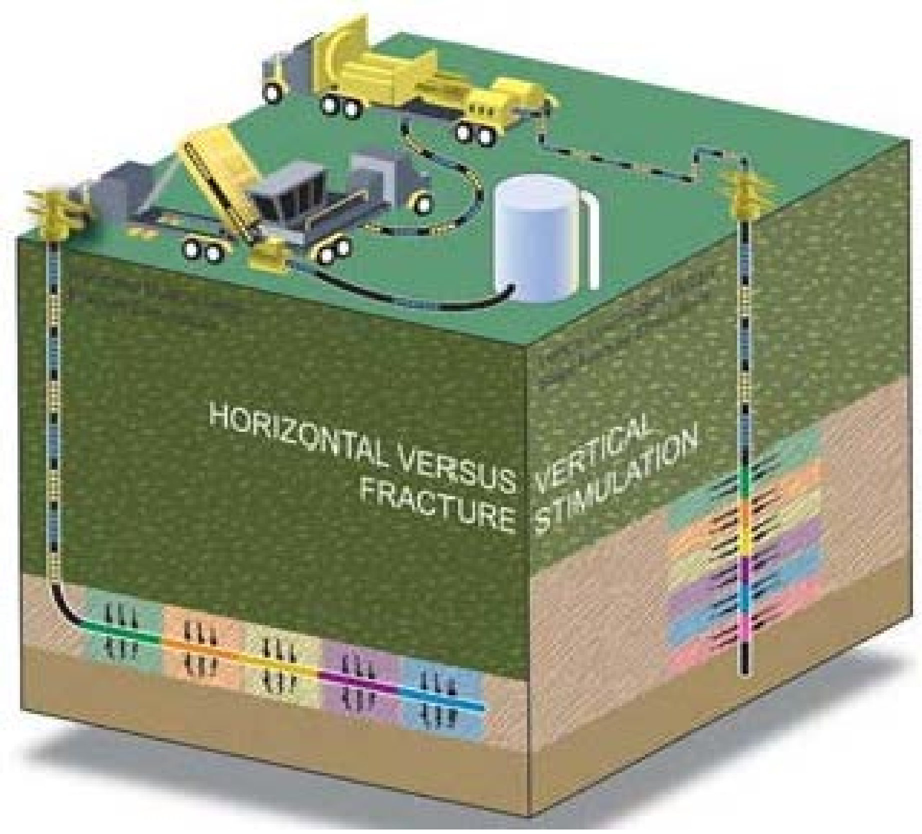


Figure 1. Horizontal versus vertical fracture stimulation (Soliman, 2020).

When decided to fracture a reservoir to increase production rate, there are lots of considerations that the engineer has to take into account: the fluid used; the proppant used; the pressure used; the numbers of fractures; how far the fracture goes; the time used to fracture and the amount of oil to produce.

When fracturing a well, one of the main challenge is the high fracture gradient due probably to near-wellbore tortuosity, damage induce by the drilling fluid, high buildup of filter cake, or far-field tectonics (Rahim, 2019).

With regard to formation type, permeability or location, the use of FRACPRO can provide understanding fracture design, analysis and controlling functions to improve efficiency fracture geometry, proppant conductivity, contact area, spacing, estimated ultimate recovery and economic performance of any formation type and help engineers improve productivity, reservoir recovery and economic benefits.

Statement of the Problem

In the nature there are oil and gas reservoirs that cannot naturally produce economic quantity of oil and/or gas so these reservoirs need a specific treatment. Carbonate reservoirs are heterogenenous in terms of porosity and permeability, there fore it need a specific treatment to connect pore and increase the permeability. In petroleum industry today the most common technique used is hydraulic fracturing.

Purpose of the Study

The purpose of this research study is to fracture a reservoir using FRACPRO; analysis and controlling functions to enhance effiency fracture geometry, proppant conductivity, using different scenarios to select the optimum estimated ultimate recovery (EUR).

Research Questions/Hypotheses

Instead of super high-quality reservoirs which produce normally without stimulation, reserves today are mostly found in tight and unconventional reservoir that need to be fractured to produce oil in commercial quantity (Rahim, 2017).

Since it can be hard to foretell production of oil and gas in carbonate reservoirs because of their heterogeneities in permeability and porosity, recovery in carbonate reservoir must be taken with great consideration.

However carbonate reservoirs are familiar but some characteristics of these rocks make the recovery of oil they contained very difficult. Such reservoirs need to be stimulated with the aim of maximizing the production rate of oil and gas they hold. Hydraulic fracturing appears today as the best stimulation solution to solve this problem.

In this research a vertical well model is investigated. The key questions are: What is the minimum pressure required to fracture the formation? How far from the wellbore fractures propagate? In which direction fractures are propagated? How much is the production rate? How to maintain induced fractures open to let fluid to flow easily. These and others controversial pertinent aspects of hydraulic fracturing are what this research study will focus on.

Significance of the Study

The findings of this research study will serve to the benefit of the science and technology considering that hydraulic fracturing by the use of FRACPRO is very important to improve the productivity of oil and/or natural gas in the reservoir. The great demand and the price grow up of oil and natural gas today justifies the use of hydraulic fracturing to maximize the productivity of the reservoir. So companies or organizations that apply the recommended approach derived from the results of this study will be able to improve their productivity and make more profit in a few as regards to the normal situation without using hydraulic fracturing simulation. Engineers will be guide by the methodology of use in this research study to improve the recovery of oil and/or gas of their firms.

Limitations

Since the geology of the Middle East is inclusively constituted by carbonate and anhydrite and the petrophysical characteristics vary widely so the result of this research study is only limited in carbonate reservoir with petrophysical characteristics use.

CHAPTER II

Literature Review

Geology and Basic Characteristics of Carbonate Reservoir

Carbonate reservoirs are reservoirs made up by porous and permeable carbonate rocks which contain oil and/or gas in commercial quantity. They are characterized by a highly heterogeneity in their permeability and porosity due to the combination of large variety of sediment during the depositional period and diagenesis.

There are lots of carbonate reservoirs around the world and most of them are found in Middle East especially the area bordering the Arabia/Persian Gulf as show in the Figure 2.

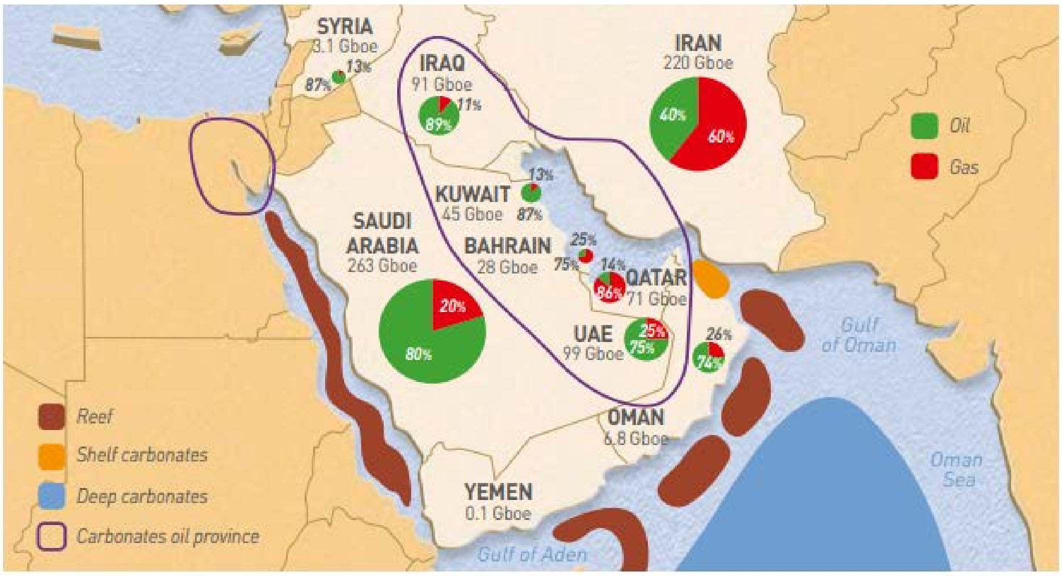


Figure 2. Carbonate reservoirs in Arabia/Persia Gulf (Total, 2009).

Geological Characteristics of Arab-C Reservoir

The Arab-C carbonate reservoir is a member of Arab carbonate reservoir formation of Kimmeridgian-Tithonian age in upper Jurassic. It consists of about 100 ft of carbonate comprises between two anhydrite layers. This formation is characterized by four different types of lithology named for the present study A (anhydrite), B (oolitic grainstone), C (pellet packstone), D (dolomite) that alternate into nine layers A, B, C, B, C, D, A, D, A (Saner & Abdulghani, 1995).

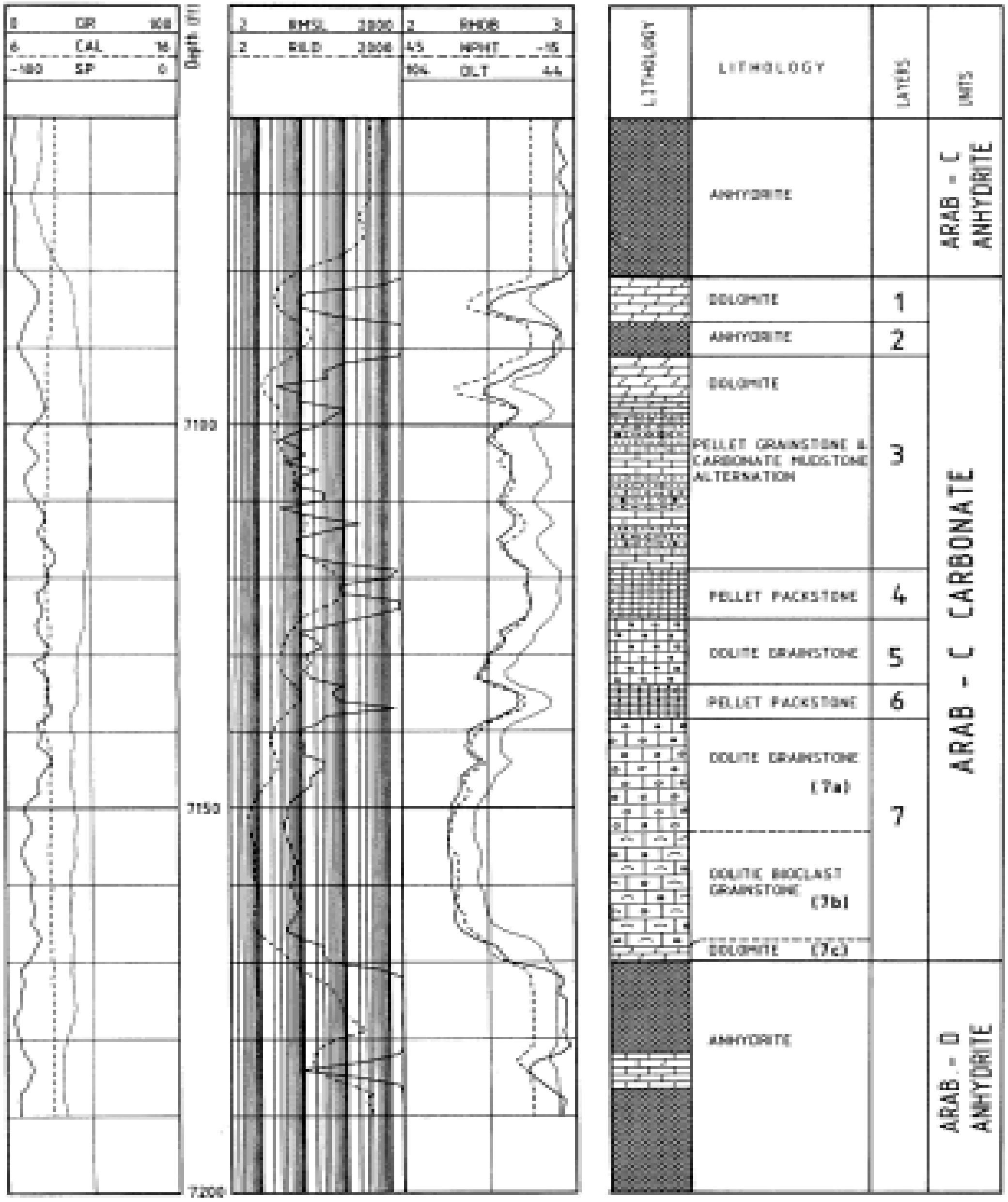


Figure 3. Typical composite lithological column of the Arab-C carbonate (Saner & Abdulghani, 1995).

Petrophysical Characteristic of Arab-C Carbonate Reservoir

In the Arab-C carbonate Reservoir, porosity and permeability decrease from the bottom to the top of the reservoir and their higher values are register in the oolitic grainstone layers (Saner and Abdulghani, 1995). Table 1 below shows the petrophysical characteristics of the Arab-C.

Table 1.

Petrophysical parameter of the Arab-C.

Thickness (ft)	Thickness (ft)	Lithology	Porosity (%)	Permeability (mD)
0-7080	708	Anhydrite	0	0.20
7080-7086	6	Dolomite	12.5	16.63
7086-7091	5	Anhydrite	0	0.20
7091-7097	6	Dolomite	12.5	16.63
7097-7118	21	Pellet grainstone and carbonate mudstone alteration	5	1.19
7118-7125	7	Pellet packstone	0	0.20
7125-7134	9	Oolite grainstone	15	39.95
7134-7138	4	Pellet packstone	0	0.20
7138-7170	32	Oolite grainstone	22.5	553.85
7170-7182	12	Anhydrite	0	0.20

History of Hydraulic Fracturing

The process of fracturing unconventional reservoirs to increase well productivity has a long history. Firstly from 1890-1960, the process used explosives to fracture the formation. Secondly acids were used to create paths in the reservoir. Nowadays hydraulic fracturing is the technique widely selected to break down rock formation and create path in the reservoir. Hydraulic fracturing has been used for the first time in the Hugoton field in Grant County, Kanas, Kelpper Well No.1 (Sergiu, 2004).

Data Required for Hydraulic Fracturing

There are two kinds of data required to hydraulically fracturing the reservoir, data to be obtained and data to be controlled. The first one is obtained from well log and well test such as permeability, formation depth, layers thickness, lithology and the mechanical characteristics of layers which also generated by FRACPRO software. The second one ıs the data that engineer have to control they are: injection rate, clean volume, slurry volume, proppant concentration, propping agent type.

Log Analysis Techniques

Log analysis technics consists of the record of depth versus measured parameter during the voyage of well log tool in the wellbore. Hydraulic fracturing used data from sonic log, density log, and gamma ray log.

Sonic Measurements

Sonic logging tool emits a sound wave that travels from the source to the formation and back to a receiver which is at a few feet from the transmitter. It records the depth versus Δt transit time. Sonic log is used for: porosity measurement, mechanical rock properties measurement, lithology determination and correlation, fracture determination, cement bond evaluation, borehole and casing inspection, seismic calibration, abnormal formation pressure detection and gas-bearing formations identification.

Density Measurements

The process of measuring formation density can be subdivided into 3 steps: 1) the collision between gamma ray energy emitted with the electrons of the formation; 2) loose of energy by gamma ray to electrons and continues with diminish energy(Compton scattering); 3) gamma ray with diminished energy which reached the detectors are counted as indication of formation density. Density log is used for: porosity measurement, lithology determination, determination of hydrocarbon density, gas detection, evaluation of shaly sands and complex lithologies, determination of oil-shale –yield.

Gamma Ray Measurements

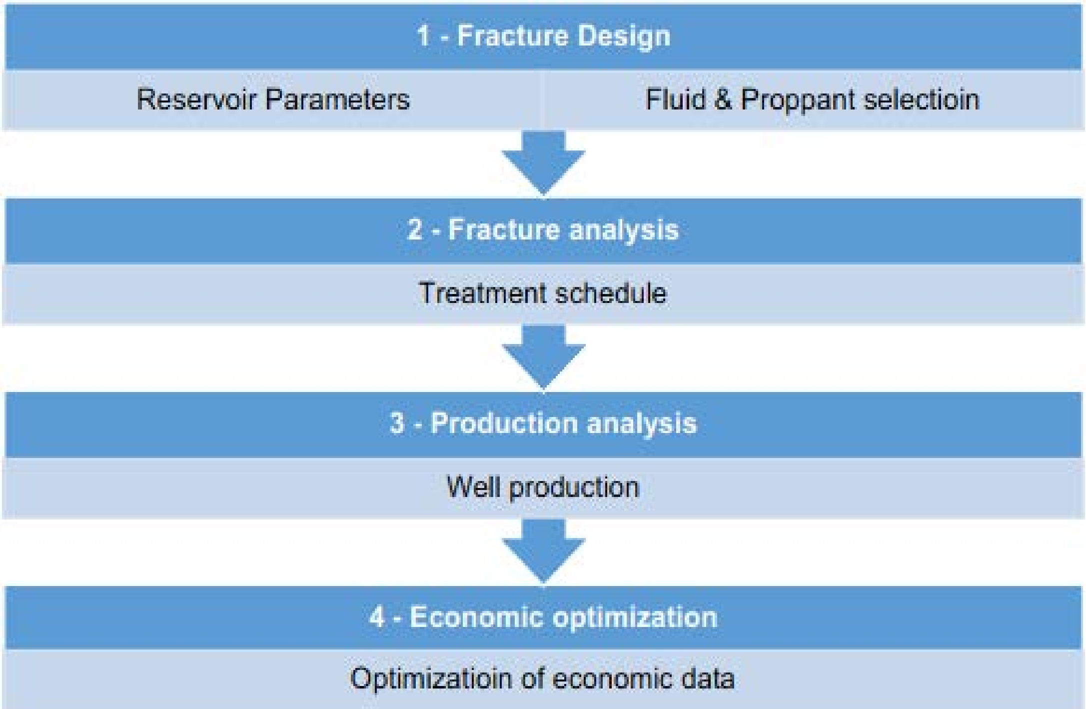
Gamma ray log consists of the measurement of natural radioactivity of the formation. It is used to determine, correlation, and to calculate the volume of shale. There is no source of gamma ray in gamma ray tool it contains only a detector. Gamma ray logs are usually paired with resistivity or neutron logs.

Hydraulic Fracturing Treatment Using FRACPRO

Hydraulic fracturing treatment consist to create fracture in rock formation by using fluids and proppants to enhance the productivity rate of oil and natural gas. There are four modes of operation when using FRACPRO to stimulate the reservoir: fracture design, fracture analysis, production analysis and economic optimization as show in the Table 2 below.

Table 2.

Modes of operation of achieving hydraulic fracturing (Humoodi, et al., 2019).



Fracture Design

Fracture design deals with two principals domains: reservoir characterization, fluid type and proppant selection. Fluid type and propping agent are key components of hydraulic fracturing design. The fluid selected have to : match with formation rock and fluid, bring enough pressure to create path, be competent to carry the proppant to the path, break back to a low-viscosity fluid, be low-cost. There are four family of fracture fluid: water-based fluids, oil-based fluids, acid-based fluid and foam fluids. The most important characteristics of fracturing fluid is viscosity. High viscosity creates wide fracture and low viscosity small fracture or not. The role of propping agent is to maintain the fracture open after the treatment. There are five proppant characteristics that determine the conductivity of the fracture: proppant strength, grain size and grain size distribution, quality of the proppant, roundness and sphericity, proppant density (Sergiu, 2004).

The most important reservoir characteristics in hydraulic fracture design are petrophysical (porosity and permeability) and mechanical characteristics. There are five main parameters that characterize the mechanics of the rock: Young's modulus, Poisson's ratio, fracture toughness and fluid loss coefficient.

Young's modulus: is the rock mechanical characteristics that express how easy the rock can stretch and deform. Young's modulus is classified into two types: dynamic and static. There is a relation between dynamic Young's modulus (E_{dyn}) (P_a), rock density, compression (V_p) (m/s), and shear wave velocity (V_s) (m/s) as show in equation 2 below (Bakhshi, et al., 2021).

$$E_{dyn} = \frac{\rho V_s^2\ (3V_p^2\ - 4V_s^2)}{V_p^2 - V_s^2} \tag{2}$$

And the static Young's modulus can be determined based on equation 3 below:

$$E_{sta} = 0.7E_{dyna} \tag{3}$$

Poisson's ratio: is a dimensionless rock mechanical characteristics that measure the deformation in direction of the applied force. It does not have unit and has value from 0.1 to 0.5. Low Poisson's ratio from 0.1 to 0.25 means that rocks fracture easier whereas high Poisson's ratio from 0.35 to 0.45 indicates that the rocks are harder to fracture. The best formations to hydraulically fracture have the lowest Poisson's ratios (Belyadi, et al., 2019). Poisson's ratio depends on lithology, confining stress, pore pressure and porosity. The dynamic Poisson's ν_{dyna} ratio is in relation with compression (V_p) (m/s), and shear wave velocity (V_s) (m/s) as show in equation 3 bellow (Bakhshi, et al., 2021).

$$\nu_{dyn} = \frac{(V_p^2\ - 2V_s^2)}{2(V_p^2 - V_s^2)} \tag{4}$$

And the static Poisson's ratio ν_{sta} can be determined based on equation 5 bellow:

$$\nu_{sta} = \nu_{dyna} \tag{5}$$

Fracture toughness: is a rock mechanical characteristics that determine the resistance of a material to fracture when enduring a crack. To determine the fracture toughness, two methods are used. The direct method using mechanical experiments and the indirect method which consist to measure the toughness of the rock using the relation between the fracture toughness and the tensile strength. Figure 4 below shows the relation between fracture toughness and the tensile strength (Li, et al., 2019).

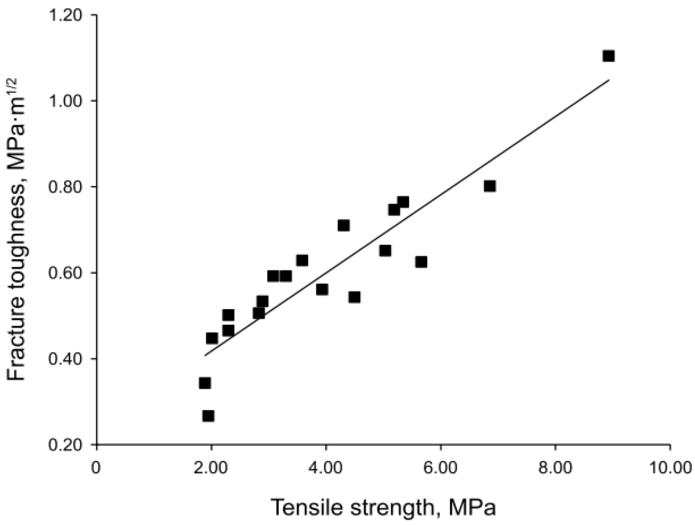


Figure 4. Fracture toughness versus strength in different material (Li, et al., 2019).

Leakoff coefficient: a technic of hydraulic fracturing consist to pumped fluid into a formation target zone (permeable rock even if it is a low permeable zone). Because of the rock permeability, certain amount of fluid will be lost into a formation, this phenomena is called leak-off coefficient. It was demonstrated that the presence of natural fracture has significant impact in fluid leak-off. The Figure 5 below illustrates the schematic view of leak-off zones in homogeneous reservoirs (Liu, et al., 2016).

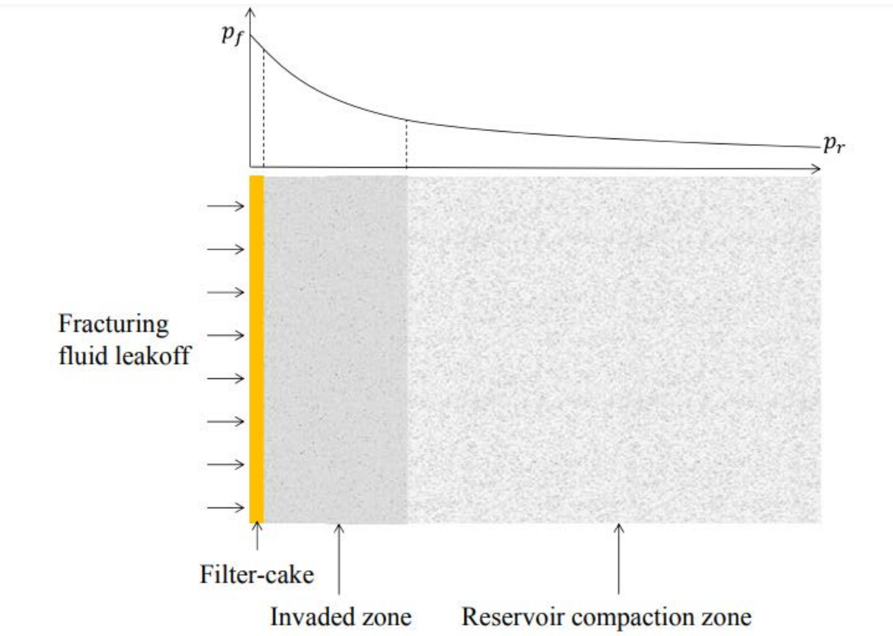


Figure 5. Leak-off zones in homogeneous reservoirs (Liu, et al., 2016).

Fracture analysis

This step consists of the selection of the optimum flow rate, optimum clean volume, proppant concentration and fluid type and proppant type. This step is also called treatment schedule and generally can be divided into three main stages: pad stage, slurry stage, and flush stage as indicted in the Table 3 below.

Table 3.

Fracture analysis treatment schedule (Sergiu, 2004).

No	Stage	Volume (gal)	Rate (bbl/min)	Starting Proppant Conc (ppg)	Final Proppant Conc (ppg)	Fluid Type
1	Pad	21598	20	-	-	HL_HYB_30_1
2	Slurry	4773	20	1.5	1.5	HL_HYB_30_1
3	Slurry	4773	20	3	3	HL_HYB_30_1
4	Slurry	9546	20	4.5	4.5	HL_HYB_30_1
5	Slurry	11932	20	6	6	HL_HYB_30_1
6	Slurry	14318	20	7.5	7.5	HL_HYB_30_1
7	Flush	2150	20	-	-	SLICKWATER

In the fracture analysis treatment schedule table above, there are seven stages: one pad stage, five slurry stages, and one flush stage. Each stage correspond to the specific volume of fluid, proppant concentration and the constant injection rate.

The stage pad consist to inject fluid into the formation to break down the formation and create a fracture. The slurry stage consists of the injection of the mixture proppant and fluid into the fracture. In the last stage, flush stage fluid is pumped into the well to clean tubing and/or casing from the remaining slurry of the slurry stage.

Fracture Growth, Orientation, and Geometry

It is very important to understand the growth and the orientation of the fracture when fracturing a reservoir. In hydraulic fracturing, all fractures propagate orthogonal to the minimum horizontal stress that means in the direction of least resistance. The study of Wolgast and Komietzky shows that the direction of the fracture is related to in situ stress. In hydraulic fracturing treatment, the geometry of the fracture is determine by: the fracture width (aperture), the half-length and the height of the fracture (Kemal, et al., 2017).

Interaction between Natural Fractures and Hydraulic Fracture

One of the use of hydraulic fracturing is to connect natural fractures in the formation into a well. When natural fractures interact with induced fractures, three scenarios can be possible according to the approach of angle between them. The cross take place when the induce fracture without being enough disturbed. Offset take place when the induce fracture is not able to intersect the natural fracture. The last one is called arrest which take place when the pressure inside the fracture is not considerable to cross and the induce fracture stops after reaching the natural fracture. Table 4 below illustrates the difference between the horizontal stress and the approach of angle which demonstrates the three scenarios (Li, et al., 2019).

Table 4.
Horizontal stress versus the approach angle (Li, et al., 2019).

Approach angle (°)	Horizontal stress contrast (MPa)	State
No natural fracture	Indifferent	Moderate
$\theta < 45°$	Indifferent	Very poor
$45° < \theta < 60°$	$\Delta S < 10$	Poor
$45° < \theta < 60°$	$\Delta S > 10$	Good
$\theta > 60°$	Indifferent	Very good

Fracability

The determination of the optimum interval to fracture is one of the challenges in hydraulic fracturing. Fracability can be used to select the interval in which the probability of success is high when creating a fracture. It is an important index to evaluate the fracture effectiveness of the rock during hydraulic fracturing treatment. The fracability is related to the degree of difficulty for fracture initiation and propagation (Li, et al., 2019). Equation 6 bilow illustrates the fracability index in case of carbonate reservoirs (Hamed et al., 2021).

$$\mathrm{FI} = \frac{E_n - 2B_r}{3\sin(\varphi)} \tag{6}$$

Where B_r is brittleness and E_n is the normalized young modulus.

The Notion of Stress Barrier in Hydraulic Fracturing

The most complex challenge when fracturing the target zone using FRACPRO is to contain the fracture in this zone. The study of Wu et al. (2022) shows that the key factor to imprison fracture in the reservoir rock is the difference in term of minimum horizontal stress values between the cap rock and the reservoir rock. That means that fracture will be contained on the target zone if only the above and down layers have minimum horizontal stress values higher that the target zone. So in case of the stress contrast between the target layer and the upper and lower layers, the fracture will be developed on the target layer if it has the smaller minimum stress than the upper and lower layers. In the case of shale tight reservoir where shale has the higher minimum horizontal stress, the fracture will be more developed out the target zone. The minimum horizontal stress depends also on the lithology, the layer having high Poisson's ratio should be the layer with larger horizontal stress (Zhang, et al., 2018). Figure 6 below illustrates the stress barrier in hydraulic fracturing treatment.

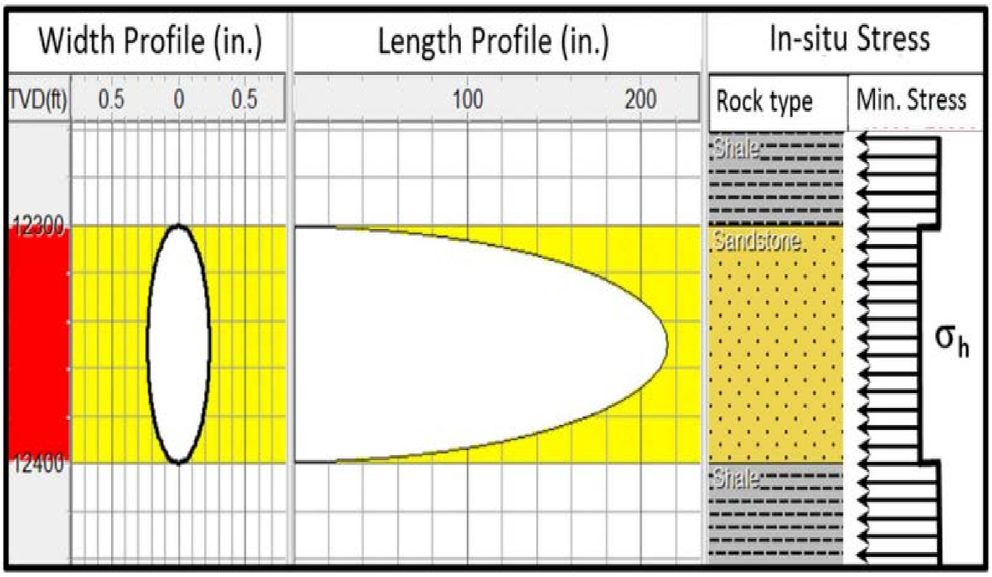


Figure 6. Stress barrier in hydraulic fracturing treatment (Zhang, et al., 2018).

Change of Fracture Pressure During Hydraulic Fracturing Treatment

During hydraulic fracturing operation, fluid pressure inside the fracture can widely vary and impact the propagation of the fracture. Four main points can be individualized during hydraulic fracture treatment: breakdown pressure, end of pumping, instantaneous shut in pressure (ISIP), and closure pressure. The Figure 7 below illustrates the change of fracture pressure during hydraulic fracturing treatment.

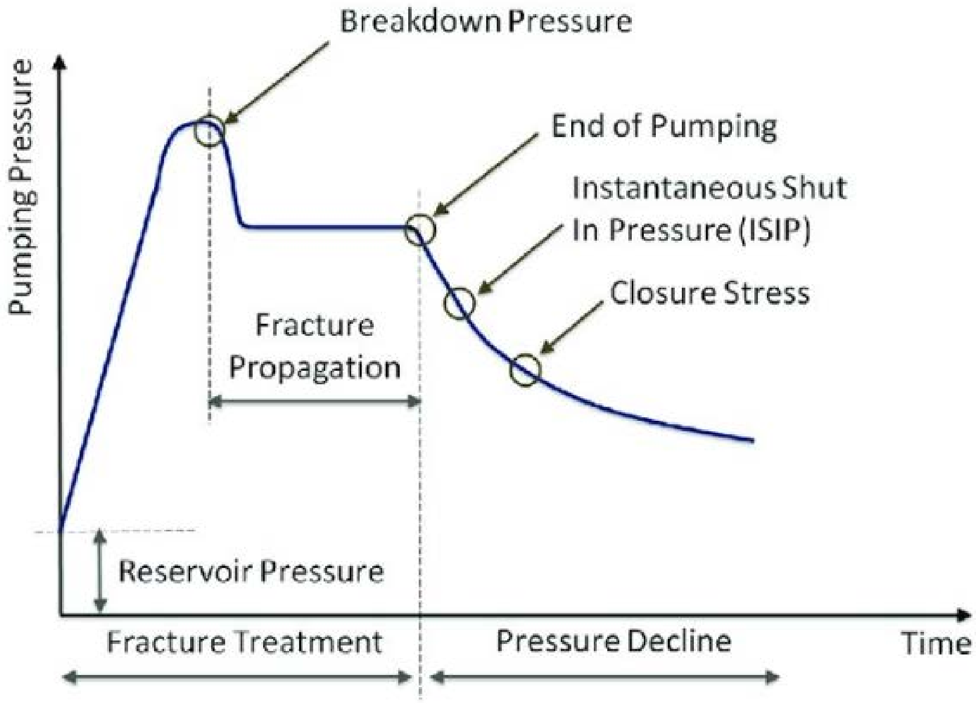


Figure 7. Change of fracture pressure during hydraulic fracturing treatment (Hamed et al., 2021).

Induce Fracture Pressure

The study of Zhang et al. (2018) demonstrates that the induce fracture take place during the hydraulic fracturing treatment when the tangential stress reaches the tensile stress of the formation. In a vertical well and in case of non-penetrating injection fluid they prosed the equation 7 below to determine the induce fracture pressure.

$$P_i = 3\sigma_h - \sigma_H - P_p + T_0 \quad (7)$$

In which: P_i is the induce fracture pressure, P_p is the pore pressure, T_0 is the tensile strength of the formation, and σ_h and σ_H are respectively the minimum and maximum horizontal stress.

Theoretical Framework

In petroleum industry today, hydraulic fracturing plays an important role to enhance the productivity of natural gas and oil from low permeability reservoirs. This technique is also used in others domains such as in mining and geotechnical engineering. The use of hydraulic fracturing is not for today it is old for more than 50 years. Hydraulic fracturing uses mainly hydraulic and proppant to create fractures in the target zone to improve the permeability of the formation. Specifically we conduct hydraulic fracturing to provide optimum length and conductivity in petroleum industry.

Rock mechanics and petrophysics are two mains domains in which engineers have to be excellent before fracturing a reservoir because petrophysical and mechanical characteristics of rocks have a crucial impact in the orientation, and geometry of the induce fracture. These two mains parameters, fluid and proppant must be chosen according to the aim of project or the study because they play a key role on the geometry of the fracture.

CHAPTER III

Methodology

The goal of this research study to fracture the reservoir using FRACPRO Software. The methodology used consist of five steps:

1) Literature review
2) Data collection
3) Data selection
4) Put data into FRACPRO Software
5) Run the Simulation

Data Collection Procedures:

Data were collected by accessing available literature (paper, journal, book, and website). Well log data were used to determine the thickness, lithology, permeability and porosity of the each layer in the formation.

Hydraulic fracturing treatment needs two types of input data: formation data and treatment data. The first one are data that we can obtain from well log published by Saner and Abdulghani (1995) above and the second one consist of data that we can select or choose from FRACPRO Software as concern.

Data Analysis Plan

Fracpro uses petrophisical and geometrical parametrs, and four modes of operation to stimulate a reservoir. The first mode is called fracture design, in this mode of operation we first of all choose wellbore configuration dimension as in the Figure 8 below.

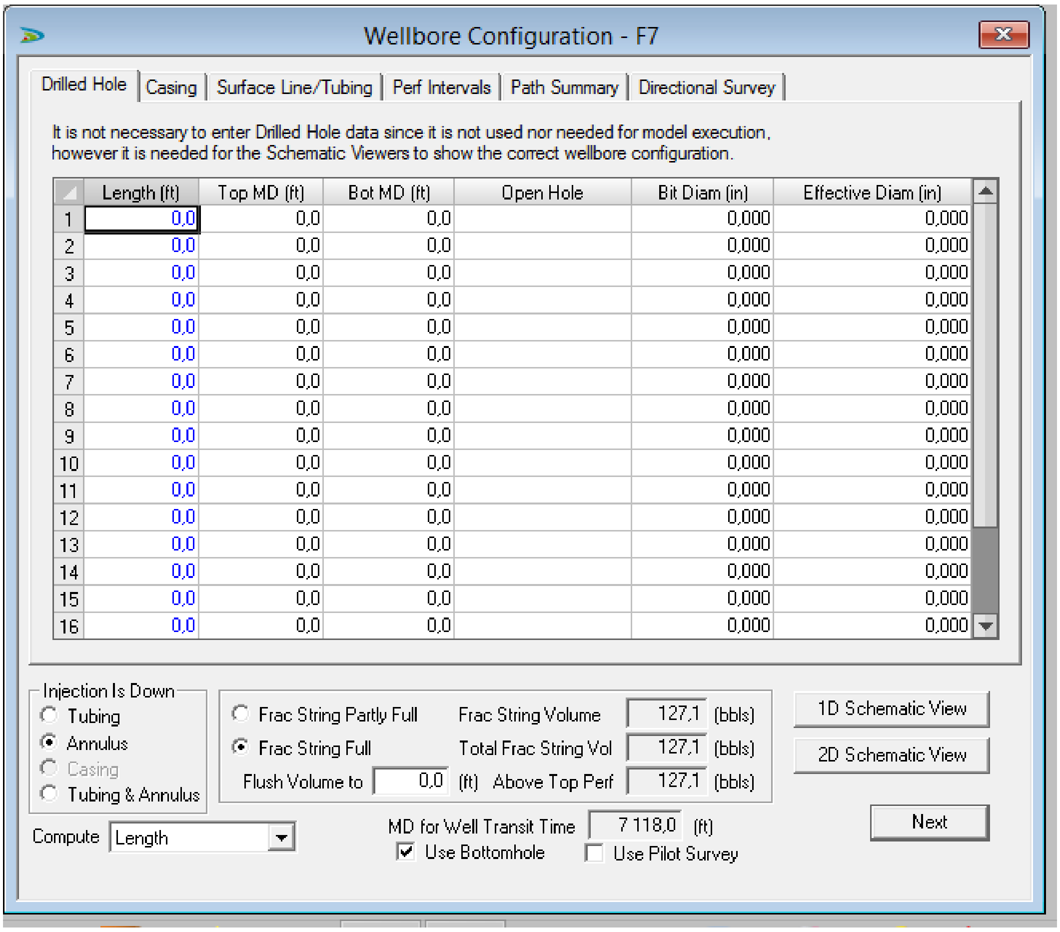


Figure 8. Wellbore configuration.

second of all we select fluid and proppant based on the lithology of the reservoir and fluid and proppant properties sach as viscosity of the fluid granulometry of the proppant. The Figure 9 below shows proppant and fluid selection.

The second mode of the operation is called fracture analysis in this mode, we select the optimum fluid injection rate, proppant type and concentration, slurry volume, and fluid types and volumes in order to obtain the best combination which respect that three condtion relative to the fracture in this study: the containment of the fracture in the selected interval; good conductivity; good lenght. The Figure 10 below illustrates fracture treatment schedule.

Several well log data were collected based on literature review. Data were been selected function of publish date, methodology used and details gave. The most recent published data giving more details were our target. Based on petrophysical characteristics of layers, three main zones were selected to conduct hydraulic fracturing to look for the optimum zone in which productivity will be the best.

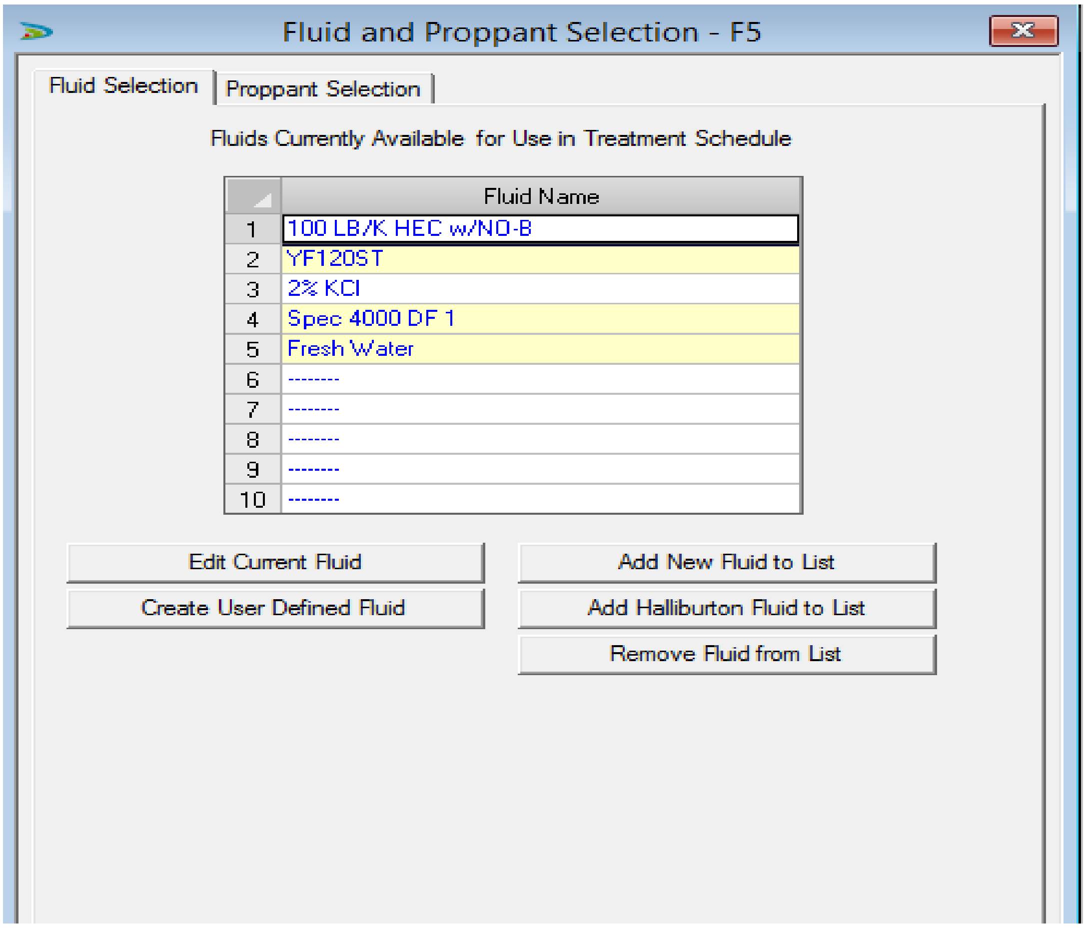
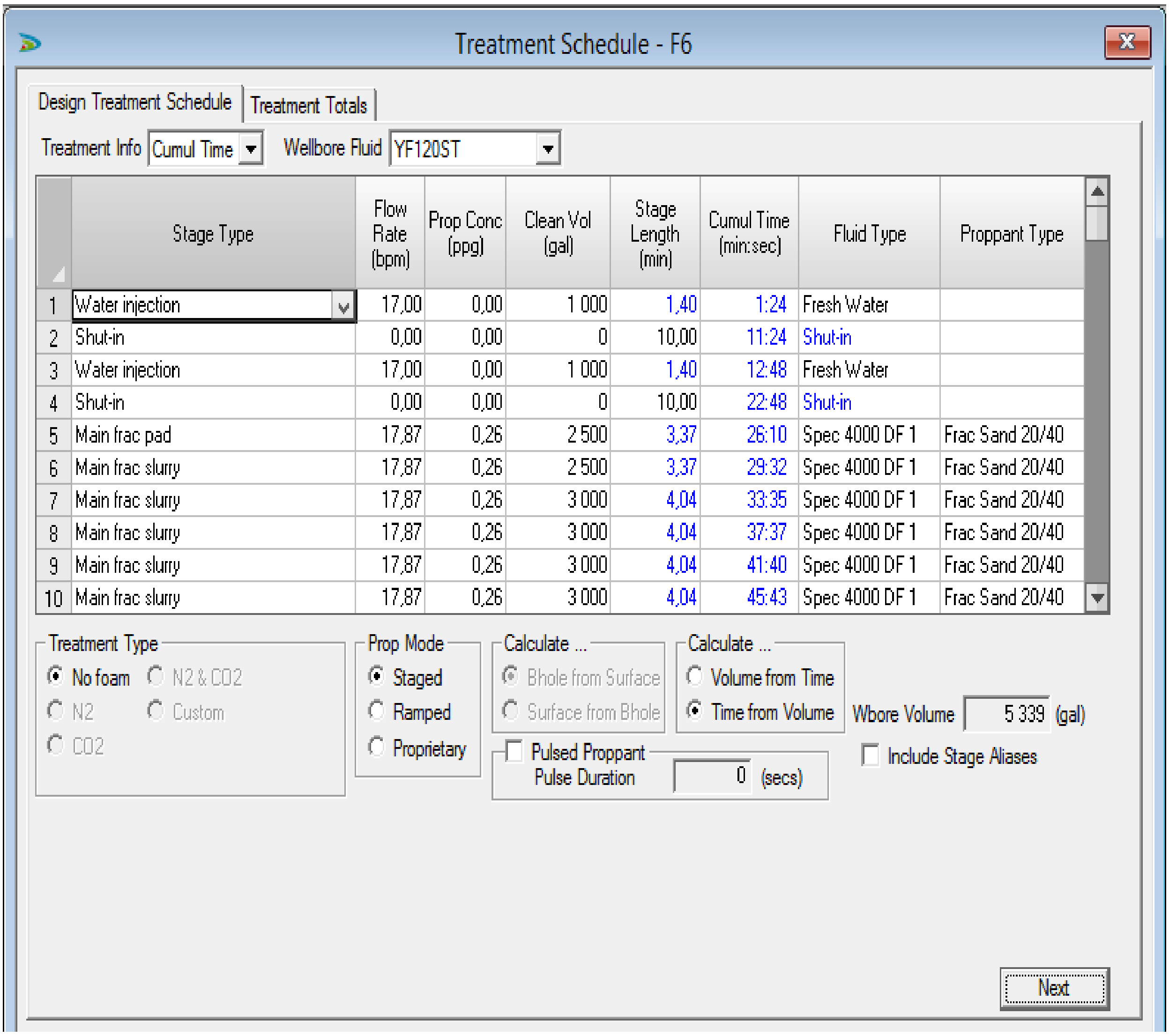


Figure 9. Fluid and proppant selection.



	Stage Type	Flow Rate (bpm)	Prop Conc (ppg)	Clean Vol (gal)	Stage Length (min)	Cumul Time (min:sec)	Fluid Type	Proppant Type
1	Water injection	17,00	0,00	1 000	1,40	1:24	Fresh Water	
2	Shut-in	0,00	0,00	0	10,00	11:24	Shut-in	
3	Water injection	17,00	0,00	1 000	1,40	12:48	Fresh Water	
4	Shut-in	0,00	0,00	0	10,00	22:48	Shut-in	
5	Main frac pad	17,87	0,26	2 500	3,37	26:10	Spec 4000 DF 1	Frac Sand 20/40
6	Main frac slurry	17,87	0,26	2 500	3,37	29:32	Spec 4000 DF 1	Frac Sand 20/40
7	Main frac slurry	17,87	0,26	3 000	4,04	33:35	Spec 4000 DF 1	Frac Sand 20/40
8	Main frac slurry	17,87	0,26	3 000	4,04	37:37	Spec 4000 DF 1	Frac Sand 20/40
9	Main frac slurry	17,87	0,26	3 000	4,04	41:40	Spec 4000 DF 1	Frac Sand 20/40
10	Main frac slurry	17,87	0,26	3 000	4,04	45:43	Spec 4000 DF 1	Frac Sand 20/40

Figure 10. Ttreatment Schedule.

Permeability Determination

In this study porosity, lithology, layears thickness are determined using the log in the Figure 3 on page 6. Permeability is determined by the use of the equation 8 below:

$$Y = 1.5359e^{-2} \quad 10^{(0.1525X)} \tag{8}$$

Were : Y is permeability and X is porosity

The equation above was established by Saner and Sahin (1999), they ploted permeability versus porosity for the Arab-C carbonate reservoir on a semilogarithmic scale and established the corelation between these two parameters. İn this study we use this equation to calculate for each layer and porosity the corresponding permeabolity.

Study Plan

At the end of this research study, a detailed report on the hydraulic fracturing modeling in fining up ward Middle East to significantly enhance the recovery of oil and gas will be presented.

This report will serve as a guideline and process operation to fracture fining upward carbonate reservoirs in Middle East.

This research study is expected to spend six months and would be completed by June, 2022. Detailed tasks schedule chart is shown below and enlarged copy is attached.

Table 5.

Chart showing the schedule of key task throughout the research study.

task name	1st trimester			2nd trimester			3rd trimester		
	November	December	January	February	March	April	June		
1.litterature review									
2.details analysis of applied method									
3.independent comparative analysis									
4.detailed report writing									
5. presentations (once a month to thesis committee)									
6.final presentations									

CHAPTER IV

Finding and Discussion

The results obtained in this research are mainly in form of tables, figures and graphs. Certain results in form of tables allowed to create others graphs.

Figure 11 below shows layers properties of Arab-C reservoir in the Abqaiq Field, Eastern Saudi Arabia. Permeability increase form the top to the bottom and its maximum value is recorded in limestone on the bottom of the reservoir.

Young's modulus has low values in limestone, dolomite and its high value is recorded in anhydrite, and this result is conform to the result in Table 6 below obtained by Ameen et al. (2009) where we can read 49Gpa and 33Gpa respectively as the values of young's modulus in dolomite and limestone.

Toughness values are high in anhydrite and low in limestone and dolomite that means it need more pressure to break anhydrite than limestone and dolomite.

The values of Poisson's ratio on the Figure 11 below is between 0.2 and 0.3 and has the maximum value in limestone which the layer with high porosity and permeability. This result is conform to the result of the study of Jincai (2019) that shows Poisson's ratio depends on porosity as we can see in the Figure 11 below. The Equation 9 below shows that Poisson's ratio is proportional to porosity that means when porosity increases, Poisson's ration increases too.

$$\nu = 0.2+0.61\phi \qquad (9)$$

Where: ν and ϕ are respectively Poisson's ratio and porosity.

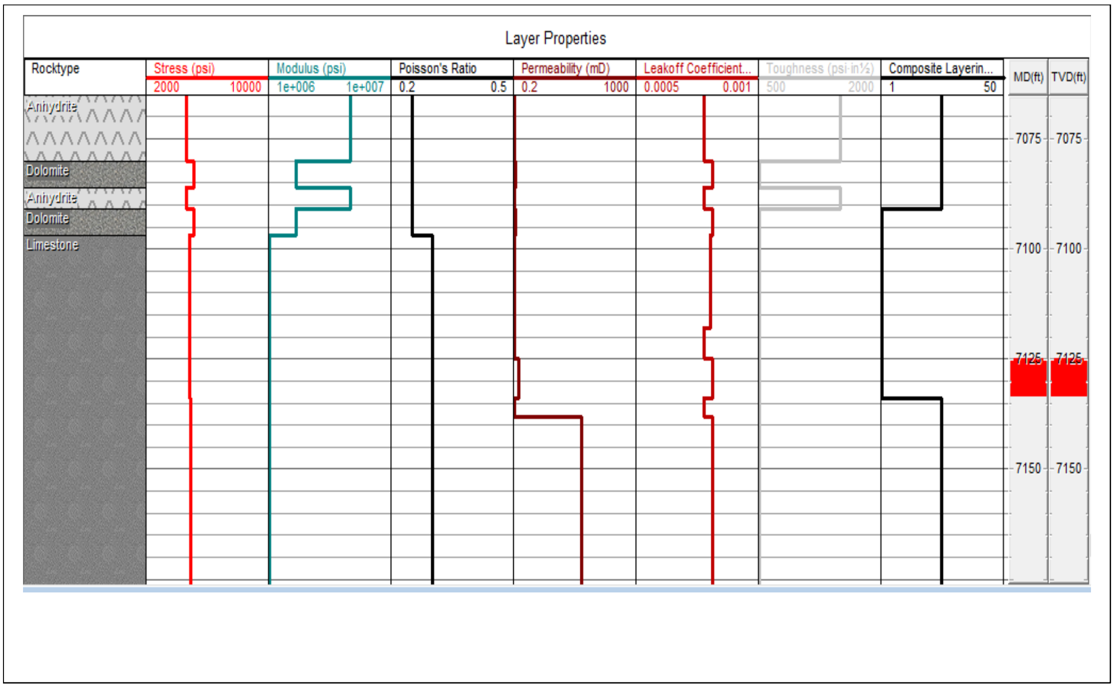


Figure 11. Layer properties of the zone of the study.

Table 6.

Comparison of rock mechanical parameter in limestone and dolomite (Ameen, et al., 2009).

Rock mechanical parameter	Dolomite	Limestone	Difference%
P-Wave Velocity (m/s)	5344	4238	26
S-Wave Velocity (m/s)	3150	2454	28
Static Young's Modulus (Gpa)	49	33	50
Static Bulk Modulus (Gpa)	30	18	64
Static Shear Modulus (Gpa)	20	11	72
Dynamic Young's Modulus (Gpa)	57	32	80
Dynamic Bulk Modulus (Gpa)	33	22	45
Dynamic Shear Modulus (Gpa)	24	13	85
Angle of Internal Friction (Degrees)	33	23	46
Unconfined Compressive Strength (MPa)	45	32	40

To select the optimum interval giving the best recovery, three main scenarios were used.

1st Scenario

For the 1st scenario, our target was to fracture the entire reservoir from 7080 to 7170ft. to come out to the result we used Frac Sand 20/40 as a proppant, Spec 4000 DF 1 as fluid type for pad and slurry stages. The Table 7 below illustrates the 13 stages of treatment schedule. It needs 571.4bbls, 577.6bbls, 5.7klbs respectively for design clean volume, design slurry volume and design proppant pumped to fracture the all reservoir.

Figure 12 below illustrates the stage profile and width profile of the induce fracture and characterises the geometry of this induce fracture. The fracture half-length, fracture height and fracture, the average fracture width and conductivity are respectively 139ft, 95ft, 0.225in and 506.4mD-ft. before the hydraulic fracturing treatment the average permeability was about 63mD that means hydraulic fracturing treatment improved the permeability of this reservoir.

Net pressure which is the pressure inside the fracture minus the closure pressure is 300psi and the fracture slurry efficiency is 0.61.

In the width profile from 7100 to 7080ft, we can see the narrow fracture due to low porosity and high young’s modulus and its conform to the study of Bakshshi et al. (2021) which assert that layers with higher young’s modulus and lower porosity lead to the narrow fractures.

Table 7.

Fracture treatment schedule for the 1st scenario.

Stage #	Stage Type	Elapsed Time min:sec	Fluid Type	Clean Volume (gal)	Prop Conc (ppg)	Stage Prop. (klbs)	Slurry Rate (bpm)	Proppant Type
Wellbore Fluid			YF120ST	5 339				
1	Water injection	1:24	Fresh Water	1 000	0,00	0,0	17,00	
2	Shut-in	11:24	SHUT-IN	0	0,00	0,0	0,00	
3	Water injection	12:48	Fresh Water	1 000	0,00	0,0	17,00	
4	Shut-in	22:48	SHUT-IN	0	0,00	0,0	0,00	
5	Main frac pad	26:10	Spec 4000 DF 1	2 500	0,26	0,7	17,87	Frac Sand 20/40
6	Main frac slurry	29:32	Spec 4000 DF 1	2 500	0,26	0,7	17,87	Frac Sand 20/40
7	Main frac slurry	33:35	Spec 4000 DF 1	3 000	0,26	0,8	17,87	Frac Sand 20/40
8	Main frac slurry	37:37	Spec 4000 DF 1	3 000	0,26	0,8	17,87	Frac Sand 20/40
9	Main frac slurry	41:40	Spec 4000 DF 1	3 000	0,26	0,8	17,87	Frac Sand 20/40
10	Main frac slurry	45:43	Spec 4000 DF 1	3 000	0,26	0,8	17,87	Frac Sand 20/40
11	Main frac slurry	49:05	Spec 4000 DF 1	2 500	0,26	0,7	17,87	Frac Sand 20/40
12	Main frac flush	52:27	Spec 4000 DF 1	2 500	0,26	0,7	17,87	Frac Sand 20/40
13	Shut-in	58:27	SHUT-IN	0	0,00	0,0	0,00	

Design clean volume (bbls)	571,4	Design proppant pumped (klbs)	5,7
Design slurry volume (bbls)	577,6		

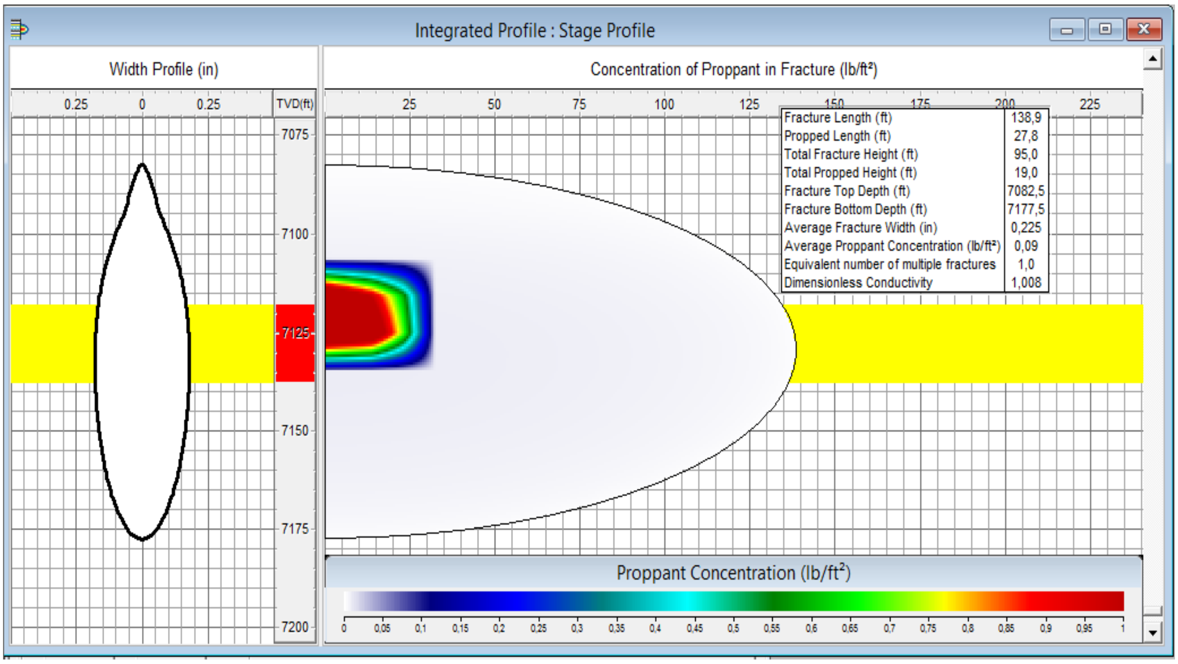


Figure 12. Width and stage profiles for the 1st scenario.

2nd Scenario

For the 2nd scenario, our target was to fracture the uper reservoir from 7080 to 7134ft. to come out to the result we used Frac Sand 20/40 as a proppant, Spec 4000 DF 1 as fluid type for pad and slurry stages. The Table 9 below illustrates the 13 stages of treatment schedule. It needs 571.4bbls, 577.3bbls, 5.5klbs respectively for design clean volume, design slurry volume and design proppant pumped to fracture the all reservoir.

Figure 13 bellow illustrates the stage profile and width profile of the induce fracture and characterises the geometry of this induce fracture. The fracture half-length, fracture height, the average fracture width and fracture conductivity are respectively 83.4ft, 51.4ft, 0.080in and 71.2mD-ft. before the hydraulic fracturing treatment the average permeability was about 63mD that means hydraulic fracturing treatment improved the permeability of this reservoir.

Net pressure which is the pressure inside the fracture minus the closure pressure is 256 psi and the fracture slurry efficiency is 0.82.

In the width profile from 7100 to 7080ft, we can see like in 1st scenario the narrow fracture due to low porosity and high young's modulus and its conform to the study of Bakshshi et al. (2021) which assert that layers with higher young's modulus and lower porosity lead to the narrow fractures.

Table 8.

Fracture treatment schedule in the 2nd scenario.

Stage #	Stage Type	Elapsed Time min:sec	Fluid Type	Clean Volume (gal)	Prop Conc (ppg)	Stage Prop. (klbs)	Slurry Rate (bpm)	Proppant Type
Wellbore Fluid			YF120ST	5 319				
1	Water injection	1:29	Fresh Water	1 000	0,00	0,0	16,00	
2	Shut-in	11:29	SHUT-IN	0	0,00	0,0	0,00	
3	Water injection	12:58	Fresh Water	1 000	0,00	0,0	16,00	
4	Shut-in	19:38	SHUT-IN	0	0,00	0,0	0,00	
5	Main frac pad	23:11	Spec 4000 DF 1	2 500	0,25	0,6	17,00	Frac Sand 20/40
6	Main frac slurry	26:43	Spec 4000 DF 1	2 500	0,25	0,6	17,00	Frac Sand 20/40
7	Main frac slurry	30:58	Spec 4000 DF 1	3 000	0,25	0,8	17,00	Frac Sand 20/40
8	Main frac slurry	35:13	Spec 4000 DF 1	3 000	0,25	0,8	17,00	Frac Sand 20/40
9	Main frac slurry	39:28	Spec 4000 DF 1	3 000	0,25	0,8	17,00	Frac Sand 20/40
10	Main frac slurry	43:43	Spec 4000 DF 1	3 000	0,25	0,8	17,00	Frac Sand 20/40
11	Main frac slurry	47:15	Spec 4000 DF 1	2 500	0,25	0,6	17,00	Frac Sand 20/40
12	Main frac flush	50:48	Spec 4000 DF 1	2 500	0,25	0,6	17,00	Frac Sand 20/40
13	Shut-in	56:49	SHUT-IN	0	0,00	0,0	0,00	
14	Shut-in	57:49	SHUT-IN	0	0,00	0,0	0,00	
15	Shut-in	58:49	SHUT-IN	0	0,00	0,0	0,00	
16	Shut-in	59:49	SHUT-IN	0	0,00	0,0	0,00	

Design clean volume (bbls) 571,4 Design proppant pumped (klbs) 5,5
Design slurry volume (bbls) 577,3

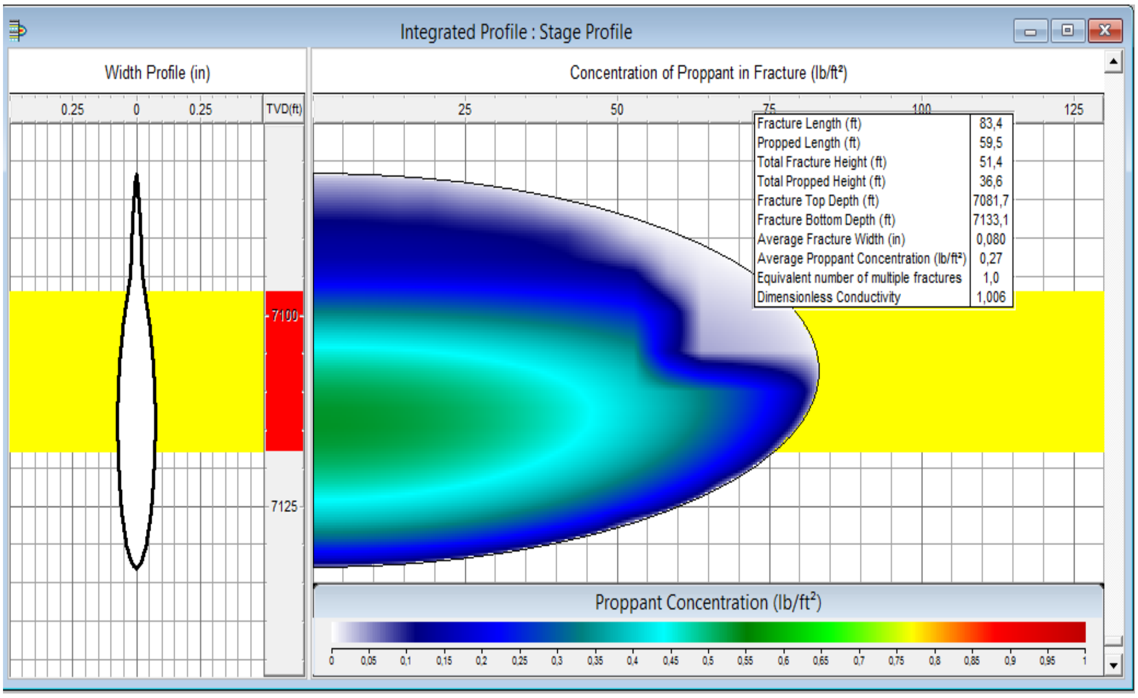


Figure 13. Width and stage profiles for the 2nd scenario.

3rd Scenario

In this scenario our target was to fracture from 7140 to 7170ft. we used 523.8bbls, 529.2bbls, and 5klbs respectively for clean volume, slurry volume, and proppant pumped as show in Table 9 below. We obtained fracture conductivity to be 0.00mD and net pressure – 754psi Due to fluid leak-off, because of high permeability in this interval, pumped fluid leak-off into the formation and significantly decreases the net pressure. This result is conform to the result of Liu (2016) which shows that leak-off affects net pressure.

Table 9.

Fracture treatment schedule in the 2nd scenario.

Stage #	Stage Type	Elapsed Time min:sec	Fluid Type	Clean Volume (gal)	Prop Conc (ppg)	Stage Prop. (klbs)	Slurry Rate (bpm)	Proppant Type
Wellbore Fluid			YF120ST	5 370				
1	Water injection	1:29	Fresh Water	1 000	0,00	0,0	16,00	
2	Shut-in	11:29	SHUT-IN	0	0,00	0,0	0,00	
3	Water injection	12:58	Fresh Water	1 000	0,00	0,0	16,00	
4	Shut-in	19:38	SHUT-IN	0	0,00	0,0	0,00	
5	Main frac pad	22:55	Spec 4000 DF 1	2 300	0,25	0,6	16,91	Frac Sand 20/40
6	Main frac slurry	26:11	Spec 4000 DF 1	2 300	0,25	0,6	16,91	Frac Sand 20/40
7	Main frac slurry	30:02	Spec 4000 DF 1	2 700	0,25	0,7	16,91	Frac Sand 20/40
8	Main frac slurry	33:52	Spec 4000 DF 1	2 700	0,25	0,7	16,91	Frac Sand 20/40
9	Main frac slurry	37:43	Spec 4000 DF 1	2 700	0,25	0,7	16,91	Frac Sand 20/40
10	Main frac slurry	41:34	Spec 4000 DF 1	2 700	0,25	0,7	16,91	Frac Sand 20/40
11	Main frac slurry	44:50	Spec 4000 DF 1	2 300	0,25	0,6	16,91	Frac Sand 20/40
12	Main frac flush	48:07	Spec 4000 DF 1	2 300	0,25	0,6	16,91	Frac Sand 20/40
13	Shut-in	54:08	SHUT-IN	0	0,00	0,0	0,00	
14	Shut-in	55:08	SHUT-IN	0	0,00	0,0	0,00	
15	Shut-in	56:08	SHUT-IN	0	0,00	0,0	0,00	
16	Shut-in	57:08	SHUT-IN	0	0,00	0,0	0,00	

The Figure 14 below shows the geometry of the fracture in 3nd scenario.

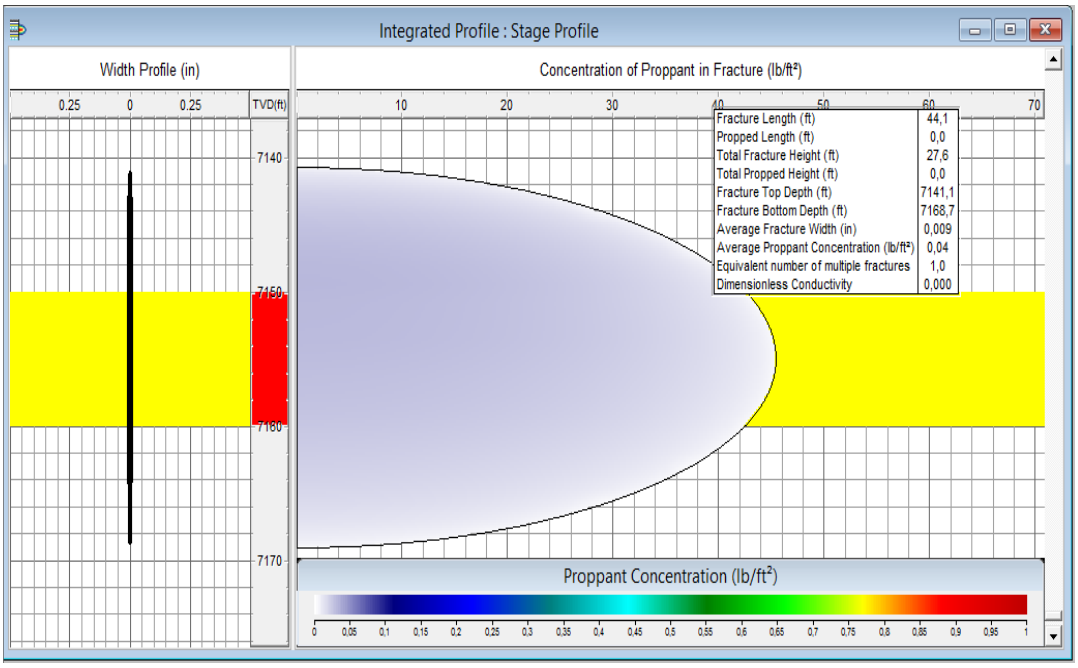


Figure 14. Width and stage profiles for the 3rd scenario.

Figures 15, 16, 17 below illustrate the behavior of propped fracture properties with the increasing of the distance from the well at fracture center at the depth 7130ft in the 1st scenario. They show that propped fracture properties decrease with the increasing of the distance from the well.

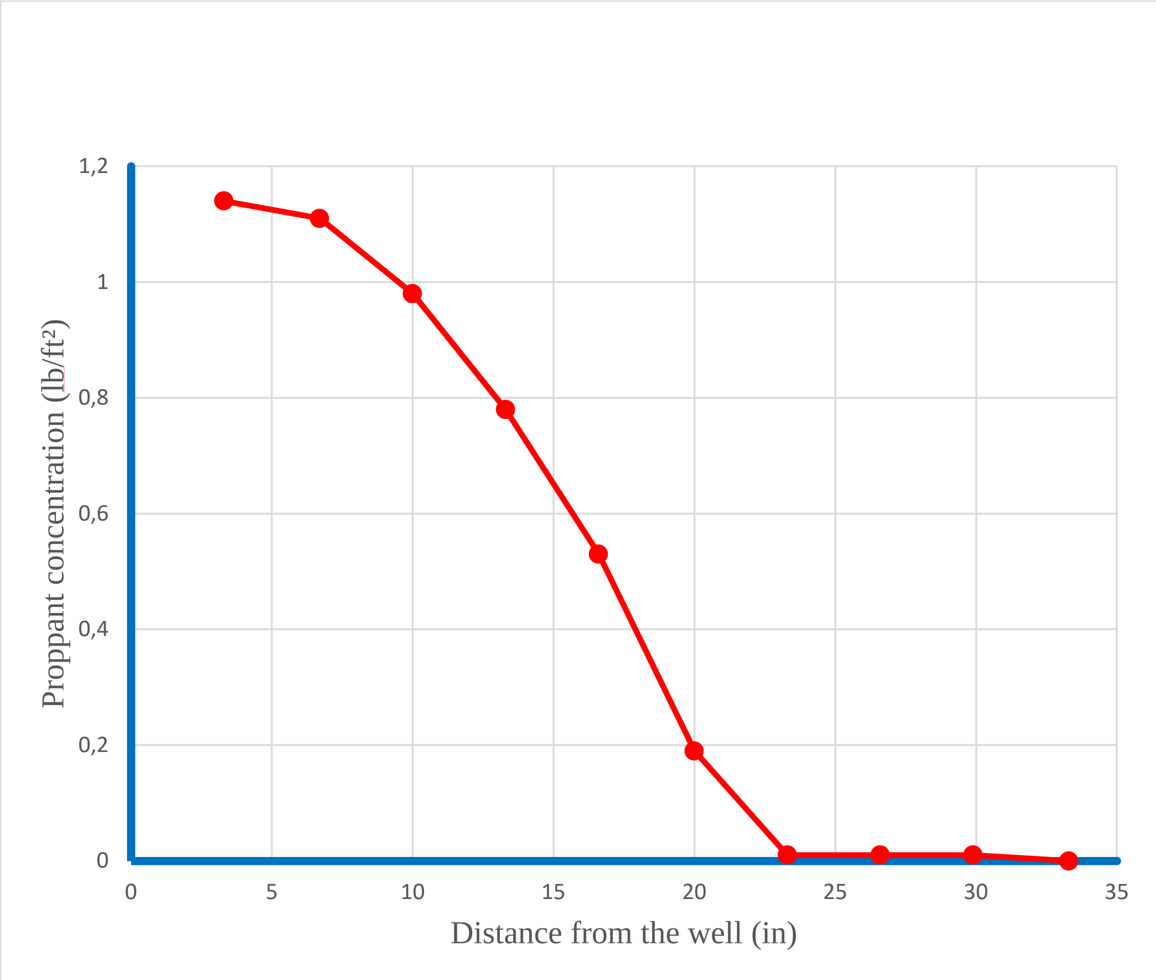


Figure 15. Distance from the well vs proppant concentration.

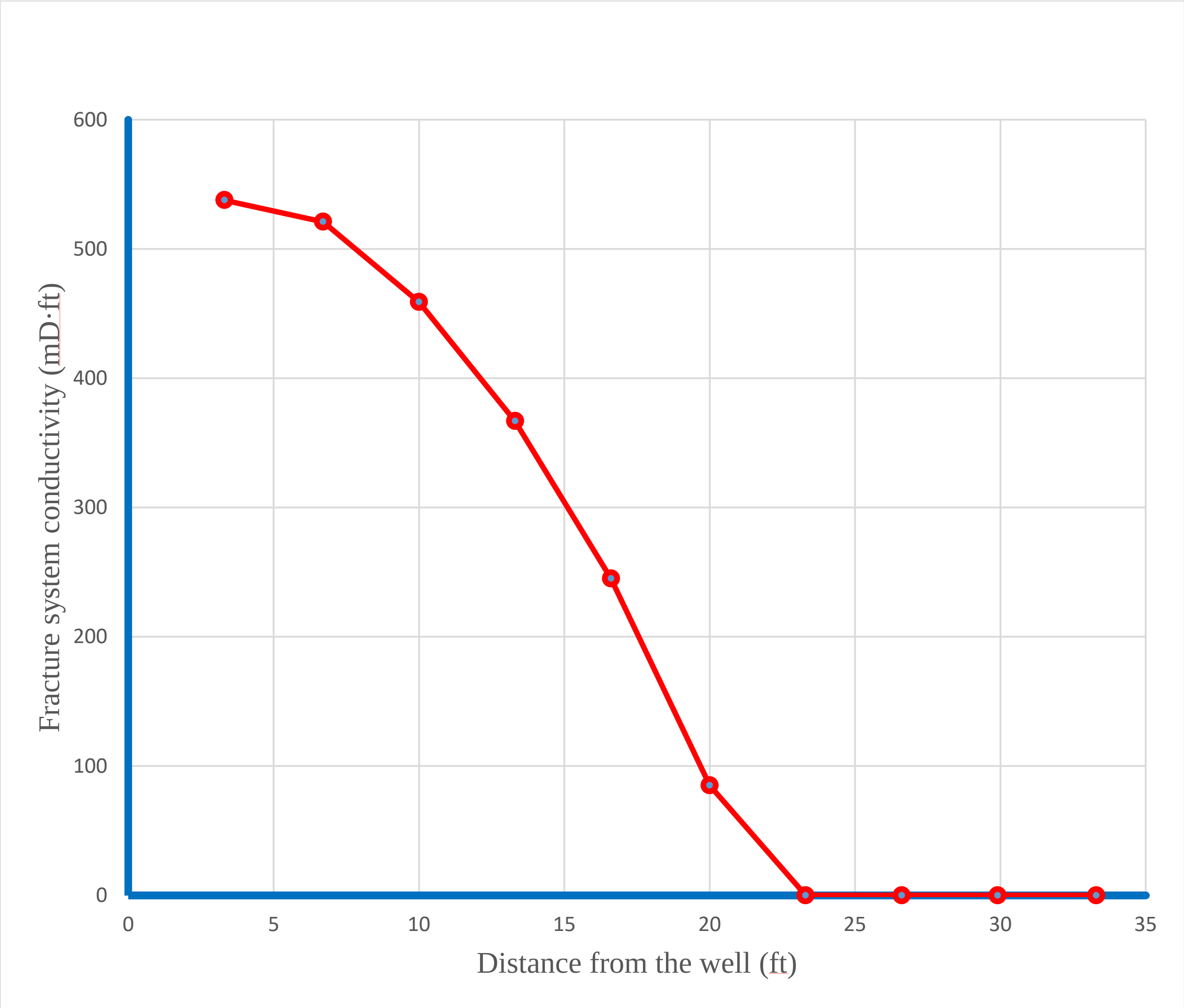


Figure 16. Distance from the well vs frac system conductivity.

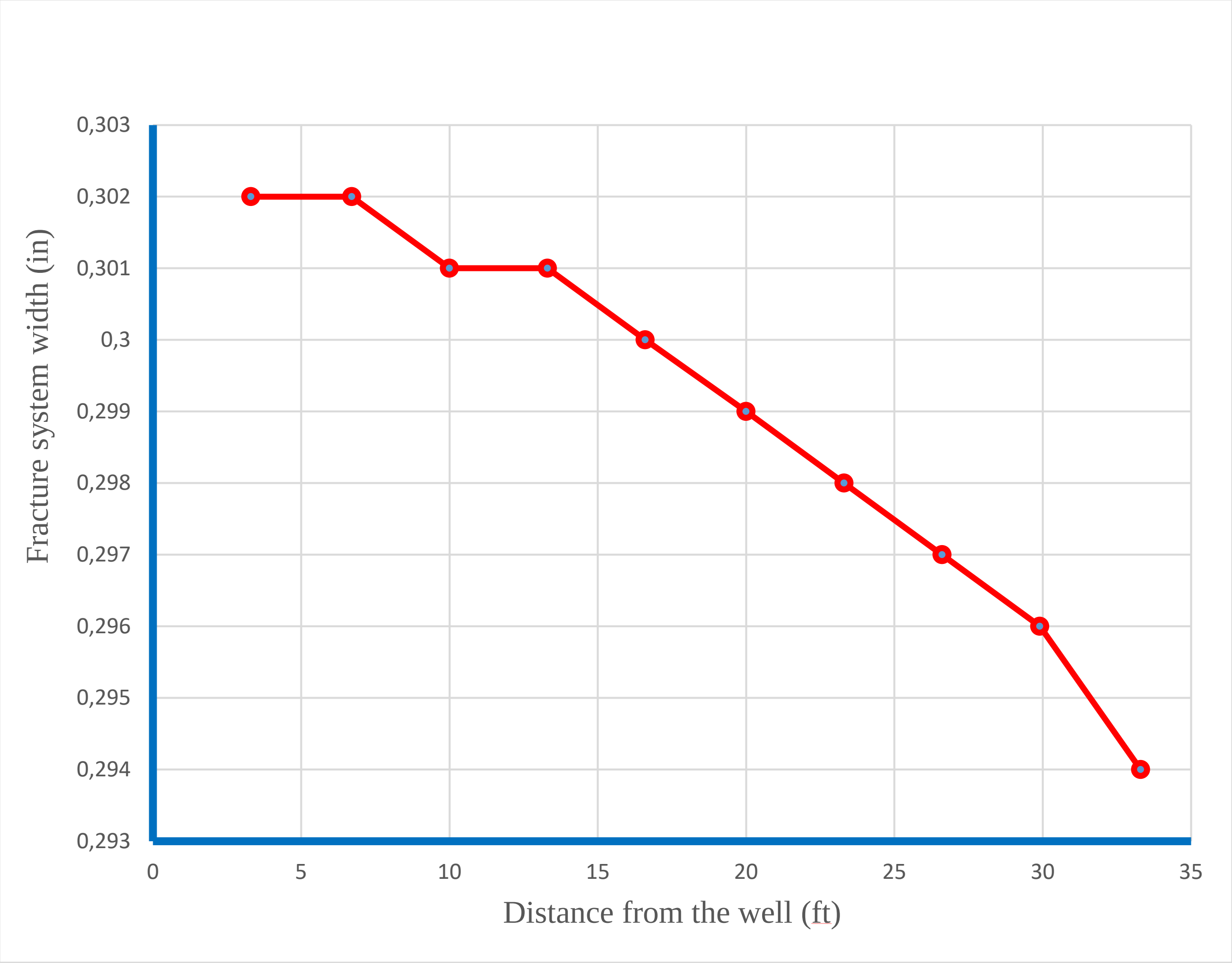


Figure 17. Distance from the well vs fracture system width.

CHAPTER V

Conclusion and Recommendation

Conclusion

In reference to this study, we come out to these conclusions: the geometry of the fracture is dependent on the properties of the formation and its petrophysical properties; proppant conductivity tends to zero in high permeable layers; to fracture the all reservoir thickness of Abqaiq Field using Frac sand 20/40 it needs about 5.5klbs of proppant, 571.4bbls of clean volume and 577.3bbls of slurry. The generated fracture occurred at 7083ft from the surface. The average permeability before the fracture treatment is 30mD and after treatment, the average conductivity has considerably increased to 506.4mD-ft. Net pressure, Fracture slurry efficiency and average conductivity are respectively 300 psi, 0.61, and 506mD.ft.

Recommendation

According to this research, the recommendations below can be drawn: conduct hydraulic fracturing operation in layers of high permeability and compare with the results of this study; conduct the same study using others software to compare the results; using different types of proppant and fluid to compare with Frac sand and Spec 4000 DF 1.

REFERENCES

Andrei, S. (2004). Automatic Fracturing Design for Low Permeability Reservoirs Using Artificial intelligence. Morgantown, West Virgina.

Akram, H., Maha, R.H., & Rasan, S. (2019). Implementation of Hydraulic Fracture Operation for a Reservoir in KRG. Department of Naturel Ressource Engineering and Management, University of Kurdistan Hewler, Iraq. UKH Journal of Science and Engineering, Volume 3 Number 2, 2019.

Baocheng, W., Xiaochen, W., Wanbin, W., Jiaqi, L., Tong, L., & Xuancheng, W. (2022). Effect of stress and material barriers on hydraulic fracture height containment in layered formations. Environmental earth sciences (2002) 81: 255.

Daniel, R., & David, K. (2013). Hydraulic fracturing of oil and gas wells in Kansas. Kansas geological survey, public information circular (PIC) 32.

Bakshsh, E., Shahrabadi, A., Golsanami, N., Seyedsajadi, S., Liu X., & Wang, Z., (2021). The joint application of diagenetic, petrophysical and geomechanical data for selecting hydraulic fracturing candidate zone: a case study from carbonate reservoir in Iran. International journal of petroleum technology.

Hamed, A., Ahmad, R., Mohamadali, C., & Mohammadreza, P. (2021). Recognizing the best intervals for hydraulic fracturing using a new Fracability index. Journal of petroleum Exploration and production technology (2021) 11:3193-3201.

Hoss, B., Ebrahim, F., & Fatemeh, B. (2019). Hydraulic fracturing in unconventional reservoirs. Second edition. ScienceDirect.

Jonathan, K., Mary, E., & Brent, R. (2014). Hydraulic Fracturing Overview: How, where, and its role in oil and gas. Journal Awwa.106:11.

Jing, L., Xiao-Rong, L., Hong- Bin, Z., Ming-Shui, S., Chen, L., Xiang-Chao, K., & Lu-Ning, S. (2019). Modified method for fracability evaluation of tight sandstones based on interval transit time. Petroleum Science (2020) 17:477-486.

Luca, G., & Ulrik, V. (2013). An overview of hydraulic fracturing and other formation stimulation technologies for shale gas production. Report EUR 26347 EN.

Matthew, T., Moridis, G., Keen, N., & Johnson, J. (2014). Numerical simulation of the environmental impact of hydraulic fracturing of tight/shale gas reservoirs on near-surface groundwater: background, base cases, shallow reservoirs, short-term gas, and water transport.

Mohamed, S., Brian G.D, J., Sally, S., & Nassir, A. (2009). Predicting rock mechanical properties of carbonates from wireline logs (a case study: Arab-D reservoir, Ghawar field, Saudi Arabia).

Zoveidavianpoor, M., Samsuri, A., & Shadizadeh, S. (2011). Well stimulation in carbonate reservoirs: the need and superiority of hydraulic fracturing. Faculty of petroleum and renewable energy engineering.

Liew, M., Kamaluddeen, U., & Noor, A. (2020). A comprehensive Guide to different fracturing technology: a review. Published: 30 June 2020.

Soliman, M. (2020). Hydraulic fracturing. University of Houston, PhD, PE, NAI.

Salih, S., & Abdulghani, W. M. (1995). Lithostratigraphy and depositional environments of the upper Jurassic Arab-c carbonate and associated evaporates in the Abqaid field, eastern Saudi Arabia. AAPG Bulletin, V. 79, No.3 (March 1995), P.394-409.

Salih, S., & Ali, S. (1999). Lithological and zonal porosity-permeability distributions in the Arab-D reservoir, Uthmaniyah field, Saudi Arabia. AAPG Bulletin, v.83, No. 2, P. 230-243.

Tanya, J. (2015). Trends in hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010, data analysis and comparison to the literature. Science for a changing world.

Total. (2009). Carbonate reservoirs extracting their value.

Trevor, P. B. (2012). Carbonate rocks and petroleum reservoirs: a geological perspective from the industry. Geological society, London, special publications published online October 16, 2012 as doi: 10.1144/sp370.14.

Wayen, M. (2008). Geology of carbonate reservoirs. The identification, description, and characterization of hydrocarbon reservoirs in carbonate rocks. ISBN 978-0-470-16491-4 (cloth).

Yuxuan, L., Jianchu, G., & Zhangxin, C. (2016). Leakoff characteristics and an equivalent leakoff coefficient in fracture tight gas reservoirs. Journal of natural gas science and engineering 31 (2016) 603-611.

Yushuai, Z., Jincai, Z., Bin, Y., & Shangxian, Y. (2018). In-situ stress controlling hydraulic fracturing propagation and fracture break down pressure. Journal of petroleum science and engineering 164 (2018) 164-173.

Zillur, R. (2017). Hydraulic fracturing. Journal of petroleum technology.

Zillur, R. (June, 2019). Hydraulic fracturing. Journal of petroleum technology. Volume 71. Number 6.

Appendices

Appendix 1. Scenario 1 Data

Table 1.1.

Distance from the well versus propped properties in the 1st scenario.

Distance from Well (ft)	Fracture System Width* (in)	Conductivity per Frac** (mD·ft)	Frac System Conductivity*** (mD·ft)	Prop Conc per Frac (lb/ft²)	Frac System Prop Conc**** (lb/ft²)
2,8	0,359	663,7	663,7	1,33	1,33
5,6	0,359	610,1	610,1	1,23	1,23
8,3	0,358	526,6	526,6	1,06	1,06
11,1	0,358	398,3	398,3	0,80	0,80
13,9	0,357	226,1	226,1	0,46	0,46
16,7	0,356	34,9	34,9	0,08	0,08
19,4	0,355	0,0	0,0	0,01	0,01
22,2	0,354	0,0	0,0	0,01	0,01
25,0	0,353	0,0	0,0	0,01	0,01
27,8	0,352	0,0	0,0	0,00	0,00

* Width values reported are for the entire fracture system.
** Fracture conductivity reported for total proppant damage of 0,50 and 0,018 in of proppant embedment.
*** Frac system conductivity reported for 1,0 equivalent multiple fractures with 100% considered conductive.
**** Frac system proppant concentration reported for 1,0 equivalent multiple fractures.

Table 1.2.

Fracture pressure summary in the 1st scenario.

Model Net Pressure** (psi)	300	BH Fracture Closure Stress (psi)	4 848
Observed Net Pressure** (psi)	0	Closure Stress Gradient (psi/ft)	0,680
Hydrostatic Head*** (psi)	3 989	Avg. Surface Pressure (psi)	29 055 050
Reservoir Pressure (psi)	4 111	Max. Surface Pressure (psi)	3 274 853 888

* Averages and maxima reported for Main Frac stages.
** Values reported for the end of the last pumping stage (Stage 12, Main frac flush)
*** Value reported for clean fluid

Table 1.3.

Fracture geometry summary in 1st scenario.

Fracture Half-Length (ft)	139	Propped Half-Length (ft)	28
Total Fracture Height (ft)	95	Total Propped Height (ft)	19
Depth to Fracture Top (ft)	7 083	Depth to Propped Fracture Top (ft)	7 111
Depth to Fracture Bottom (ft)	7 178	Depth to Propped Fracture Bottom (ft)	7 130
Equivalent Number of Multiple Fracs	1,0	Max. Fracture Width (in)	0,36
Fracture Slurry Efficiency**	0,61	Avg. Fracture Width (in)	0,22
		Avg. Proppant Concentration (lb/ft²)	0,09

* All values reported are for the entire fracture system at a model time of 58,60 min (end of Stage 13 Shut-in after Main frac flush)
** Value is reported for the end of the last pumping stage (Stage 12, Main frac flush)

Appendix 2. Scenario 2 Data

Table 2.1.

Distance from the well versus propped properties in the 2nd scenario.

Distance from Well (ft)	Fracture System Width* (in)	Conductivity per Frac** (mD·ft)	Frac System Conductivity*** (mD·ft)	Prop Conc per Frac (lb/ft²)	Frac System Prop Conc**** (lb/ft²)
5,9	0,137	121,0	121,0	0,49	0,49
11,9	0,136	118,6	118,6	0,48	0,48
17,8	0,134	114,5	114,5	0,48	0,48
23,8	0,131	108,6	108,6	0,47	0,47
29,7	0,128	101,0	101,0	0,46	0,46
35,7	0,124	91,3	91,3	0,44	0,44
41,6	0,119	79,5	79,5	0,42	0,42
47,6	0,113	65,1	65,1	0,40	0,40
53,5	0,105	45,1	45,1	0,35	0,35
59,5	0,096	0,0	0,0	0,00	0,00

* Width values reported are for the entire fracture system.
** Fracture conductivity reported for total proppant damage of 0,50 and 0,018 in of proppant embedment.
*** Frac system conductivity reported for 1,0 equivalent multiple fractures with 100% considered conductive.
**** Frac system proppant concentration reported for 1,0 equivalent multiple fractures.

Table 2.2.

Fracture pressure summary in the 2nd scenario.

Model Net Pressure (psi)**	256	**BH Fracture Closure Stress (psi)**	4 833
Observed Net Pressure (psi)**	0	**Closure Stress Gradient (psi/ft)**	0,680
Hydrostatic Head* (psi)**	3 959	**Avg. Surface Pressure (psi)**	504 284
Reservoir Pressure (psi)	4 111	**Max. Surface Pressure (psi)**	6 418 290

* Averages and maxima reported for Main Frac stages.
** Values reported for the end of the last pumping stage (Stage 12, Main frac flush)
*** Value reported for clean fluid

Table 2.3.

Fracture geometry summary in the 2nd scenario.

Fracture Half-Length (ft)	83	**Propped Half-Length (ft)**	59
Total Fracture Height (ft)	51	**Total Propped Height (ft)**	37
Depth to Fracture Top (ft)	7 082	**Depth to Propped Fracture Top (ft)**	7 082
Depth to Fracture Bottom (ft)	7 133	**Depth to Propped Fracture Bottom (ft)**	7 118
Equivalent Number of Multiple Fracs	1,0	**Max. Fracture Width (in)**	0,15
Fracture Slurry Efficiency**	0,82	**Avg. Fracture Width (in)**	0,08
		Avg. Proppant Concentration (lb/ft²)	0,27

* All values reported are for the entire fracture system at a model time of 60,00 min (end of Stage 16 Shut-in after Shut-in)
** Value is reported for the end of the last pumping stage (Stage 12, Main frac flush)

Appendix 3. Scenario 3 Data

Table 3.1.

Distance from the well versus propped properties in the 3rd scenario.

Distance from Well (ft)	Fracture System Width* (in)	Conductivity per Frac** (mD·ft)	Frac System Conductivity*** (mD·ft)	Prop Conc per Frac (lb/ft²)	Frac System Prop Conc**** (lb/ft²)
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00
0,0	0,013	0,0	0,0	0,00	0,00

* Width values reported are for the entire fracture system.
** Fracture conductivity reported for total proppant damage of 0,50 and 0,018 in of proppant embedment.
*** Frac system conductivity reported for 1,0 equivalent multiple fractures with 100% considered conductive.
**** Frac system proppant concentration reported for 1,0 equivalent multiple fractures.

Table 3.2.

Fracture pressure summary in the 3rd scenario.

Model Net Pressure (psi)**	-754	**BH Fracture Closure Stress (psi)**	4 865
Observed Net Pressure (psi)**	0	**Closure Stress Gradient (psi/ft)**	0,680
Hydrostatic Head* (psi)**	3 623	**Avg. Surface Pressure (psi)**	1 330
Reservoir Pressure (psi)	4 111	**Max. Surface Pressure (psi)**	96 439

* Averages and maxima reported for Main Frac stages.
** Values reported for the end of the last pumping stage (Stage 12, Main frac flush)
*** Value reported for clean fluid

Table 3.3.

Fracture geometry summary in the 2nd scenario.

Fracture Half-Length (ft)	44	**Propped Half-Length (ft)**	0
Total Fracture Height (ft)	28	**Total Propped Height (ft)**	0
Depth to Fracture Top (ft)	7 141	**Depth to Propped Fracture Top (ft)**	7 155
Depth to Fracture Bottom (ft)	7 169	**Depth to Propped Fracture Bottom (ft)**	7 155
Equivalent Number of Multiple Fracs	1,0	**Max. Fracture Width (in)**	0,01
Fracture Slurry Efficiency**	0,07	**Avg. Fracture Width (in)**	0,01
		Avg. Proppant Concentration (lb/ft²)	0,04

* All values reported are for the entire fracture system at a model time of 57,20 min (end of Stage 16 Shut-in after Shut-in)
** Value is reported for the end of the last pumping stage (Stage 12, Main frac flush)

Appendix 4.

Turnitin Similarity Report

turnitin

Cavit Atalar | User Info | Messages | Instructor ▾ | English ▾ | Community | ? Help | Logout

Assignments | Students | Grade Book | Libraries | Calendar | Discussion | Preferences

NOW VIEWING: HOME > MASTER > MOUANDA BAKA GRACE PREDY

About this page

This is your assignment inbox. To view a paper, select the paper's title. To view a Similarity Report, select the paper's Similarity Report icon in the similarity column. A ghosted icon indicates that the Similarity Report has not yet been generated.

Mouanda Baka Grace Predy

INBOX | NOW VIEWING: NEW PAPERS ▾

Submit File

Online Grading Report | Edit assignment settings | Email non-submitters

AUTHOR	TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID	DATE
Mouanda Baka Grace P...	ABSTRACT	0%	--	--		1906935027	23-Sep-2022
Mouanda Baka Grace P...	CHAPTER 1	15%	--	--		1906934525	23-Sep-2022
Mouanda Baka Grace P...	CHAPTER 2	14%	--	--		1906934535	23-Sep-2022
Mouanda Baka Grace P...	CHAPTER 3	3%	--	--		1906934547	23-Sep-2022
Mouanda Baka Grace P...	CHAPTER 4	3%	--	--		1906935003	23-Sep-2022
Mouanda Baka Grace P...	CONCLUSION	0%	--	--		1906935046	23-Sep-2022
Mouanda Baka Grace P...	THESIS	11%	--	--		1906935019	23-Sep-2022

Copyright © 1998 – 2022 Turnitin, LLC. All rights reserved.

Privacy Policy | Privacy Pledge | Terms of Service | EU Data Protection Compliance | Copyright Protection | Legal FAQs | Helpdesk | Research Resources

Prof. Dr. Salih Saner

Supervisor

....

Appendix 5

Ethical Approval Letter

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APROVAL DOCUMENT

Date: 10/06/2022

To the Institute of Graduate Studies

The research project titled "**Hydraulic Fracture Modeling in a Fining upward Middle East Carbonate Reservoir**'' has been evaluated. Since the researcher will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

Title: Prof. Dr.

Name Surname: Salih SANER

Signature:

Role in the Research Project: Supervisor